

**Clear Roads Problem Statements  
January 2008**

<b>Page</b>	<b>Title</b>	<b>Description</b>	<b>Estimated Cost</b>	<b>Estimated Duration</b>	<b>Proposer</b>
1	Nation-wide System for Snow/Ice Condition Reporting	Develop a set of winter weather roadway condition ratings, complete with descriptors and pictures which can be used by all states to advise the public of roadway conditions	\$25, 000?	15 months	Allen Williams - VDOT
3	Performance Standards for Snow Removal and Ice Control	Develop a set of performance standards which can effectively be used in managing performance based Snow Removal and Ice Control Contracts	\$35,000?	12 to 15 months	Allen Williams - VDOT
7	Moldboard alarm system to maximize carbide blade wear	Develop a moldboard alarm system that would provide snow plow operators a warning that the plows carbide blade inserts have reached their usable life.	\$100,000	24 months	Cliff Spoonemore, WY-DOT
9	Near Snow Fence options or alternative uses	Determine if current snow fence approach is the best or only snow fence that can be used to fight near snow drifting problems or if a fence with different porosity or design layout could be used to effectively fight near snow.	\$5,000 for a Synthesis \$100,000 for a Study	3 Months for a Synthesis 18-24 months, for a Study. It may take two winters for field research to be conducted.	Cliff Spoonemore, WY-DOT
11	National Driver Education training curriculum	Develop driver education curriculum and materials to support a short course on winter driving safety for new drivers	\$150,000-200,000	2 Years	Dennis Burkheimer, IOWA-DOT
13	National Winter Maintenance Testing facility (Proving Grounds)	Establish a reliable winter research facility that could be highly instrumented to provide very high quality research results	Unknown but this is very likely a project that would best be funded through FHWA or SICOP.	Unknown	Dennis Burkheimer, IOWA-DOT
15	Time released salt	Develop an encapsulating agent that could be added to salt that slows the activation process of the salt	\$150,000	3 years	Dennis Burkheimer, IOWA-DOT

Page	Title	Description	Estimated Cost	Estimated Duration	Proposer
17	Development of Public Service Announcement (PSA) for, Ice and Snow ...Take it slow" media campaign	Create one or two 30-second Public Service Announcements	Approximately \$75,000 is expected for the cost of this effort (The original campaign was funded at \$10,000 but no funding has been used for the initial media efforts.)		Dennis Burkheimer, IOWA-DOT
19	National Specifications or Standards for fleet communications to support GPS/AVL	Develop a common standard or specification that allows agencies to purchase a variety of different sensors that all use a common communication protocol and data format to make it possible to plug-and-play new sensors into the GPS/AVL system with little effort.	\$150,000-200,000	1 year	Dennis Burkheimer, IOWA-DOT
23	Effective Anti-icing Strategies	Develop a Guideline of Best Practice for Anti-icing for Winter Maintenance	\$100,000 to 150,000	18 to 24 months	Paul Brown - MassHighway
27	Cost-Benefit analysis of winter maintenance practices, equipment and operations	Develop a standard method to measure the cost/benefit of adding operational components, GPS, RWIS Stations, Wings, Guidance systems. The standards will address expected service life and life cycle costs.	\$100,000-150,000	1 year	Paul Brown - MassHighway
31	Friction and anti-icing surface treatment study	Evaluate friction and anti-icing surface treatments to determine how long the products last and how much the life cycle cost is	Unknown, but perhaps vendors would donate product	5 years	Mike Sproul - WisDOT
33	Safe Winter Driving Campaign – Focus Groups	Determine the best method to get out a national message concerning winter safety.	\$10,000 per state	3-4 months	Mike Sproul - WisDOT
35	The true costs/benefits of anti-icing	Develop a report on the costs/benefits of anti-icing.	Unknown	3-4 months	Mike Sproul - WisDOT
39	The use of sand for winter maintenance	Develop a report that shows the real costs associated with using sand as well as the outcomes.	Unknown	3-4 months	Mike Sproul - WisDOT
41	Development of a standard storm severity index and snow and ice removal performance standard.	Develop an automated method to calculate storm severity indexes and performance measures after each winter event.	\$200,000	18 to 24 months	Shane Larson - IL DOT

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Allen Williams, VDOT, allen.williams@vdot.virginia.gov

**Title of proposed research project:**

Nation-wide System for Snow/Ice Condition Reporting

**1) Background:**

With every year, we see more inter-state travel and more of those travelers using technology to help determine their trip planning. During winter travel these inter-state travelers depend on internet reports and systems like 511 for trip planning and route selection.

**2) What is the specific problem or issue?**

When travelers long onto a state's website or dial into a state's 511 system, they are provided winter weather conditions for routes using the states system. There is no uniform set of conditions so what may sound like a fairly passable rating in one state may indicate an almost impassable route in another. Some states use a numerical rating while others use some type of descriptor or color rating.

**3) List the proposed research objectives and tasks.**

Review what each state uses as a rating system for winter weather conditions. Select one or several of the best system to be tested for telling the public roadway conditions. Develop a system that test s with the public shows to be efficient and accurate in telling the public roadway conditions.

**4) What would be the product(s) of the research?**

A set of winter weather roadway condition ratings, complete with descriptors and pictures which can be used by all states to advise the public of roadway conditions.

**5) How would the results benefit DOTs? How would they be used?**

States would be able to provide a consistent message to the traveling public concerning winter weather roadway conditions. These could be used in communicating with the media, systems like 511 and internet web pages. Consistency across the nation would especially be beneficial to freight haulers as well as passenger transport. Media outlets with multiple DOT's in their report areas and the Weather Channel could use one set of descriptors to report conditions.

**6) List the estimated funding needed.**

\$25,000?????

**7) List the estimated timeline for completing the research.**

Three months to conduct literature review and contact all states for their systems. Three months to select the top rating systems being used nation-wide. Six months to ready an interview questionnaire, picture boards and conduct interviews. Three months to interpret interview results and develop final product. In total about 15 months

**8) Are you aware of any related research on this topic? If so, please list below. None known**

Sampling of state color rating systems for winter road conditions:

**Illinois**

Winter Road Conditions (Illinois DOT) <http://wrc.gettingaroundillinois.com/winterroadconditions/>

**Iowa**

Winter Road Conditions (Iowa DOT) <http://www.iowaroadconditions.org/roadconditions.asp>

**Missouri**

Traveler Information Map (Missouri DOT)

<http://maps.modot.mo.gov/travelerinformation/TravelerInformation.aspx>

**Montana**

Road Report Map (Montana DOT) [http://www.mdt.mt.gov/travinfo/map/mtmap\\_frame.html](http://www.mdt.mt.gov/travinfo/map/mtmap_frame.html)

**Ohio**

Winter Conditions (Ohio DOT, apply Winter Conditions filter to map) <http://www.buckeyetraffic.org/>

**Washington**

Road Temperatures (Washington State DOT) <http://www.wsdot.wa.gov/traffic/RoadTemps/>

**Wisconsin**

Winter Road Conditions (Wisconsin DOT) <http://www.dot.wisconsin.gov/travel/road/winter-roads.htm#map>

**Interstate**

Interstate Forecast (Weather Channel) [http://www.weather.com/maps/activity/driving/index\\_large.html](http://www.weather.com/maps/activity/driving/index_large.html)

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Allen K. Williams, Virginia DOT, allen.williams@vdot.virginia.gov

**Title of proposed research project:**

Performance Standards for Snow Removal and Ice Control

**1) Background:**

Snow removal and ice control has not traditionally been an item most states and localities look to contract out in a “turn-key” style contract. Most contracting has predominately been accomplished via hourly or by-the-mile contracts.

**2) What is the specific problem or issue?**

As more and more states are moving toward contracting maintenance operations with performance based contracts, there is an increasing need to develop performance standards to be specified in the contracts. These performance based standards provide the basis for assessing the contractor’s level of performance during winter weather operations. Standards must be well enough defined and clearly understood so as to apply penalties to contractors for not meeting the standards.

**3) List the proposed research objectives and tasks.**

To develop an easily understandable/recognizable set of performance standards that can be applied to performance based contracts. Conduct literature and nation-wide state/locality search to find any standards that have been developed. Combine all sets of standards into a survey with depictions of performance conditions. Investigate possible alternatives for measuring performance such as friction meter readings to be applied with the traditional performance standards. Apply appropriate testing methods to determine effectiveness of standards in managing contracts.

**4) What would be the product(s) of the research?**

A set of performance standards which can effectively be used in managing performance based Snow Removal and Ice Control Contracts.

**5) How would the results benefit DOTs? How would they be used?**

DOT’s would have a ready set of performance based standards to be used in contracting. These standards would be tested for understandability/reasonability in application to winter operations. DOTs would not need to struggle to develop standards which may or may not achieve the results they anticipate. These standards could be modified to the state’s desired operational conditions and funding levels.

**6) List the estimated funding needed.**

\$35,000???

**7) List the estimated timeline for completing the research.**

2 months to conduct literature search while developing a survey document and an additional 2 months to survey states/localities to find performance standards in use. Month to assemble the results of surveys and searches, and develop set of topic for discussion with a panel of experts. Four months to assemble a panel of experts to address issues with performance standards, arrive at a set of standards to be tested, develop the test methods, conduct test and make recommendations. Two months to finalize the testing recommendations, prepare the product and present to the committee. Two months to develop the presentation product and send out to interested states and localities.

**8) Are you aware of any related research on this topic? If so, please list below. None specifically on performance standards.**

Friction wheel being conducted by Virginia Tech Transportation Institute/Virginia Transportation Research Council

Paul Brown, Boston, MA has indicated they are interested in performing some friction wheel research.

**Alberta's Benchmark Model for Maintenance Winter Service Delivery**

Otto, S., Alberta Transportation

Transportation Research Circular E-C063, Sixth International Symposium on Snow Removal and Ice Control Technology, June 2004

<http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf>

From: introductory comments, page 496 of the PDF –

Starting in 1998, the government began selling Alberta Transportation maintenance shops, and by 2000 most properties were no longer under government control. In autumn 2000, the government began to transfer road authority for secondary highways from the municipal governments (that is, counties) and more than doubled the length of the network under provincial jurisdiction. Prospective contractors for contracts tendered after 2001 were required to propose new shop locations and the shop size and number of trucks to be provided in their new contract area. AT's tasks were to:

- Benchmark the existing (2000) winter maintenance service on the existing network
- Predict the requirements for the number of trucks needed to meet provincial standards on the new (expanded) network and provide the same level of performance, and
- Evaluate contract proposals when shop locations and number of plow trucks were not specified.

The department's solution was a spreadsheet model of plowing and sanding-salting times with the total calculated time to complete one pass of the entire network as the benchmark. The model was used to determine how many trucks to add within each district as the secondary highways were transferred to provincial control. Contract proposals from prospective contractors were evaluated on whether their proposals showed equal to or slightly better than benchmark parameters. This paper gives details of the benchmarking process, including assumptions used, how highway topography and geometric characteristics were used to affect the length of highway each plow truck can be assigned before it was fully allocated, the business rules chosen to model actual work habits, calculations used to determine the time required to plow and spread sand or salt over each segment, and the improvements made over three successive rounds of tendering.

**Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility**

NCHRP Web Document 53 (Project 6-14): Contractor's Final Report, November 2002

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_w53.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w53.pdf)

This report indicates that the use of friction measurements to improve winter maintenance operations and mobility is feasible (especially when deceleration devices are used), but devices with an extra wheel may not represent a practical solution to friction measurement.

From: Chapter 2, Findings; Section 2.1.6, Operation Performance Evaluation (pages 39 to 41 of the PDF) –

The privatization of winter maintenance operations on public roads created a need for better methods of quality assurance.\* This need arises for two primary reasons. The first is to ensure that winter maintenance operations are performed within specified standards. The second is to guarantee objective ways to evaluate winter maintenance operations in case of contract disputes. To assure quality of winter maintenance operations, friction measurements could be used in three different ways: the threshold level approach, the contaminant classification approach, and the spatial homogeneity approach. Preliminary studies have shown that the three approaches are promising...

\*Perchanok, M., "Friction Based Quality Assurance Measures for Snow Clearing Operations." Xth PIARC International Winter Road Congress, Luleå, Sweden (1998) pp. 199-208.

Drawing on five data sets (three data sets of variable slip friction and two data sets of snow-covered conditions), Perchanok\* has suggested that data obtained by variable slip devices could be used qualitatively to measure compliance with level of service standards on snow-covered roads. However, to classify the snow type, further research was recommended.

\*Perchanok, M., "Patchiness of Snow Cover and Its Relation to Quality Assurance in Winter Operations." XIth PIARC International Winter Road Congress, Sapporo, Japan, (2002).

Vaa\* has presented a procedure for measuring winter maintenance activities that combines friction measurement, photographs, activity logs and observations. While this procedure is currently used in Norway to evaluate the performance of specific friction improvement methods, it could also be used to document winter maintenance practice and evaluate overall performance. The procedure uses the four processes listed above to evaluate test sections for compliance with established standards.

\*Vaa, T., "Methods for Measuring and Reporting Winter Maintenance Activities." Vth International Symposium on Snow Removal and Ice Control Technology, Roanoke, VA, Paper No. K-1 (2000).





# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Clifford Spoonemore, Wyoming Department of Transportation, cliff.spoonemore@dot.state.wy.us

**Title of proposed research project:**

Moldboard alarm system to maximize carbide blade wear

**1) Background:**

Snow plow blades use a carbide insert to extend their service life and protect the plow mold board. Wear on carbide blades is typically based on the type of roadway environment (concrete or bituminous), contamination (snow, snow pack, ice pack or variations there of) on the roadway, angle of attack and pressure applied to the roadway surface. The angle of attack and pressure are often controlled by the equipment operator based on what they feel is required to remove the roadway contaminate (snow and ice) from the roadway. Equipment operators often estimates the remaining service life of a carbide blade based on past wear history and estimated wear during his/her shift. The agency is often placed in a lose/lose cost situation, by the operator replacing the carbide blade too soon there is a waste of material. If the carbide blade is replaced too late the wear will move into the mold board causing damage to the plow resulting in down time and repair expenses to the agency. Agencies have experimented with applying extra carbide blades trying to extend the wear time and saving the time lost during a storm to change out worn blades. This has proved to be some what successful, but at double the cost per plow and putting extra weight on the front ends of the snow plow frame.

**2) What is the specific problem or issue?**

Equipment operators do not know the optimal time for replacing carbide inserts. If replaced too early, there is a cost to the agency for wasted materials. If replaced too late the wear will move into the mold board at a significant cost to the agency and down time for the plow.

**3) List the proposed research objectives and tasks.**

The objectives for this project are:

1. Complete a literature search of research conducted on devices used to measure wear in a related industry.
2. Develop and test a prototype of the moldboard alarm system in a Clear Roads state
3. Provide final design and specifications for the moldboard alarm system
4. Provide cost benefit ratio for maximizing carbide blade use and damages to plow moldboards

**4) What would be the product(s) of the research?**

Develop a moldboard alarm system that would provide snow plow operators a warning that the plows carbide blade inserts have reached their usable life. The alarm system would be a back up to visual plow inspections and assist in preventing moldboard damage caused by running beyond the usable life of the carbide blade.

**5) How would the results benefit DOTs? How would they be used?**

A state DOT may use several thousand carbide blades in a winter season. Additional wear life on carbide blades would result in savings to the agency for materials and labor. Snowplows could operate longer periods without changing plows blades. Damage to moldboards is reduced because of carbide blade wear. Alarm system could have the capability to store blade hours to assist management decisions.

**6) List the estimated funding needed.**

\$100,000

**7) List the estimated timeline for completing the research.**

24 months, from August 2008 (award of RFP) to August 2010 (Deliverables)

**8) Are you aware of any related research on this topic? If so, please list below.**

Research in progress – New Mexico State Highway and Transportation Department

<http://rip.trb.org/browse/dproject.asp?n=3345>

Abstract: If snowplow blades are not replaced when worn, there is the potential for damage to the mold board. Damage results in cost to the department, as well as down time for repair when needed for snow removal. There is a need for a low-cost sensor to alert snowplow operators when it is time to replace the blades. The first sensors were installed in December 2000, a product report is forthcoming.

Snowplow Wear Sensor, New Mexico DOT

Refer to the attached PDF.

The sensor activates a light in the cab indicating when plow bits have worn down. The product report includes a parts list and instructions for making and installing the sensor. For further information about the report, Deirdre may be contacted at: (505) 841-9147, [Deirdre.Billingsley@state.nm.us](mailto:Deirdre.Billingsley@state.nm.us)

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Clifford Spoonemore, Wyoming Department of Transportation, cliff.spoonemore@dot.state.wy.us

**Title of proposed research project:**

Near Snow Fence options or alternative uses

**1) Background:**

Large structural or living snow fence has been installed along side our Roadway Systems to capture far snow and protect trouble areas such as large cuts. Structural and living snow fence has proven there effectiveness and they have been studied in the past for efficiency and cost benefit.

Experts such as Dr. Ronald Tabler of Tabler and Associates has complete extensive research on snow fence but have not reach a uniform conclusion about how to handle near snow. Near snow is defined as the snow that falls and becomes the source of blowing snow between the structural or living snow fence and the Roadway. Most often the near snow effect is handled using 4' high wooden fence system that has many names such as corn cribbing, lath fence, and several others depending on your local terminology.

**2) What is the specific problem or issue?**

This fence has been used because it has many characteristics that make it easy to use. It is able to be purchased from a local hardware store at about \$1.00 per foot. Has about 50% porosity, easy to handle at 4' high and can be attached to existing Right-of-Way fence or temporary fence posts.

The question of this study or possible Synthesis is; "Is this method the best or only snow fence that can be used to fight near snow drifting problems?" Can fence with different porosity or design layout be used to effectively fight near snow?

**3) List the proposed research objectives and tasks.**

The objectives for this project are:

5. Complete a literature search of research conducted on fence systems used by others.
6. Develop new or improve existing snow fence systems to fight near snow by taking advantage of existing knowledge of porosity, bottom gap, height, skew angle and blow cast distance.
7. Provide final design layouts and specifications for snow fence systems developed or modified.
8. Complete field testing in both Great Plains States and Mountainous Terrain in several situations, such as protecting cuts, overpass/underpass interchanges, icing conditions on superelevated curves and bridge end protection by W-Beam guardrail.
9. Provide cost benefit ratio for extra snow fence to fight the near snow problem.

**4) What would be the product(s) of the research?**

New technology developed that would be added to a snow fighter's toolbox. Use known facts and technology to develop new near snow fence. Take advantage of existing knowledge to enhance our current systems by modifying their applications. With this knowledge application within the Right-of-Way and closer to the Roadway may be used.

**5) How would the results benefit DOTs? How would they be used?**

States have several areas where landowners will not allow more or larger snow fence systems on their land. Having alternative solutions to fight near snow can be most useful as we all know there is no such thing as a one size fits all solution to every situation when fighting snow.

The use of these alternatives could be varied as the locations in which they will be used. Each maintenance section will select a solution that fits their terrain, weather, and roadway conditions.

**6) List the estimated funding needed.**

\$5,000 for a Synthesis

\$100,000 for a Study

**7) List the estimated timeline for completing the research.**

3 Months for a Synthesis

18-24 months, for a Study. It may take two winters for field research to be conducted.

**8) Are you aware of any related research on this topic? If so, please list below.**

NCHRP Project 20-7(147) "Controlling Blowing and Drifting Snow with Snow Fences and Road Design", Dr Ronald D. Tabler, Tabler & Associates, Niwot, CO., August 2003

**Drift Free Roads Design Module**

University of Minnesota

[http://climate.umn.edu/snow\\_fence/Components/Design/introduction.htm](http://climate.umn.edu/snow_fence/Components/Design/introduction.htm)

This online tool allows users to examine solutions to site-specific blowing snow problems by either designing a snow fence or utilizing road design techniques.

**Highway Snowstorm Countermeasure Manual: Abridged Edition**

Civil Engineering Research Institute of Hokkaido, Japan

[http://www2.ceri.go.jp/eng/fubuki\\_manual/outline\\_e.pdf](http://www2.ceri.go.jp/eng/fubuki_manual/outline_e.pdf)

This report is a synopsis of the Highway Snowstorm Countermeasure Manual revised in July 2003. The manual explains basic ideas and describes technical data and general technological standards related to snow-control facilities used against snowdrifts and blowing snow induced visibility hindrance. Volume 3, Snow Fences, begins on page 39 of the PDF and describes the technological standards for planning, design and maintenance of snow fences. Traditional collector snow fences and collector snow fences are reviewed in terms of design conditions, such as design height and design wind velocity.

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Dennis Burkheimer, Iowa DOT, dennis.burkheimer@dot.iowa.gov

**Title of proposed research project:**

National Driver Education training curriculum

**1) Background:**

Every year hundreds of thousands of new drivers are driving on snow and ice covered roadways for the first time. In most states driver education training classes are conducted during the summer months and the curriculum covered in the training is often mandated by the Board of Education or some other agency. Very little is taught on how to operate a vehicle safely when roads are covered with snow and ice.

**2) What is the specific problem or issue?**

Many driver education training programs lack good information on how to operate motor vehicles when roads are covered with snow and ice leaving many new drivers unprepared for the hazards they face during winter driving conditions.

**3) List the proposed research objectives and tasks.**

- Survey of states to determine extent of winter driver education training currently available
- Develop curriculum and accompanying materials for a short course on safe winter driving
- Develop test questions for driver license examinations
- Provide self-help kits for individual states to use to encourage adoption of the winter driver education training program in their states
- Develop Strategic plan for technology transfer

**4) What would be the product(s) of the research?**

Driver education curriculum and materials to support a short course on winter driving safety for new drivers

**5) How would the results benefit DOTs? How would they be used?**

Properly trained young drivers would hopefully reduce the number of young people involved in winter crashes. Hopefully the product would be a stand alone product that could be distributed to driver education trainers or made available online.

**6) List the estimated funding needed.**

\$150,000-200,000

**7) List the estimated timeline for completing the research.**

2 Years

**8) Are you aware of any related research on this topic? If so, please list below.**

Operation Lifesaver has been successful in making training about crossing railroad tracks a requirement in some driver education classes.

## **Winter Traffic and Winter Road Maintenance Research**

Swedish National Road and Transport Research Institute (VTI)

[http://www.vti.se/templates/Page\\_5267.aspx](http://www.vti.se/templates/Page_5267.aspx)

Research conducted by VTI covers driver education (improved training in slippery conditions) and driver behavior in winter, as well as the vehicle and its winter equipment.

Winter driver training and driver behavior

[http://www.vti.se/templates/Page\\_5268.aspx](http://www.vti.se/templates/Page_5268.aspx)

Skid training is a compulsory part of driver licensing. However, international experience indicates that the increase in the traffic safety effect may be lost if the training is not correctly designed.

VTI's research comprises:

- Development of Swedish skid training so that it actually leads to improved safety. Among other things, this work has contributed to further emphasis during training on risk awareness and insight into the learner driver's own limitations. VTI's research work, partly in the form of a long-term research program conducted jointly with the Swedish Road Administration and the various educational organizations, has laid the foundation for a recently executed reconstruction and implementation of a new national course schedule for obligatory skid training.
- The knowledge of factors influencing road user behavior in winter traffic is poor and little is known about which senses (visual, auditory and tactile) the driver uses when judging road condition. This can be studied both experimentally on the road and in the VTI driving simulator.

## **YouTube.com – Winter Driving Training Video**

*Winter driving course: having fun and learning to be safe (1:52)*

<http://www.youtube.com/watch?v=77eQJznmJxM&feature=related>

## **Driver Education for Safety in Adverse Driving Conditions**

Transportation Research Board, Research in Progress Database

<http://rip.trb.org/browse/dproject.asp?n=11504>

Under certain adverse and unavoidable driving conditions, drivers often become confused and take wrongful action, leading to severe crashes. Scenarios would include driving during a dust storm, a tire blowout in the middle of a high speed facility, driving behind a large truck, running off the road, sudden bottleneck or emergency vehicles on the way. The objective of this Arizona DOT research is to ascertain how to educate drivers for safety under certain adverse and unavoidable driving conditions. An improved education program is expected to reduce the number of crashes and injuries and to reduce the severity of crashes.

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Dennis Burkheimer, Iowa DOT, Dennis.burkheimer@dot.iowa.gov

**Title of proposed research project:**

National Winter Maintenance Testing facility (Proving Grounds)

**1) Background:**

There is a need for a nationally recognized winter testing facility that can test and evaluate all winter maintenance equipment, methods, materials and Weather sensors.

**2) What is the specific problem or issue?**

Currently testing of new winter maintenance materials, equipment, methods and Weather sensors is done at DOT facilities with limited testing done in laboratories. When using different testing facilities and researchers test protocols, procedures and results may be questionable

**3) List the proposed research objectives and tasks.**

- Identify key partners that could help establish and fund a test facility (Aurora, PNS, FHWA, SICOP)
- Begin the process to seek additional funding to help support the effort
- Identify researchers and location best suited for a winter testing facility

**4) What would be the product(s) of the research?**

The main product would be a reliable winter research facility that could be highly instrumented to provide very high quality research results

**5) How would the results benefit DOTs? How would they be used?**

It would provide DOTs and the vendor community an opportunity to test winter maintenance materials, equipment, methods and weather sensors at one location under the supervision of quality researchers

**6) List the estimated funding needed.**

Unknown but this is very likely a project that would best be funded through FHWA or SICOP.

**7) List the estimated timeline for completing the research.**

Unknown

**8) Are you aware of any related research on this topic? If so, please list below.**

There are a number of winter testing facilities (University of North Dakota, MNRoads, Virginia Tech, Western Transportation Institute) currently established in the US. All could be examples to pattern this effort.

**Examples of Winter Maintenance Testing Facilities Overseas:**

**Civil Engineering Research Institute for Cold Region**

Hokkaido, Japan

[http://www.ceri.go.jp/english/01\\_institute.html](http://www.ceri.go.jp/english/01_institute.html)

Hokkaido is distinguished by its cold, snowy climate and soft, peaty soils. These can often be problematic for civil engineering works. The institute conducts advanced research for cost-effective development of infrastructure, environmentally friendly improvements to infrastructure and the mitigation of natural disaster damages to infrastructure.

The institute's research teams include:

- Snow and Ice (<http://www2.ceri.go.jp/eng/bousai.htm>). To mitigate the risk of snow and ice disasters, including snowstorms and avalanches, the team performs research to develop methods for measuring road visibility under snowstorm conditions, monitoring avalanche likelihood and forecasting road icing. The team also studies performance assessment of snow-protection facilities (for example, snow fences and snowbreak woods), measures against snow and ice adhesion, and better use of road-related data through more sophisticated winter road management. Research outcomes include The Highway Snowstorm Countermeasure Manual and RWML (Road Web Markup Language).
- Traffic Engineering (<http://www2.ceri.go.jp/eng/koutsu.htm>). To secure the safety and mobility of traffic in cold, snowy regions, the team studies methods for efficient and effective winter road management, analyzes the causes of traffic accidents specific to cold regions toward developing countermeasures, and researches road structural design and traffic management tailored to regional and traffic characteristics.

The institute's indoor research facilities include an icy road driving test machine, and outdoor research facilities include a test driving course for cold, snowy regions ([http://www.ceri.go.jp/english/07\\_facilities.html](http://www.ceri.go.jp/english/07_facilities.html)).

### **Swedish National Road and Transport Research Institute (VTI)**

Winter Traffic and Winter Road Maintenance

[http://www.vti.se/templates/Page\\_5268.aspx](http://www.vti.se/templates/Page_5268.aspx)

VTI winter traffic and winter road maintenance research covers a broad spectrum and encompasses methods and characteristics as well as the influence of winter road management on road safety, accessibility and the environment. Research areas include winter road maintenance, vehicles and their winter equipment, and winter driver training and driver behavior. In addition, studies are made of the effects of using various types of tires and the economic consequences for the community.



# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Dennis Burkheimer, Iowa DOT, Dennis.burkheimer@dot.iowa.gov

**Title of proposed research project:**

Time released salt

**1) Background:**

Salt is the most common deicer used in the United States to clear roads of ice and snow. Salt requires moisture and a heat source to become activated and begin melting snow and ice. Once salt begins the melting process it continues melting at basically the same rate until it becomes diluted or temperatures drop below the freezing point of the solution.

**2) What is the specific problem or issue?**

Many times the material on the roadway will dilute or refreeze before the plow truck can apply additional materials to the roadway. Salt has a limited time it can work on the roadway.

**3) List the proposed research objectives and tasks.**

- Literature search
- Laboratory tests
- Field testing

**4) What would be the product(s) of the research?**

The end product would be an encapsulating agent that could be added to salt that slows the activation process of the salt. A portion of a salt stockpile could then be treated with the encapsulating agent while the remainder of the pile would be untreated. As the mixture of treated and untreated salt reaches the roadway surface the untreated salt would begin working immediately while the encapsulated salt would be delayed until the encapsulating agent dissolved, then releasing the straight salt to continue the melting process.

**5) How would the results benefit DOTs? How would they be used?**

This would extend the melting period for the application of materials and hopefully allow agencies to lengthen their snow removal routes. Service to the public would increase due to the road being passable for longer periods of time

**6) List the estimated funding needed.**

\$150,000

**7) List the estimated timeline for completing the research.**

3 years

**8) Are you aware of any related research on this topic? If so, please list below.**

Should be something in the chemistry area that is related to this effort

An email query to Dick Hanneman, President of the Salt Institute, produced the following response:

“I am unaware of any time-release salt (or other deicer). Of course, larger particles last longer and release their melting power over a longer period of time, but the closest thing I know is the SafeLane overlay system by Cargill where the deicer is placed into the roadway surface and lasts a long time. Earlier, verglimit was used, embedding a deicer into the pavement when it was installed; this is no longer done.”



# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Dennis Burkheimer, Iowa DOT, dennis.burkheimer@dot.iowa.gov

**Title of proposed research project:**

Development of Public Service Announcement (PSA) for, Ice and Snow ...Take it slow" media campaign

**1) Background:**

Clear Roads initiated a national media effort in 2007 to develop a national winter driving safety campaign. The safety campaign drew the expertise of 12 state DOT Public Information Officers to help with the campaign. The campaign continues to grow in different states

**2) What is the specific problem or issue?**

The Public Information Officers feel that 1-2 30 second generic videos would be beneficial to this campaign. It is felt that many states would be able to use the segments on local TV stations to help get critical safety messages out to the general public.

**3) List the proposed research objectives and tasks.**

1. Identify 1-2 main themes for a winter safety PSA
2. Develop script and storyboard of PSA
3. Develop PSA
4. Distribute PSA to all state DOTs

**4) What would be the product(s) of the research?**

1-2 30 second Public Service Announcements

**5) How would the results benefit DOTs? How would they be used?**

State DOTs could send the PSA's to television stations in their states and ask them to be aired during winter events.

**6) List the estimated funding needed.**

Approximately \$75,000 is expected for the cost of this effort (The original campaign was funded at \$10,000 but no funding has been used for the initial media efforts.

**7) List the estimated timeline for completing the research.**

**8) Are you aware of any related research on this topic? If so, please list below.**

Continuation of existing project

**YouTube.com -- Videos Containing Safe Winter Driving Tips**

*Winter Driving Tips* (1:00)

<http://www.youtube.com/watch?v=wq7ZJ0E-UCM>

*AAA Offers Winter Driving Tips* (2:48)

[http://www.youtube.com/watch?v=tKdaaRz\\_yv4](http://www.youtube.com/watch?v=tKdaaRz_yv4)

*Safe Winter Driving* (4:27)

<http://www.youtube.com/watch?v=PxsLcltAl-U>

*Winter Car Tips* (5:09)

<http://www.youtube.com/watch?v=GkQtxcLr1zk>

## **Colorado DOT -- Television Public Service Announcements**

*Winter Driving Preparation* (:30)

[http://www.dot.state.co.us/travelinfo/006\\_PSA-DriverPrepPSA.MPG](http://www.dot.state.co.us/travelinfo/006_PSA-DriverPrepPSA.MPG)

*Driver Safety* (:30)

[http://www.dot.state.co.us/travelinfo/006\\_PSA-DriverSafetyPSA.MPG](http://www.dot.state.co.us/travelinfo/006_PSA-DriverSafetyPSA.MPG)

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Dennis Burkheimer, Iowa DOT, dennis.burkheimer@dot.iowa.gov

**Title of proposed research project:**

National Specifications or Standards for fleet communications to support GPS/AVL

**1) Background:**

Sensors and other devices used on snowplows are often provided by different vendors and each component may have a different communication protocol and/or data formats that require extra steps and money to coordinate and integrate the different systems into one data stream.

**2) What is the specific problem or issue?**

Most of the onboard sensors and components used to monitor snow removal operations are developed and sold as independent systems that have their own proprietary communication and data protocols and formats. If an agency wants to develop a GPS/AVL system to track plowing operations they must work with each of the independent device manufacturers to convert their communications or data formats into a common format for use in the GPS/AVL system. If an agency changes one of the components in the system they often are required to work with the new component manufacturer to make sure the data output works with their existing GPS/AVL system. Agencies that are considering GPS/AVL need a common standard or specification that allows them to purchase a variety of different sensors that all use a common communication protocol and data format to make it possible to plug-and-play new sensors into the GPS/AVL system with little effort. This would provide more flexibility for state agencies and reduce the overall costs to develop and maintain a GPS/AVL system.

**3) List the proposed research objectives and tasks.**

- Literature search of existing communication standards, protocols and data formats used in GPS/AVL technology that might be applicable to snowplow operations. This search should look to ITS applications and other countries to determine if any standards exist that could be adopted by state agencies
- Work with Clear Roads states to determine the types of sensors (spreader controls, infrared thermometers, plow position, wing position, engine buss, etc.) and outputs (dry and liquid application rates, engine data, plow position, temperature, etc.) required in a GPS/AVL system used to support snow removal operations
- Develop recommended specifications that can be used by states when ordering components that can be used in a GPS/AVL environment
- Develop a strategy to transfer the technology learned from this research to manufacturers and government agencies for a national system

**4) What would be the product(s) of the research?**

Specifications or standards that can be used by agencies

**5) How would the results benefit DOTs? How would they be used?**

Development of standards or a set of standard specifications could be used by all state DOTs to resolve the problem of continuously needing to spend money for integration of sensors or other applications used in snow plowing operations. This could then also be used to support other maintenance operations conducted during the non-winter period of time and be expanded to include other maintenance operations.

**6) List the estimated funding needed.**

\$150,000-200,000

**7) List the estimated timeline for completing the research.**

1 Year

**8) Are you aware of any related research on this topic? If so, please list below.**

Europe has developed a draft standard for snow removal operations

**Conversion of Volunteer-Collected GPS Diary Data into Travel Time Performance Measures: Literature Review, Data Requirements, and Data Acquisition Efforts**

Bhat, C., Srinivasan, S. and Bricka, S., Center for Transportation Research - University of Texas at Austin

Report No. FHWA/TX-05/0-5176-1, December 2004 (revised January 2005)

[http://www.utexas.edu/research/ctr/pdf\\_reports/0\\_5176\\_1.pdf](http://www.utexas.edu/research/ctr/pdf_reports/0_5176_1.pdf)

From: Abstract (page 1 of the PDF) –

Advances in GPS technology have provided transportation planners with an alternative and powerful tool for more accurate travel data collection with minimal user burden. The data recorded by GPS devices, however, does not directly yield travel information; the navigational streams have to be processed and the travel patterns derived from it. The focus of this research project is to develop software to automate the processing of raw GPS data and to generate outputs of activity-travel patterns in the conventional travel diary format. The software will identify trips and characterize them by several attributes including trip-end locations, trip purpose, time of day, distance and speed. Within the overall focus of the research, this report describes the data collection equipment specifications, data collection protocols, and data formats, and presents a comprehensive synthesis of the state of the practice/art in processing GPS data to derive travel diaries. This synthesis is intended as the basis for developing input specifications and processing algorithms for the researchers' software. A second objective of this report is to identify the data requirements for the software development purposes and document the efforts undertaken to acquire the data.

**Simulation Study of Bus Signal Priority Strategy Based on GPS/AVL and Wireless Communications**

Liao, C. and Davis, G., University of Minnesota (submitted for presentation at the TRB 86<sup>th</sup> Annual Meeting, 2007)

Refer to the attached PDF.

From: Abstract (page 2 of the PDF) –

Current signal priority strategies implemented in various U.S. cities mostly utilize sensors to detect buses at a fixed or preset distance away from an intersection. Traditional presence detection systems, ideally designed for emergency vehicles, usually send a signal priority request after a preprogrammed time offset as soon as transit vehicles are detected without the consideration of bus readiness. The objective of this study is to take advantage of the already equipped GPS/AVL system on buses in Minneapolis and develop an adaptive signal priority strategy that could consider the bus schedule adherence, its number of passengers, location and speed. Buses can communicate with intersection signal controllers using wireless technology to request signal priority. Communication with the roadside unit (for example, traffic controller) for signal priority may be established using the readily available 802.11x WLAN or the DSRC (Dedicated Short Range Communication) 802.11p protocol currently under development for wireless access to and from the vehicular environment. This paper describes the researchers' proposed priority logic and its evaluation using microscopic traffic simulation.

## **A Reliable Link-Layer Protocol for Robust and Scalable Intervehicle Communications**

Blum, J. and Eskandarian, A.

IEEE Transactions on Intelligent Transportation Systems, Vol. 8 No. 1, posted online February 2007

Document available for purchase from Institute of Electrical and Electronics Engineers:

[http://ieeexplore.ieee.org/xpl/freeabs\\_all.jsp?tp=&arnumber=4114331&isnumber=4114329](http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=4114331&isnumber=4114329)

This paper presents a developed link layer protocol for use in inter-vehicle communications and road transportation communication (IVC) that researchers call Adaptive Space Division Multiplexing (ASDM). Some of the exigencies for a new protocol design are listed, primary among them the vulnerability of wireless computer network security systems to denial of service (DoS). The protocol should also improve bandwidth of these types of networks while also automatically adjusting time slot allocation. Some prerequisites for the ASDM system listed are vehicles equipped to provide their own vehicle's spatial position in addition to the preceding vehicles, which can be accomplished using dead reckoning and GPS, mapping functionality, and a common, universal timing mechanism. Simulations were also conducted to test the efficacy of the proposed protocol.





# 2008 Clear Roads Research Proposal Form

## Proposer name, organization and e-mail address:

Linda Taylor  
Mn/DOT – Office of Maintenance  
[Linda.taylor@dot.state.mn.us](mailto:Linda.taylor@dot.state.mn.us)  
(651) 282-2281

Paul G. Brown  
MassHighway  
[Paul.Brown@mhd.state.ma.us](mailto:Paul.Brown@mhd.state.ma.us)

## Title of proposed research project:

Effective Anti-icing Strategies

### 1) Background:

Anti-icing operation is all over the board as to how it is being administered within any state, let alone any truck-station or sub-area. Some areas are only anti-icing bridge decks, while others have extensive programs to anti-ice mainlines, ramps, shady areas, and bridge decks on a routine basis. Brine, hot brine, and/or liquid chemicals are commonly used for anti-icing operations. There is no consistency as to when, where, and what material or amount is being applied or the frequency of applications. The equipment used for anti-icing ranges from tanks on back of trucks to trailer mounted tank to tanker trucks. There are a lot of informal, pilot tests being conducted dealing with anti-icing. But uniform evaluation and testing has not been applied in most cases. The results and lessons learned are used locally and not shared with other areas or districts.

A formal evaluation of anti-icing materials and procedures are needed to help managers justify their investment and to quantify the benefits to operators and customers. Based on a literature review and on-going studies, testing criteria will be developed to uniformly quantify the benefits. Field testing of various anti-icing materials will be examined on various roadway types and level of service, with a control section in one direction. Guidelines will be developed for anti-icing material for various weather, roadway types, level of service, climatological conditions, and traffic volumes.

### 2) What is the specific problem or issue?

- There is no uniformity or constancy in how, where, when and what materials are being used to anti-ice to get the biggest return on investment.
- Anti-icing priorities need to be established to guide agencies to developing or enhancing their winter programs.
- Good test results and quantified benefits of anti-icing are needed to assist managers in adopting anti-icing strategies into their winter maintenance program.

### 3) List the proposed research objectives and tasks.

Objective 1: Assessment of current anti-icing practices and quantifies cost, benefits and best practice of anti-icing for the different conditions (weather, roadway types and conditions, road classifications (level of service/ADT, material used and application rates).

Task 1: Conduct a literature and document review to include publications, standards, specification, standard operating procedures, instruction memorandums etc. to better understand what guides the snow and ice control operations and decision making at each organization

Deliverable: Summary of literature and document review

Task 2: Conduct user assessment to identify the DOT's anti-icing best practices currently in-place. The assessment will evaluate agencies level of confidence with chemicals, summary of material being used, awareness of benefits and outcomes, barriers to implementation, identify inconsistencies in practices and document what causes these non-conformities and summarize best practices in anti-icing. Some agencies have sufficient resources (equipment, human resources, and budget) and some don't. This

causes difference in level of service objectives and response to snow and ice control, thus achieving consistency and uniformity is nearly impossible. Each state has different environment (climate, traffic, terrain, land use, etc. to consider.

Task 2.1: Develop an implementation plan to address the barriers and inconsistencies in operating practices. Specific attention should be given to misunderstanding of benefits and outcomes of anti-icing due to lack of equipment, training, and management support, accurate weather forecasts, adverse affects of chemicals (slipperiness effect), material handling, and public perceptions. Perhaps a PPT presentation produced to assist in implementing a program.

Deliverable: Summary of User Assessment which outlines finding.  
Implementation Plan

Task 3: Develop a Guideline of Best Practice for Anti-icing for Winter Maintenance. Guidelines will be developed for best practices in effective anti-icing along with guidance on equipment (trucks, facilities, and storage). The guide would identify a phase in approach or timeline to anti-icing to assist agencies in implementing anti-icing strategies to better utilize equipment, materials and resources. The phased in approach can be used by agencies whether just getting started in anti-icing or looking to expand existing program. .

Deliverables: Guideline of Best Practices for Anti-icing

Task 4: Update the *FHWA Test and Evaluation Project No. 28, "Anti-Icing Technology, "Field Evaluation Report.* Hanover, New Hampshire, 1996. "*Manual of Practice for Effective Anti-Icing Program, A Guide for Highway Winter Maintenance Personnel.*"

Task 4.1: Review the existing resources on anti-icing and identify gaps, obsolete and new sections that should be added based on technology changes, evolving equipment, and procedures (ie. Calibration of equipment) to bring the document up-to-date. Also make recommendation on further field testing needed. The field testing should supplement what was done by U.S Army Cold Regions Research and Engineering Laboratory for FHWA Test and evaluation Project No. 28 and NCHRP Report 526 "Snow and Ice Control: Guidelines for Materials and Methods". Additional anti-icing field experiments will be identified using liquid chemicals under a variety of winter storm, roadway, and traffic conditions. Special attention should be placed on the role that traffic volumes have on anti-icing chemical treatment. Determine the number of field test sites required to effectively evaluate anti-icing in both urban and rural settings. Other conditions to consider:

- five roadway classification/ADT (5 types – super commuter, urban commuter, primary and secondary);
- roadway type and condition
- topography of land
- roadway directionality (N-S or E-W orientation);
- anti-icing material used and application rates
- environmental impact

Deliverables: Summarize anti-icing gaps, identify additional field testing needed, and portion of the document that should be updated, added or should be eliminated because they are now obsolete.

Task 5: Cost Benefit Analysis – A cost benefit analysis will be developed comparing cost of various anti-icing procedures. Both cost and benefit criteria needs to be established to quantify the benefits of anti-icing. This effort needs to be compared and coordinated with the Aurora Project 2006-03 "Update of H-350 and H-351".

Deliverable: Document cost benefit analysis of anti-icing procedures

Task 6: Final Report would include all the tasks outlined in this work scope. The report will include the uniform glossary of terms that all participants can utilize to discuss "Anti-icing Strategies".

Task 6.1: Develop a final report outline.

**Task 6.2:** Distribute draft final report for review by the taskforce members. Both an electronic and fourteen hardcopy of the draft final report will be distributed to the Clear Roads members. Taskforce member will be given ten working days to review the draft final report and provide feedback to the consultant.

Deliverable: Final Report

#### **4) What would be the product(s) of the research?**

- Summary of Literature Search
- Summary of User Assessment which outlines finding.
- Implementation Plan
- Summarize anti-icing field data gaps, identify additional field testing needed and propose potential field sites.
- Document cost benefit analysis of anti-icing procedures
- Final Report
- PowerPoint presentation

#### **5) How would the results benefit DOTs? How would they be used?**

- Training tool can be developed that would quantify benefits to operators and managers so that program would be expanded or enhanced.
- Provide guidance to manager on how to most effectively use anti-icing methods to improve winter operation.
- Provide operators with a real world guide to anti-icing so that they can deliver the most effective program.
- Produce an implementation plan to overcome barrier and inconsistencies in operating practices.

#### **6) List the estimated funding needed.**

\$100,000-150,000

#### **7) List the estimated timeline for completing the research.**

Timeframe for project: 1-1/2 to 2 years

#### **8) Are you aware of any related research on this topic? If so, please list below.**

- Katie O'Keefe, Xianming Shi, Bozeman. "Synthesis of Information on Anti-icing and Pre-wetting for winter Highway Maintenance Practices in North America" Western Transportation Institute August 2005.
- NCHRP Report 526: 2004. " Snow and Ice Control : Guidelines for Materials and Methods"
- NCHRP Report 577 "Guidelines for the Selection of Snow and Ice Materials to Mitigate Environmental Impacts" TRB 2007
- Federal Highway Administration. "Manual of Practice for Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel." Report No. FHWA-RD-95-202. June 1996
- Federal Highway Administration. FHWA Test and Evaluation Project No. 28, "Anti-Icing Technology, "Field Evaluation Report. Hanover, New Hampshire, 1996.
- Blackburn R.R., E.J. McGrane, C.C. Chappelow, D.W. Harwood, and E. J. Fleege. "Development of Anti-icing Technology". Report SHRP-H-385, national Research Council, Washington D.C., 1994.
- NCHRP Synthesis 344 " Winter Highway Operations- A Synthesis of Highway Practice" TRB 2005
- Mn/DOT's Anti-icing Guidelines and Minnesota Snow and Ice Control: Field Handbook for Snowplow Operators (2005)
- Ohio University study on snow & ice pretreatment techniques
- Cornell University Study "Liquid Anti-icing study"
- The Snowfighter's Handbook. The Salt Institute, Alexandria, Virginia, 1991.
- Boselly, S.E. and D. Ernst. "Road Weather Information Systems, Volume 2: Implementation Guide". Report SHRP-H-351, SHRP, National Research Council, Washington, DC. 1993.

- Keep, D. and Parker, D. "Proactive Guide to Snow and Ice Control: A Guide for Highway Winter maintenance Personnel" Insurance Corporation of British Columbia, Kamloops, BC. May 2000
- Liping Fu, Rudolph Sooklall, Max Perchanok. "Effectiveness of Alternative Chemicals for Snow Removal on Highways". TRB 85<sup>th</sup> Annual Meeting Compendium of Papers CD-ROM
- Gayle Mitchell, Christopher Hunt, Wallace Richardson. "Prediction of Brine Application for Pretreatment/Anti-icing". TRB 83<sup>rd</sup> Annual Meeting Compendium of papers CD-ROM
- AASHTO: 1999 " Guide for Snow and Ice Control"
- American Public Works Association, 2003. Why aren't YOU Anti-icing Yet? Five Common Excuses Debunked. American Public Works report On-line. September, 2003, Article Number 687.
- Federal Highway Administration, 2005. How do Weather Events Impact Roads. May 3, 2005.
- Salt Institute, 2005, Highway Deicing and Anti-icing for Safety and Mobility. May 3, 2005
- Salt Institute, "Salt and Highway Deicing, 2005. Winter Maintenance Command Center, the Heart of a Winter Maintenance Management System". Vol. 41, No. 1, Winter 2005.

### **Anti Icing Success Fuels Expansion of the Program in Idaho**

Breen, B., Idaho Transportation Department, March 2001

<http://www.transportation.org/sites/sicop/docs/US-12%20Anti%20Icing%20Success.pdf>

From the report:

One particular success story for ITD, related to the use of liquid magnesium chloride as an anti-icing agent, is on a section of U.S. Highway 12 in the northern part of the state. This paper summarizes the successful anti-icing program of ITD's maintenance crews from the Orofino shed.

In the wintertime, the Orofino Foreman Area operates with an eight-man crew. The main triggers for applying magnesium chloride are forecasted storms or frost events. An important part of proactive anti-icing is access to real-time pavement and weather conditions. Typically, Road Weather Information System (RWIS) roadside weather observation sites are used for the real-time weather data. However, currently there are no RWIS sites in the area for the crews to use. Although RWIS is planned for the area, currently the crews rely on the Internet to obtain area weather forecasts. The crews pre-treat ahead of the storm or frost event, typically applying about 20 to 30 gallons per lane mile. But application rates can vary from around 10 gallons to 50 gallons per lane mile depending on the forecasted weather event. A single application has remained effective for up to seven days for frost events. The length of effectiveness is highly dependent on the amount of precipitation, humidity and pavement temperature; but typically stays effective for frost for about three to four days.

Because the crews do not have RWIS to provide data on the chemical concentration on the road, they have developed their own set of indicators that enable them to retreat the road before the chemical concentration drops too low to be effective. The crews do regular checks of four indicator areas along the highway. When they see frost on the shoulder of the road starting to migrate back into the travel way, they know it is time for another application.

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Paul G. Brown, MassHighway, Paul.Brown@mhd.state.ma.us

**Title of proposed research project:**

Cost-Benefit analysis of winter maintenance practices, equipment and operations. Develop a standard method to measure the cost/benefit of adding operational components, GPS, RWIS Stations, Wings, Guidance systems. The standards will address expected service life and life cycle costs.

**1) Background:**

Agencies for the last ten years have reduced budgets and as a result every purchase has to have a cost/benefit component to every decision. The innovations in the snow and ice industry have increased exponentially and as a result agencies have to prioritize innovations. The addition of a infrared sensor has a cost/benefit ratio that can be quantified, GPS/AVL what is its value? These and many more need to be addressed to assist the program manager to make better and cost effective decisions.

**2) What is the specific problem or issue?**

The issue is that managers do not have an effective method of determining the cost/benefit of the many new innovations being developed in the snow and ice business. If a methodology was available for the manager, he or she would be able to justify to those not familiar with our industry why expenditures need to be made and the benefit they would produce. The cost saving in materials, time or equipment repair; even level of service provided.

**3) List the proposed research objectives and tasks.**

- Literature search of existing reports, data formats used in cost accounting that might be applicable to winter operations and snow removal equipment. This search should look to TRB publications and other agencies to determine if any reports exist that could be adopted.
- Work with Clear Roads states to determine the needs of the members and what could be utilized to implement and support winter operations advancements.
- Develop clear and concise methodologies and spread sheets that can be used by agencies when ordering snow and ice operations components or upgrading equipment, materials, tools and other innovations.
- Develop a strategy to transfer the technology learned from this research to manufacturers and government agencies for a national system

**4) What would be the product(s) of the research?**

A "plug and play" spread sheet or other means of helping program managers address the cost/benefit of changing winter operations, equipment, materials or tools.

**5) How would the results benefit DOTs? How would they be used?**

Development of tools for managers that could be used by all state DOTs to resolve the problem of continuously needing to spend considerable time reinventing cost accounting cost/benefit spreadsheets to justify expenditures for new methodologies and applications used in winter operations. This could then also be used to support other maintenance operations conducted during the non-winter period of time and be expanded to include other maintenance operations.

**6) List the estimated funding needed.**

\$100,000-150,000

**7) List the estimated timeline for completing the research.**

1 Year

**8) Are you aware of any related research on this topic? If so, please list below.**

Not aware of any at this time.

**Business Case for Winter Maintenance Technology Applications: Highway Maintenance Concept Vehicle**

Transportation Research Circular E-C063 - Sixth International Symposium on Snow Removal and Ice Control Technology, June 2004

Kroeger, D. and Sinhaa, R., Iowa State University

<http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf>

From: the opening statement (page 332 of the PDF) –

The use of commercial off-the-shelf and prototype technologies to improve winter maintenance operations has been in practice for several years; however, it has been difficult to quantify the benefits achieved by adopting these technologies. This paper documents the business case to be made for the technology applications on the Highway Maintenance Concept Vehicle project by examining the business implications of many benefits such as increased safety, reduced environmental impacts and increased efficiency. A benefit-cost framework is established whereby the current methods of performing the analysis can be compared with other proposed winter maintenance technology improvements.

From: Methodology (page 335 of the PDF) –

The methodology for conducting the BCA is based on the guidelines outlined for generally accepted practices for federal projects and on the “Benefit/Cost Analysis of ITS Applications for Winter Maintenance” conducted by Stowe.\* With information obtained from DOT officials from the Washington and Arizona DOTs, it was established that the benefit-cost worksheet for collision reduction was an appropriate and a valid tool in computing the benefits and costs for collision reduction.

\*Stowe, R. D. Benefit-Cost Analysis of Intelligent Transportation System Applications for Winter Maintenance. Presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C., 2001.

**Benefit/Cost Study of RWIS and Anti-icing Technologies: Final Report**

Boselly, S.E., Weather Solutions Group (prepared for NCHRP), March 2001

<http://www.transportation.org/sites/sicop/docs/NCHRP20-7%28117%29.pdf>

From: Abstract (page 5 of the PDF) –

This report describes RWIS and anti-icing research, implementation efforts by highway agencies, and summarizes the current practice of anti-icing technology. The benefits and costs of RWIS and anti-icing, as reported in the literature and supplemented with information provided in interviews of highway professionals, are outlined. Conclusions and recommendations regarding anti-icing and RWIS use are also presented.

From: Chapter 5, Benefits/Costs of Anti-icing/RWIS, RWIS Cost Savings (page 20 of the PDF) –

In the SHRP RWIS investigation a benefit-cost model was developed to show the potential return on the investment for RWIS in terms of a benefit/cost ratio.\* Model inputs included the cost of RWIS hardware and weather forecasting services; the road network being maintained; and the labor, equipment and material costs for snow and ice control. The model was run using variations in forecast accuracy above a baseline level of 50% accuracy. The model used an initial RWIS procurement in Washington State and the in-place system in the Denver area as examples. Washington State DOT purchased five systems to test in the Seattle metropolitan area while the Colorado DOT had installed 14 systems at that time in the Denver area. The model results showed a B/C of 5.0 for the Seattle area system and a 1.1 for the Denver system. The difference in the results was basically a function of the cost of the hardware purchased.

\*Boselly, S. "A Benefit-Cost Assessment of the Utility of Road Weather Information Systems for Snow and Ice Control," Transportation Research Board, January 1992.

Minnesota DOT investigated the development of a statewide RWIS in the mid-1990s. Even though Mn/DOT initially planned a system of approximately 270 sites, the agency calculated that the savings in winter maintenance would amortize the fully loaded (included projected communications, maintenance and training costs as well as hardware costs) system cost in six years. Over the next few years, FHWA asked agencies to document cost savings from RWIS. Table 2 provides a list of RWIS cost savings documented in articles and FHWA Technical Briefs. All of the articles related to RWIS mentioned cost savings. Only those with actual cost savings are listed.

**Table 2**

Agency	Publication Reference	Cost Savings
Maryland DOT	[13]	MD projects a \$4.5M system will pay for itself in 5-7 years just with reduced standby time.
Massachusetts Highway Department	[14]	1. Saved \$53K in first year with nine RWIS in Boston area; \$21K in one storm alone. 2. Estimated savings of \$150-\$250K over a typical Boston winter.
Minnesota DOT	[15]	Estimates a 200-1300 percent return on the investment.
Nevada DOT	[16]	Projects a \$7M savings over 25 years in the Lake Tahoe basin area due to reduce chemical usage, more efficient scheduling, and less damage to vegetation.
New Jersey DOT	[17]	Agency has cut snow and ice costs 10-20 percent or more.
North Dakota DOT	[18]	Saved \$10K-\$15K on one bridge in 4 storms with reduced sand usage.
Texas DOT	[19]	Savings in labor, equipment, and materials in the first two or three storms paid for the RWIS installations
West Virginia	[20]	1. Saved \$2,300 per storm in labor. 2. Saved \$6,500 of salt per storm. 3. Estimate \$200K/yr savings for typical winter weather 4. Paid for the RWIS in one year.





# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Mike Sproul, WisDOT, michael.sproul@dot.state.wi.us

**Title of proposed research project:**

Friction and anti-icing surface treatment study

**1) Background:**

Vendors contact us with the latest in friction treatments and anti-icing overlays but where is the evidence of what really works?

**2) What is the specific problem or issue?**

Too many choices and not enough research and field testing.

**3) List the proposed research objectives and tasks.**

Install all the various treatments on one section of roadway and look at them side by side.

**4) What would be the product(s) of the research?**

Results on how the products last and how much is the life cycle cost.

**5) How would the results benefit DOTs? How would they be used?**

It would help us decide on what treatments to go with.

**6) List the estimated funding needed. \$\$\$\$**

Maybe we could get each vendor to donate some of their product for the study.

**7) List the estimated timeline for completing the research.**

5 years

**8) Are you aware of any related research on this topic? If so, please list below.**

**An Analysis of the Performance of the Safelane™ Overlay During Winter 2005-06**

Nixon, W., Asset Insight Technologies, April 2006 (prepared for Cargill)

<http://www.cargillsafelane.com/documents/Nixon%20Cargill%20Safelane%20report1.pdf>

From: Introduction (page 1 of the PDF) –

Prior to the 2005-06 winter season, a pavement overlay product, Safelane™, was installed at eight locations around the United States. In 2003, the overlay had been installed at one single location for lengthier testing. The overlay uses a special aggregate that acts, together with an adhesive, in a sponge-like manner such that when an anti-icing liquid is applied to the surface, it is retained for a significant portion of time (typically, many days) and remains effective as an anti-icing chemical during that time. From a winter maintenance perspective, the purpose of the testing was twofold. The first goal was to determine the extent to which the overlay would extend anti-icing chemical effectiveness. In some of the installations, this goal was further refined to indicate a desire for reduction of accidents, a normal beneficial outcome of successful anti-icing activities. A second goal was to determine whether there were any unforeseen problems arising with the use of the product. The different locations allowed the product to be evaluated under a number of different conditions, including not only bridges, but also on- and off-ramps.

From: Conclusions (page 13 of the PDF) –

Observations at these sites allow the following preliminary conclusions to be made:

- The SafeLane™ overlay did not cause any problems with winter maintenance. In particular, no concerns with chemical slickness or slipperiness arose even though chemical was applied on some occasions under weather conditions where such slickness might have been a concern.
- Test sections remained clear of snow or ice under weather conditions when snow and ice were accumulating on control sections. In some circumstances these accumulations on control sections were sufficient to contribute to crashes.
- When accumulation did occur on the test sections, bonding of snow and ice to the pavement was not observed, and the accumulation could be controlled by plowing and application of chemicals. Further, the quantity of chemicals needed to obtain these good conditions was less on the test sections than on the control sections.
- One implication of the above two points is that SafeLane™-treated segments of the highway infrastructure maintained mobility longer, and could be returned to full mobility more easily than non-treated sections.
- A second implication of these two points is that bare pavement conditions could be maintained on the test sections with approximately 50% of the chemicals applied to control sections.
- While the data are preliminary, there is evidence that the improved performance of the SafeLane™ overlay under winter conditions discussed above does indeed translate into safety improvements for the traveling public.

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Mike Sproul, WisDOT, michael.sproul@dot.state.wi.us

**Title of proposed research project:**

Safe Winter Driving Campaign – Focus Groups

**1) Background:**

In Wisconsin when we did a follow up of our campaign with focus groups specifically to see if the public was getting the message and if they were, was it changing their behavior. I'd like to look at what all the states are doing with the "ice and snow, take it slow" campaign and research the best way to get the message out.

**2) What is the specific problem or issue?**

What is the best method to get out a national message concerning winter safety.

**3) List the proposed research objectives and tasks.**

- Identify what each state is doing
- Design questionnaires and conduct focus groups in each state
- Report the findings

**4) What would be the product(s) of the research?**

Recommendation as to where money should be spent on campaigns within each state.

**5) How would the results benefit DOTs? How would they be used?**

We would better focus our limited budget to get the most bang for the buck with our safe winter driving campaign.

**6) List the estimated funding needed.**

About \$10k per state.

**7) List the estimated timeline for completing the research.**

3-4 months

**8) Are you aware of any related research on this topic? If so, please list below.**

Wisconsin has an example of what was done when they last developed a campaign

A limited search of the Internet (utilizing the Google State DOT search engine) indicates that the following state DOTs are utilizing "Ice & Snow... Take It Slow" campaign materials:

Colorado- materials are utilized on the Winter Driving Web page, and include: logo, slim card handout, 8x10.7 poster, driving safety tips PSA, safety around snowplows PSA, preparing for a trip PSA.

<http://www.dot.state.co.us/travelinfo/winterdriving/Publications.cfm>

Iowa- materials are utilized on the Safe Winter Driving Tips Web page, and include: logo, driver behavior messages (reduce speed, safe travel around snowplows, driving maneuvers, trip preparedness).

<http://www.dot.state.ia.us/maintenance/internetpages/safedrives/trips/safewinterdriving.htm>

Michigan- links to the large and small “reduce your speed, travel safely, be prepared” posters are provided as part of a news announcement about the campaign.

<http://www.michigan.gov/mdot/0,1607,7-151--180917--,00.html>

Missouri- materials are utilized on a dedicated “Ice and Snow...” Web page, and include: logo, grey scale logo, several public safety announcements (abbreviated), all of the ad slick samples, three of the posters.

[http://www.modot.org/road\\_conditions/IceandSnow.htm](http://www.modot.org/road_conditions/IceandSnow.htm)

Nevada- materials are utilized for Winter Driving Tips and Winter Driving Brochure Web pages, and include: logo, and all driver behavior messages.

<http://www.nevadadot.com/safety/winter/tips.asp>

<http://www.nevadadot.com/safety/pdfs/winterdrivinginfo.pdf>

Ohio- logo is utilized in an employee newsletter announcement about the campaign. Materials are utilized on a dedicated “Ice and Snow...” Web page, and include: logo and all driver behavior messages, and a link to the slim card. Logo is also utilized in an Ohio winter weather history article.

<http://www.dot.state.oh.us/PressRoom/Transcript/Transcript-Oct07.pdf>

<http://www.dot.state.oh.us/ice%2Bsnow/>

<http://www.dot.state.oh.us/dist3/ddd/pio/Press/Winter%20Weather%20History.pdf>

Rhode Island- driver behavior messages (reduce speed, trip preparedness) appear to have been utilized in a RIDOT snowstorm news release.

<http://www.dot.state.ri.us/news/pages/dispNews.asp?id=354>

Washington State- materials are utilized on the Winter Travel Web page, and include: logo, and all driver behavior messages. A link is provided to a specially designed “Safe Winter Driving Tips” brochure.

<http://www.wsdot.wa.gov/winter/>

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Mike Sproul, WisDOT, michael.sproul@dot.state.wi.us

**Title of proposed research project:**

The true costs/benefits of anti-icing

**1) Background:**

Thus far it's been difficult to get and information on the benefits of anti-icing. Most information is anecdotal and therefore difficult to sell to the operators.

**2) What is the specific problem or issue?**

We haven't been able to convince our entire operation that anti-icing is a benefit. Thus not all of them are doing it.

**3) List the proposed research objectives and tasks.**

- Literary search
- Data collection
- Report writing

**4) What would be the product(s) of the research?**

Report on the costs/benefits of anti-icing.

**5) How would the results benefit DOTs? How would they be used?**

Results would be used to develop policy.

**6) List the estimated funding needed.**

**7) List the estimated timeline for completing the research.**

3-4 months

**8) Are you aware of any related research on this topic? If so, please list below.**

Yes but not specific to actually quantifying the results of anti-icing. Most operations can supply the costs but I don't know if anyone has been able to quantify the benefits or cost savings.

**Benefit/Cost Study of RWIS and Anti-icing Technologies: Final Report**

Boselly, S.E., Weather Solutions Group (prepared for NCHRP), March 2001

<http://www.transportation.org/sites/sicop/docs/NCHRP20-7%28117%29.pdf>

From: Abstract (page 5 of the PDF) –

This report describes anti-icing and RWIS research, implementation efforts by highway agencies, and summarizes the current practice of anti-icing technology. The benefits and costs of anti-icing and RWIS, as reported in the literature and supplemented with information provided in interviews of highway professionals, are outlined. Conclusions and recommendations regarding anti-icing and RWIS use are also presented.

From: Chapter 5, Benefits/Costs of RWIS/Anti-icing (page 27 of the PDF) –

Anti-icing has its own associated cost savings. Table 3 provides stated cost savings associated with anti-icing obtained from the FHWA Winter Maintenance Clearinghouse documents.

**Table 3**

Agency	Publication Reference	Cost Savings
Colorado DOT	[21]	Sand use has decreased 55 percent. All costs considered, winter operations now cost \$2,500 per lane mile versus \$5,200 previously.
Kansas DOT	[22]	Saved \$12,700 in labor and materials at one location in the first eight responses using an anti-icing strategy.
Oregon DOT	[23]	Reduced costs for snow and ice control from \$96 per lane mile to \$24 per lane mile in freezing rain events.
Washington DOT	[24]	Save \$7,000 in labor and chemicals for three test locations.
ICBC (Insurance Corporation of British Columbia)	[25]	<ol style="list-style-type: none"> <li>1. Accident claims reduced 8% on snow days in Kamloops, BC; estimated savings to ICBC \$350,000-\$750,000 in Kamloops</li> <li>2. Potential annual savings of up to \$6 million with reduced windshield damage.</li> </ol>

As the North Central Region of Washington State DOT transitioned to anti-icing, it made a concerted effort to try to document savings over the 1991-2000 winter. Table 4 provides documented savings identified by separate area superintendents and shed supervisors for pretreatment anti-icing activities in the NCR. The information was obtained from an April 2000 post-winter meeting held in Wenatchee, WA.

**Table 4**

Location	Savings
Wenatchee	Used 64% more liquid but 70% less sand compared to the 3-year average. \$23,000 savings on the books.
Leavenworth	<ol style="list-style-type: none"> <li>1. Blewett Pass shed: Reduced sand usage from 12,000 yd average to 4,000 yd. Also less accidents, less overtime.</li> <li>2. Scenic shed: 5000 yd sand cut down to 2600 yd.</li> <li>3. Stevens Pass shed: Less tort claims, less guardrail damage.</li> <li>4. Leavenworth shed: Eliminated need to clean up sand; removed impact on salmon</li> </ol>
Moses Lake	<ol style="list-style-type: none"> <li>1. Moses Lake Area: Able to use contingency shifts with four 10-hr shifts. Eliminated weekend work and overtime and freed personnel to do other highway maintenance. Less facility damage repair.</li> <li>2. Moses Lake and Othello sheds: Lowest cost per lane mile for snow and ice control in Eastern Washington. Accident rates way down.</li> </ol>
Omak	<ol style="list-style-type: none"> <li>1. Okanogan shed: Less sand used, accident rates way down.</li> <li>2. Twisp shed: Cut sand usage by 1/3; reduced tort claims.</li> <li>3. Electric City: Saved call out and overtime during weekends and the holidays.</li> </ol>

From: Chapter 6, Conclusions and Recommendations (page 33 of the PDF) –  
Anti-icing can reduce costs of providing a specified level of service. Based on the surveys and interviews, savings of 10 to 20% of an agency’s snow and ice control budget can be realized once fully implemented. Snow and ice control costs per lane mile can be reduced up to 50%.

### **Anti-icing and Pre-wetting: Improved Methods for Winter Highway Maintenance in North America**

O’Keefe, K. and Shi, X., Western Transportation Institute, Montana State University  
Paper submitted for presentation at TRB 85<sup>th</sup> Annual Meeting, January 2006  
Refer to the attached PDF.

Through a project with the Pacific Northwest Snowfighters Association, the authors synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion and costs. The research indicates that compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction and lower accident rates.

Pertinent excerpts include –

[Page 5 of the PDF]

When applied correctly, anti-icing can reduce plowing time and decrease the quantity of chemicals used.\*

\*United States Environmental Protection Agency. Stormwater Management Fact Sheet – Minimizing Effects from Highway De-icing. Office of Water, EPA 832-F-99-016, 1999.

[Page 8 of the PDF]

Both anti-icing and pre-wetting are efficient means of winter maintenance and have been found to decrease maintenance costs while reducing the vulnerability of the highway system to winter weather. In Washington State, the implementation of anti-icing in the North Central Region has resulted in improved level-of-service at the same cost as previous maintenance practices.\* Other benefits include: improved winter driving safety, reduced environmental impacts, reduced human health impacts, and reduced corrosion effects.

\*Boon, C.B. and Cluett, C., *Road Weather Information Systems: Enabling Proactive Maintenance Practices in Washington State*. [http://www.its.dot.gov/JPODOCS/REPTS\\_TE/13660.html](http://www.its.dot.gov/JPODOCS/REPTS_TE/13660.html)

Overall, maintenance agencies are confident that pre-wetting strategies significantly improve material retention and speed up the melting process. Pre-wet abrasives will refreeze quickly to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50% in cold temperatures.\*

\*Williams, D. *Past and Current Practices of Winter Maintenance at the Montana Department of Transportation (MDT)*. White Paper, Prepared December 2001, updated December 2003.

[Page 10 of the PDF]

The research indicates that agencies see cost savings derived from anti-icing and pre-wetting practices for snow and ice control. Overall, agencies felt that they were able to apply less material and clear the roads faster without the need for overtime. One agency reported that “trucks are off and parked 20% faster than the ones not using liquid.”\*

\*Lupton, W., Colorado Department of Transportation, Personal Communication, April 2005.





# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Mike Sproul, WisDOT, michael.sproul@dot.state.wi.us

**Title of proposed research project:** The use of sand for winter maintenance

**1) Background:**

Our counties still use sand on the highways and claim that it is useful. We've been trying to get them away from using it.

**2) What is the specific problem or issue?**

Would like to see definitive proof on whether or not sand does anything. Would also like to see the real costs associated with using sand.

**3) List the proposed research objectives and tasks.**

- Friction testing of sanded surfaces at different intervals after application
- Testing on different volume type highways
- Detail cost analysis
- Real world case study
- Accident analysis

**4) What would be the product(s) of the research?**

A report detailing the outcomes.

**5) How would the results benefit DOTs? How would they be used?**

We would use the results in policy development.

**6) List the estimated funding needed.**

**7) List the estimated timeline for completing the research.**

- 2-3 months of data collection
- 1 month for report

**8) Are you aware of any related research on this topic? If so, please list below.**

Yes, but they are sketchy, relatively old, and anecdotal.

**Effects of Winter Weather and Maintenance Treatments on Highway Safety**

Fu, L., Shah, Q.A. and Moreno, L.F.M., University of Waterloo; and Perchanok, M., Ontario Ministry of Transportation

Paper submitted for presentation at the TRB 85<sup>th</sup> Annual Meeting, January 2006

Refer to the attached PDF.

Two highway routes from Ontario, Canada were selected and data on daily accident occurrences, weather conditions and winter maintenances operations were obtained for this analysis. A statistical analysis was performed on the integrated dataset with the goal of identifying those weather and maintenance factors that had a significant impact on crash frequency. Sanding operations were found to have a positive effect on the safety at both maintenance routes.

### **The Use of Abrasives in Winter Maintenance: Final Report of Project TR 434**

Nixon, W., Iowa Department of Transportation and Iowa Highway Research Board, March 2001

<http://www.transportation.org/sites/sicop/docs/Abrasives%20report.pdf>

From: Chapter 1, Introduction (page 6 of the PDF) –

This report reviews the state-of-the-practice of abrasive usage in Iowa counties. Chapter 2 presents a complete review of the published literature, discussing how various factors (for example, amount of sand, temperature, type of sand) influence the friction experienced after an application of abrasives. It will become apparent from Chapter 2 that when placed “dry” on the road surface (that is, without significant pre-wetting at the spinner) abrasives provide at best a very short-term increase in road surface friction, especially on roads where vehicle speeds are typically high (greater than 30 mph or 48 kph).

From: Chapter 2, Previous Studies on Abrasive Usage, Cost Benefit Analysis (page 10 of the PDF) –

A study by Kuemmel and Bari (1996) examined how cost effective it was to use either abrasives or a salt-abrasive mixture for winter maintenance. This study built off an earlier study (Kuemmel and Hanbali, 1992) which examined the cost benefits of using salt (not mixed with abrasives) for winter maintenance purposes. The benefit/cost ratio of using straight salt was 12:1 for two lane highways and 3:1 for freeways (divided highways). In contrast, the benefit/cost ratio for abrasives and salt/abrasive mixtures on two lane highways was 0.8:1. In other words, the use of abrasives or salt/abrasive mixtures is not economically justifiable for two lane highways.

### **Braking Traction on Sanded Ice**

Borland, S. and Blaisdell, G., U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, 1992

Refer to the attached PDF.

This paper describes an evaluation of traction enhancement on iced pavements using abrasives. The abrasives tested were five distinct gradations of sand built from a single host material. Four of the sands represented standard gradations as specified by the FAA, SAE, ASTM and Transport Canada. Braking traction at a relatively fixed slip rate was measured with a full-size, self-contained instrumented vehicle. All tests were performed on an ice sheet inside a large refrigerated room. Results showed that coarse sands perform best on cold ice surfaces and that finer sands excel on warm ice. Sands with most of their grains about 1 to 2 mm in diameter performed well independent of ice temperature. The concentration of a sand on ice strongly influences the degree of traction enhancement, as does the temperature of the sand when applied to the ice. The results suggest that a mathematical expression could be generated that would relate sand type and concentration, along with several other influential parameters, to braking traction coefficient on ice.

### **Implementation of New Sanding Method in Norway**

Vaa, T., SINTEF Roads and Transport

Transportation Research Circular E-CO63 -- Sixth International Symposium on Snow Removal and Ice Control Technology, June 2004

<http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf>

From: the introductory statement, page 482 of the PDF –

One of the main achievements in the Winter Friction Project in Norway has been the development of a new sanding method based on a mix of hot water and sand. Scientific studies have revealed that maintenance measures carried out with the new sanding method last longer than traditional sanding methods. It has been proved that by adding warm water to the sand it is easy to maintain a friction level above the standard even after the passage of 2,000 vehicles. Under favorable road and weather conditions, satisfactory friction values have been maintained for up to three to seven days on roads with annual average daily traffic of 1,500 vehicles.

# 2008 Clear Roads Research Proposal Form

**Proposer name, organization and e-mail address:**

Shane Larson, IL Department of Transportation (IDOT), shane.larson@illinois.gov

**Title of proposed research project:**

Development of a standard storm severity index and snow and ice removal performance standard.

**1) Background:**

Several states have developed storm severity indexes and performance standards.

**2) What is the specific problem or issue?**

A performance standard for snow and ice removal activities is needed. With the use of numerous different deicing chemicals, techniques and equipment, it would be beneficial for agencies to be able to accurately determine their performance. The different weather conditions have to be taken into account when determining performance; therefore, it is important that a standard storm severity index is also developed along with the performance standards.

**3) List the proposed research objectives and tasks.**

The primary objectives would be to develop an automated method to accurately determine storm severity indexes along with a standard performance measures.

**4) What would be the product(s) of the research?**

The research would provide an automated method to calculate storm severity indexes and performance measures after each winter event.

**5) How would the results benefit DOTs? How would they be used?**

Storm Severity Indexes and performance measures are currently being used throughout the United States. The data to calculate these items is being collected manually and often inaccurately. The results of this research could provide an automated collection and calculation of storm indexes and snow and ice removal performance measures. An accurately calculated performance measure will assist DOTs determine the effectiveness of their snow and ice removal operations.

**6) List the estimated funding needed.**

\$200,000

**7) List the estimated timeline for completing the research.**

18 to 24 months.

**8) Are you aware of any related research on this topic? If so, please list below.**

**Developing a Storm Severity Index**

Nixon, W. and Qiu, L., University of Iowa

TRB Transportation Research Record 1911, 2005, pages 143 to 148

Refer to the attached PDF.

From: introductory comments (page 1 of the PDF) –

The purpose of this paper is to develop an algorithm that evaluates to what extent an individual storm poses difficulty to maintenance activities. Three steps will be taken in this development:

- Various storms have been classified by six factors.
- A multiple regression model has been built to produce a storm severity index between 0 and 1.

- Representative storms have been ranked in severity by winter maintenance personnel and the model has been modified to reflect this ranking.

The storm severity index thus produced can be used as an objective measure of the challenge that an individual storm poses to a maintenance agency.

From: Results (page 5 of the PDF) –

From the regression model developed, given as Equation 1, and the assigned values as shown in Table 1 (inside parentheses), the storm severity index for 252 different storms can be provided from 0 to 1, with 0 indicating a very mild storm and 1 indicating a very severe storm. The distribution of storm severity index is plotted in Figure 3, which confirms that the computed results accord approximately with a normal distribution. Table 4 shows 10 storm scenarios derived from Figure 2, with their associated storm severity indices. The index can be used to measure the performance of an agency in handling a given storm and thus represents an important part of a quality control process for winter maintenance.

Literature Search Attachments  
for 2008 Problem Statements



## Research Product Announcement

# Snow Plow Wear Sensor

*Every year thousands of dollars are used to repair snowplows in the State of New Mexico. The down time for the truck and operator can be several days. This always happens when the snowplows are needed most.*

The New Mexico State Highway and Transportation Department's Research Bureau developed a Snow Plow Wear Sensor.

The Snow Plow Wear Sensor activates a light indicating that the snowplow bits have worn down. The snowplow operator no longer has to check the snowplow bits every 50-100 miles. The Snow Plow Wear Sensor increases safety while it decreases maintenance costs!

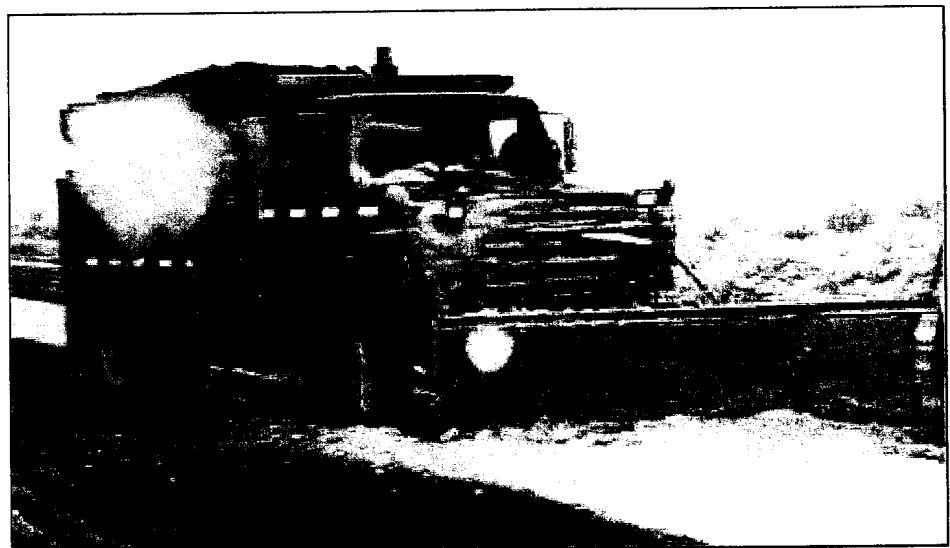
The Snow Plow Wear Sensor is:

- ✓ Easy to Install
- ✓ Easy to Maintain
- ✓ Easy to Use

Using the Snow Plow Wear Sensor Results in:

- ✓ Decreased Maintenance Costs
- ✓ Increased Safety – Less Operator Checks
- ✓ Increased Snow Plow Life

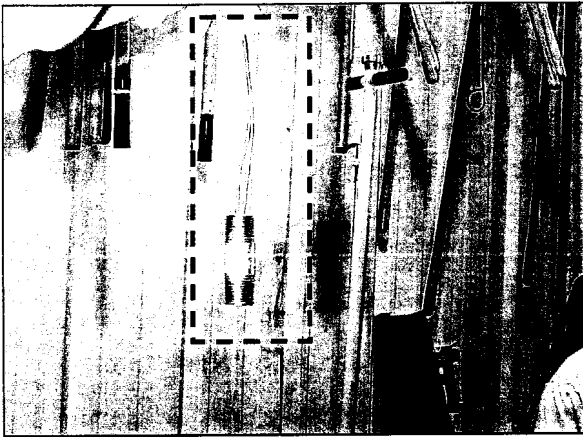
This product was a cooperative effort between the New Mexico State Highway and Transportation Department's District 5 – Dulce patrol, University of New Mexico's ATR Institute, and the Research Bureau.



**Maintenance**

## Parts List for Constructing a Snow Plow Wear Sensor

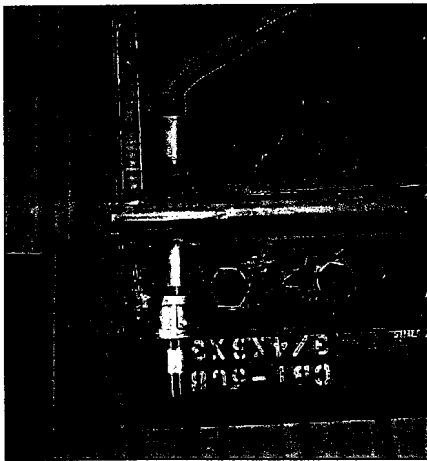
1. Female disconnects (insulated), gauge 22-18, stud ¼" (1 package)
2. Female disconnects (insulated), gauge 16-14, stud ¼" (1 package)
3. Butt connectors (insulated), gauge 16-14 (1 package)
4. Butt connectors (insulated), gauge 22-18 (1 package)
5. Female and male (terminal tower) weatherproof automotive connectors (2 each)
6. One (1) relay switch (R51-5D40-12), 12-volt dc-SPDT
7. One (1) strobe light, 12-volt dc
8. Two part epoxy (1 package)
9. One (1) roll 100 ft. 18 AWG 300-volt Solid
10. One (1) roll 100 ft 20 AWG 300-volt Solid
11. One (1) roll electrical tape
12. One (1) roll duct tape
13. 1 3/8" steel pipe nipple (length to be determined by type of mold board used)
14. 1 3/8" x 2" steel pipe nipple (for sensor)
15. 1 3/8" female union connector
16. Black 1/2" wire protector



1

### Making of Sensor

Take 1 3/8" x 2" steel pipe nipple and make a cut 1/2" from the bottom that extends halfway through the pipe (this is so the sensor will break when the blade is ground to that point). Cut should face forward. Take approximately 20 inches of 20-gauge wire and stick inside the pipe, looping it so that the looped end is flush with the bottom of the pipe. At that end of the pipe, place a piece of duct tape over the opening so that the epoxy (that will be inserted later) won't fall through. Fill entire length with epoxy and let dry. Final product is depicted in Figure 1.



2

### Mold Board Preparation

In bottom corner of mold board, cut a hole wide enough for 1 3/8" steel pipe nipple (length to be determined by type of mold board used) to fit through and be welded in place (see Figure 2).



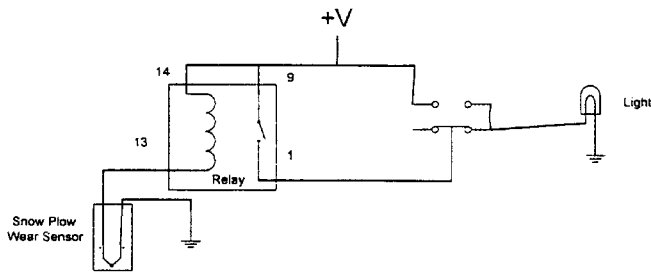
3

### Placement of Sensor on Plow

Then attach the female union connector to bottom of pipe. Attach sensor to bottom of union. Bottom of sensor should be roughly 1 inch above the bottom of carbide blade as shown in Figure 3. Make adjustments as needed. Note: Use Locktight for threads.

## Maintenance

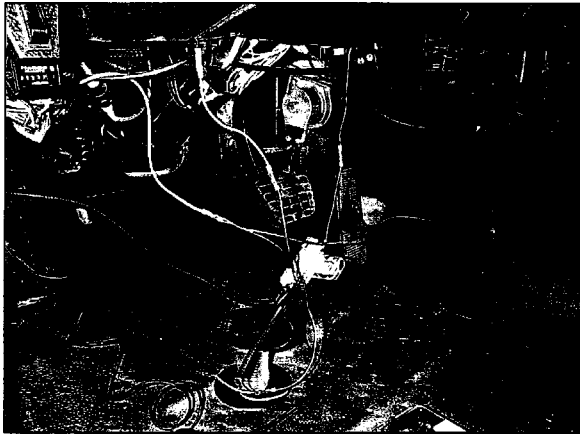




### Truck Wiring Schematic

Follow schematic that is given to properly install wiring harness in truck.

4



### Light and Switch Placement

Relay, light, and switch should be mounted within the cab itself. Light for truck should be mounted in an easily visible location that is out of the way. Switch for turning off the light should be mounted in easily accessible location (see Figure 4).

5



### Wiring from Plow to Truck

Route wiring around the rear of the mold board in such a way that it will not get damaged by movement of the plow (see Figure 5).

6

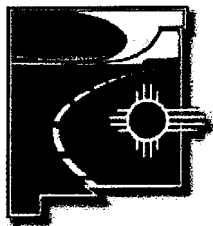


### Final Placement of Wiring

Use weatherproof connectors to attach plow wiring to truck wiring (see Figure 6).

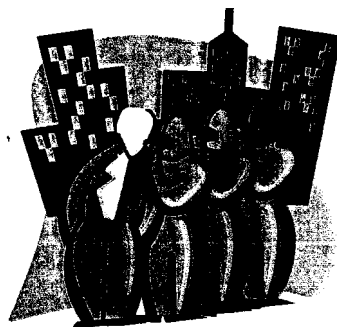
## Maintenance

# New Mexico State Highway and Transportation Department RESEARCH BUREAU



Committed to improving transportation for the people who reside in and travel to and through our State, the Research Bureau has an important role in helping realize this commitment. We identify transportation needs, then develop and assess technologies, procedures, and policies with the potential to meet those needs.

We have a talented staff of researchers who listen and respond to the concerns of persons in our Department and individuals in communities across the State. These are our primary customers. They know the transportation problems because they experience them every day. Our researchers work to understand their problems, consider alternative approaches, then develop, test, and evaluate the research. Our research products are the result of a close working relationship with our customers.



All of our activities are in partnership with the Federal Highway Administration. The FHWA – New Mexico Division Office, located in Santa Fe, provides guidance and financial support to our work.

**FHWA**

Each year we invite individuals from across the state to the Research Bureau's Research Quality Initiative (RQI). At the RQI we gather suggestions for research projects such as the Snow Plow Sensor. The Research Bureau displays products throughout the year in our Research Products Room, as well as in Roswell at the annual Equipment Rodeo.

## Research Participants in the Development of this Product

NMSHTD–District 5, Dulce Patrol: Jose Avalos, Gilbert Garcia, Napoleon Garcia, Patrick Hinds, Mark Montano, and Isaac Sedillo.

ATR Institute: Ken Martinez and Gordon McKeen.

NMSHTD–Research Bureau: Chuck Slocter.

For more information:

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New Mexico State Highway and Transportation Department  
1001 University Boulevard SE, Suite 103  
Albuquerque, NM 87106  
Telephone: 505 246-6410 Fax: 505 246-6221

**Maintenance**

**Research Project NM98MNT-01**

## **Simulation Study of a Bus Signal Priority Strategy Based on GPS/AVL and Wireless Communications**

### **Chen-Fu Liao\***

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**ABSTRACT**

Providing signal priority for buses has been proposed as an inexpensive way to improve transit efficiency, productivity and reduce operation costs [1]. Bus signal priority has been implemented in several US cities to improve schedule adherence, reduce transit operation costs, and improve customer ride quality [2]. Current signal priority strategies implemented in various US cities mostly utilize sensors to detect buses at a fixed or preset distance away from an intersection. Traditional presence detection systems, ideally designed for emergency vehicles, usually send signal priority request after a preprogrammed time offset as soon as transit vehicles were detected without the consideration of bus readiness. The objective of this study is to take advantage of the already equipped GPS/AVL system on the buses in Minneapolis and develop an adaptive signal priority strategy that could consider the bus schedule adherence, its number of passengers, location and speed. Buses can communicate with intersection signal controllers using wireless technology to request signal priority. Communication with the roadside unit (e.g., traffic controller) for signal priority may be established using the readily available 802.11x WLAN or the DSRC (Dedicated Short Range Communication) 802.11p protocol currently under development for wireless access to and from the vehicular environment. This paper describes our proposed priority logic, and its evaluation using microscopic traffic simulation. Simulation results indicate that a 12-15% reduction in bus travel time during AM peak hours (7AM-9AM) and 4-11% reduction in PM peak hours (4PM-6PM) could be achieved by providing signal priority for buses. Average bus delay time was reduced in the range of 16-20% and 5-14% during AM and PM peak periods, respectively.

**KEYWORDS**

Transit Signal Priority, GPS/AVL, Wireless Communication, Vehicle to Roadside Communication

## INTRODUCTION

Signal Priority for transit has been studied and proposed as an efficient way to improve transit travel and operation. Bus signal priority has been implemented in several US cities to improve schedule adherence, reduce transit operation costs, and improve customer ride quality. Signal priority strategies have helped reduce the transit travel time delay, as discussed in the literature [1], but the transit travel time reduction varies considerably across studies [2]. Unlike signal preemption, which interrupts normal intersection signal process to provide high priority for special events (emergency vehicle or railroad crossing), transit signal priority (TSP) modifies the normal signal operation in order to accommodate better service for transit vehicles [3].

Metro Transit in Twin Cities Metro area (<http://www.metrotransit.org/>) previously performed an evaluation of providing signal priority for buses on Lake Street in Minneapolis, using Opticom™ systems [4]. A special software modification was made to provide transit priority using green extension and red truncation strategies. However, the Opticom™ system, ideally designed for emergency vehicle preemption (EVP), was not able to adjust the trigger timing for buses approaching nearside bus stops, and buses often missed the priority green period when they were ready to depart. Since several intersections along Lake Street were already operating at their capacity. The potential for providing transit priority without delaying vehicle traffic was somewhat constrained. There were also issues of buses traveling across different municipalities that were unwilling to provide signal priority. Results from the previous evaluation study were not promising.

Bus signal priority has also been implemented in several US cities (Seattle, Portland, Los Angeles, and Chicago) as well as in Europe. Various technologies have been deployed for bus priority including Opticom™ (St. Cloud) [5], Loopcom (Los Angeles), and RF tag (Seattle, King County) [6]. Recently, Crout [7] at Tri-County Metropolitan Transportation District of Oregon (TriMet) proposed two types of analyses (corridor and intersection level) to evaluate the effectiveness of the TSP effort on transit operations over 300 signals implemented with signal priority.

With the installation of GPS system on its fleet, Metro Transit now constantly monitoring buses locations in relation to their schedules, in order to provide more reliable transit services and enhance transit operation and management. Bus location, travel time information and other traffic information can also be integrated and provided for traffic operations or to the traveling public. Metro Transit would prefer to use the already installed GPS/AVL system as the basis of a TSP system. Current signal priority strategies implemented in various US cities mostly utilize sensors to detect buses at a fixed or at a preset distance away from the intersection. Signal priority is usually granted after a preprogrammed time-offset, after detection. Engineers usually have to adjust the detector location, receiver line of sight and timing offset for each intersection in order to ensure its effectiveness. These TSP strategies do not consider the bus's speed and its distance from intersection when determining the appropriate time to request signal priority.

Wireless communications systems have made rapid progress and are commercially available. Bus information (e.g. speed, location, number of passengers, bus ID) can be transmitted wirelessly to a traffic controller or to a regional Traffic Management Center (TMC) for making decisions for signal priority. There are several wireless communication systems installed on each bus under the current Metro Transit setup. An 800-MHz Motorola digital voice radio is used for communication between bus driver and Transit Control Center (TCC). Another 800-MHz analog data radio is used to poll bus location and passenger count data every minute. A Wireless Local Area Network (WLAN) 802.11x is also installed on the bus. This is used to upload/download files between the bus and the TCC central server, when the bus is within the proximity of the transit garage.

Los Angeles County Metropolitan Transportation Authority (MTA) has implemented wireless technology in a transit signal priority system along a corridor using IEEE 802.11b standard [29]. The wireless card on each bus sends IP addressable message to an access point which covers 3~4 intersections. A wireless client installed in the signal cabinet communicates with modified traffic controller to request for signal priority. King County MTA in Washington is also designing wireless TSP system similar to that in LA County.

### Literature Review

A research group at California PATH (Partners for Advanced Transit and Highways) is pursuing a study titled "Adaptive Bus Signal Priority" (ABSP) to apply an active priority strategy for buses, by including bus GPS

information, traffic detector data, and a travel-time predictor to an adaptive model [8]. Yin et al proposed a heuristic TSP algorithm to provide signal priority to buses as well as limit negative impact on cross-street traffic [9]. Traditional TSP strategies implemented in other cities are fixed-location detection systems and implemented with time-of-day signal control systems. TSP systems using fixed-location detection mostly do not work well with nearside bus stops, due to the uncertainty in bus dwell time. Kim and Rilett [10] proposed a weighted least squares regression model in simulation to estimate bus dwell time in order to overcome nearside bus stop challenges. Rakha et al. [11] performed field and simulation evaluation along US Route 1 corridor. They recommended further consideration on existence of queues in transit signal priority strategy and not implementing near-side bus stops.

A bus priority algorithm could also be integrated into an adaptive intersection signal control model. Research based on the bus priority facilities available within the Split Cycle Offset Optimization Technique (SCOOT) [12] traffic signal control system was conducted by Bretherton et al in 1996 [13]. Traffic signal priorities can be controlled by a central SCOOT computer or by a local traffic signal controller. A local controller can achieve faster TSP response to buses than a centralized control. Different strategy options for providing bus priority at signals are compared by McLeod & Hounsell [14] using the simulation model called Selective Priority to Late buses Implemented at Traffic signals (SPLIT). McLeod suggested that differential (conditional) priority strategies (e.g. granting priority for lateness) give the best results, as these provide a good balance between travel time and passenger waiting time. Furth and Mueller [15] conducted a field study with three priority conditions (no priority, absolute priority, and conditional priority) at a transit route in the Netherlands. The study found absolute priority caused large delays to other traffic while conditional priority caused little, if any additional delay. Dion and Rakha [16] developed a simulation approach to integrate TSP within an adaptive traffic control system. They evaluate three different signal control scenarios and found adaptive signal control reduced negative impacts on general traffic while providing signal priority to buses. Recently, Mirchandani & Lucas [17] developed a Categorized Arrival-based Phase Reoptimization at Intersection (CAPRI) strategy that integrates transit signal priority within a real-time traffic adaptive signal control system, called RHODES (Real-time Hierarchical Optimized Distributed Effective System) [18]. “Weighted bus” and “phase constrained” approaches were developed for providing transit priority through the RHODES-CAPRI framework. Mirchandani et al [19] proposed a hierarchical optimization approach where traffic signals are determined by considering delays of all vehicles on the network as well as bus passenger counts and schedule while providing transit priority (RHODES/BUSBAND).

### **Objective**

With GPS/AVL system on the bus, we believe we can provide signal priority to buses with minimal impact on other traffic because GPS offers better information regarding bus trajectory than the sensors used previously to provide traffic signal priority. Our objective is to investigate the performance of GPS and a wireless-based adaptive signal priority strategy to provide reliable and efficient bus transit services with minimal impact on traffic flow. The improved service will hopefully make the transit system more attractive to the public and increase ridership. Simulation studies and field measurements will be used to estimate changes in bus travel time, as well as effects on other traffic.

## **DEVELOPMENT OF TRAFFIC SIMULATION MODEL**

### **Study Site Selection**

Bus route #2, operating on Franklin Ave from S Dupont Ave to S 27<sup>th</sup> Ave in City of Minneapolis, was selected for the bus signal priority study after discussions with City of Minneapolis and Metro Transit. The Franklin corridor, located south of downtown Minneapolis, runs in an east-west direction parallel to interstate highway I-94, as shown in Figure 1. The study section of the Franklin Corridor consisted of 22 signalized intersections with total travel distance of about 3 miles. On the west end, at Hennepin and Lyndale Ave, Franklin Avenue provides connection to the interstate I-94 & I-394. Toward the east side, the bus stop at south 17<sup>th</sup> Ave connects the bus route #2 to the recently opened Minnesota Hiawatha Light Rail Transit (LRT) line, which in turn connects the traffic from downtown Minneapolis to the Minneapolis-St. Paul (MSP) international airport, and to the Mall of America.

### **Intersection Capacity Analysis**

Intersection capacity analyses were performed at several major intersections on the study corridor, in order to better understand the existing traffic condition. The intersection capacity of the following intersections was identified and analyzed: Hennepin, Lyndale, Nicollet, Chicago, 11<sup>th</sup>, Cedar, and Minnehaha Avenue. Traffic volume,

turning movements and signal timing data for each intersection were entered in Synchro [20] to calculate intersection delay and Level Of Service (LOS). For the intersections currently having significant delay, the effect on cross street traffic needs to be carefully analyzed when providing bus signal priority on Franklin Ave.

### **Bus Travel Time**

Current average travel time for buses was computed using the per-minute bus GPS data. The data set from Metro Transit included 5 days of bus GPS data of route #2. A computer program was developed to extract the data collected on Franklin Ave. during the AM and PM peak hours. In addition to the estimates of the bus travel times from the GPS data, field observations were performed by taking several bus trips during both peak hours, along Franklin Ave. The collected data were also used to calculate average travel times. These measured bus travel times were compared to those produced by the simulation model in order to verify the accuracy of the public transit model used in the simulator.

### **Bus Intersection Delay**

The purpose of providing signal priority to a transit vehicle is to minimize its waiting time at intersections. It is important to know how much time buses spend waiting at red lights as compared to their total travel times. Collecting the bus delay times at red signals will provide information on the degree of improvement that bus signal priority could provide to the existing bus operation. Based on the collected data buses traveling westbound require on average about 18 minutes to traverse study site with approximately 210 seconds of delay at red signals. Buses traveling in the eastbound direction spend about 20 minutes in average, including about 260 seconds of signal delay per trip. By comparing the average intersection delay to the average bus travel time, a bus generally spent on average around 18% to 23% of its travel time (3.3~4.8 minutes) waiting for green lights at intersection along Franklin Avenue.

### **Bus Dwell Time**

Bus dwell time at each bus stop consists of the boarding/alighting of passengers, door opening/closing and clearance time. The per-minute bus GPS data provided by Metro Transit does not provide sufficient resolution for us to calculate and estimate the bus dwell time at each bus stop. Also, Metro Transit was not able to provide passenger counts at the time of this study using the APC (automatic passenger count) unit integrated with the bus GPS/AVL data collection system along Franklin Avenue. However, Metro Transit conducted passenger boarding/alighting counts at every bus stop along bus route #2 from 6AM to 12AM during 2000 and 2001. Bus dwell time at each stop can therefore be calculated using the recommended formulas from Transit Capacity and Quality of Service Manual [21].

### **Traffic Simulation**

A microscopic traffic simulation package, AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks, <http://www.aimsun.com>) [22] was selected for this study. AIMSUN includes an Application Programming Interface (API) to allow interfacing to other simulation or assignment models. An additional library of DLL (Dynamic Link Library) functions enables the system to communicate with external applications [22, 23]. AIMSUN has been used successfully for several large-scale traffic modeling research projects [24] and provides a well-documented API to access and modify all elements of the simulation state (signal control, sensing, vehicle characteristics and state), while the simulation is running. A C++ program was developed to interface with the microsimulator through the API. Bus location, speed, and bus stop information can be sent to the external bus signal priority application, and a priority request can be sent back to the simulator, in real-time.

Digital Orthophotos Quad aerial images (DOQs) around Franklin Avenue were acquired from Twin Cities Metropolitan Council (<http://www.datafinder.org/metadata/orthos2000.htm>). The aerial images were then used to create the arterial network geometry for the AIMSUN simulation model. Bus route and bus stop locations were selected and specified in the network geometry and bus dwell time statistics were entered in the transit model. Intersection signal timing and phase assignments were specified in the signal control model. Three different vehicle types, passenger car, light truck, and bus, were included in the simulation model. The 15-minute traffic volume and turning proportions collected at each intersection were entered. Before entering the traffic volume inputs at the boundary links and the turning ratio at each intersection, the collected traffic counts were adjusted to satisfy the traffic flow conservation principle. Signalized intersection traffic counts were obtained from City of Minneapolis, while traffic volumes at un-signalized intersection were collected on 20 different weekdays for this study. The

inconsistencies between the network inflow and outflow must then be “balanced” before applying the data to any traffic operation analysis.

An arterial traffic volume balance technique is used by Minnesota Department of Transportation (MnDOT), includes intersections on both sides of an on-ramp or off-ramp intersection, when conducting highway traffic simulation. Traffic volume and turning movements at arterial intersections are often collected on different days and different days of the week, and these traffic volumes need to be adjusted to conserve the inflow and outflow traffic at each link. By adjusting the arterial traffic volume from upstream to downstream intersections in both directions recursively, the arterial network traffic volume will reach an equilibrium state. A Java program was developed to read a text file with intersection traffic volume data filenames listed sequentially. The program then reads all intersection traffic volume data in JAMAR [25] data format from a specified directory and automatically computes the adjustments iteratively until the total traffic volume balanced.

When the intersection traffic data were balanced and entered in the AIMSUN simulation model for each 15-minute interval, an error-checking task was performed by running a trial simulation in order to visually identify any unusual traffic conditions. For example, incorrect intersection signal phasing or offset may cause unusual queue buildup. A working model of Franklin Avenue is available for calibration upon the completion of the error-checking tasks. The traffic simulation model can only include a portion of all parameters that affect the real-world traffic conditions. The calibration process helps improve the ability of traffic model to accurately reproduce the local traffic conditions [26].

## ADAPTIVE BUS SIGNAL PRIORITY STRATEGY

To illustrate our priority strategy, consider a simple eastbound/westbound corridor as shown in Figure 2. For a bus approaching a bus stop or signalized intersection, there are basically two scenarios, a nearside bus stop or a far-side bus stop. For the nearside bus stop, a bus will stop for boarding/alighting before passing the signalized intersection, as illustrated in Figure 2 by the eastbound bus approaching stop  $j$  and intersection  $i$ . Estimated bus dwell time at the nearside bus stop needs to be considered by the signal controller to provide signal priority to the bus in a timely manner. For the far-side bus stop, a bus passes through the intersection first before its arrival at the stop (see Figure 2 westbound bus approaching intersection  $i$  and bus stop  $k$ ). Bus travel time to the intersection needs to be considered when providing priority.

### Nearside Bus Stop

Consider the bus traveling in the eastbound as shown in Figure 2. Expected bus dwell time,  $T_{dj}$ , at bus stop  $j$  can be forecasted using historical dwell time statistics. Expected bus travel time,  $T_{aj}$ , from its current location to bus stop can be calculated via,

$$T_{aj} = \frac{d_{e,j}}{1.467 \times v_b} + T_{br} + T_{delay} \quad (1)$$

Where,

$v_b$  : is bus speed, in MPH,

$d_{e,j}$  : is the distance from the current bus location to bus stop  $j$ , in feet,

$T_{br}$  : is bus braking/stopping time, and

$T_{delay}$  : is the traffic delay on bus route.

The expected bus travel time ( $T_{ji}$ ) from bus stop  $j$  to intersection  $i$  can also be calculated as follows, assuming the distance from the nearside bus stop to the intersection is relatively short compared to the distance needed to accelerate to running speed.



$$T_{ji} = \sqrt{\frac{2(d_{e,i} - d_{e,j})}{a}} + T_{bc} \quad (2)$$

Where,

$d_{e,i}$ : is the distance from eastbound bus to intersection  $i$  (ft),

$d_{e,j}$ : is the distance from eastbound bus to bus stop  $j$  (ft),

$a$ : is the bus acceleration in ft/s/s, and

$T_{bc}$ : is the bus clearance time.

Therefore the predicted time at which the eastbound bus passes intersection  $i$  can be calculated as follows.

$$\hat{t}_{ei} = t + T_{aj} + T_{dj} + T_{ji} \quad (3)$$

Where,

$t$ : is the current time, sec.

And estimated time for the bus leaving stop  $j$  is,

$$\hat{t}_{lj} = t + T_{aj} + T_{dj} \quad (4)$$

The desired signal priority request should then be sent at  $\delta_n$  seconds prior to the bus departure time at stop  $j$ .

That is, at time  $\hat{t}_{lj} - \delta_n$ , where

$$\delta_n = t_{cp} + t_{comm} + t_{const} \quad (5)$$

$t_{cp}$ : is the controller processing time,

$t_{comm}$ : is the communication latency time, and

$t_{const}$ : is an additional time constant.

The signal priority service should be ended at  $\hat{t}_{ei} + T_{xi}$ , where  $T_{xi}$  is the time for the bus to cross intersection  $i$ . If both beginning ( $\hat{t}_{lj} - \delta_n$ ) and ending ( $\hat{t}_{ei} + T_{xi}$ ) of the estimated priority service fall within the green split, no action needs to be taken at the controller. If  $\hat{t}_{lj} - \delta_n$  falls in the green split and  $\hat{t}_{ei} + T_{xi}$  falls in the red split, extended green time is needed to ensure that bus could pass the intersection. However, if the estimated beginning of priority service time ( $\hat{t}_{lj} - \delta_n$ ) falls within the red light period, red signal truncation or early green light treatment is needed to provide bus signal priority.

### Far-side Bus Stop

For a bus approaching an intersection prior to its arrival at next bus stop, for example, the bus traveling in westbound as shown in Figure 2, signal priority should be provided based on bus traveling speed and traffic conditions. The estimated time ( $T_{ai}$ ) to arrive at intersection  $i$  can be calculated as,

$$T_{ai} = \frac{d_{w,i}}{1.467 \times v_b} + T_{delay} \quad (6)$$

Where,

$d_{w,i}$ : is the distance from westbound bus to intersection  $i$  (ft),

$v_b$ : is bus speed in MPH, and

$T_{delay}$ : is the traffic delay on bus route.

Therefore the estimated time for westbound bus passing intersection  $i$  can be calculated as follows.

$$\hat{t}_{wi} = t + T_{ai} \quad (7)$$

Where,

$t$ : is the current time, sec.

The desired signal priority would need to begin at  $\delta_n$  seconds prior to the bus arriving intersection  $i$  ( $\hat{t}_{wi} - \delta_n$ ), where  $\delta_n$  is defined as equation (5). The signal priority service can be ended at  $\hat{t}_{wi} + T_{xi}$ , where  $T_{xi}$  is the time for bus to cross intersection  $i$ . If both beginning ( $\hat{t}_{wi} - \delta_n$ ) and ending ( $\hat{t}_{wi} + T_{xi}$ ) of the estimated priority service fall within the green split, no action needs to be taken by the controller. If  $\hat{t}_{wi} - \delta_n$  falls in the green split and  $\hat{t}_{wi} + T_{xi}$  falls in the red split, extended green time is need to ensure bus could pass the intersection. However, if the estimated beginning of priority service time ( $\hat{t}_{wi} - \delta_n$ ) falls within the red light period, red signal truncation or early green light treatment is needed to offer bus priority.

### Estimation of Passenger Arrival Rate at Bus Stop

Estimated passenger arrival rates will be used to forecast bus dwell time at each stop. Based on the collected data, we assume the passenger arrivals at each stop follow a Poisson distribution with an arrival rate,  $\lambda$ , calculated from the mean of the collected passenger arrival rate. A Poisson process subroutine was developed to generate numbers of passengers boarding and alighting at each stop during the simulation.

### Estimation of Bus Dwell Time at Bus Stop

Bus dwell time at a bus stop for boarding can be estimated using the following equation.

$$T_{dj}^B = \lambda_j(t) \times [t_k(j) - t_{k-1}(j)] \times T_{boarding} \quad (8)$$

Where,

$T_{dj}^B$  is the bus dwell time for boarding at stop j,

$\lambda_j(t)$  is the passenger arrival rate for stop j,

$t_k(j)$  is the arrival time of bus k at stop j,

$t_{k-1}(j)$  is the arrival time of bus k-1 at stop j, and

$T_{boarding}$  is the average boarding time per passenger.

### Priority Acknowledgement Rules

After receiving a signal priority request from a bus, the signal controller has to determine whether or not to grant the request. Only one bus will get the priority service if there are multiple requests at the same intersection from buses on different approaches. The signal controller will ignore all bus priority requests if there is an emergency vehicle preemption request. The signal controller will consider the following three components when determining which bus will receive the priority service.

#### 1. Priority request time, Time Factor (TF)

$$TF(A, B) = \begin{cases} A = W_T, B = 1 & t_A < t_B \\ A = 1, B = W_T & t_A > t_B \end{cases}$$

Bus A wins if it requests earlier than bus B does, where  $W_T$  is the request time weighting factor ( $W_T \geq 1$ ).

#### 2. Bus schedule adherence, Lateness Factor (LF)

$$LF = W_L \times T_{Late}$$

Where  $W_L$  is the bus late time weighting factor ( $W_L \geq 1$ ) and  $T_{Late}$  is the number of minute the bus was late.  $LF = 0$  when bus is ahead of its schedule.

### 3. Number of passengers on the bus, Passenger Factor (PF)

$$PF = W_p \times N_{passenger}$$

Where  $W_p$  is the bus passenger count weighting factor ( $W_p \geq 1$ ) and  $N_{passenger}$  is the number of passengers on the bus.

The priority acknowledgement functions for bus  $A$  and  $B$  are defined as follows.

$$\begin{aligned} f(A) &= TF(A, B) \times \{LF(A) + PF(A)\} \\ f(B) &= TF(A, B) \times \{LF(B) + PF(B)\} \end{aligned} \quad (9)$$

If the priority acknowledgement function,  $f(A)$  is greater than  $f(B)$ , bus  $A$  will be granted for signal priority. No signal priority request is granted if the acknowledge function  $f$  equals zero, which means there is no passengers on the bus and no delay on bus schedule adherence.

### Green Extension and Red Truncation

The projected signal phase estimated arrival time for a bus passing a signalized intersection can be calculated using the equations discussed in the previous section. When the projected signal phase coincides with the priority phase, which is the phase where a bus requires passing through an intersection, green extension is considered if the remaining green time is insufficient. However, if the projected arriving phase is different from the priority phase, phase arrangement, such as phase suppression or red truncation, is needed to provide green time to the buses. A minimum green time has to be served prior to terminating the phase.

### Signal Recovery/Resynchronization Consideration

It has been a concern to return the intersection timing back to its coordination often providing signal priority to buses. Some priority strategies require many cycles before the signal timing is resynchronized to its regional coordination [27]. Recently, an advanced controller provides the signal priority recovery with a cycle by including optional transit phases in the timing plan [28]. Our bus signal priority strategy will resynchronize to its neighbor intersections in the next cycle by reducing the amount of green time extended in the next cycle priority phase. Signal priority requests in the following cycle will be ignored in order to facilitate coordination recovery. For example, if the request from bus  $A$  or  $B$  in cycle  $i$  was granted at an intersection, priority requests from bus  $C$  and  $D$  will not be considered because cycle  $i+1$  will be used for coordination recovery.

### Bus Signal Priority Modeling in the Simulator

The priority strategy was implemented using the C++ programming language and integrated with the simulator through the AIMSUN API interface. At each simulation step, the bus location and its distance corresponding to the next bus stop and signalized intersection were calculated to identify a nearside versus a far side bus stop scenario. The control diagram for the priority strategy is shown in Figure 3. Bus dwell time at each stop was computed based on the passenger arrival using the Poisson distribution. Bus travel times to the intersection and the bus stop were calculated to determine when to submit priority request prior to its arrival at the signalized intersection.

### Signal Control Model

An external signal control logic was programmed to emulate the green extension and red truncation functionality. In order to ensure that the intersection returns back to its timing plan prior to the priority request and remains coordinated with the neighboring intersections, signal timing recovery and resynchronization were also considered. For example, extend green and maintain coordination, early green or red truncation, and phase insertion and coordination recovery in the next cycle.

## SIMULATION RESULTS ANALYSIS

Traffic data produced by the simulation model were used to compare the measures of effectiveness of the signal priority strategy. System statistics as described in the AIMSUN User's Manual are defined as follows.

**Flow:** Average number of vehicles per hour that have passed through the network during the simulation period.  
**Average Travel time:** Average time a vehicle needs to travel one kilometer inside the network.  
**Average Delay Time:** Average delay time per vehicle per kilometer. This is the difference between the expected travel time (the time it would take to traverse the system under ideal conditions) and actual travel time.  
**Average Stops:** Average number of stops per vehicle per kilometer.

The overall statistics of the simulation network without applying signal priority strategy were first collected. During the PM peak period (4-6PM), traffic is much heavier than that in the morning hours (7-9AM). There were about 40% increases of traffic flow in PM peak hours. The PM average speed in the system dropped by 9%, from 19.8 to 18 MPH, as compared to the AM peak period. The average travel time, delay time and number of stops per vehicle in the afternoon rush hours also increased by about 21%, 31.7%, and 25% respectively.

### **Bus Measures of Effectiveness (MOE) Analysis**

Bus average speed, travel time, and stop time were collected during simulations to measure the effectiveness with and without priority strategy. These measures are defined as follows.

**Bus Travel time:** Average time it takes for a bus to travel along a public transport line. This is the mean of all the single travel times for each bus.

**Bus Delay Time:** Average delay time per bus to make the trip. This is the difference between the expected travel time (time it takes to go from the origin to the destination under ideal conditions) and the actual travel time.

**Bus Stop Time:** Average time spent at a stop per bus during the trip.

#### AM Peak

By applying the signal priority strategy with 15-sec of extension time, the bus travel time was reduced by about 12% in EB and 14% in WB, respectively. Bus delay time was reduced by about 16%~19% and the stop time was reduced around 18% as well as listed in Table 1(a). For the 10-sec extension time scenario, the bus travel time was reduced by about 10% in EB and 9% in WB. And, bus delay time was reduced by about 14%~12% and the stop time was reduced around 15% for both approach as listed in Table 2(a).

#### PM Peak

There was about a 40% increase in traffic flow during the PM peak hours. Bus statistics from the simulation with and without signal priority strategy are listed in Table 1(a) for PM peak hours. Bus travel time and speed are also plotted in Figure 4. In the PM peak hours, it took about 22(23) minutes for a EB (WB) bus to travel between Hennepin Ave and 27<sup>th</sup> Ave on Franklin Ave without signal priority. By applying the signal priority strategy for the buses, the bus travel time was reduced by about 2 minutes in EB and 1.5 minutes in WB direction, or 10.5% in EB and 7% in WB, respectively. Bus delay time was reduced by about 9%~14% and the stop time was reduced around 10%~14% as well.

As the simulation results show, the signal priority strategy during the PM peak hours provided relatively less travel time reduction in WB (about 1-minute less) as compared to the AM scenario. There were mostly nearside bus stops at our study site. During the PM peak hours, there were longer queues at intersections from 11<sup>th</sup> Ave to Cedar Avenue, so that a bus was not able to get in to its service bay when it approached a queue at the intersection. The bus stuck behind the queue had to wait until the queue cleared at the next green in order to provide service. Also, when there was a queue built up during the bus service period at a nearside bus stop, the bus had to wait to find an acceptable gap in order to join the traffic. The priority request will help clear the queue to reduce bus clearance time. However, if knowledge of the queue length could be obtained and processed to submit a priority request earlier, the bus waiting time could be reduced during the busier PM period. Future enhancements to the priority strategy can include consideration of queue detection at the intersection.

### **Overall Network System MOE Analysis**

The measures of effectiveness for the whole network were obtained for the simulation period.

#### AM Peak

Network system statistics from the simulation with and without the signal priority strategy are listed in Table 1(b) for the AM peak hours with signal priority extension time of 15 sec. There was about a 7 seconds increase in

average travel time. Average delay increased by 6 seconds for the 15-sec extension scenario. The average number of stops per vehicle was increased by 0.1 stop per vehicle for both cases. Table 2(b) shows the AM peak hours statistics with an extension time of 10 sec. There was about a 31 seconds increase in average travel time and average delay for the 10-sec extension scenario. The average number of stops per vehicle was increased by 0.8 stop per vehicle for both cases.

### PM Peak

As a result of heavier traffic flow during the PM peak hours, the overall network statistics from the simulation with and without signal priority strategy generated longer delay and more vehicle stops. As listed in Table 1(b), the travel time during the PM period was increased by 22 seconds per kilometer when providing signal priority. Average delay was increased by 23 seconds while average stops increased by 0.6 stop per vehicle with the priority strategy. More simulation statistics are available in the project final report [30].

## **SUMMARY**

Current signal priority strategies implemented in various US cities mostly utilize sensors to detect buses at a fixed or preset distance away from an intersection. Traditional presence detection systems, ideally designed for emergency vehicles, usually send signal priority request after a preprogrammed time offset as soon as transit vehicles were detected without the consideration of bus readiness. This study proposed an adaptive signal priority strategy to request for signal priority when bus is ready to pass through an intersection by taking advantage of the location and speed information from GPS/AVL system as well as the bus schedule and number of passengers on board. Traffic model of Franklin Avenue, consisting of 22 signalized intersections, in Minneapolis was developed, calibrated, and simulated in order to compare the measures of effectiveness before and after applying the signal priority strategy. Vehicle travel time, delay, speed and number of stops were measured to evaluate the effectiveness of the transit priority strategy. Simulation results indicate that a 12-15% reduction in bus travel time during AM peak hours (7AM-9AM) and 4-11% reduction in PM peak hours (4PM-6PM) could be achieved by providing signal priority for buses. Average bus delay time was reduced in the range of 16-20% and 5-14% during AM and PM peak periods, respectively.

## **FUTURE WORK**

We would like to investigate the 800 MHz radios and WLAN (Wireless Local Area Networks) systems already equipped on the bus. A voice radio on the bus is linked to a regional 800MHz digital voice communication system. Metro Transit Control Center uses another analog 800 MHz radio to poll bus GPS data every minute. In addition, each bus has a wireless communication system that is used to download/upload files between the central server and the bus computer when the bus is within proximity of the bus garage. We would like to investigate the possibility of integrating a signal priority strategy using one of the existing communication systems on the bus with the traffic controller. We also plan to develop a prototype system to validate the bus signal priority algorithm using wireless communication technology in the second phase study. We also would like to work with Metro Transit and City of Minneapolis to discuss the potential opportunity of bus signal priority deployment. Metro Transit is planning the Northwest Corridor (Bottineau Corridor) project so as to include a bus way that will offer high-quality transit service from downtown Minneapolis through Crystal, Brooklyn Park, Maple Grove and Rogers (<http://www.metrotransit.org/improvingTransit/northwestCorridor.asp>). In this project, bus signal priority will be considered in order to improve bus travel time and reduce bus delay at signalized intersections. Transit Signal Priority conceptual design along Bottineau Corridor is currently being investigated by SEH Inc. (<http://www.sehinc.com/>).

The vision of the VII (Vehicle Infrastructure Integration, <http://www.its.dot.gov/vii/index.htm>) is to deploy a nationwide network that enables communications between vehicles and roadside infrastructure for various transportation operations and applications. Signal priority requests for transit or emergency vehicles can potentially be sent to the signal controller through the vehicle-to-infrastructure communication architecture described in VII. Communication with the roadside unit (e.g., traffic controller) for signal priority may be established using the existing 802.11x WLAN on the bus or the DSRC (Dedicated Short Range Communication) 802.11p protocol

currently under development for wireless access to and from the vehicular environment. Work in next phase will concentrate first on the more readily available protocols. However the system will be designed so that it can be ported to the new 802.11p protocol when it becomes more readily available.

## ACKNOWLEDGEMENT

We would like to thank the Intelligent Transportation Systems (ITS) Institute and Center for Transportation Studies, University of Minnesota, for supporting this project. The ITS Institute is a federally funded program administrated through the Research & Innovative Technology Administration (RITA). We also would like to thank Scott Tacheny at City of Minneapolis public works, Aaron Isaac and Gary Nyberg at Metro Transit, and graduate student Hun-Wen Tao for collecting the field data.

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Figure 1. Bus Signal Priority Study Site – Franklin Ave From Dupont to 27<sup>th</sup> Ave \*

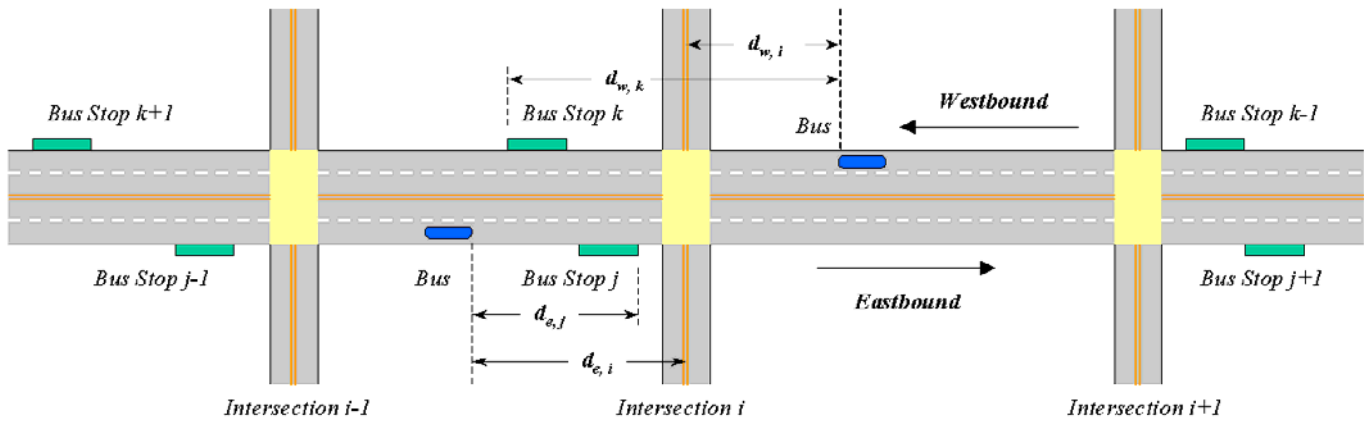


Figure 2. An East-West Corridor Example for Signal Priority

\* Map adopted from MapQuest, Inc. (<http://www.mapquest.com/>)

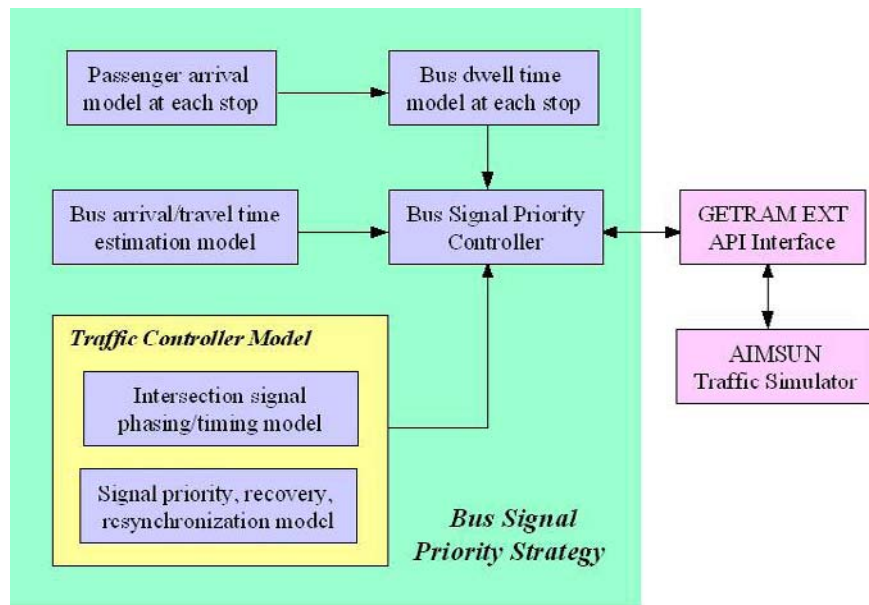


Figure 3. Control Diagram of Bus Signal Priority Strategy

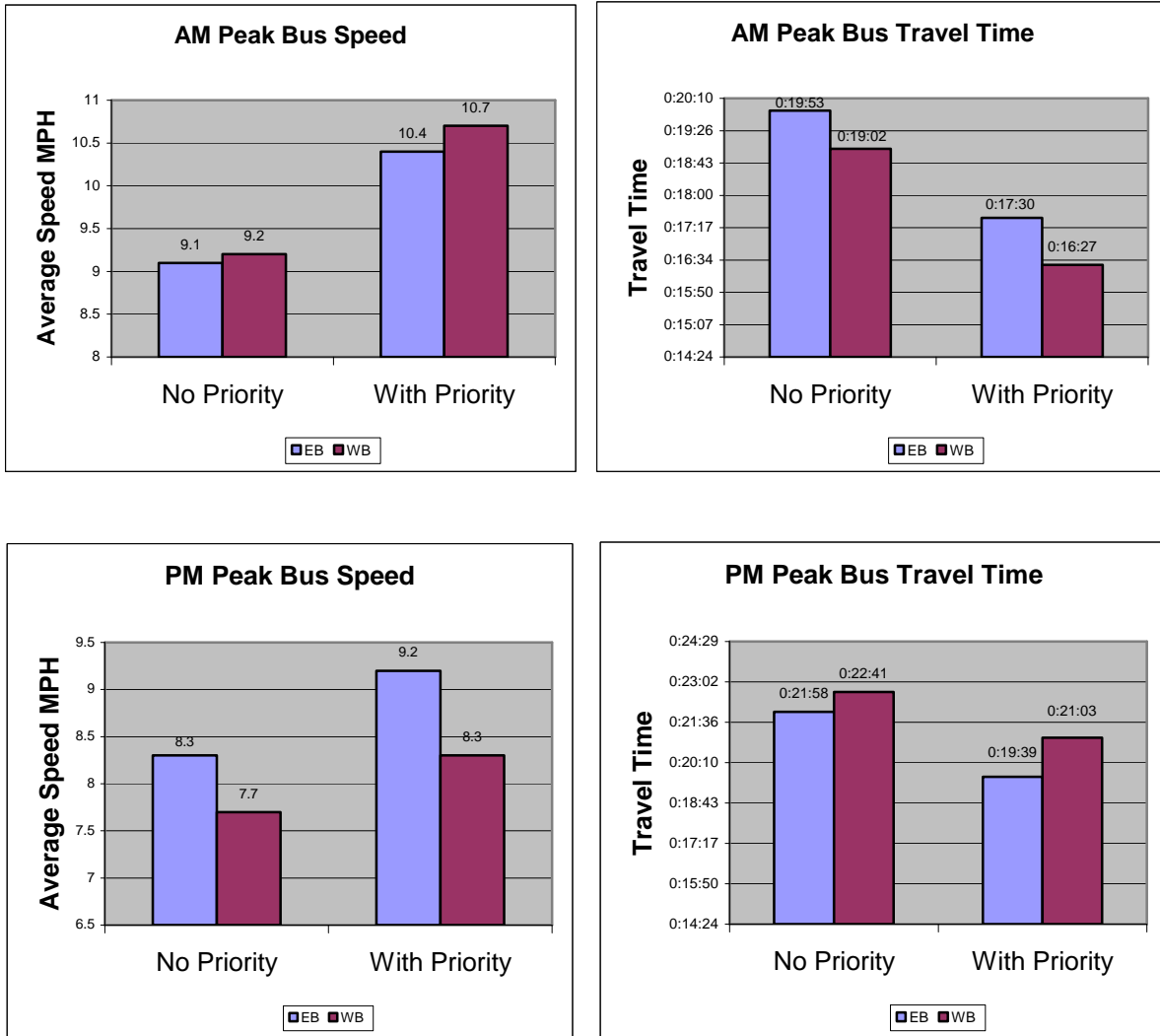


Figure 4. AM and PM Peak Bus Speed and Travel Time

Public Transit, Priority Extension Time = 15 sec					
AM PEAK		Speed	Bus Travel Time	Bus Delay Time	Bus Stop Time
Bus Statistics		MPH	hh:mm:ss	hh:mm:ss	hh:mm:ss
No Priority	EB	9.1	0:19:53	0:14:49	0:10:05
	WB	9.2	0:19:08	0:14:08	0:09:30
With Priority	EB	10.4	0:17:30	0:12:26	0:08:17
	WB	10.7	0:16:27	0:11:27	0:07:50
Average Change	EB	1.30	- 0:02:23	- 0:02:23	- 0:01:48
	WB	1.50	- 0:02:41	- 0:02:41	- 0:01:40
Average Change %	EB	14.29%	-11.99%	-16.09%	-17.85%
	WB	16.30%	-14.02%	-18.99%	-17.54%

Public Transit, Priority Extension Time = 15 sec					
PM PEAK		Speed	Bus Travel Time	Bus Delay Time	Bus Stop Time
Bus Statistics		MPH	hh:mm:ss	hh:mm:ss	hh:mm:ss
No Priority	EB	8.3	0:21:58	0:16:55	0:10:14
	WB	7.7	0:22:41	0:17:41	0:10:10
With Priority	EB	9.2	0:19:39	0:14:35	0:09:15
	WB	8.3	0:21:03	0:16:02	0:08:47
Average Change	EB	0.90	- 0:02:19	- 0:02:20	- 0:00:59
	WB	0.60	- 0:01:38	- 0:01:39	- 0:01:23
Average Change %	EB	10.84%	-10.55%	-13.79%	-9.61%
	WB	7.79%	-7.20%	-9.33%	-13.61%

Table 1(a). AM and PM Peak Bus Statistics, Extension Time = 15 sec.

Overall Network System, Priority Extension Time = 15 sec					
AM PEAK		Speed	Avg. Travel Time	Avg. Delay Time	Avg. Stops
Network Statistics		MPH	hh:mm:ss	hh:mm:ss	#/veh
No Priority		19.8	0:01:35	0:01:00	1.60
Priority		19.1	0:01:42	0:01:06	1.70
Average Change		-0.70	0:00:07	0:00:06	0.10

Overall Network System, Priority Extension Time = 15 sec					
PM PEAK		Speed	Avg. Travel Time	Avg. Delay Time	Avg. Stops
Network Statistics		MPH	hh:mm:ss	hh:mm:ss	#/veh
No Priority		18.1	0:01:55	0:01:19	2.00
Priority		16.0	0:02:17	0:01:42	2.60
Average Change		-2.10	0:00:22	0:00:23	0.60

Table 1(b). Overall Network Statistics, Extension Time = 15 sec.

<b>Public Transit, Priority Extension Time = 10 sec</b>						
<b>AM PEAK Bus Statistics</b>		<b>Speed</b>	<b>Bus Travel Time</b>	<b>Bus Delay Time</b>	<b>Bus Stop Time</b>	
		MPH	hh:mm:ss	hh:mm:ss	hh:mm:ss	
<b>No Priority</b>	<b>EB</b>	9.1	0:19:53	0:14:49	0:10:05	
	<b>WB</b>	9.2	0:19:08	0:14:08	0:09:30	
<b>With Priority</b>	<b>EB</b>	10.2	0:17:54	0:12:50	0:08:34	
	<b>WB</b>	10.1	0:17:30	0:12:29	0:08:08	
<b>Average Change</b>	<b>EB</b>	<b>1.10</b>	<b>- 0:01:59</b>	<b>- 0:01:59</b>	<b>- 0:01:31</b>	
	<b>WB</b>	<b>0.90</b>	<b>- 0:01:38</b>	<b>- 0:01:39</b>	<b>- 0:01:22</b>	
<b>Average Change %</b>	<b>EB</b>	<b>12.09%</b>	<b>-9.97%</b>	<b>-13.39%</b>	<b>-15.04%</b>	
	<b>WB</b>	<b>9.78%</b>	<b>-8.54%</b>	<b>-11.67%</b>	<b>-14.39%</b>	

Table 2(a). AM Peak Bus Statistics, Extension Time = 10 sec.

<b>Overall Network System, Priority Extension Time = 10 sec</b>				
<b>AM PEAK Network Statistics</b>	<b>Speed</b>	<b>Avg. Travel Time</b>	<b>Avg. Delay Time</b>	<b>Avg. Stops</b>
	MPH	hh:mm:ss	hh:mm:ss	#/veh
<b>No Priority</b>	19.8	0:01:35	0:01:00	1.60
<b>Priority</b>	16.9	0:02:06	0:01:31	2.40
<b>Average Change</b>	-2.90	0:00:31	0:00:31	0.80

Table 2(b). Overall Network Statistics, Extension Time = 10 sec.



## **Anti-icing and Pre-wetting: Improved Methods for Winter Highway Maintenance in North America**

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## **ABSTRACT**

In recent years, anti-icing and pre-wetting practices have been gradually accepted and adopted by the North American highway agencies. One of the greatest challenges of implementing these practices has been the misunderstanding of the benefits and outcomes of their use. Members of the general public and organized groups such as trucking associations have been critical of these strategies, which may be a result of insufficient information, limited understanding and speculation. Therefore, research is needed to synthesize the information on these strategies in an objective manner.

Through a project with the Pacific Northwest Snowfighters Association, the authors synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion, costs, etc.

The research indicates that compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates. Anti-icing has been recognized as a pro-active approach to winter driver safety. Pre-wetting has shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required.

The information in this paper will benefit maintenance agencies and transportation officials who seek to fully understand the benefits derived from improved winter maintenance technologies, identify areas for improvement within their own jurisdiction, and learn about related experiences from other agencies.



## BACKGROUND

In the northern states and Canada, transportation agencies face a difficult challenge to keep roadways open and safe during heavy snowfall, low visibility, and icy conditions. Each winter, large amounts of solid and liquid chemicals, along with abrasives, are applied onto the roadways to keep roads clear of ice and snow. The widely used chemicals include: sodium chloride, calcium chloride, magnesium chloride, potassium acetate, calcium magnesium acetate, and agricultural byproducts. They can melt ice and snow by lowering the freezing point of the snow-salt mixture.

Winter highway maintenance practices in North America have traditionally been based on reactive strategies where the launch of maintenance operations relied on signs of snow and ice accumulation. After snowfall, the *de-icing* process uses granular materials that penetrate accumulated snow and ice in order to break the bond that has formed with the roadway. Once the bond is broken, the layer of snow and ice can be easily removed by mechanical means such as snowplows. In addition, through *sanding* operations, abrasives such as sand are applied onto the roadways to provide temporary traction in slippery conditions. Such reactive strategies are generally reliable and well understood.

One concern regarding reactive maintenance practices is the increased potential for accidents and injuries due to poor road conditions while maintenance crews are being deployed. Another problem with reactive practices is the quantity of materials and labor hours needed to maintain the level of service for winter roadways.

However, in the past decade or so, an improved approach termed *anti-icing* has been adopted by winter maintenance personnel, which is the early application of chemicals to help prevent black ice and prevent or weaken the bond between ice and the roadway surface. While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used. Another innovative practice in winter road maintenance is termed *pre-wetting*, i.e., the addition of a liquid chemical to an abrasive or solid chemical before it is applied to the road. The pre-wetting of solids is performed either at the stockpile or at the spreader.

As improved maintenance strategies, anti-icing and pre-wetting are seeing increased implementation in North America. One of the greatest challenges of the implementation has been the misunderstanding of the benefits and outcomes of their use. Members of the general public and organized groups such as trucking associations have been critical of these strategies, which may be a result of insufficient information, limited understanding and speculation. Therefore, research is needed to synthesize the information on these strategies in an objective manner.

Through a project with the Pacific Northwest Snowfighters Association (PNS), the authors at the Western Transportation Institute at Montana State University (WTI) synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion, costs, etc.

## METHODOLOGY

This paper summarizes up-to-date information regarding the practices of anti-icing and pre-wetting for winter maintenance in North America, gathered through a literature review and a questionnaire to the snow and ice control community followed by phone interviews.

The questionnaire was sent as an email attachment to maintenance professionals in eighteen state departments of transportation and two Canadian provincial ministries of transportation, including the six participating PNS states (and provinces) and twelve states involved with the Federal Highway Administration Test and Evaluation Project #28. The contact list was developed by the project's advisory committee, and included maintenance managers, directors, superintendents, and engineers.

Fifteen of the twenty contacted professionals agreed to participate in the questionnaire, including: Alaska, Alberta, British Columbia, Colorado, Idaho, Minnesota, Missouri, Montana, Nevada, New York, Oregon, Vermont, Washington, Wisconsin, and Wyoming. Upon confirmation of participation, maintenance professionals were given a week to review the questionnaire and gather any needed information at which time an interview was scheduled. All interviews and responses to the questionnaire were completed by April 2005. With only one contact per state or province, the results presented herein are reflective upon the opinions of the interviewee, and are not necessarily representative of the entire state or province.

The questionnaire focused on the current state of practice for winter road maintenance as well as any advantages or disadvantages experienced while implementing anti-icing or pre-wetting strategies. It also addressed concerns associated with winter maintenance practices such as driver safety, human health, environmental stewardship, vehicular and infrastructure corrosion, and costs.

## **DISCUSSION**

### **Why Winter Highway Maintenance Planning and Management Is Needed**

Snow and ice control methods allow maintenance agencies to keep the road system safe, mobile, and productive, striving to ensure that:

- Traveler safety is maximized by the reduction of vehicular accidents and associated fatalities and injuries;
- Merchandise and services can arrive to their destinations throughout the winter;
- Emergency service vehicles can continue to provide timely response and assistance;
- Travelers can access winter recreation activities and support the local tourist economy; and
- Daily routines are uninterrupted.

It has been shown that repeated applications of winter maintenance chemicals and abrasives may adversely affect the surrounding vegetation, water bodies, aquatic biota, and wildlife (1,2). Expert opinions indicate that the environmental impacts of abrasives are generally a much greater concern than those of chemicals (3). However, winter maintenance chemicals may cause corrosion of and damage to pre-stressed or normally reinforced concrete structures, steel bridges, motor vehicles, and paved surfaces (4).

Snow and ice control operations call for agencies to strike the right balance among their multiple objectives including: traveler safety, environmental stewardship, infrastructure preservation, and economics during winter seasons. By examining alternatives to conventional snow and ice control strategies and applying improved technologies, maintenance agencies have been able to reduce costs, labor hours and material usage while providing safe roadways and minimizing environmental and corrosion impacts. The ultimate goal is *to deliver the right amount of materials in the right place at the right time.*

New advancements in science and engineering, specifically, reliable weather forecasting and new equipment and materials, are making it possible for highway agencies to implement improved snow and ice control strategies that benefit the public and help minimize the effects of winter weather on roadway surfaces.

For instance, anti-icing introduces a proactive concept for maintaining winter roads because it treats potential conditions before problems arise, thus giving maintenance crews an advantage when fighting winter storms. The roads remain wet and slushy longer and return to *bare pavement* conditions earlier when anti-iced. As a proactive strategy, successful use of anti-icing chemicals requires application immediately prior to a storm, and thus entails accurate weather forecast. When applied correctly, anti-icing can reduce plowing time and decrease the quantity of chemicals used (5).

### **Snow and Ice Control Operations: Benefits and Concerns**

Investing in clear roads is essential and beneficial to the public and the economy. Winter maintenance activities offer such direct benefits to the public as fewer accidents, improved mobility, and reduced travel costs. A study found that “failure to get snowplows out and salt on the roads during a single day of a winter storm costs almost three times more in lost wages than the total annual costs for snowfighting” (6).

For the public, all maintenance activities decrease the potential for accidents and increase the ability to travel. Improved maintenance strategies, however, have lowered accident rates even further. Colorado has seen a 14% decrease in snow and ice related crashes during a twelve-year study involving advanced maintenance strategies on the interstate system in the Denver metro area (7).

While providing improved driving conditions, chemical products and abrasives used have the potential to harm the surrounding environment. Studies have shown vegetative damage and die-off near roadways due to salt spray and runoff. It has also been shown that water quality may be affected, at least temporarily, in areas utilizing chemicals and abrasives for snow and ice control.

Abrasives may also become particulate matter and contribute to poor air quality. Particles smaller than 10 microns (0.01mm) in diameter, known as PM-10, may become suspended in the air and lead to air quality issues, especially in urban settings, which is a primary reason behind passage of the U.S. Clean Air Act (9). Inhaled particulate matter may increase breathing difficulties for sensitive populations causing respiratory damage and possibly lung cancer.

Another concern of winter maintenance products is corrosion to both motor vehicles and the highway infrastructure. For motor vehicles, corrosion from winter maintenance chemicals is generally cosmetic, however, brake linings, frames, bumpers, and tailpipes may also show signs of corrosion related to these products. Potential damages to the highway infrastructure include concrete deterioration due to corrosion of the reinforced steel, surface deterioration known as scaling, and degradation of the concrete matrix. Large span supported structures, steel bridges, and even parking garages are susceptible to corrosion derived from winter maintenance chemicals. It is difficult, however, to determine the extent of damages caused by winter maintenance chemicals.

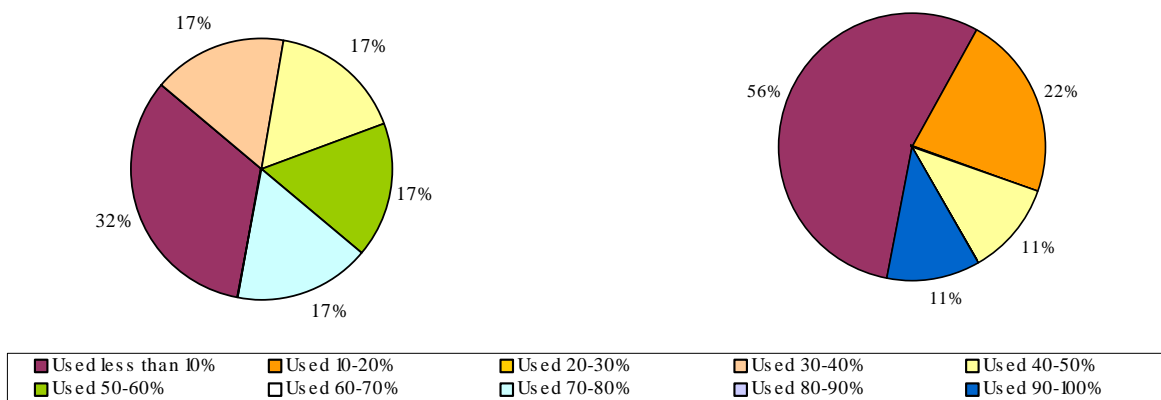
Prevention of future problems requires adopting design practices for corrosion prevention, utilizing non-corrosive, environmentally friendly chemical products, and minimizing material usage while maximizing performance. In order to reduce costs and improve levels-of-service, it

is important that individual maintenance agencies improve their snow and ice control strategies and tactics and implement a quality assurance program for snow and ice control products.

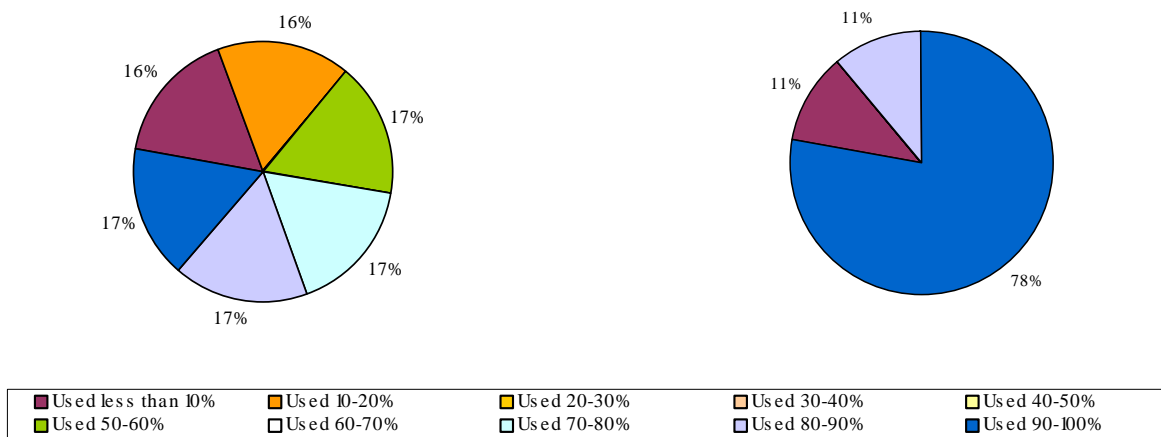
PNS has become a recognized pioneer in establishing and standardizing chemical products for snow and ice control, and numerous states and provinces outside the Pacific Northwest have adopted the PNS specifications. The members of the PNS are the transportation agencies in the states of Washington, Oregon, Montana, Idaho, Colorado, and British Columbia. Throughout this analysis, for comparison, results will be presented in two categories: 1. PNS States (and Provinces), and 2. Non-PNS States.

**Winter Highway Maintenance Practices in North America: A Snapshot**

The U.S. spends over \$2.3 billion annually on snow and ice control operations (8). The states of Colorado, Idaho, Montana, Oregon and Washington are part of the PNS association and comprise 5% of this expense at approximately \$114 million (estimates based on the questionnaire results).



**FIGURE 1 Percent roadways using anti-icing: (left) PNS states, (right) non-PNS states**

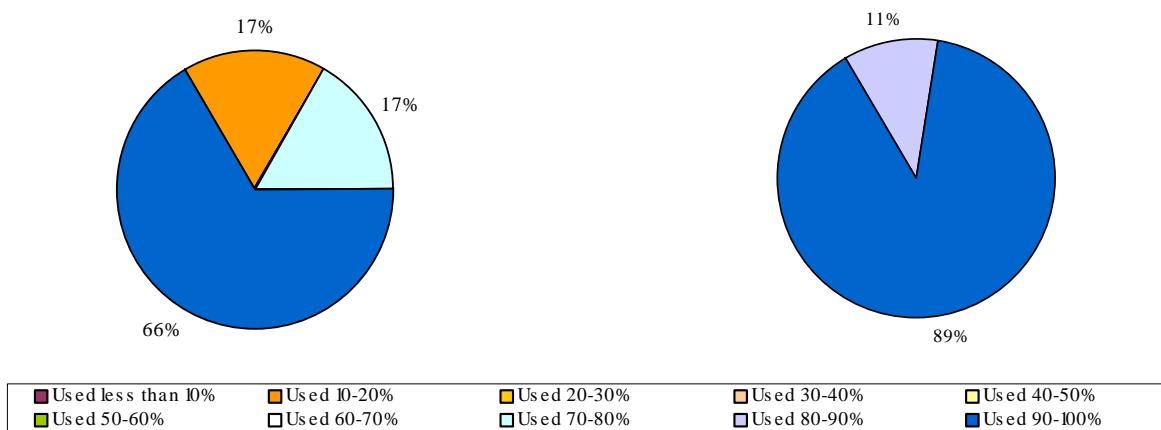


**FIGURE 2 Percent roadways using de-icing: (left) PNS states, (right) non-PNS states**

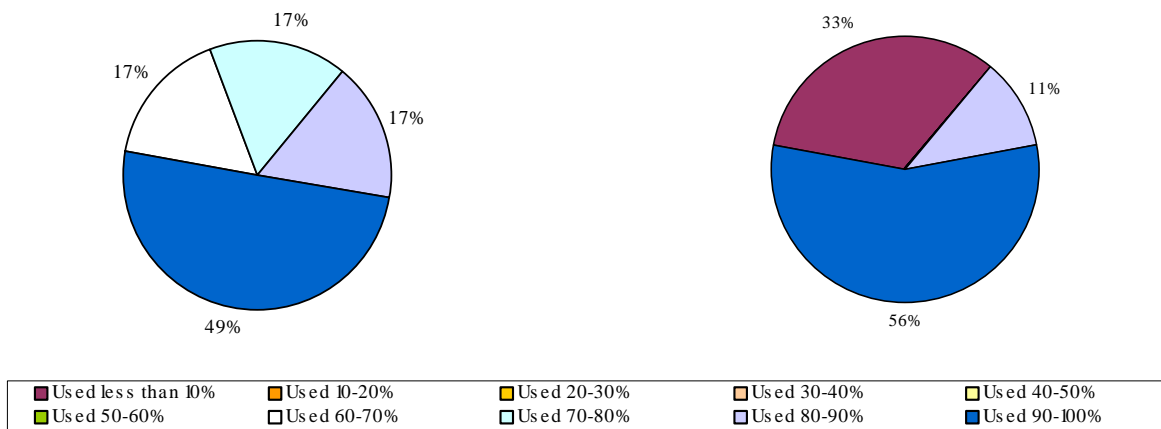
Traditionally, winter highway maintenance was heavily reliant on snowplowing, sanding and de-icing. Through this research, it was apparent that these traditional means of snow and ice control are all still heavily utilized today.

When asked “What do you see as the best method for maintaining safe winter driving conditions”, all respondents stated that a combination of all available tools was best. As a follow-up question, professionals were asked “what percentages of your roadway use anti-icing,

de-icing, snowplowing and sanding”. It was found that on average of the fifteen states, snowplowing was used 92% of the time, sanding – 75% of the time, de-icing – 76% of the time, and anti-icing – 29% of the time. FIGURES 1 - 4 show the percentage of agencies in the PNS and non-PNS states that use these practices, ranging from less than 10% of the time to 100% of the time.



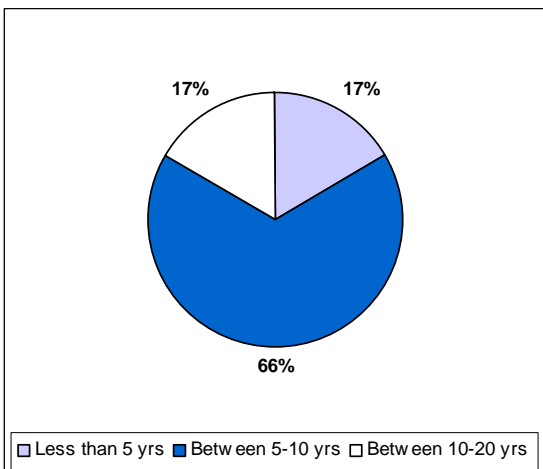
**FIGURE 3 Percent roadways using snowplowing: (left) PNS states, (right) non-PNS states**



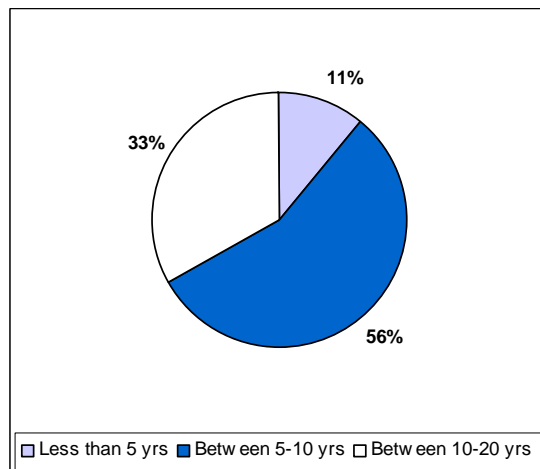
**FIGURE 4 Percent roadways using sanding: (left) PNS states, (right) non-PNS states**

**Anti-icing and Pre-wetting: Improved Methods for Winter Highway Maintenance**

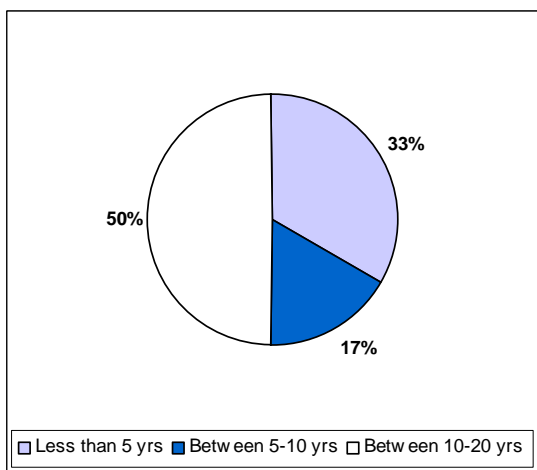
Anti-icing and pre-wetting are maintenance methods that are improving the way agencies across North America manage roadway surfaces during inclement winter weather. The majority of agencies from both PNS and non-PNS states have had 5-10 years of experience with pre-wetting, whereas the difference in experience with anti-icing was far greater. Fifty percent of PNS states had more than 10 years of experience with anti-icing, whereas none of the non-PNS states falls into this category. The differences in experience levels between the two groups of agencies implementing these improved tactics are shown in FIGURES 5 - 8.



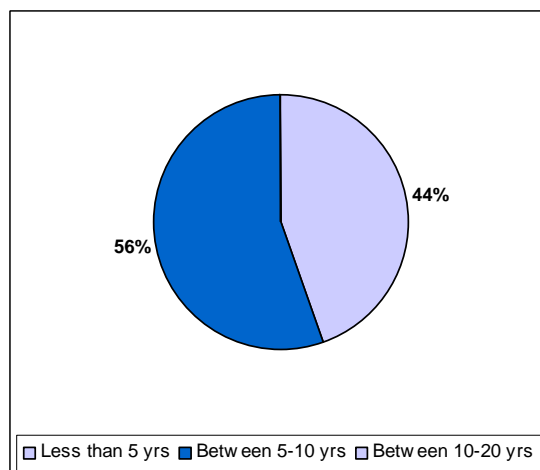
**FIGURE 5 Years of experience with pre-wetting – PNS states**



**FIGURE 6 Years of experience with pre-wetting – non-PNS states**



**FIGURE 7 Years of experience with anti-icing – PNS states**



**FIGURE 8 Years of experience with anti-icing – non-PNS states**

Both anti-icing and pre-wetting are efficient means of winter maintenance and have been found to decrease maintenance costs while reducing the vulnerability of the highway system to winter weather. In Washington State, the implementation of anti-icing in the North Central Region has resulted in improved level-of-service at the same cost as previous maintenance practices (10). Other benefits include: improved winter driving safety, reduced environmental impacts, reduced human health impacts, and reduced corrosion effects.

Interviewed experts agree that roads have increased traction more of the time when anti-icing and pre-wetting have been utilized. When asked “Have the practices of anti-icing and pre-wetting improved roadway safety for your jurisdiction”, the answer was unanimously positive.

Overall, maintenance agencies are confident that pre-wetting strategies significantly improve material retention and speed up the melting process. Pre-wet abrasives will refreeze quickly to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50% in cold temperatures (9). If warm, chemicals can accelerate break-up of snow pack while providing a traction aid to the public (9).

While pre-wetting is a useful technique in fighting snow and ice pack and for use in areas with high winds, the best way to keep roadways safe is to be proactive and implement anti-icing techniques ahead of a winter storm event. In many conditions, anti-icing eliminates the need for abrasives because it eliminates the cause for slipperiness (9). In Montana, benefits of this proactive strategy were witnessed during a winter storm that hit State Route 200 in December of 2000. The crew responsible for the Plains section used anti-icing techniques whereas the Thompson Falls crew implemented pre-wetting techniques. Of the two sections, the Plains section achieved bare pavement conditions while the Thompson Falls section remained snow packed, suggesting the success of anti-icing (11).

Idaho has also seen the benefits of anti-icing. On US 12, once anti-icing was implemented, accidents were reduced by 83% each year compared to years before the start of the pilot program (12).

Environmentally, anti-icing and pre-wetting help reduce chemical and sand levels in waterways and particulate matter in the air. Both practices reduce the total amount of materials needed, which helps reduce negative environmental impacts. When asked “Are there environmental benefits offered by the practices of anti-icing and pre-wetting”, most agencies believed so but such benefits are hard to monitor. When asked “Have the practices of anti-icing and pre-wetting significantly reduced your application rate of chemicals or sand”, some managers indicated a reduction of 20-30% for sanding applications and about 10% for chemical applications.

Concerns regarding human health and the use of chemicals and abrasives on winter roads are generally mild. In addition, agencies have found that through anti-icing and pre-wetting, they were able to reduce material usage and thus reduce potential health risks. Most agencies surveyed have experienced contamination due to winter maintenance chemicals in some form, but felt that anti-icing and pre-wetting reduce chances of reoccurrences. Survey responses are included in TABLE 1.

**TABLE 1. Survey Responses Regarding Environmental Concerns**

<b>Environmental Concerns</b>	<b>AL</b>	<b>AB</b>	<b>BC*</b>	<b>CO*</b>	<b>ID*</b>	<b>MN</b>	<b>MO</b>	<b>MI*</b>	<b>NV</b>	<b>NY</b>	<b>OR*</b>	<b>VT</b>	<b>WA*</b>	<b>WI</b>	<b>WY</b>
Claims	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No
Groundwater Contamination	X	X	X	X						X				X	
Soils and Vegetation		X	X					X	X					X	
Air Particulates				X					X						
Beneficial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

\*Current PNS Association Participating Members

Corrosion related to winter maintenance chemicals is a great concern to motorists as well as state Departments and Provincial Ministries of Transportation. Most questionnaire respondents felt that corrosion was minimal with a few complaints of cosmetic corrosion on vehicles. In one instance, an allegation was made by the power authorities, claiming that the use of magnesium chloride was corroding wires and short-circuiting some of the hydropower lines. Some agencies responded that corrosion to maintenance vehicles was high when lots of salt was used, but with the use of liquid chemicals, there is less corrosion to the body of a truck and more on the wiring. Very few agencies, however, linked winter maintenance practices to the infrastructure damage.

In examining economics related to snow and ice control, all costs should be considered such as material costs, labor hours, cleanup and repair, vehicle damage, travel delays associated

with winter road closures and construction, human health and litigation. While some of these numbers are difficult to estimate, all are important in balancing the equation to determine the best management practices.

Materials and labor hours are two categories that are easily estimated, however, not all agencies separate costs in terms of practice. Instead, they may only report a lump sum, which raises a problem when trying to differentiate whether or not anti-icing and pre-wetting are economical. However, both practices may reduce labor hours and materials while providing a safer roadway, leading to the assumption of cost savings.

The research indicates that agencies see cost savings derived from anti-icing and pre-wetting practices for snow and ice control. Overall, agencies felt that they were able to apply less material and clear the roads faster without the need for overtime. One agency reported that "trucks are off and parked 20% faster than the ones not using liquid" (13). It should be noted that economic benefits was not the number one reason for a switch in maintenance practices, but more for the improved level-of-service and safety for motorists.

### **Constraints Associated with Improved Technologies**

Constraints of implementing anti-icing or pre-wetting generally relate to the lack of equipment or training. While most agencies agree that these practices are extremely beneficial for the driving public and the environment, one respondent commented that it was difficult to implement and execute these practices in a methodical manner. On the contrary, participating PNS members overcame this kind of problem years ago. Following are some of the identified constraints associated with anti-icing and pre-wetting.

#### Anti-icing:

- Training and management,
- Equipment costs,
- Reliance on accurate weather forecasts,
- Casual slipperiness effect,
- Material handling, and
- Public perception

#### Pre-wetting:

- Training and management,
- Equipment costs,
- Material handling, and
- Public perception

It should be noted that not all conditions warrant the use of anti-icing. Under some climatic conditions such as high wind and very cold temperatures, anti-icing should be avoided (14, 15, and 16).

### **CONCLUDING REMARKS**

Anti-icing and pre-wetting offer many benefits and have great potential in changing the way maintenance agencies approach snow and ice control. Anti-icing and pre-wetting both present a viable option in reducing materials applied to roadways and maintenance costs while providing



safer traveling conditions. Both practices also lead to less corrosion and environmental impacts due to snow and ice control operations.

Materials chosen for anti-icing and pre-wetting are often similar to those used for de-icing. However, improved application techniques allow agencies to achieve safer roadways sooner with less material. By implementing anti-icing and pre-wetting, fewer chemicals and abrasives have a chance to enter soil, waterways and the atmosphere.

Compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates. Anti-icing has been recognized as a pro-active approach to winter driver safety. Pre-wetting has shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required.

Areas for improvement may include, but not limited to: better products and equipment for snow and ice control, better weather forecasting, better deployment and utilization of road weather information systems (RWIS), and most importantly, more training. Understanding the fundamental concepts behind the anti-icing and pre-wetting practices would allow agencies to use them correctly. Training and good management practices would help agencies select the best tools available for the specific combination of site, traffic and climatic conditions, including conventional snow and ice control methods.

Surveyed agencies felt that the use of anti-icing and pre-wetting techniques would become more widespread in the next five to ten years. For anti-icing, its widespread use will be possible with an improved RWIS network and reliable, site-specific local weather forecasts (such as those provided by the Weather Operations Program at the Utah Department of Transportation). A less desirable option is termed *just-in-time anti-icing*, which is suitable for agencies without access to reliable weather forecasts (such as the Montana Department of Transportation). This requires maintenance agencies to watch for visual signs that a weather event is approaching such as moisture and temperature drops, at which time, crews will begin deploying anti-icing trucks.

Agencies should continue to implement these improved practices for winter highway maintenance and further tailor the techniques to meet their localized needs. A better understanding of these practices is expected in both fundamental science and engineering aspects, as implementation is increased and additional research is performed.

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# Effects of Winter Weather and Maintenance Treatments on Highway Safety

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**ABSTRACT:**

This research has conducted an analysis of the effects of winter weather and maintenance treatments on the safety of highways as related to factors such as weather, road, and treatment characteristics. The ability to assess and quantify these effects is essential for a comprehensive cost-benefit analysis of alternative maintenance strategies and methods and effective communication of the impacts of these strategies and methods to the decision-makers and the public. Two highway routes from Ontario, Canada were selected and data on daily accident occurrences, weather conditions and winter maintenances operations were obtained for this analysis. A statistical analysis was performed on the integrated dataset with the goal of identifying those weather and maintenance factors that had a significant impact on crash frequency. The modelling results indicate that weather conditions such as temperature and precipitation (mainly snow fall) had a significant effect on the crash risk. Anti-icing and pre-wetting operations were found to have improved road safety at one of the study sites. Sanding operations were found to have a positive effect on the safety at both maintenance routes. The research however could not statistically confirm the safety effect of conventional maintenance operations – plowing and salting with dry salt.

## **INTRODUCTION**

Winter weather has a significant impact on highway safety and mobility. Past research indicates that highway accident rates during a snow storm increase considerably as compared to a non winter storm condition (Andrey and Knapper 2003). Slippery road conditions and poor visibility during a winter storm also create undesirable travel environments for travellers and cause substantial delay due to reduced traffic speed and road capability and increased accidents.

To reduce the impacts of winter storms, the province of Ontario, Canada spends more than \$100 million and spreads approximately 600 million tonnes of salt every year to keep roads and highways clear of snow and ice for safe and smooth travel conditions. Both the expenditure level and the potential environmental impact of road salt (Morin and Perchanok, 2003) have lead the Ministry of Transportation to search for and implement more effective methods of winter maintenance -, such as electronic spreader controls, thermal mapping, pre-wetting, anti-icing or direct liquid application (DLA), and fixed automated spray technology, that have the potential of providing more effective and timely removal of snow and ice while requiring significantly less amount of chemicals (Perchanok et al 1991; MTO 2004).

Most of these alternative maintenance techniques require installation of advanced information technologies such as road weather information systems (RWIS), automatic vehicle location (AVL) and fleet management systems and wireless communication to obtain real-time information on weather and road conditions. As a result these new solutions incur greater capital and operating costs from conventional operations. This difference in cost structure has lead to a wide spread of interest in and debate on the cost-effectiveness of these new methods and technologies. How much improvement can be expected from these technology-enhanced maintenance systems and operations? How extensively should these practices be adopted - should they be applied over the entire highway network or only to the most critical locations? What are the application conditions under which these practices are most cost-effective? A comprehensive approach to addressing these questions requires a better understanding of the relationship between highway performance, such as accident rates and traffic congestion and delay, and storm characteristics and road conditions under different maintenance policies and practices.

A lot of past research has been devoted to the subject of quantifying the impacts of weather on road safety; little research has been conducted on the issue of the effects of road maintenance on road safety and mobility. Existing knowledge on the safety and mobility effects of maintenance operations is not sufficient for a reliable evaluation of the benefits of

implementing new maintenance methods, materials and technologies at an operational level. The primary goal of the first phase of this research is to quantify the effects of winter storms on the safety of Ontario highways as related to factors such as storm characteristics, road and traffic characteristics, and maintenance methods.

## **IMPACTS OF WEATHER AND WINTER MAINTENANCE TREATMENT ON ROAD SAFETY – OVERVIEW OF LITERATURE**

Weather has both direct and indirect impacts on highway safety. According to Ontario Road Safety Annual Report (MTO, 2002), in spite of the rare occurrence of adverse weather in daily traffic, many crashes occurred during rainfall and snowfall in Ontario in the year 2002. Also, crashes that occurred on wet and snowy road surface account for high proportions of total crashes. This is because adverse weather reduces the friction between vehicles and the road surface and drivers' visibility, and drivers are more likely to misjudge prevailing friction conditions (Wallman, 1997). A similar trend was observed in the United States where over 22 percent of total crashes were weather-related, of which 49 percent and 13 percent occurred during rainfall and snowfall respectively (Goodwin, 2003).

Many studies have reported that snowy weather conditions during winter have more severe impacts on roadway safety than weather conditions during summer due to increased crash risk and exposure to hazards. Nilsson and Obrenovic (1998) suggested that drivers are twice as likely to be involved in an accident in winter than in summer for the given distance of travel. Wallman et al. (1997) observed that more crashes tend to occur in the beginning of winter and when there are fewer snowy road conditions during winter because drivers are suddenly exposed to hazardous conditions after a long break of non-winter weather. However, snowfall-related crashes tend to be less serious than rainfall-related crashes (Andrey et al., 2003a). In this regard, Knapp et al. (2000) speculated that drivers may react to the snowy weather by driving slower, thus reducing the consequent impact of a collision.

A recent study by Iowa State University (Knapp and Smithson, 2000) focuses on the effects of winter storms on traffic safety for a 48-km long highway section in Iowa. They investigated the factors affecting volume reduction during storm events and found that total snow fall (depth of snow), average minimum wind speed, and square of maximum gust wind speed have positive effects on traffic volume reduction. They concluded that crashes are more likely to occur during storm event time periods (2 crashes/event) than non-storm event time periods (0.65 crashes/event). However, this study limited the scope of winter storms to those storm events with more than 4-hour duration and more than 0.51 cm/hour snowfall intensity. Thus, the study does

not take into account the variable effects of winter storms with different severity on traffic safety in a broader scope. Also, they did not consider the presence of winter maintenance activity during storm events and therefore, it is unclear whether the model reflects the sole effect of winter storms on road conditions and safety.

Khattack et al. (2000) found that there is a close relationship between crash frequency and characteristics of storm events such as snowfall intensity, snow fall duration, and maximum wind gust speed. They also considered the effect of exposure (i.e. number of vehicles during a snowfall event on a highway section under the same weather condition) and found that snowfall events are associated with reduced traffic volume (i.e. exposure to hazardous road conditions) which a higher crash rate (= crash frequency divided by exposure). Note that these studies mainly focused on the effects of storm characteristics on crash risk without controlling for maintenance operations.

There is abundant empirical evidence showing that winter road maintenance significantly improves road safety. Quantitative investigations on this subject were however scarce. Hanbali (1994) found a significant reduction in crash rate after de-icing maintenance activity. The Swedish Road and Traffic Road Institute (VTI) investigated the relationship between winter road safety and road maintenance for many years with most of the findings reviewed and summarized by Wallman et al. (1997) as follows:

- The accident rate reached its maximum one hour before the maintenance action and the accident rate was reduced by 50 percent a half-hour after the action. The number of accidents was reduced to 1/6 6-12 hours after winter maintenance was implemented. They also cited that the numbers of accidents were reduced up to 1/5 and 1/8 after maintenance was carried out in Germany and U.S., respectively. These findings demonstrate that winter road maintenance does improve road conditions and lower crash risk
- Some before-after studies and parallel comparisons of similar roads with different maintenance intensities indicated that the effects of road salt with regard to road safety could not be statistically confirmed. It had been reported that reduction in crash frequency was not in proportion to the improvement in road conditions. Many studies attributed these counter-intuitive results to the road user's risk compensation behaviour, that is, road users utilise the apparent increase in road friction (e.g. due to salting) by increasing their speed.
- It has been observed that preventive salting (anti-icing) was more effective than conventional, reactive salting, in reducing the crash rate.

There are a number of problems with past research on the effects of weather and winter road maintenance on road safety, specifically,

- Most research relied on data that was either inaccurate or incomplete. For example, many studies have used aggregated seasonal and yearly average for weather and traffic conditions because daily and hourly weather and traffic counts were not available. Also, road condition data and accident reports obtained from different organizations were not consistent with each other.
- Most investigations cover large regions with large spatial and temporal analysis units. Such macro-level analysis cannot take into account local variations in weather and road conditions, traffic and maintenance operations.
- Most studies did not consider the effects of winter road maintenance treatments on road safety, mostly, due to the fact that detailed maintenance records were not available.
- Most findings and results reported in literature were obtained directly from observations with simple before-after analysis with few resulting from systematic statistical analysis accounting for effects of multiple factors.

## **DESCRIPTION OF STUDY SITES AND DATA**

In order to identify the impacts of winter snow storms and winter maintenance activities on road safety, observational data on these “effects” (e.g., accidents) under different conditions (e.g. road and weather conditions) and treatments (i.e. maintenance operations) must be obtained. The first step of this research was therefore to identify sites or highway sections for which the following three data sources were available: traffic and accident records, weather reports and maintenance operations records. This section details the study sites identified and data sources used in this investigation.

### **Study Sites**

Two maintenance routes on Ontario provincial highways were identified that had data suitable for analysis (Figure 1).

The first route is a section of Hwy 401 covered by the London patrol yard, starting from the intersection of Hwy 402 and running west of Hwy 401 to the intersection of Hwy 40. The total length of the maintenance route is approximately 94 km. The patrol yard had used plowing



and salting as the primary means for snow and ice control. Sanding was applied on those days with an extremely low temperature.

The second route is a section of Hwy 401 from Hwy 40 (the west end of the London patrol yard) to the Canada-US border. The route is covered by the Iona patrol yard with a total length of approximately 80 km. The Iona patrol yard has been using new de-icing and anti-icing methods, including pre-wetting and DLA, in addition to plowing and salting.

### **Data Sources and Data Integration**

In order to investigate the impacts of weather conditions and maintenance operations on road safety, the following three types of data are required:

- Accidents and traffic volume
- Daily weather conditions
- Winter maintenance activities

The details of these data sets are discussed in the following section.

### **Accidents and Traffic Volume Data**

MTO maintains a database of all accidents occurring on all provincial highways in its Accident Database System (ADS). The data is collected by the Ontario Provincial Police (OPP), and contains the characteristics of all accidents under the jurisdiction of the provincial authorities, including provincial highways, municipal, township, county, regional, private property, and federal roads. The database contains information such as accident location, date, accident type and consequence, road and weather conditions etc. The traffic database available from MTO contains highly aggregated traffic data including AADT (Annual Average Daily Traffic) and WADT (Winter Average Daily Traffic).

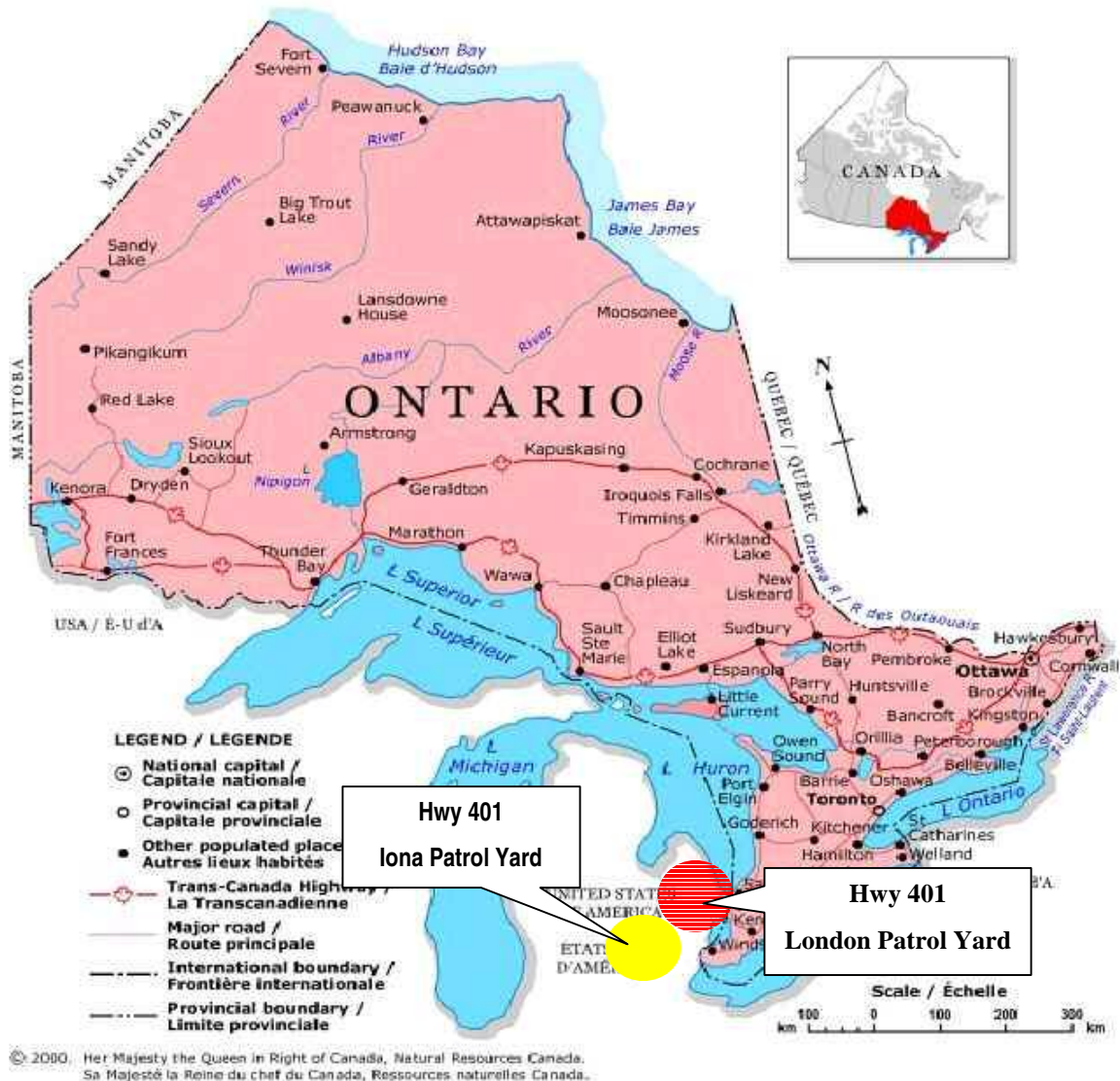


Figure 1: Study Sites

## **Weather Conditions Data**

Environment Canada maintains a website from which daily climate data for each specific weather station can be downloaded. The archived daily climate data contains information such as mean temperature, total precipitation (mm) and snow fall. It should be noted that in this analysis we considered only temperature and daily total precipitation.

## **Winter Maintenance Activities**

MTO classifies winter maintenance operations into eight (8) types based on the nature of the operations such as equipment type and materials used, as described in Table 1. All maintenance operations performed by a patrol yard are reported on the daily Winter Operations Record (WOR). MTO maintains a database of daily summary of maintenance activities using its Maintenance Management Information System (MMIS). Daily summary reports on the selected routes were extracted from the MMIS, which contains the following information: Operation Number (defines the type of the maintenance operation), amount of salt, sand, and liquid (brine), and distance of service (km).

## **Database Integration and Pre-processing**

The three data sources described previously (ADS, weather and MMIS) were integrated for analysis over the period Nov. 2002 to Dec. 2003. The common field - date was used as the primary key to integrate them together. Prior to integration the accident data records were pre-processed using a summary query to aggregate the occurrence records into records of daily accident frequency. After the databases were integrated, a pre-processing process was taken to ensure the integrity and consistence of the data.

Preprocessing and filtering of the data resulted in a total of 102 and 130, days of high quality observations for Hwy 401 (Iona) and Hwy 401 (London), respectively. Tables 1 provide a summary of the explanatory variables along with two descriptive statistics.

**Table 1: Variables and Statistical Properties**

Category	Variable	Description	Iona Route			London Route		
			#Days	Mean	Stdev	#Days	Mean	Stdev
Crash Freq/ Days	Y/n	Crash frequency (accidents/days)	97/102	0.83	1.05	141/130	0.9	1.9
Weather	T	Average of the daily min and max temperature (C)	102	-7.2	5.3	130	-5.9	4.2
	P	Total precipitation (mm)	102	3.2	5.2	130	1.6	4.1
Winter Maintenance Operations (Treatments)	AI <sub>1</sub>	Anti-Icing – Total lane-km	12	10.7	34.2			
	AI <sub>2</sub>	Anti-Icing – Total amount (litres)	*	*	*			
	ST <sub>1</sub>	Salting with Dry Salt – Total lane-km	5	5.2	35.2	90	928.9	1111.0
	ST <sub>2</sub>	Salting with Dry Salt – Total amount (tons)	*	*	*	90	80.1	101.8
	PST <sub>1</sub>	Pre-wet Salting – Total lane-km	34	95.2	185.9			
	PST <sub>2</sub>	Pre-wet Salting – Total amount (tons)	*	*	*			
	PW <sub>1</sub>	Plowing – Total lane-km	30	112.7	257.8	53	783.8	1752.3
	SD <sub>1</sub>	Sanding – Total lane-km	37	12.5	25.0	11	8.4	40.3
	SD <sub>2</sub>	Sanding – Total amount (tons)	*	*	*	11	0.9	6.2
	PW_S <sub>1</sub>	Combo (plowing + sanding/salting) - Total lane-km				66	288.5	442.6
	PW_S <sub>2</sub>	Combo (plowing + sanding/salting) Total amount (tons)				66	12.4	20.0
	PSD <sub>1</sub>	Pre-wet Sanding – Total lane-km						
	PSD <sub>2</sub>	Pre-wet Sanding – Total amount (tons)						
	PW_PS <sub>1</sub>	Combo (Plowing + Pre-wet sanding/salting) - Total lane-km	23	138.1	345.3			
	PW_PS <sub>2</sub>	Combo (Plowing + Pre-wet sanding/salting) Total amount (tons)	*	*	*			

\* Data incomplete

## DATA ANALYSIS AND MODEL CALIBRATION

### Methodology

Regression analysis is one of the most commonly used techniques for quantifying effects of different factors (independent variables) on a response variable. In regression analysis, models are calibrated to represent relationships between the response variable and a set of explanatory variables based on observational data. These models can be used to explain the degree of effects that individual factors have on the response variable and also to predict future responses under given conditions. In safety analysis, the response variable is the average number of crashes (or crash frequency) occurring on a particular highway section or intersection and the independent variables are factors influencing crash frequency such as road geometry, weather and traffic.

The simplest regression models are the ordinary *linear* regression models (OLR), assuming that the response variable is continuous and normally distributed with its expected value linearly depending on explanatory variables. Safety analysis does not meet the assumptions of OLR because the response variable - crash frequency is a discrete number that usually follows a counting distribution such as Poisson distribution. The commonly used regression model for this type of response variables is the Generalized Linear Model (GLM), which is an extension of OLR. GLM allows models to be fit to data that follow probability distributions other than the Normal distribution, such as Poisson, Negative Binomial and Multinomial distributions.

In this research, we started with the most commonly used GLM for modeling accident data – the standard Poisson regression model. Specifically, we assume that the number of accidents  $Y_i$  occurring on a particular day  $i$  on a given maintenance route is independently Poisson distributed, that is:

$$Y_i | \mu_i \sim \text{Poisson}(\mu_i) \quad (1)$$

where the set of independent observations for the  $n$  days is represented by the vector  $(y_1, y_2, \dots, y_n)$ , with corresponding accident mean  $(\mu_1, \mu_2, \dots, \mu_n)'$ . The accident mean  $(\mu_i)$  is commonly defined as an exponential function of a vector of covariates as follows:

$$\mu_i = F_1^{\beta_1} \exp(\beta_0 + \beta_2 x_2 + \dots + \beta_k x_k) \quad (2)$$

where  $F_1$  is traffic exposure such as traffic volume;  $(x_2, x_3, \dots, x_k)$  are covariates representing factors such as weather conditions and treatment variables, and  $(\beta_0, \beta_1, \dots, \beta_k)$  are regression parameters to be estimated from the data. Because data on daily traffic volumes were not available, the exposure term was considered as a constant term for a given maintenance route.

The model may also include interaction terms of two or more explanatory variables, represented by a product term inside the regression model. Two-interaction terms usually have a

physical meaning and relations between variables are straightforward to interpret; more complicated terms are not recommended to include in regression models due to their higher complexity.

Once a model form is assumed, coefficients of the model can be estimated by fitting the model to the observed data and testing their significance. In this research, we used SAS to calibrate all the models described in the following section.

## **Calibration of Crash Frequency Models**

### *Crash Frequency Models for Hwy 401-Iona Patrol Yard*

The case of Iona patrol yard is of most interest to us as it involved many different types of maintenance operations, such as anti-icing, pre-wet salting and sanding. The available data set includes a total of 102 days of observations with a total of 97 accidents. We first conducted an exploratory analysis of the correlation between the independent variables (notations of these variables and their units are given in Table 1). It was found that there was a noticeable correlation between combined operations of plowing and sanding (PW\_S<sub>1</sub>) and combined operations of plowing and pre-wet salting (PW\_PS<sub>1</sub>), salting with dry salt (ST<sub>1</sub>) and plowing (PW<sub>1</sub>). The plowing operations were also correlated with the combo operations of plowing and pre-wet salting (PW\_PS<sub>1</sub>). With this correlation information, we started with a model including all uncorrelated independent variables and then step-wise eliminate those that were not found to be significant. Table 2 summarizes two calibrated models as the outcome of this process.

Model I treats all variables as they are without any modification. As can be seen, the two weather condition variables -- temperature and precipitation -- are statistically significant at a 95% level of confidence. The signs of the associated coefficients make intuitive sense, suggesting that crash risk would increase as the temperature decreases and precipitation increases. Also, three of the six variables representing maintenance treatments, including anti-icing, pre-wet salting with plowing and sanding, were found significant at a level of confidence slightly over 80%. The signs of the coefficients related to treatment operations are all negative, implying that these operations had a positive impact on road safety.

**Table 2 - Model estimation results: parameter values and significance tests (Hwy 401 – Iona)**

Variables	Model I				Type	Model II			
	Coeff.	Std.Err.	t-ratio	P-value		Coeff.	Std.Err.	t-ratio	P-value
Constant	-0.6710	0.237	-2.836	0.005	continuous	-0.5113	0.236	-2.171	0.030
T	-0.0692	0.024	-2.888	0.004	continuous	-0.0697	0.023	-3.009	0.003
P	0.1269	0.018	7.102	0.000	continuous	0.1423	0.019	7.368	0.000
AI <sub>1</sub>	-0.0069	0.005	-1.420	0.156	(1,0)	-1.0244	0.521	-1.966	0.049
PW_PS <sub>1</sub>	-0.0005	0.000	-1.370	0.171	continuous	-0.0007	0.000	-1.886	0.059
SD <sub>1</sub>	-0.0071	0.005	-0.318	0.188	(1,0)	-0.6729	0.250	-2.690	0.007
Log Likelihood	-154.6				-151.1				
Likelihood Ratio	47.2				54.2				

Because the confidence level for these treatment-related variables in Model I are lower than the commonly accepted threshold value 95%, we explored an alternative model form in which treatment variables are represented as binary variables with a value of 1 representing cases with maintenance operations and 0 for those without any maintenance operations. From a statistical point of view, this analysis is essentially a generalized form of the ANOVA process commonly used to evaluate the differences between different treatments. Table 3 shows the result of this analysis (Model II), with AI<sub>1</sub> and SD<sub>1</sub> being assumed as binary variables. Note that this new model includes the same variables as the first model (Model I); however, all variables are now significant at or near a 95% level of confidence. This new result further confirmed the finding from the previous model, that is, anti-icing, pre-wet salting with plowing and sanding all had statistically significant effects on reducing the number of accidents on this maintenance route.

Another interesting outcome of this analysis is that the safety effects of salting with dry granular salt and plowing operations could not be confirmed statistically. Similar findings were also found in the analysis of other two highway sections discussed in the following sections. It is important to point out that while this result seems to be consistent with some of the findings from existing studies (Wallman et al. 1997), its generalization should be cautious. Further discussion of this issue is provided in the following sections.

The likelihood ratio generated by the parameter estimation process is an indicator that can be used to test the significance of the resulting model. By comparing the likelihood ratio to the critical  $\chi^2$  value, we can test the null hypothesis (i.e.,  $H_0$ : there is a single common slope parameter for each one of the explanatory variables through different categories). The statistics shown in Table 3 indicates both models fit adequately the data at a level of significance ( $\alpha$ ) of 5%. Equation 3 presents the resulting model for the expected crash frequency on this highway section.

$$\mu = e^{-0.671} \cdot e^{-0.069T} \cdot e^{0.127P} \cdot e^{-0.007AI_1} \cdot e^{-0.001PW\_PS_1} \cdot e^{-0.007SD_1} \quad (3)$$

The calibrated model can be used to evaluate the relative effectiveness of the individual treatment operations included in the model, allowing comparisons to be made between different treatment methods. For example, anti-icing operations ( $AI_1$ ) and combined plowing and pre-wet salting ( $PW\_PS_1$ ) were both used under similar weather conditions, but based on the analysis results, the former (with a coefficient of -0.0069) was approximately ten times more effective than the latter (with a coefficient of -0.0005) under the same kilometre of operations (Note the units associated with both variables are kilometres). A comparison between sanding ( $SD_1$ ) and other operations should however *not* be made directly as they were generally used under different weather conditions.

With the calibrated model, we can also quantify the marginal effect of a given treatment. Because of the exponential functional form, the exponent in the model (e.g.  $-0.0071SD_1$ ) is a measure of sensitivity of crash frequency to the corresponding variable ( $SD_1$ ). For example, the exponent associated with sanding operation,  $-0.0071SD_1$ , suggests that 1 percent of increase in sanding kilometres would lead to  $0.0071SD_1$  percent of reduction in the number of crashes. If the mean of the observed sanding kilometres (34.5km/operation-day) is used as the base value for  $SD_1$ , a 1% increase in sanding operations (km) would result in 0.245% ( $0.0071 \times 34.5$ ) reduction in crashes.

#### *Crash Frequency Models for Hwy 401-London Patrol Yard*

The winter maintenance operations performed by the London Patrol Yard were mostly conventional (i.e. plowing and salting) with a few sanding operations. The data set includes a total of 130 days of observations with a total of 141 crashes. Similar to the previous analysis, we first evaluated the correlation patterns among the variables. A strong positive correlation existed between the plowing operation ( $PW_1$ ) and other maintenance operations including salting with dry salt (both in total kilometres  $-SD_1$  and total tons -  $SD_2$ ) and combined plowing and salting ( $PW\_S_1$  and  $PW\_S_2$ ). Applications of dry salt (ST) were also positively correlated with the combined operation of plowing and salting ( $PW\_S_1$  and  $PW\_S_2$ ). Variables representing different measures of the same operations (e.g. total kilometres  $-SD_1$  vs. total tons -  $SD_2$ ) are highly correlated as expected and should not be included together in a same regression equation. There are also traces of correlations between maintenance operations and precipitation  $r$  ( $>0.30$ ).

A number of attempts were made to identify the best models that could be fit to the data. Table 3 gives the results of an initial attempt (Model I), which includes two weather variables and four maintenance treatment variables. It can be seen that two maintenance treatment variables,  $PW\_S_1$  and  $ST_1$ , are significant at a level of confidence of 95%. However, the coefficients associated with these two maintenance operations are positive, implying that the crash frequency on this route had increased as the amount of maintenance operations increased. This result is counterintuitive and should be interpreted with caution. First, the positive correlation could be because decisions on the amount of maintenance work to undertake are reflective of actual -snow accumulation on the road. For example, more maintenance trucks could have been dispatched if there were more accidents on the road. The correlation



coefficients between the maintenance treatment variables and total precipitation are as high as 0.39, which is an indication of some correlation.

Second, many patrol yards follows a minimum level of service standard in deciding when, where and at what frequency certain maintenance operations are applied. Such a policy-based maintenance approach may limit the variation in maintenance operations that could be observed in field under a given weather condition.

A series of alternative model forms and variable representation schemes were subsequently attempted. Table 7 gives the best model - Model II, in which the only significant variables (at a level of significance 5%) are temperature and precipitation. One observation that can be made from these two models is that the coefficients associated with temperature and precipitation in this model are comparable with those in the models for the Iona route.

**Table 3: Model estimation results: parameter values and significance tests (Hwy 401 - London)**

	Model I				Model II			
	Coeff.	Std.Err.	t-ratio	P-value	Coeff.	Std.Err.	t-ratio	P-value
ONE	-0.8928	0.203	-4.390	0.000	-0.4248	0.169	-2.508	0.012
TEMP	-0.0324	0.030	-1.096	0.273	-0.0582	0.026	-2.225	0.026
PRCP	0.0364	0.014	2.639	0.008	0.0801	0.011	7.549	0.000
PW_S <sub>1</sub>	0.0007	0.000	2.590	0.010				
PW <sub>1</sub>	-0.0001	0.000	-1.048	0.295				
ST <sub>1</sub>	0.0003	0.000	3.272	0.001				
SD <sub>1</sub>	-0.0008	0.001	-0.579	0.563				
Log Likelihood	-211.4				-224.7			
Chi Squared	81.81				55.18			

## CONCLUDING REMARKS

This paper has described an in-depth analysis on the relationship between winter road crash risk and weather conditions and snow and ice control operations. Two highway sections were selected for this investigation. Data on daily accident occurrences, weather conditions and winter maintenances operations were obtained from various data sources. A systematic statistical analysis was performed on the integrated data set with the goal of identifying quantitative effects of weather and maintenance operations on road safety. The following is a list of major conclusions and findings obtained from this research:

- A series of Poisson regression models have been developed for the relationship between daily crash frequency and various influencing factors at the two study sites. These models could be used both for sensitivity analysis and prediction of the effects of weather and alternative maintenance operations;

- The effects of weather conditions, including temperature and precipitation, on crash frequency were found to be significant as expected and consistent across the two sites. The model coefficients associated with temperature and precipitation were also found to be comparable across the two sites (e.g. -0.058 vs. -0.069 for temperature and 0.080 vs. 0.127 for precipitation).
- Sanding operations have been carried out in Iona patrol yard and were found to have a significant impact on the safety of this maintenance route.
- Of the two study sites, the Iona patrol yard is the only one that had performed anti-icing (DLA) operations. Our analysis confirmed that the anti-icing operations performed by the Iona patrol yard had a positive effect in reducing the number of crashes on this route. The effectiveness of anti-icing operations was also found to be much higher than the combined operations of plowing and pre-wet salting when kilometres of spreader or plow travel are considered.
- Plowing and salting with dry salt are two most commonly used methods in practice for snow and ice removal. Our statistical analysis on the three data sets, however, could not confirm the safety effect of these two treatment methods. While similar findings have been reported in literature (Wallman et al. 1997), a further investigation on other contributing factors is needed before a general conclusion can be reached. For example, there could be inter-dependency between maintenance operations and snow cover conditions; more maintenance operations were dispatched under more severe weather conditions. Also, maintenance operations on a highway usually vary according to weather conditions and consequently variation in these operations under a given weather condition may be small. When the observed variation of an independent variable (e.g. salting) in a data set is small, its association with the response variable (crash frequency) becomes less quantifiable. Furthermore, significant local variation in snow conditions due to drifting and shading may also result in large variation in snow cover and thus safety.

The research project has initiated the challenging task of quantifying impacts of winter snow storms and winter maintenance operations on highway safety. This exploratory analysis has identified a viable method of analysis that relates maintenance practices to road safety outcomes. The research, however, needs to be expanded with data at a finer scale and additional sites providing a wider range of predictor values. Specifically,

- More study sites covering a wider spectrum of geography (urban vs. suburban), road classes and geometry, weather conditions and treatment options should be considered in future research. Ideally, the sites selected should have implemented different types of winter maintenance treatments, such as salting with different application rates, pre-wetting and anti-icing.
- This research treats a whole maintenance route as an analysis unit. It would also be interesting in future research to look into smaller spatial units such as sub-sections of a maintenance route, ramps and bridges. Such a micro-level analysis is necessary when there is a large variation in road weather conditions and treatment applications over a maintenance route and there is a need to evaluate maintenance technologies that are applied only to small road segments (e.g. fixed automated spray technology). In order to perform this type of analysis, data on weather, road surface conditions, and maintenance treatments at a sub-section level need to be collected. Collecting such disaggregate data

will likely require supports of automated data collection systems such as AVL, mobile computer based condition reporting and real-time thermal mapping. –add discussion of drifting and shading?

- Traffic exposure is one of the important factors influencing road safety. To incorporate traffic exposure in safety analysis, daily traffic counts must be made available. Unfortunately, for the patrol routes selected in this analysis, this information was not available (the permanent counting stations are all located outside of these patrol routes). In this research, we tried to circumvent this issue by modeling individual routes separately, instead of, a mix of different highways together. This approach would however not resolve the issue completely as traffic also varies from day to day, especially during the days of severe weather conditions. With continuous traffic counts (and a detailed highway inventory), it would be possible to consider such day-by-day variations in traffic and even combine multiple highways (and patrol yards) together in modeling, thus having a much larger sample size for a more robust statistical analysis. In conclusion, for safety, mobility and performance analysis, it is necessary to collect daily or hourly traffic volume data at individual patrol routes along with road weather and conditions data.
- In a rigorous sense, crash risk of a highway is the product of the expected crash frequency (or probability of having a crash) and the expected consequence resulting from a crash. This research has focused only on modeling the effects of weather and maintenance operations on crash frequency. Future research should also examine the impact of these factors on crash consequences. While past studies have found that the consequence of a crash was usually lower in winter seasons due to reduced travel speeds under adverse weather conditions than non-winter seasons, the effects of maintenance operations on crash consequences have yet to be quantified.

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# Braking Traction on Sanded Ice

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Traction enhancement on iced pavements using abrasives was evaluated. The abrasives tested were five distinct gradations of sand built from a single host material. Four of the sands represented standard gradations as specified by the FAA, SAE, ASTM, and Transport Canada. Braking traction at a relatively fixed slip rate was measured with a full-size, self-contained instrumented vehicle. All tests were performed on an ice sheet inside a large refrigerated room. Results showed that coarse sands perform best on cold ice surfaces and that finer sands excel on warm ice. Sands with most of their grains about 1 to 2 mm in diameter performed well independent of ice temperature. The concentration of a sand on ice strongly influences the degree of traction enhancement, as does the temperature of the sand when applied to the ice. The results suggest that a mathematical expression could be generated that would relate sand type and concentration, along with several other influential parameters, to braking traction coefficient on ice.

Driving and braking traction on roads and runways in regions affected by subfreezing temperatures is often degraded by ice. Depending on the circumstances, an abrasive product may be the only way to enhance traction on iced operating surfaces. Natural sands are the most common abrasive product. Several standard gradations are identified by various agencies for specific applications. The use of abrasives at most airports is regulated by the FAA, which specifies the type of sand allowed for use on runways and the conditions and methods surrounding its use in its Airport Winter Safety and Operations Advisory Circular 150/5200-30.

This study was initiated as a result of concerns expressed by many airport operators about the lack of readily available sources of the FAA sand and its high cost relative to other sand types. At least one aircraft manufacturer has also expressed concern about the current FAA-specified sand. The manufacturer objects to the allowance of sand particles that are larger than 3.30 mm in diameter (No. 6 sieve), which the manufacturer claims can cause serious damage when ingested in turbine engines.

The goal of this study was to compare the ice braking friction coefficient of the FAA sand with that of other specified sands. The sands tested in this study were those specified by ASTM for mortar, SAE for runways, Transport Canada (TC) for runways (Table 1), and a very fine graded sand. The fine sand was included in this study because of our interest in determining the contribution of fine particles to traction enhancement. Sands containing a high fine content are generally less costly, and some aircraft personnel believe that fine particles are less likely to damage aircraft engines (1).

## BACKGROUND

The frictional properties of sanded ice as a function of grain size has been addressed in the literature. Hegmon and Meyer tested four granular materials on ice: boiler house cinders, coke cinders, sand, and crushed stone (2). In their tests they used a full-size tire mounted on a pivot arm that traveled around a circular ice track in a cold room. The test temperature was held at  $-6^{\circ}\text{C}$ , and the abrasives were applied to the ice to yield surface concentrations between 160 and 650  $\text{g}/\text{m}^2$ . Their study concluded that size fractions between 1.18 and 4.76 mm in diameter (falling between sieves No. 16 and No. 4) contribute most to the friction coefficient; they recommended that finer and coarser fractions be eliminated or minimized.

Hayhoe tested crushed and uncrushed materials of three distinct size gradations at a surface concentration of 980  $\text{g}/\text{m}^2$  (3). Hayhoe was primarily interested in the effect of varying sand and air temperatures on the friction coefficient. The uncrushed material consisted of a mixture of roofing gravel and concrete sand. The crushed material used was Pennsylvania Department of Transportation and mortar sand. Hayhoe also used a full-size tire on an indoor circular ice track. Test results for an ice temperature of  $-24^{\circ}\text{C}$  indicated that the friction coefficient improved with coarsening of a sand; for ice temperatures near melting ( $-1^{\circ}\text{C}$ ), the friction coefficient improved with greater fine grain content. At intermediate temperatures (about  $-12^{\circ}\text{C}$ ), Hayhoe's results agreed with those of Hegmon and Meyer, that a sand consisting of grains between 1.18 and 4.76 mm in size (No. 16 and No. 4 sieves) gave the highest friction coefficient.

Connor tested four materials using both laboratory and field test methods: the British pendulum test, Tapley deceleration meter, and stopping distance measurement using a full-size automobile (4). The abrasives used in Connor's study included crushed stone, "pit-run" stone (source aggregate for the crushed stone), concrete aggregate with a high fine sand content, and coal cinders. All abrasives were applied in surface concentrations between 100 and 2000  $\text{g}/\text{m}^2$  on ice at temperatures of  $-23$ ,  $-18$ ,  $-9$ , and  $-1^{\circ}\text{C}$  for the laboratory tests and at  $-20^{\circ}\text{C}$  in the field. Connor found that coal ash—by far the finest of the four materials with 44 percent of the grains finer (by weight) than 0.297 mm in diameter (No. 50 sieve) and 20 percent finer than 0.074 mm (No. 200 sieve)—outperformed the other materials in most cases. Connor also concluded that angular material provided higher friction coefficients than rounded particles. The results were presented as a function of sand concentration on the ice.

The Airports Authority Group of Canada also studied the effect of grain size on ice friction at ice temperatures of  $-9$  and  $-3^{\circ}\text{C}$  (5). Their tests were designed to determine the

**TABLE 1** Allowable Gradations for Several Specified Sands

Sand Type	Sieve Number	Percent Finer by Weight
FAA	4	100
	8	97-100
	16	30-60
	50	0-10
TC	4	100
	8	30-50
	16	0-20
	50	0-2
SAE	6	100
	8	60-100
	25	0-20
	40	0-5
ASTM	4	100
	8	95-100
	16	40-75
	50	10-35
	100	2-15

relative surface concentrations of two sands that would give the same coefficient of friction. One sand had grain sizes no larger than 2.36 mm (No. 8 sieve), and the other allowed grains up to 4.76 mm in diameter (No. 4 sieve). Measurements were made on an actual iced runway with a Tapley deceleration meter and a Saab friction tester. They concluded that the finer material must be applied at a surface concentration of 85 to 95 g/m<sup>2</sup> to match the braking performance that was measured on ice treated with the coarser sand at a surface concentration of 50 g/m<sup>2</sup>. For concentrations greater than 120 g/m<sup>2</sup> on cold ice or 240 g/m<sup>2</sup> on warm ice, however, the finer sand provided a higher coefficient of friction.

In a precursor to the study reported here, the authors performed an initial assessment of frictional qualities of four sand types on ice (6). They compared the FAA sand with three other popular sand types: from SAE (SAE AMS 1448), International Civil Aviation Organization (ICAO), and ASTM (ASTM C144). Using a small-scale sliding friction table, the sliding friction of a rubber-faced slider on sanded ice at -10°C was measured. Tests were done on bare ice, loosely sanded ice, and ice with sand frozen on at a single concentration of 1750 g/cm<sup>2</sup>. The friction coefficients for the slider on bare ice were found to be higher than those measured on loosely sanded ice and, in some cases, on ice with sand frozen on. Test results were presented as a performance ratio (friction coefficients for sanded ice to bare ice), which allowed the sands to be ranked distinctly—in order of decreasing effectiveness—as ASTM, FAA, SAE, and ICAO. The performance ratio showed a strong, linearly increasing trend as the percentage of a given fine grain size in the sand was increased. Greater increases in traction with increases in fines were found for frozen-on sand than for loosely sanded ice.

## EQUIPMENT AND FACILITIES

To ensure environmental control for our tests, the entire test program was conducted inside the Frost Effects Research

Facility (FERF) at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. The FERF is a large building capable of holding a constant ambient air temperature ranging between -12 and 15°C. For a test surface, we constructed a temporary ice rink 30 m long and 3.6 m wide inside the building. Controlling the temperature of glycol that was passed through cooling coils in the ice enabled the temperature of the ice to be controlled. Thermocouple strings frozen into the ice sheet at three locations were used as feedback to the glycol source to attain the desired ice-surface temperature.

Traction was measured using a versatile instrumented vehicle that can operate in a variety of measurement modes. The CRREL instrumented vehicle (CIV) is based on a 1972 Jeep Cherokee and measures three mutually perpendicular forces at the contact patch for each of the four tires, the speed of each tire, and the speed of the vehicle itself. A computer-based data acquisition system collects data at a rate of 10 samples per second and stores the data in a spreadsheet format for later analysis. Further details on the CIV are given elsewhere (7).

To match the measurements taken by the usual FAA-endorsed devices (skidometer, Saab and K.J. Law friction testers, Tapley meter), the CIV was configured to operate at a constant rate of negative slip (braking) of between 10 and 20 percent. To accomplish this, all four tires were driven at a common rate of rotation, but they were installed with a 15 percent difference in circumference on the front and rear axles. Thus, the tires with the least vertical load (normal force) were forced to slip to take up the difference in rotation. For the CIV, the rear wheels have the least normal load. With smaller-diameter tires installed on the rear axles, all the slip took place there.

Data were collected with the vehicle operating at a constant ground speed of 5 km/hr over a 17-m segment of the ice surface. This yielded at least 10 sec of data collected at steady-state conditions (at least 100 data points for each tire).

During a braking traction test, the CIV measured the total tire-dragging force of the slipping tires, which included both the interfacial force at the tire-ice contact patch and the internal resistance to rolling naturally present in a tire (caused by flexing of the tire belts and carcass). To isolate the interfacial (friction) force, the internal resistance was determined in separate tests in which the CIV measured the tire-dragging force of the tires in a nonslip condition. This resistance force was subtracted from the total tire-dragging force to obtain the desired friction force.

New tires (P185/75R14 Goodyear Invicta) were installed on the rear axles where braking traction was measured; they were inflated to 240 kPa for all tests. Average dynamic vertical load on the rear axles was 5575 N/tire, and the average static contact patch measured 190 cm<sup>2</sup> in area.

## TEST VARIABLES

The primary test variable in this study was sand gradation. A single source material from a local sand pit was used to produce all five of the test sands, which are given in Table 2. This material was a naturally occurring sand (glacial stream deposited) with semirounded particles.



**TABLE 2 Grain Size Gradations for Study Sands and Source Material (percentage finer by weight)**

Sieve		TC	FAA	SAE	ASTM	Fine	Source <sup>a</sup>
Number	Opening (mm)						
4	4.75	100	100	100	100	100	100
8	2.36	42.8	97.7	99.0	97.7	100	87.8
16	1.18	20.3	57.2	71.1	95.1	100	58.3
30	0.59	7.9	19.3	11.9	68.8	83.9	26.1
50	0.30	1.3	3.5	1.4	28.2	38.1	11.5
80	0.18	0.5	1.1	0.5	11.0	18.7	6.4
100	0.15	0.4	0.7	0.4	7.6	15.0	5.2

<sup>a</sup>Material taken from sand pit and selectively sieved to produce all study sands.

Tests were performed at two air and ice temperatures. To represent a "cold" condition, the ice was kept at  $-10^{\circ}\text{C}$  and the air at  $-12^{\circ}\text{C}$ . A "warm" ice condition was represented by ice at  $-3^{\circ}\text{C}$  and air at  $-1^{\circ}\text{C}$ .

Since abrasive performance is related to the quantity of material applied to the ice, two and sometimes three distinct concentrations of each sand type were tested for each set of conditions. Currently, the FAA recommends a sand application rate (concentration) of 49 to 98 g/m<sup>2</sup>. We chose a concentration of 73 g/m<sup>2</sup> to fit the FAA specification and concentrations of 34 and 142 g/m<sup>2</sup> to represent half and double this.

All the test sands were heated to  $70^{\circ}\text{C}$  before application to ensure adherence of the sand particles to the ice surface. To determine the effect of sand temperature on abrasive "bonding" to the ice, a test series was performed in which the sand temperature was varied before application. A local sand pit product that had been run through a 9.5-mm slotted screen (3/8-in. sieve) was applied at 3, 20, and  $70^{\circ}\text{C}$  to simulate a sand kept in an unheated building, sand kept in a building with conventional heating, and sand that was super-heated just before distribution, respectively.

## TEST PROCEDURE

Each test series began with traction and resistance tests run on a clean, smooth ice sheet immediately before application of a test sand. This provided a baseline reference of friction coefficient and was used to monitor the comparability of prepared ice surfaces. The ice sheet used for testing was much more slippery than would ever be allowed to exist on an operational runway, but the surface maximized our chances of detecting any differences in the frictional characteristics of various sand types.

After the bare-ice friction tests, sand heated to  $70^{\circ}\text{C}$  was applied to the ice surface with a conventional lawn broadcast spreader. Five minutes after sand application, four resistance tests followed by six traction tests were performed. Since measurements were being taken on both rear tires, 12 separate measures of traction were obtained. Each test was run in a fresh track on the sanded ice to avoid any areas disturbed by the slipping tires from a prior test.

After the completion of a test series, the test sand was removed from the ice sheet and the ice surface was restored to a clean, smooth surface for the next set of tests. A total

of 560 tests were performed between March 18 and April 13, 1992.

## RESULTS AND ANALYSIS

Measurements of friction force and normal load on each tire were taken during steady state conditions of speed, slip, and direction, allowing average values to be calculated for each test. Friction coefficient, often referred to as  $\mu$ , was calculated for each test as the ratio of friction force to normal force. Within the FAA, and at most airports, it is customary to refer to a friction number, which is a whole number obtained by multiplying  $\mu$  by 100. Friction numbers for our tests are shown graphically in Figure 1.

Our initial analysis considered the FAA sand at its recommended concentration of 73 g/m<sup>2</sup> to be the standard for comparison. At this concentration, the FAA, fine, and ASTM sands provided about the same amount of traction enhancement on cold ( $-10^{\circ}\text{C}$ ) ice, as shown in Figure 1 (*top*). These sands provide a friction number of about 15, an 83 percent increase over the bare-ice friction of 8.2. The SAE and TC sands gave higher friction numbers, roughly equal at close to 20, a 140 percent improvement in traction on bare ice.

On the warm ( $-3^{\circ}\text{C}$ ) ice [Figure 1 (*top*)], the FAA sand had the lowest friction number (15.2). The TC, SAE, and ASTM sands showed better performance, respectively, averaging a friction number of 17.2. This was a 53 percent increase over the bare ice and 13 percent better than the FAA sand. The fine sand gave the highest friction number (18.4), giving a 64 percent improvement over bare ice and a 21 percent better friction number than the FAA sand.

For the two ice temperatures tested, the FAA sand is the least effective of most of the test sands at the 73 g/m<sup>2</sup> concentration. The fine sand gives the best performance on the warm ice, but the poorest on the cold ice. The best all-temperature sand would appear to be the SAE sand, although the TC sand shows nearly equal effectiveness.

The trends noted are not readily explained by the gradations of the sands. Plots of performance against percentage passing any given sieve size (example shown in Figure 2) looks similar for all the size fractions identified in Table 2. A slightly increasing (for  $-3^{\circ}\text{C}$  ice) or slightly decreasing (for  $-10^{\circ}\text{C}$  ice) friction number is seen with increasing percentages of fine material in these plots.

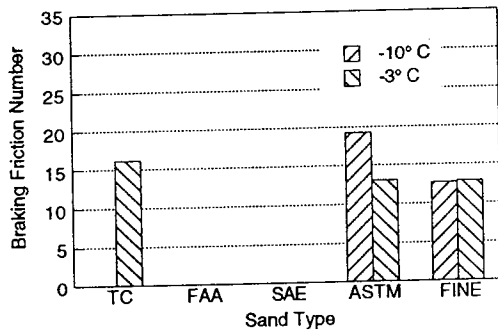
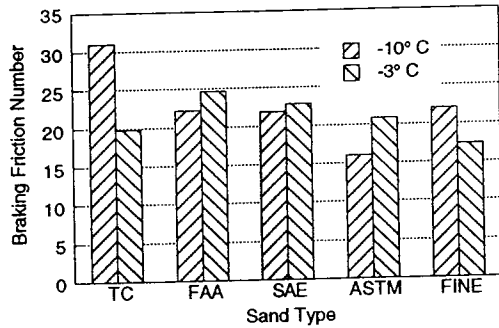
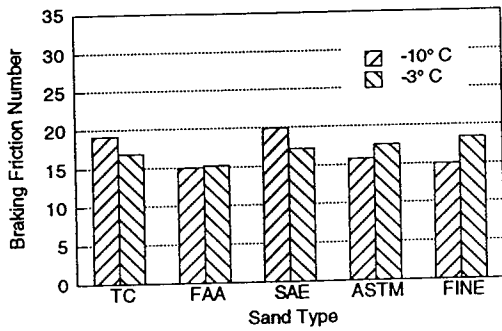


FIGURE 1 Braking friction performance at FAA-recommended sand concentration (73 g/m<sup>2</sup>) (top), twice the FAA-recommended sand concentration (142 g/m<sup>2</sup>) (middle), and half the FAA-recommended sand concentration (34 g/m<sup>2</sup>) (bottom).

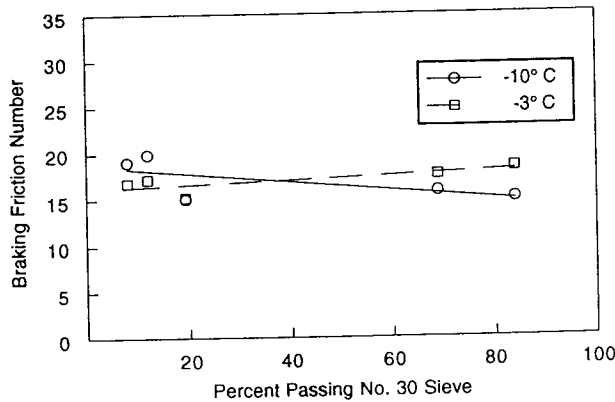


FIGURE 2 Variation in braking friction performance with fraction of sand smaller than a No. 30 sieve (0.595 mm) for the FAA-recommended sand concentration (73 g/m<sup>2</sup>) at 70°C.

Comparing the rankings of the sands at the two ice temperatures, the ASTM and fine sands had improved friction numbers at the higher temperature, the TC and SAE sands had diminished performance, and the FAA sand remained unchanged. This may be related to the relative percentage of fines contained in each sand type. To check for this trend, each sand's warm-to-cold ice tractive performance was plotted against the percentage of material less than 0.595 mm in diameter (No. 30 sieve) (Figure 3). A performance ratio greater than 1 indicates a sand that works better at higher temperatures, and a ratio less than 1 indicates a sand that works better at lower temperatures.

Freehand curves highlight the trends indicated by the data in Figure 3. The data for the 73-g/m<sup>2</sup> concentration indicate that when an abrasive contains at least 20 percent material passing the No. 30 sieve, the performance of the sands is independent of temperature. As the percentage of fines becomes less than about 20 percent, a very strong decrease in friction number occurs for warm ice compared with cold ice. For sands with high fines content (greater than 20 percent), only a slight increase in performance is seen for warm ice as compared with cold ice. Because the sand types used in this study leave a large gap between those containing large and small amounts of fines, a regression analysis could not legitimately be performed on the data in Figure 3.

With higher concentrations of sand applied to the ice, higher friction numbers were expected. This was found for all but one case; the fine sand showed a drop in performance when the sands were applied at a concentration of 142 g/m<sup>2</sup> on the warm ice sheet. [Relative performances of the sands at this concentration are shown in Figure 1 (middle).] On cold ice, the FAA, SAE, and fine sands had equal performance, giving a friction number of about 22. This was nearly 170 percent better traction than the bare ice. By comparison, the ASTM sand provided 27 percent less friction (16), and the TC sand 41 percent better performance (31), than the FAA, SAE, and fine sands.

At the high sand concentration on warm ice, the FAA sand showed the highest friction number (24.7). This represented a 120 percent increase in traction over the untreated ice. The

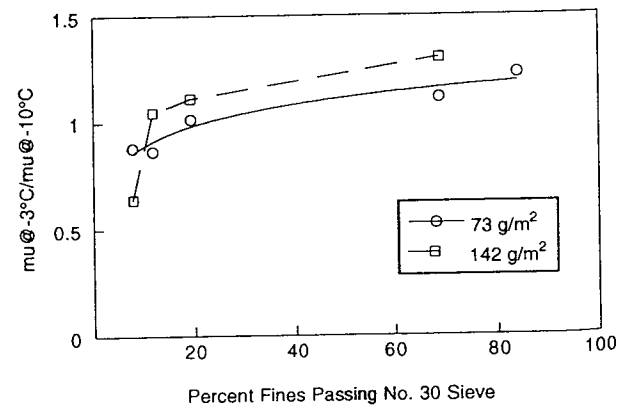


FIGURE 3 Relative improvement in tractive performance with ice temperature increase as a function of fraction of sand smaller than a No. 30 sieve (0.595 mm) for two sand concentrations.

other sand types provided 7 percent (SAE), 20 percent (TC), 25 percent (ASTM), and 30 percent (fine) less traction than the FAA sand. The friction number obtained for the fine sand in this case is suspect, since it did not follow the trend of improved performance with increased concentration that was seen for all the other sands.

Although the TC sand showed clearly superior traction on the cold ice, it displayed only mediocre performance on the warm ice. However, the SAE sand provided high friction numbers relative to the other sands and its relative ranking was not significantly affected by ice temperature.

The percentage improvement in traction with increasing ice temperature at the 142-g/m<sup>2</sup> concentration was also plotted (Figure 3). The fine sand was not included in this plot since, as noted, its behavior was anomalous. At this concentration, it is also clear that sand performance changes with ice temperature as a function of the amount of fines the sand contains. At the high sand concentration, this trend seems to be somewhat stronger than was observed at the recommended concentration. It also appears that the transition (performance ratio of 1) occurs at about 20 percent material passing the No. 30 sieve.

For the higher sand concentration, the results shown in Figure 1 (middle) do not correspond with the behavior displayed at the recommended concentration [Figure 1 (top)]. In fact, it can roughly be said that the rankings for the recommended concentration are the inverse of those found at twice this concentration (this is more true for the warm ice than the cold ice). This implies that traction is a strong function of concentration of abrasives on ice. By themselves, the physical characteristics of sand grains and the size distribution of the grains cannot be used to determine traction enhancement potential; application concentration must be included to make a determination.

Several tests were also performed at a sand concentration (34 g/m<sup>2</sup>) below that recommended by the FAA. The ASTM and fine sands were tested on the cold ice. Results showed a surprisingly high friction number for ASTM sand (19.3) and a value of 12.7 for the fine sand [Figure 1 (bottom)]. On the warmer ice, the two sands showed essentially equal performance with friction numbers of 13. The TC sand was also tested on the warm ice, on which it yielded a friction number of 16.2.

The results of the low sand concentration tests show that, even with minimal abrasive application, at least a 50 percent improvement over bare-ice traction is possible.

Braking friction number was plotted against concentration for each sand type at both temperatures (Figure 4). Linear regression analyses were performed for each sand type by itself, and in nearly all cases a strong correlation resulted. The bare-ice friction number was included in the regression, corresponding with a sand concentration of zero.

Table 3 lists the regression coefficients and R<sup>2</sup>, a measure of variability. The ASTM sand at low temperature showed a poor linear correlation because of the high performance recorded at the low concentration. The fine sand at the warm temperature also had a low regression correlation owing to the lower performance recorded at the highest concentration. A second-order regression on each of these data sets would yield a much better fit. However, confirmation of the trends shown by these two sands would be prudent before attempting to move to higher-order regression analyses.

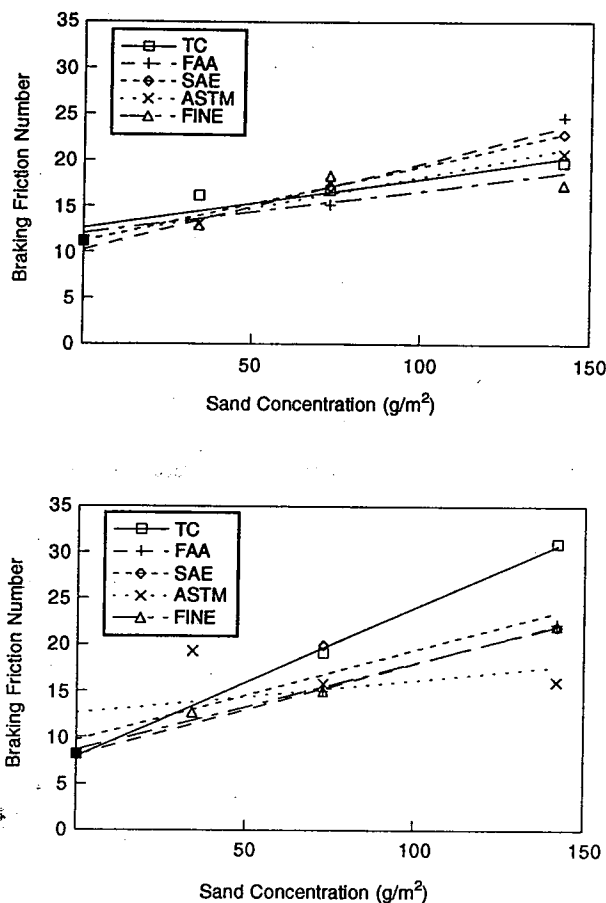


FIGURE 4 Braking friction number variation with application rate for test sands at -3°C (top) and -10°C (bottom).

On the basis of the regression analyses, increasing the concentration of any of the study sands on the ice caused an increase in traction coefficient. The expected increase in friction number ranges from 6 to 16 for each 100-g/m<sup>2</sup> increase in sand concentration, ignoring the two cases with poor correlation.

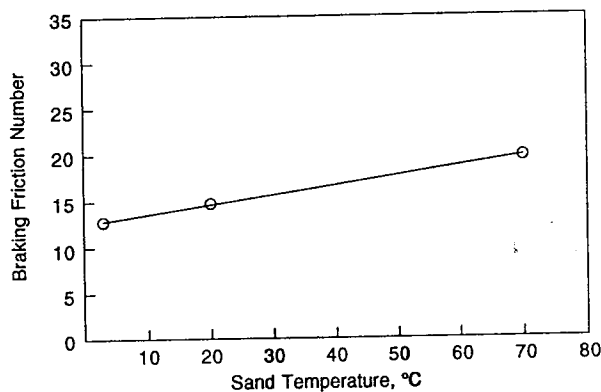
Comparing the slopes of the regression lines for the warm and cold ice for a given sand type supports the trend depicted in Figure 3. The TC sand, with very few fines, has a much stronger performance increase with concentration on the cold ice. The FAA and SAE sands show a nearly identical slope for the cold and warm ice. The ASTM sand has a stronger concentration dependence on the warm ice, as would the fine sand if the anomalous data point for 142 g/m<sup>2</sup> were not considered.

The test series designed to look at the effect of sand temperature was performed with the source material used for the study sands. This sand had a more evenly distributed range of grain sizes (Table 2) than the study sands. Tests were performed only on the warm ice (-3°C), with a concentration of 73 g/m<sup>2</sup>. The sand was applied at a low temperature (3°C), a typical room temperature (20°C), and a super-heated temperature (70°C); braking friction numbers of 12.8, 14.7, and 19.7, respectively, were measured. Regression analysis on these data showed an excellent fit (Figure 5) to a linear equation, with increasing performance achieved for higher sand

**TABLE 3 Regression Coefficients for Braking Traction as a Function of Sand Concentration for Each Study Sand**

Regression coefficients: ( $Y = mX + b$ ) <sup>a</sup>					
	TC	FAA	SAE	ASTM	FINE
Ice temperature: -10° C					
b	7.9	8.1	9.7	12.6	8.6
m	0.161	0.099	0.098	0.035	0.094
R <sup>2</sup>	0.999	0.999	0.933	0.456	0.994
Ice temperature: -3° C					
b	12.6	10.2	11.2	11.3	12.0
m	0.055	0.095	0.083	0.070	0.047
R <sup>2</sup>	0.861	0.938	0.999	0.966	0.683

<sup>a</sup>Where Y is the friction number, X is the sand concentration in g/m<sup>2</sup>, b is the y-intercept of the equation, m is the slope of the best-fit line, and R<sup>2</sup> is the coefficient of determination.



**FIGURE 5 Braking friction number variation with sand temperature for source material applied at concentration of 73 g/m<sup>2</sup> at -3°C ( $y = 12.6 + 0.102x$ ).**

temperature. From this equation, every 10°C increase in sand temperature over ice temperature increases the friction number by 1.

## DISCUSSION OF RESULTS

When comparing the results with those of past research, strong agreement was found. On cold ice with a high concentration of sand, the TC sand was found to provide significantly better performance than any of the other sands. This corresponds exactly with Hegmon and Meyer's conclusions that a coarse sand (primarily containing grain sizes between the No. 4 and 16 sieves) worked best in cold ice (-6°C temperature) tests (2). Hayhoe confirmed this result but concluded that, on warm ice (-1°C), traction was improved by increasing the percentage of fines contained in a sand (3). We also found this to be true, as shown in Figures 2 and 3.

Our results confirmed the importance of sand concentration on traction enhancement with abrasives, as pointed out by the Airports Authority Group (5). Both of the sands that they studied were coarse by comparison with some of those included in our study, but the group found that equal performance with two different sands could be obtained by applying

each sand at a different concentration. Given a particular ice temperature, Figure 4 could be used to determine an application rate for each sand that would result in equal performance for all the sands used in this study.

In our previous study, friction on a cold ice sheet was found to strongly increase with increasing fines (6). This seems generally to disagree with the study reported here. However, the nature of the friction measurement in the two studies was significantly different. In our prior study, a small slider was used to generate a friction force, which resulted in a 100 percent slip rate (i.e., corresponding to a locked-wheel skid). In the current study, a low rate of slip that duplicates the slip present at the tires of large braking aircraft was used.

The difference in the two slip rates is significant in that, with a 100 percent slip condition, the tire is not rolling. This means that abrasives on the ice surface can only enter the tire-ice contact patch by being forced under the locked tire. The potential for dislodging, tumbling, and tossing the abrasive particles out of the path of the tire is great. In fact, it is greatest for the larger sand particles since they have a higher relief above the ice surface and would be more difficult to force under the leading edge of the tire. It follows then that sands with a high percentage of fines would stand a better chance of allowing more abrasive product to be drawn under the tire where they can contribute to traction enhancement.

A tire operating at a moderate to low rate of slip is rotating at a rate that is only somewhat less than a nonslipping tire. By rotating, the tire is able to roll onto and over sand particles on the ice surface, no matter what their size.

Our results also showed that heating a sand before it is applied to an iced surface can increase the friction number significantly. This behavior is clearly the result of the sand grains bonding more fully to the ice when applied at a high temperature. A greater percentage of the sand grains were partially imbedded in the ice as the application temperature increased. Heated particles of sand melt into the ice and re-freeze to create a surface texture similar to sandpaper. The greater the difference between sand and ice temperature upon application, the stronger the mineral-ice bond and the higher the level of friction enhancement generated. Larger grains of sand held their heat longer and thus did a better job of bonding with the ice than did fine sand particles. More sand grains

remained in the tire tracks for the hot sand than for the cold sand.

## CONCLUSIONS AND RECOMMENDATIONS

Generally, coarse sands such as the TC sand provide the highest level of friction enhancement on cold ( $-10^{\circ}\text{C}$ ) ice surfaces. On ice at temperatures just below melting, sands with a large percentage of fines yield the highest friction coefficients. Sands composed mostly of grains from 1 to 2 mm in diameter (approximately No. 8 to No. 16 sieves), such as the SAE sand, showed good performance at both test temperatures.

The abrasive concentration on an ice surface is a more controlling factor than sand gradation in friction enhancement on ice surfaces. However, cost, environmental consequences, and logistics problems with storage, handling, and cleanup most likely will dictate practical limits on concentration.

The effect of sand application temperature can also easily overshadow sand type. A sand with a large percentage of 1- to 2-mm-diameter grains (approximately No. 8 to No. 16 sieves) heated to  $70^{\circ}\text{C}$  will hold its heat long enough during application to ensure a good bond to the ice. However, like sand concentration, logistical matters will govern what level of sand temperature is reasonable.

If the FAA were to endorse a single sand type, of the five sands included in this study, we would recommend that the SAE sand be specified for airport use. However, this would do little to alleviate the concerns of airport operators, because the SAE sand is no more likely to be available at sand pits than the current FAA-specified sand. Thus, a much more flexible specification must be generated to be of any practical value and to represent a step forward from current practice.

This study suggests that any sand is capable of matching the performance of another sand by the calculated selection of its application rate and the temperature at which it is applied to the ice. The effect of variable sand friction performance with ice temperature was also found to be linked to the amount of fines in the sand. Combining these factors, it

appears entirely feasible to generate a mathematical expression that would describe the general relationship between sand type (degree of fines), ice temperature, sand application rate, sand application temperature, and braking friction performance. Using this approach, an airport operator would be free to explore various options for producing a desired level of friction enhancement on iced runways.

## ACKNOWLEDGMENTS

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# Developing a Storm Severity Index

Wilfrid A. Nixon and Lin Qiu

A primary goal in winter highway maintenance is to develop various maintenance processes so that quality control can be measured. If actions can be measured, they can be improved. A difficulty with this approach is that winter maintenance addresses the impacts of winter weather on the transportation system and that weather is inherently uncontrollable. Consequently, for a quality process to be applied to winter maintenance, the severity of individual storms must be assessed. This paper presents one way in which the severity of a storm can be measured, specifically by an index. The first step in developing an index for individual storms is to develop a method of describing storms. The method here describes storms by using six factors, including prestorm and poststorm conditions and temperatures, wind speed, and precipitation type. The matrix created is a refinement of that presented in FHWA's manual of practice for effective anti-icing. With the use of a simplified variation of this matrix-based description of storms (more than 250 descriptions), a score is generated for each storm type. This score is then adjusted so that scores for all storms fall into a normal distribution between 0 and 1. This ranking of storms was evaluated by winter maintenance garage supervisors at the Iowa Department of Transportation. Supervisors were asked to rank 10 storms (presented as brief written descriptions) from easiest to hardest to handle. Results were compared with those of the initial storm severity index. From that comparison, numerical values for certain factors were adjusted so that storm severity index scores for these 10 storms agreed with rankings given by the garage supervisors.

The annual direct cost of winter maintenance has been estimated at more than \$1.5 billion in the United States (1). More recent direct costs for Iowa have been shown to be about \$35 million per year (2). These costs are significant, and containing them is a major concern for many transportation agencies. Nonetheless, winter maintenance activities are typically assessed subjectively, an imprecise method of measurement that makes any form of quality control difficult to implement. Also, any cost reductions must still address safety and environmental concerns. Therefore, there is a need to develop a series of quantitative measures to evaluate how well maintenance activities have been done to meet a broad range of expectations (3). Toward conducting a quantitative evaluation of winter maintenance activities, weather conditions, scope of road system, maintenance efforts undertaken for a given storm, resulting road condition, and interactions between these factors must all be considered. In particular, maintenance efforts largely depend on the severity of individual storms. Accordingly, there

is a need to quantify how severe a given storm is, to normalize the efforts expended fighting that storm.

Most existing weather indices work on a season-by-season basis, rather than a storm-by-storm basis. A typical winter index takes air temperature, amount of snowfall, and frequency of ground frost as parameters, and from them develops a score for the severity of the whole winter season (4). Decker et al. (5) modified this traditional winter index and developed a storm severity index, taking daily new snowfall and temperature into consideration. However, that approach is not based on storms per se, but on the snowfall and temperatures associated with the winter season.

It was believed that it might be of value to take an approach based on storm descriptions, which could then be assessed by maintenance personnel and ranked by their operational difficulty. The first step in this approach was to develop appropriate storm descriptions. To some degree, that was done in FHWA's *Manual of Practice for an Anti-Icing Program* (6), but in this paper, the storm descriptions are based on an extension of the descriptions developed by Nixon and Stowe (7).

The purpose of this paper is to develop an algorithm that evaluates to what extent an individual storm poses difficulty to maintenance activities. Three steps will be taken in this development:

1. Various storms have been classified by six factors.
2. A multiple regression model has been built to produce a storm severity index between 0 and 1.
3. Representative storms have been ranked in severity by winter maintenance personnel and the model has been modified to reflect this ranking.

The storm severity index thus produced can be used as an objective measure of the challenge that an individual storm poses to a maintenance agency.

## MODEL DEVELOPMENT

### Classification and Description of Storm Events

The matrix of possible storms developed by Nixon and Stowe (7) can be represented schematically as shown in Figure 1. This matrix is based on the storm matrix in the FHWA manual on anti-icing practice (6) yet goes beyond it, especially in how it considers prestorm and poststorm behavior. By taking one item from each of the five categories or factors and combining the items, a large number of potential storms can be described. Nixon and Stowe (7) discarded some unlikely storm scenarios and considered a total of 312 storm scenarios (96 for each of the snow events, and 12 each for the frost and freezing rain events). However, those storm scenarios were adapted somewhat for the purposes of generating the storm severity index, as discussed in the following section.

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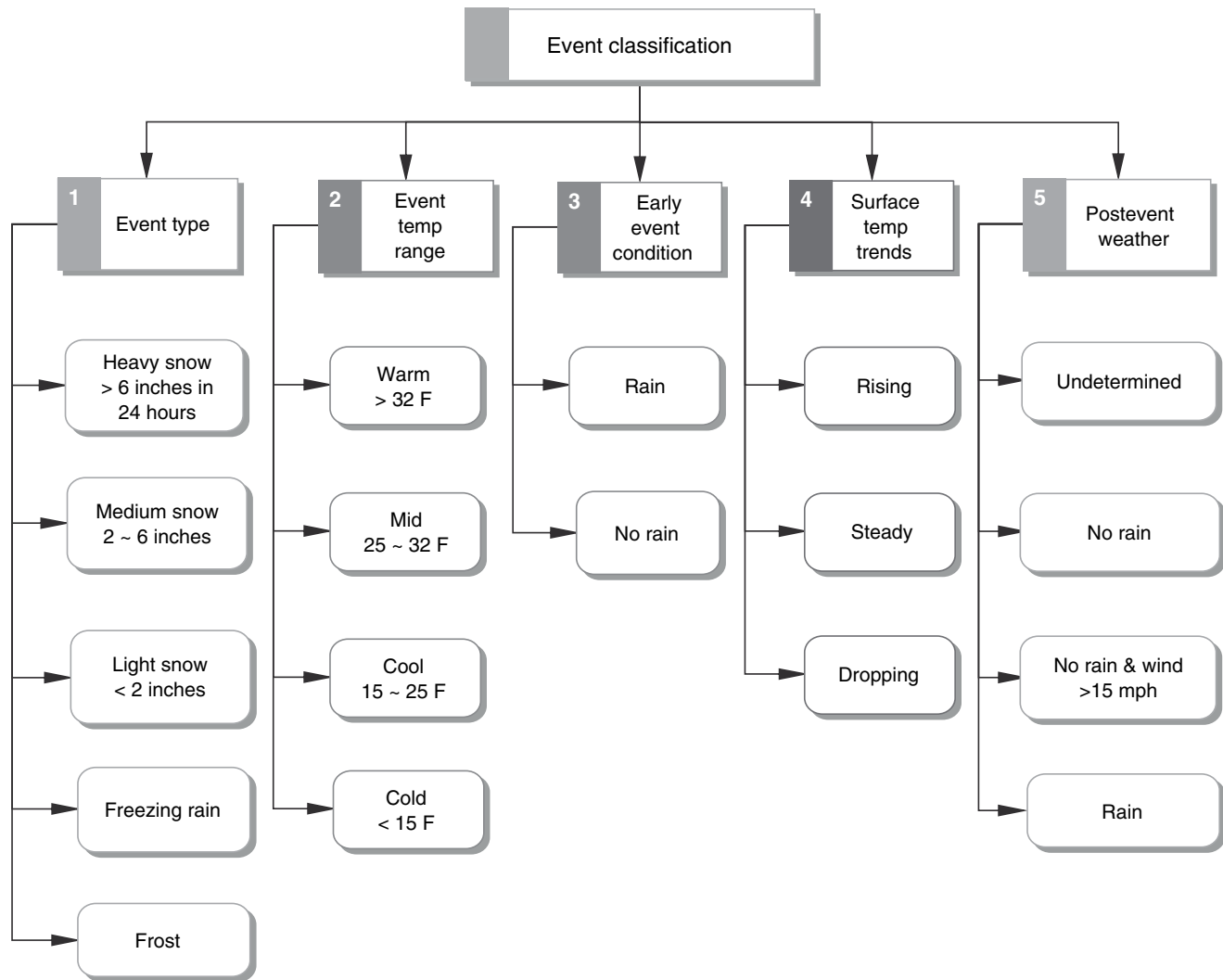


FIGURE 1 Event classification.

### Modifications to Event Classification

To simplify the development of the storm severity index, the event classification was adjusted in the following ways:

- Because the focus of this effort was on storm events, it was decided to remove frost as a possible event type. Thus, only four possible storm event types were considered: heavy snow, medium snow, light snow, and freezing rain.

- Because the levels of wind during a storm can have a significant impact on the challenges faced while maintaining roads during the storm, it was decided to incorporate the in-storm wind condition as another factor. Wind condition during a storm is an important factor to be taken into account, because cross-wind speeds in excess of about 12 to 15 mph may cause a drifting snow problem and, when the pavement is wet, cause retention of snow [e.g., Illinois DOT (8)].

- It was decided to simplify the options for temperature ranges from four ranges (warm, midrange, cool, and cold) to three ranges, by combining the cool range (15°F ~ 25°F) and the cold range (<15°F) into one single range (<25°F) in the new classification. Thus, the storm

severity index has only three temperature ranges: warm, midrange, and cool.

- The poststorm conditions appeared overly complex for the purposes of the storm index, so they were simplified into two categories rather than four. Thus, the four conditions from Nixon and Stowe (7) of “undetermined,” “no rain,” “no rain with wind above 15 mph,” and “rain” are simplified to “light wind” and “strong wind” instead, because the impact of poststorm winds was considered to be much more important than the impact of poststorm rains.

The event classification used in this study is as shown in Figure 2.

### Development of Multiple Regression Model to Produce Storm Severity Index

With the use of the foregoing modifications, any given storm can now be described by six variables (see Equation 1). To develop a storm severity index between 0 and 1, each condition for the six vari-



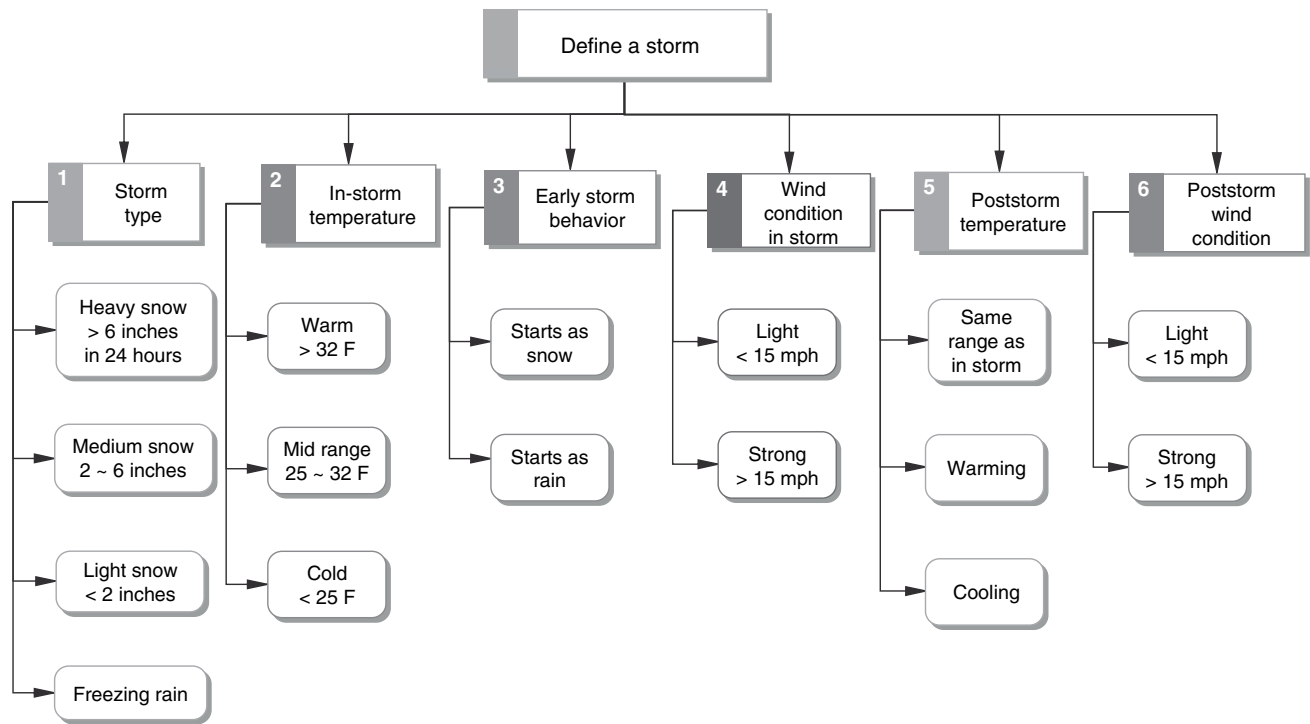


FIGURE 2 Modified event classification.

ables must be assigned a score, and these scores must then be combined in some manner to create a composite score. The composite score can then be normalized to create the storm severity index.

The format of the storm severity index was based on that used by Boselly et al. in SHRP-H-350 (4). Thus, the general form of the index equation is given as the following:

$$SSI = \left\{ \frac{1}{b} * [(ST * T_i * W_i) + B_i + T_p + W_p - a] \right\}^{0.5} \quad (1)$$

where

- SSI = storm severity index,
- ST = storm type,
- $T_i$  = in-storm road surface temperature,
- $W_i$  = in-storm wind condition,
- $B_i$  = early storm behavior,
- $T_p$  = poststorm temperature,
- $W_p$  = poststorm wind condition, and
- $a, b$  = parameters to normalize storm severity index from 0 to 1.

The storm type is clearly modified by the in-storm road surface temperature and the in-storm wind condition; thus, those three terms are multiplicative. In contrast, the various prestorm and poststorm behaviors are considered to be additive to the main storm and are expressed accordingly Equation 1. The two constants  $a$  and  $b$  are used to normalize the storm severity index between 0 and 1.

Once the form of the equation is established, the relative scores between the values of the factors must be estimated. This involves attempting to assess how much worse a cold storm (with road surface temperatures below 25°F) is to handle than is a warm storm (with sur-

face temperatures above 32°F). A first approximation of these values can be obtained by studying the FHWA manual’s recommended treatments (6) and comparing, for example, how road temperature has an impact on treatment amounts and frequency. However, that does not go much beyond a ballpark guess. The guesses that were made initially in this case are listed in Table 1.

TABLE 1 Modified Scores for Each Storm Index Factor

Storm type			
Freezing rain	Light snow	Medium snow	Heavy snow
0.4 (0.72)	0.35	0.65 (0.52)	1
Storm temperature			
Warm	Midrange	Cold	
0.25	0.6 (0.4)	1	
Wind conditions in storm			
Light	Strong		
1	1.2		
Early storm behavior			
Starts as snow	Starts as rain		
0	0.1		
Poststorm temperature			
Same	Warming	Cooling	
0	-0.087	0.15	
Poststorm wind conditions			
Light	Strong		
0	0.15 (0.25)		

NOTE: Values inside the parentheses indicate values modified after the supervisors’ evaluations.

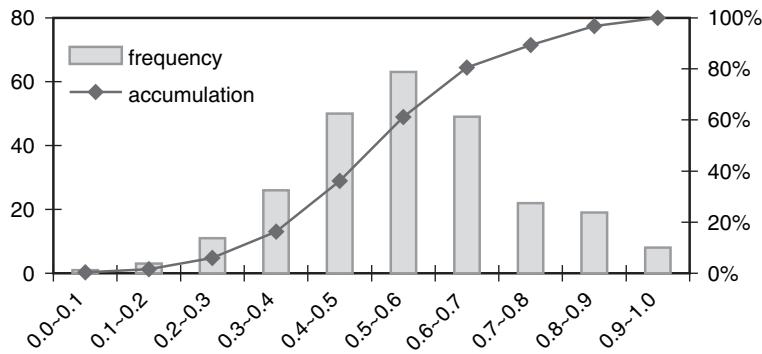


FIGURE 3 Distribution of storm severity index.

### Model Adjustment to Obtain Approximately Normal Distribution

With the use of estimates for the six factors listed in Table 1, the storm severity index was calculated for 252 different storms, as based on the initial algorithm and scores. Then the initial scores were modified (by using the constants *a* and *b*) so that the computed storm severity index values have an approximately normal distribution, as shown in Figure 3. The scores used for the six factors are shown in Table 1.

### Selected 10 Storms Ranked in Severity by Winter Maintenance Supervisors

To test the accuracy and reliability of model, 10 representative storm scenarios were selected out of 252 possible storm events and described in a survey form, as shown in Table 2. The storms were labeled A through J. Their order on the survey form was randomized so as to min-

imize bias. Maintenance garage supervisors from the Iowa Department of Transportation (DOT) ranked these 10 scenarios according to the level of difficulty that these events would pose in their maintenance activities. The hardest was ranked as 10, and the easiest as 1. The storms were ranked by 38 supervisors throughout Iowa.

### Storm Index Ranks in Comparison with Experts' Ranks

Table 3 shows the average rank that the 38 supervisors assigned to the 10 storms, together with the rankings developed from the initial form of the storm severity index. It is clear that while there is general agreement between the supervisors and the initial index, there are also areas of significant disagreement, as will be discussed. A fuller (also more complex) representation of the supervisors' responses is given in Figure 4.

The 10 storms are listed on the x-axis in Figure 4, and for each storm the solid black line is the mean response. The box represents

TABLE 2 Storm Scenario Descriptions from Expert Survey Form

Storm Scenario	Description
A	A storm with freezing rain and temperatures in the warm range (above 33°F) that starts as rain. Winds in the storm are strong (over 15 mph). After the storm, winds become light and temperatures warm up.
B	A storm with heavy snow (above 6 inches) and temperatures in the midrange (25°F to 32°F) that starts as snow. Winds in the storm are strong (over 15 mph). After the storm, winds become light and temperatures cool down.
C	A storm with heavy snow (above 6 inches) and temperatures in the warm range (above 33°F) that starts as rain. Winds in the storm are light (less than 15 mph). After the storm, winds become strong and temperatures cool down.
D	A storm with heavy snow (above 6 inches) and temperatures in the warm range (above 33°F) that starts as snow. Winds in the storm are light (less than 15 mph). After the storm, winds become strong and temperatures cool down.
E	A storm with light snow (up to 2 inches) and temperatures in the warm range (above 33°F) that starts as snow. Winds in the storm are light (less than 15 mph). After the storm, winds remain light and temperatures warm up.
F	A storm with freezing rain and temperatures in the cold range (15°F to 25°F) that starts as rain. Winds in the storm are light (less than 15 mph). After the storm, winds remain light and temperatures remain cold.
G	A storm with medium snow (2 inches to 6 inches) and temperatures in the midrange (25°F to 32°F) that starts as snow. Winds in the storm are light (less than 15 mph). After the storm, winds become strong and temperatures warm up.
H	A storm with medium snow (2 inches to 6 inches) and temperatures in the midrange (25°F to 32°F) that starts as snow. Winds in the storm are light (less than 15 mph). After the storm, winds remain light and temperatures remain in the midrange.
I	A storm with light snow (up to 2 inches) and temperatures in the midrange (25°F to 32°F) that starts as rain. Winds in the storm are light (less than 15 mph). After the storm, winds remain light and temperatures warm up.
J	A storm with heavy snow (above 6 inches) and temperatures in the cold range (15°F to 25°F) that starts as rain. Winds in the storm are strong (over 15 mph). After the storm, winds remain strong and temperatures remain cold.

**TABLE 3 Average of Expert Rank Versus Storm Index Rank for 10 Storm Scenarios**

Storm scenario	E	A	I	H	G	F	D	C	B	J
Storm index rank	1	2	3	4	5	6	7	8	9	10
Average expert rank	1	4	2	3	5	9	7	8	6	10

the upper and lower quartiles, and the bars represent the high and low data values. The other symbols represent statistical outliers that were discarded from the final analysis.

**Model Adjustment to Ensure Agreement of Storm Index Ranks and Experts' Ranks**

As stated, there was less than total agreement between the initial storm severity index and the supervisors' rankings. Three major areas of difference pertaining to the scenarios are considered in the following sections.

*Scenarios A, H, and I*

Scenario A (freezing rain) was ranked as more severe than were Scenarios H (medium snow) and I (light snow) by the supervisors, which contrasted markedly with the initial severity index. That indicated that the score assigned to freezing rain was relatively low and the score for medium snow was relatively high. The scores were adjusted accordingly (see the values in parentheses in Table 1).

*Compare Scenarios D and B*

There was a significant degree of disagreement between the supervisors in regard to Scenarios B and D. Of the supervisors, 63% ranked Scenario B as less severe than Scenario D, whereas 27% of the super-

visors took the opposite view. It appears that the majority of supervisors believe that poststorm winds are worse operationally than in-storm winds. On the basis of that finding, the score for poststorm winds was increased (see the values in parentheses in Table 1).

*Compare Scenario F with Scenarios D and B*

Scenario F was ranked as even more severe than Scenarios D and B by the supervisors, again in contrast to the initial storm severity index. It appears that the lower temperature and the freezing rain condition (the latter as previously noted) are considered to be operationally more severe conditions than is a heavy snowstorm. Thus, the score for midrange storm temperatures was adjusted also.

As indicated in the foregoing analysis, the discordant scores were adjusted according to the supervisors' rankings. The adjusted scores are those given in parentheses, as shown in Table 1. While the index now matches well with the evaluations of winter maintenance supervisors in Iowa, it is not clear how well it would match with evaluations of similar supervisors in other midwestern states, who would experience similar weather but may have differing operational responses. Nor is it clear how the index would compare with evaluations from supervisors in other climatic regions, for example, Mountain states. Although such comparisons are clearly of interest, they lie beyond the scope of the current study.

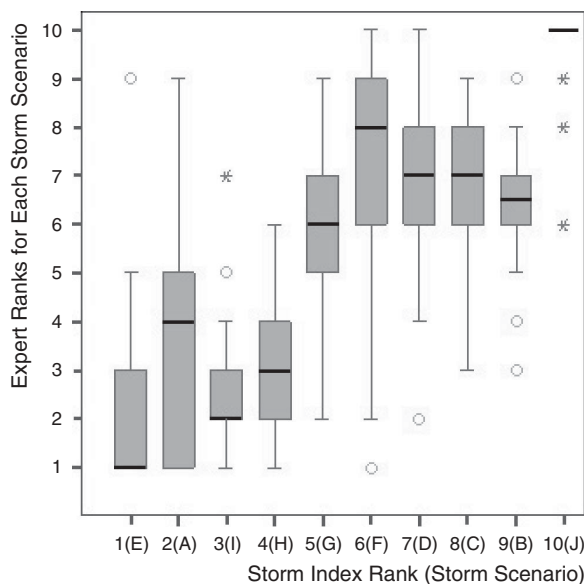
**RESULTS**

From the regression model developed, given as Equation 1, and the assigned values as shown in Table 1 (inside parentheses), the storm severity index for 252 different storms can be provided from 0 to 1, with 0 indicating a very mild storm and 1 indicating a very severe storm. The distribution of storm severity index is plotted in Figure 3, which confirms that the computed results accord approximately with a normal distribution. Table 4 shows 10 storm scenarios derived from Figure 2, with their associated storm severity indices. The index can be used to measure the performance of an agency in handling a given storm and thus represents an important part of a quality control process for winter maintenance.

**CONCLUSIONS**

The paper presents a storm severity index that can provide a measure of the severity of any given storm based solely on a meteorological description of that storm. The index provides a value between 0 (a very mild storm) and 1 (a very severe storm). The index was compared with rankings provided by winter maintenance garage supervisors from Iowa DOT, and it was adjusted to agree with those rankings.

The utility of the index is one step in the process of creating a quality controlled winter maintenance program. Specifically, the performance of an agency or a group within an agency can be meaningfully



**FIGURE 4 Expert ranks for 10 storm scenarios.**

TABLE 4 Output of Storm Severity Index

Storm Type	Storm Temperature	Early Storm Behavior	Wind Conditions in Storm	Poststorm Temperature	Poststorm Wind Conditions	Storm Severity Index
Heavy snow	Cold	Starts as rain	Strong	Cooling	Strong	1.000
Freezing rain	Cold	Starts as rain	Light	Same	Light	0.695
Heavy snow	Warm	Starts as rain	Light	Cooling	Strong	0.664
Heavy snow	Warm	Starts as snow	Light	Cooling	Strong	0.618
Heavy snow	Midrange	Starts as snow	Strong	Cooling	Light	0.609
Medium snow	Midrange	Starts as snow	Light	Warming	Strong	0.467
Freezing rain	Warm	Starts as rain	Strong	Warming	Light	0.367
Medium snow	Midrange	Starts as snow	Light	Same	Light	0.350
Light snow	Midrange	Starts as rain	Light	Warming	Light	0.300
Light snow	Warm	Starts as snow	Light	Warming	Light	0.000

assessed only if the severity of the challenge that it has faced is quantified in some manner. The index provides one way of doing such a quantification.

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