



## TRANSPORTATION RESEARCH SYNTHESIS

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### Chloride Free Snow and Ice Control Material

#### OVERVIEW

The City of Burnsville requested the Local Road Research Board (LLRRB) fund a review of areas within winter maintenance that might lead to lower salt (chloride) use. An advisory team of 9 members was assembled to direct and review the research and reports of this project. Members are listed at the end of this document. Rock salt is the most common deicer used for winter maintenance in Minnesota. It is affordable and effective but causes damage to lakes, rivers and groundwater. With the growing concern around high chloride levels in Minnesota's water, the question was asked: "What are the alternatives?"

The City of Minneapolis has a sustainability goal that implicitly includes the reduction of road salt: "reduce pollutants in stormwater runoff, establish measurements of amounts being reduced, and determine the city's allocations of the reductions needed to bring impaired water bodies into compliance," all by 2015 [6]. St. Paul's sustainability commitment also includes protection of water quality [7].

A significant number of wells in the metropolitan area have been found to exceed the federal chloride standard and more than 4,000 waterways are listed as impaired in the State. The Minnesota Pollution Control Agency (MPCA) is developing an implementation plan for managing salt use through a metro-wide Total Maximum Daily Load (TMDL) for chlorides. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. Within this context, it is vital to find new ways to maintain safety on the roadways while reducing chloride use.

An additional requirement of the contract was to make the report useful to the maintenance supervisor or non-scientist who might be searching for alternatives to road salt. The City of Burnsville and advisory team expressed through the contract and at the first team meeting that the report should include concrete recommendations for further research and/or implementation. The group started with multiple category headings provided by the LRRB, and selected four key aspects to focus upon. Two

areas proposed by the LRRB were combined to create Research Area 2. This report will be divided into these three stand-alone sections:

**Research Area 1:**

Non-Chloride Deicers

**Research Area 2:**

Task 2a – Permeable Road Surfaces

Task 2b – Pavement texture, color, material options that would provide better melting or traction

**Research Area 3:**

Winter speed limits or other winter driving changes

Fortin Consulting, Inc. (FCI) performed an internet literature review, worked with the MnDOT library research services and conducted email and phone interviews to gather information. FCI produced an intermediate version of research findings from each Research Area and provided this for review by the advisory team. Then a final approved version was created for posting on the LRRB website.

**Research Area 1: Non-chloride Deicers**

A high level synthesis of non-chloride deicers was conducted extracting the most distinguishing characteristics of the products in the eyes of the winter maintenance supervisor. Short descriptions of each type of non-chloride deicer were written and an overview table created. Blends and mixes were not included in the synthesis due to the endless variations possible. Below are short paragraphs that consolidate vast amounts of data into simple summaries.

**RESULTS**

Acetates are a family of non-chloride deicers of which the most common are Potassium Acetate (KAc), Calcium Magnesium Acetate (CMA), and Sodium Acetate (NaAc). The acetates are widely commercially available. They all melt ice and do it at a variety of pavement temperature ranges. KAc works at the coldest temperature range of the acetates (the -20 °F to 15 °F range). None of the acetates work at super cold pavement temperatures (below -20 degrees Fahrenheit). Unlike rock salt they are not very corrosive to steel however they do react with and corrode zinc (galvanized steel) [39] and are more expensive than rock salt. Once applied to the road, they are not recoverable and will migrate into the water. Once in water acetates are not recoverable, they break into a metal ion and an acetate ion. The metal ion (e.g. calcium, potassium, sodium) will remain in the water, while the acetate ion will continue to breakdown. In the breakdown process it uses oxygen, in high quantities this oxygen demand can be harmful to fish that are dependent on adequate dissolved oxygen in the water. Since

acetates decompose they don't accumulate or persist long term in the water (years). They are most threatening to aquatic systems immediately after they enter the system, as they begin to biodegrade and remove oxygen from the system.

Formates are a family of non-chloride deicers of which the most common are sodium formate ( $\text{CHO}_2\text{Na}$ ) and potassium formate ( $\text{CHO}_2\text{K}$ ). They are available in limited quantities and at high prices. They are currently used mainly at airports for deicing. Formates work within the colder range,  $-20\text{ }^\circ\text{F}$  to  $15\text{ }^\circ\text{F}$ . They have been shown to have minimal effects on steel. Similar to acetates, the formate component of the salts ( $\text{CHO}_2$ ) degrade in water. As they breakdown, they use dissolved oxygen in the water, thus reducing the amount of dissolved oxygen available to aquatic species. However of the non-chloride deicers, the formates create the smallest oxygen demand. They do not accumulate in the water over a period of years and do not appear to be a groundwater threat [35].

Urea ( $\text{CO}(\text{NH}_2)_2$ ) is a non-chloride deicer alternative that melts ice best in the  $15\text{ }^\circ\text{F}$  to  $32\text{ }^\circ\text{F} \pm 5\text{ }^\circ\text{F}$  temperature range. Urea has not been shown to increase degradation of steel. Urea is able to break down in water, this processes uses dissolved oxygen. Urea uses the largest amount of dissolved oxygen of any of the non-chloride deicers and has been shown to use more dissolved oxygen greater than Propylene Glycol [34]. Urea is a nitrogen fertilizer. Nitrogen is a pollutant much studied in Minnesota related to the agriculture industry. Excess nitrogen has been known to pollute ground water and surface water, contributing to plant and algae growth. It can also cause human health problems. Nitrogen is the primary cause of the anoxic (dead zone) in the Gulf of Mexico. Since urea degrades in water, it breaks down, consuming dissolved oxygen. Urea will not accumulate long term in lakes, rivers, and streams.

Glycerol/Glycol products are a family of non-chloride deicers that have mostly been used at airports. They melt ice at cold temperatures (in the  $-20\text{ }^\circ\text{F}$  to  $15\text{ }^\circ\text{F}$  range). Glycerol/Glycol products do not cause increased corrosion in steel. Once applied to a road, they are not recoverable, they move with the runoff water to the surface or ground water. Once in the water they are not easily recoverable. Glycerol/Glycol products do not accumulate long term in the lakes, rivers and streams, they decompose in water, creating a very high oxygen demand as they breakdown. Ethylene glycol is considered a hazardous air pollutant and is subject to reporting requirements under the Comprehensive Environmental Response, Compensation and Liability act. Glycerol can be toxic to fish [34].

Succinate products are a family of deicers that are not widely used but with interest could be locally manufactured (by a manufacturing facility, not by a maintenance organization) where there is a demand. Because they are a liquid, shipping costs are high unless the product is manufactured locally. Potassium succinate ( $\text{C}_4\text{H}_4\text{O}_4\text{K}_2$ ) is a liquid deicer and the most commonly used of the succinates. Potassium succinate is a non-chloride deicer that is comparable to potassium acetate. It melts ice at the same temperature range as KAc (the  $-20\text{ }^\circ\text{F}$  to  $15\text{ }^\circ\text{F}$  range) and is similar in price [4]. It will breakdown in the water, using dissolved oxygen in the process. Succinates do not

accumulate long term in the water. The US headquarters for research and development of potassium succinate producer is located in Plymouth Minnesota.

Additives we define as a group of organic products (beet juice, molasses, distillers' solubles, and corn syrup) that are often used in small quantities in combination with deicers. Organic additives do not melt snow or ice. If a deicer is diluted with organic additives, the total ice melt capacity will be decreased simply because there will be less deicer in the mix. Organic additives are not corrosive to steel, and in laboratory settings have been shown to lower salt brine's corrosiveness to steel when present at high enough concentrations. They, by themselves, do not increase the rate of degradation of steel or concrete. Organic additives depress (lower) the freeze point temperature of ice when mixed in salt brine. Conversely, as organics are added to salt brine, the ice melt capacity decreases [27]. Some who use additives observe that less rock salt is needed when additives are used [6]. Organic additives do not accumulate in the water over the years. They degrade or breakdown, using dissolved oxygen from the water during this process which can be harmful to aquatic life. They also may act as fertilizer to algae and aquatic plants.

Abrasives (sand) does not melt ice or snow. Since abrasives do not melt ice, sand alone often does not provide the level of service desired. It can be used to create short term traction on top of snow or ice at any temperature range. Abrasives are the only product available that will work during very cold temperatures when the deicers are ineffective. They are relatively inexpensive to purchase and available in large quantities. When sand is applied to the road it can be recovered by street sweeping. It can also be intercepted from reaching lakes, rivers and wetlands by storm drain grit chambers, storm drain filters, rain gardens and holding ponds. Sand is not a concern for ground water contamination. When sand enters the water it does not degrade. In large quantities or if stirred up by water movement it can create high turbidity, which is detrimental to aquatic life. Over time it will accumulate on the bottom of rivers, lakes, ponds and streams and fill in spaces used by aquatic life. This can cause changes in habitat and plant life, also unfavorable conditions for aquatic life. Sand can be removed from water bodies through dredging.

Chlorides are a family of deicers that are currently the most used. The most common is Sodium Chloride (NaCl) which works at average temperatures 15 °F to 32 °F ± 5 °F. Magnesium Chloride (MgCl<sub>2</sub>) and Calcium Chloride (CaCl<sub>2</sub>) work at colder temperatures (in the -20 °F to 15 °F range). They are commonly available and are relatively inexpensive. Chloride products are corrosive to steel infrastructure. Corrosion inhibitors can be added to reduce the effects. Chloride products cannot be recovered once applied to the road. They dissolve and migrate to surface and ground water. Chlorides do not break down in the water. They will persist and accumulate over time. They can also have more immediate effects on aquatic species at high levels in the water such as stunted growth, decreased reproduction, and in extreme cases death. This is a particular risk during the spring when large amounts of snow are melting. Chloride levels in the Twin Cities Metro Area show an increasing trend in both ground and surface water samples [10].

For more detailed information on these groups of products refer to the table in this report. For a discussion of the pros and cons of these products refer to the discussion section.

## **TABLES AND GRAPHS**

This table contains a simplified comparison of various types of materials that may be used in winter maintenance. The data represented is a generalization of the product line. Many manufacturers add corrosion inhibitors or other trace ingredients that will give the product different properties. For example 100% potassium acetate would be accurately recorded in this chart, but “Minnesota Monster Melt” a fictitious potassium acetate based product could very well have other ingredients added to it that would cause it to score differently. No blends are on this chart for the simple reason that there are too many unknowns.

Table 1: Deicer environmentally harmful and ice melt capability

<b>Deicer Category</b>	<b>Material</b>	<b>Environmentally Harmful (Yes/No)</b>	<b>Melts Ice (Yes/No)</b>
<b>Acetates</b>	Potassium Acetate	Yes	Yes
	Sodium Acetate	Yes	Yes
	Calcium Magnesium Acetate	Yes	Yes
<b>Formates</b>	Sodium Formate	Yes	Yes
	Potassium Formate	Yes	Yes
<b>Urea</b>	Urea, Urea/ammonium nitrate	Yes	Yes
<b>Glycerol/Glycol</b>	Glycerol	Yes	Yes
	Ethylene Glycol	Yes	Yes
	Propylene Glycol	Yes	Yes
<b>Succinate</b>	Potassium Succinate	Yes	Yes
<b>Additives</b>	"Beet Juice"	Yes	No
	Molasses	Yes	No
	Distiller's Solubles	Yes	No
	Corn Syrup	Yes	No
<b>Abrasives</b>	Sand	Yes	No
<b>Chlorides</b>	Sodium Chloride	Yes	Yes
	Sodium Chloride liquid	Yes	Yes
	Calcium Chloride	Yes	Yes
	Magnesium Chloride	Yes	Yes
<b>Explanation of Column</b>		Which products are harmful to surface or groundwater. May include high turbidity, loss of habitat, high conductivity, high dissolved oxygen demand, toxicity or nutrient loading.	Which products melt snow and ice?
<b>References</b>		[4], [13], [16], [17], [18], [23], [34]	[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]

Table 2: Common form of deicers and waste factor

<b>Deicer Category</b>	<b>Material</b>	<b>Common Form Used (Liquid/Solid)</b>	<b>Low Waste (Yes/No)</b>
<b>Acetates</b>	Potassium Acetate	Liquid	Yes
	Sodium Acetate	Solid	No
	Calcium Magnesium Acetate	Solid	No
<b>Formates</b>	Sodium Formate	Solid	No
	Potassium Formate	Liquid	Yes
<b>Urea</b>	Urea	Solid	No
<b>Glycerol/Glycol</b>	Glycerol	Liquid	Yes
	Ethylene Glycol	Liquid	Yes
	Propylene Glycol	Liquid	Yes
<b>Succinate</b>	Potassium Succinate	Liquid	Yes
<b>Additives</b>	"Beet Juice"	Liquid	Yes
	Molasses	Liquid	Yes
	Distiller's Solubles	Liquid	Yes
	Corn Syrup	Liquid	Yes
<b>Abrasives</b>	Sand	Solid	No
<b>Chlorides</b>	Sodium Chloride	Solid	No
	Sodium Chloride	Liquid	Yes
	Calcium Chloride	Liquid	Yes
	Magnesium Chloride	Liquid	Yes
<b>Explanation of Column</b>	List of non-chloride products for winter	The physical form of the product commonly used.	When applied to the road, does this product "stay put", melt the target area, and not bounce or blow off the road.
<b>References</b>		[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]	[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]

Table 3: Deicers performance in average, cold, and very cold melting ranges

Deicer Category	Material	Effective Ice Melting at Average Temperatures (15 °F to 32 °F ± 5 °F) (Yes/No)	Effective Ice Melting at Cold Temperatures (-20 °F to 15 °F ± 5 °F) (Yes/No)	Effective Ice Melting at Very Cold Temperatures (Below -20 °F ± 5 °F) (Yes/No)
<b>Acetates</b>	Potassium Acetate	Yes	Yes	No
	Sodium Acetate	Yes	No	No
	Calcium Magnesium Acetate	Yes	No	No
<b>Formates</b>	Sodium Formate	Yes	Yes	No
	Potassium Formate	Yes	Yes	No
<b>Urea</b>	Urea	Yes	No	No
<b>Glycerol/Glycol</b>	Glycerol	Yes	Yes	No
	Ethylene Glycol	Yes	Yes	No
	Propylene Glycol	Yes	Yes	No
<b>Succinate</b>	Potassium Succinate	Yes	Yes	No
<b>Additives</b>	"Beet Juice"	No	No	No
	Molasses	No	No	No
	Distiller's Solubles	No	No	No
	Corn Syrup	No	No	No
<b>Abrasives</b>	Sand	No	No	No
<b>Chlorides</b>	Sodium Chloride	Yes	No	No
	Sodium Chloride liquid	Yes	No	No
	Calcium Chloride	Yes	Yes	No
	Magnesium Chloride	Yes	Yes	No
<b>Explanation of Column</b>		Refers to pavement temperatures at which significant ice melting will likely occur. For all deicers, as temperature drops, ice melting will decrease and while two deicers may work at the same temperature range, they may not be equally effective at a given temperature		
<b>References</b>		[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]	[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]	[4], [13], [14], [16], [17], [23], [29], [30], [33], [37], [40]

Table 4: Price ranges in per gallon, ton, and lane mile and deicer availability

Deicer Category	Material	Price Estimates		Large Scale Availability  (Yes/No)
			(per lane mile)	
Acetates	Potassium Acetate	~ \$4.50/gallon	~ \$135	Yes
	Sodium Acetate	~ \$1,900/ton	~ \$190	Yes
	Calcium Magnesium Acetate	~ \$1900/ton	~ \$190	Yes
Formates	Sodium Formate	~ \$400/ton	~ \$40	No
	Potassium Formate	~ \$70/gallon	~ \$2,100	No
Urea	Urea	~ \$490/ton	~ \$49	Yes
Glycerol/Glycol	Glycerol	~ \$50/gallon	~ \$1,500	Yes
	Ethylene Glycol	~ \$40/gallon	~ \$1,200	No
	Propylene Glycol	~ \$40/gallon	~ \$1,200	Yes
Succinate	Potassium Succinate	~ \$2.50/gallon	~ \$75	Yes
Additives	"Beet Juice"	NA	N/A	NA
	Molasses	NA	N/A	NA
	Distiller's Solubles	NA	N/A	NA
	Corn Syrup	NA	N/A	NA
Abrasives	Sand	~ \$10/ton	~ \$1	Yes
Chlorides	Sodium Chloride	~ \$70/ton	~ \$7	Yes
	Sodium Chloride liquid	~ 15 cents/gallon	~ \$5	Yes
	Calcium Chloride	~ \$1.40/gallon	~ \$42	Yes
	Magnesium Chloride	~ \$1.20/gallon	~ \$36	Yes
Explanation of Column		Rough estimates of product pricing. Prices vary with availability, shipping costs, and competing markets for the same products, volume purchased and other variables. Additives are not included in pricing since they are used in much smaller amounts. The estimate per lane mile is based off the rates of 200 pounds/lane mile and 30 gallons/lane mile. These are not suggested application rates. Rates should be chosen based on road conditions, weather conditions, pavement temperature, and other contributing factors. These rates are only for cost comparison purposes.	Is the product available today in large commercial quantities such that if MnDOT switched to this product instead of salt there would be enough available	
References		[4], [7], [13], [16], [17], [23], [26], [32], [33], [37]	[3], [7], [8], [13], [26], [32], [33]	

Table 5: Deicer breaks down or accumulates in water, dissolved oxygen demand and aquatic plant growth

<b>Deicer Category</b>	<b>Material</b>	<b>Breaks down in water (Yes/No)</b>	<b>Accumulates in Water (Yes/No)</b>	<b>Uses up oxygen in the water (Yes/No)</b>	<b>Accelerates algae and aquatic plant growth (Yes/No)</b>
<b>Acetates</b>	Potassium Acetate	Yes	No	Yes	No
	Sodium Acetate	Yes	No	Yes	No
	Calcium Magnesium Acetate	Yes	No	Yes	No
<b>Formates</b>	Sodium Formate	Yes	No	Yes	No
	Potassium Formate	Yes	No	Yes	No
<b>Urea</b>	Urea	Yes	No	Yes Highest of all	Yes
<b>Glycerol/Glycol</b>	Glycerol	Yes	No	Yes	No
	Ethylene Glycol	Yes	No	Yes	No
	Propylene Glycol	Yes	No	Yes	No
<b>Succinate</b>	Potassium Succinate	Yes	No	Yes	No
<b>Additives</b>	"Beet Juice"	Yes	No	Yes	Yes
	Molasses	Yes	No	Yes	Yes
	Distiller's Solubles	Yes	No	Yes	Yes
	Corn Syrup	Yes	No	Yes	Yes
<b>Abrasives</b>	Sand	No	Yes	No	No
<b>Chlorides</b>	Sodium Chloride	No	Yes	No	No
	Sodium Chloride liquid	No	Yes	No	No
	Calcium Chloride	No	Yes	No	No
	Magnesium Chloride	No	Yes	No	No
<b>Explanation of Column</b>		When a chemical breaks down into other chemicals over time (biodegrades or decomposes)	If we stop using this chemical today, will it still be in our water in 5 years?	(BOD/COD) When chemicals breakdown in the water, they often use dissolved oxygen. This creates a hardship for aquatic life since oxygen is also needed by aquatic species (i.e. fish) in order to live.	Some products contain nutrients such as nitrogen & phosphorus. When in the water, nutrients speed up the growth of algae and aquatic plants
<b>References</b>		[4], [13], [16], [19], [23], [34]	[4], [13], [16], [19], [23], [34]	[4], [13], [16], [19], [23], [34]	[4], [13], [19], [23]

Table 6: Deicer pollutant removal, corrosive to steel

<b>Deicer Category</b>	<b>Material</b>	<b>Easily removed from water (Yes/No)</b>	<b>Ponds remove this pollutant (Yes/No)</b>	<b>Corrosive to Steel (Yes/No)</b>
<b>Acetates</b>	Potassium Acetate	No	No	No
	Sodium Acetate	No	No	No
	Calcium Magnesium Acetate	No	No	No
<b>Formates</b>	Sodium Formate	No	No	No
	Potassium Formate	No	No	No
<b>Urea</b>	Urea, Urea/ammonium nitrate	No	No	No
<b>Glycerol/Glycol</b>	Glycerol	No	No	No
	Ethylene Glycol	No	No	No
	Propylene Glycol	No	No	No
<b>Succinate</b>	Potassium Succinate	No	No	No
<b>Additives</b>	"Beet Juice"	No	No	No
	Molasses	No	No	No
	Distiller's Solubles	No	No	No
	Corn Syrup	No	No	No
<b>Abrasives</b>	Sand	Yes	Yes	No
<b>Chlorides</b>	Sodium Chloride	No	No	Yes
	Sodium Chloride liquid	No	No	Yes
	Calcium Chloride	No	No	Yes
	Magnesium Chloride	No	No	Yes
<b>Explanation of Column</b>		Can be removed by a known process and using a straight-forward, affordable procedure	Can stormwater ponds or rain gardens effectively remove this product before it reaches the lakes, rivers, or wetlands?	Will this product by itself be corrosive to steel?
<b>References</b>		[4], [13], [16], [19], [23], [34]	[38]	[4], [13], [14], [16], [17], [39]

## RESEARCH AREA 1: DISCUSSION

There are many deicing products marketed and used today that perform well and improve the safety and drivability of winter roads, parking lots and sidewalks. There are no chemicals currently marketed and used in winter maintenance that are harmless for the lakes, rivers and wetlands. When deicers are applied to a road, parking lot, or sidewalk, they dissolve the snow and ice, and the melted snow and ice along with the chemical applied migrates towards or into the surface or groundwater. Because of the volume of deicers used each winter, and because this is an annual activity, lakes and rivers are or will likely be impacted. The groundwater is also being impacted.

There is no “perfect answer” as far as product selection. The table above shows a high level summary of the functionality and the side-effects of each group of products. Most, but not all, of the products listed help melt snow and ice. The products work at a variety of pavement temperatures, they are sold in different forms and at various price ranges. There is only one thing that they all have in common, they all have the potential to harm the lakes, rivers and wetlands. The ways in which they harm the water varies depending on the type of deicer, abrasive or additive selected. These unintended side effects of deicer use are listed in the table.

To select a deicer that will be useful to you, provide the best economic and environmental return for your organization refer to the table of deicer attributes in this report.

Interpretation of data:

1. There is no “perfect” answer as far as product selection.
2. All products listed are harmful to the environment if quantities are high enough.
3. Non-chloride deicers are more expensive than chloride based deicers.
4. Many deicers are available in a liquid form. Liquid deicers are less wasteful than granular deicers in that they stay on target. In comparison, granular deicers tend to bounce or blow off of the target and a significant amount of the product is never used to melt snow and ice yet will still cause environmental harm. This is more pronounced on higher speed roads.
5. Deicers work at a variety of pavement temperatures. It is not possible to generalize by saying non-chloride deicers work at colder temperatures than chloride based products. All products must be researched independently.
6. Some of the products listed do not melt snow/ice.
7. All of the products (except sand) once applied, dissolve, and pass through ditches, storm drains, stormwater ponds and rain gardens without significant pollutant removal.
8. Non-chloride products generally do not persist very long in the water, they often have more serious short term effects and a more mild long term affects.
9. Chloride based products are persistent in the water, as more is applied, the concentration of chloride increases in the water. The major concern is the long term permanence of these products.

A brief discussion of pros and cons for deicing products can take any path. If we stopped using all deicers today, the chloride from the many years of use would still exist in our water and soil, and would continue to exist virtually forever [10]. The other deicers and additives, generally speaking, are much less persistent in the water over time. Because they are less persistent, they are often more immediately dangerous for the water as they break down and decompose, using the up the oxygen in the water.

The most strategic use of deicers is to use a selection of products that will meet your needs and reduce the total volume of deicer, abrasive or additives needed.

## **RESEARCH AREA 1: RECOMMENDATIONS FOR FUTURE STUDY**

- Research non-chemical methods for winter road maintenance
- Research ways to reduce chlorides entering the environment from other sources. Which would allow for, a higher allocation of chlorides, to be used for winter maintenance/safety with the same mass balance.
  - Develop a recommendation on how to lower salt contributions from water softeners (significant % of twin cities salt load).
  - Research winter water main breaks without salt or with lower salt use.
  - Research reuse possibilities of salt brine from city water softening operations, run off from salt storage, truck wash or other industries.
  - Investigate the possibility of creating deicers from waste streams of other industries. The waste stream may harm the water, depending on waste material treatment effectiveness, without the potential benefit of using them for deicing. Investigate putting the waste product to use by refining and repurposing it for winter road maintenance.

## **RESEARCH AREA 1: RECOMMENDATIONS FOR IMPLEMENTATION TRIALS**

Liquid Potassium Succinate: Investigate the local manufacturing and use as an anti-icing agent or deicing agent on sensitive infrastructure. Potassium Succinate is reported to act similarly to potassium acetate in environmental impacts and melting range, while possibly having slightly lower cost. A benefit may also lay in the suggested lower impact to concrete. It could be interesting to do a side by side study of potassium succinate and potassium acetate, as both succinates and acetates are not corrosive to steel and do not accumulate in the water as does  $MgCl_2$  or  $CaCl_2$ .

Before pursuing use, MnDOT should run an analysis on this product to make sure it passes their standard tests. More thorough research should be done to understand the advantages and disadvantages of the succinates, very little internet information exists on this product, especially for use as a deicer, when compared to others.

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## **Research Area 2: Permeable Road Surfaces and Pavement texture (color, material options that would provide better melting or traction)**

### **INTRODUCTION**

A significant amount of research exists on various different pavement types and designs that might yield less need for deicing. This has been a topic of research since at least 1970, and there have been field studies on some of the possible options. The research is scattered, however. The goal of this research synthesis is to look across the field of research and present useable information about pavement options in an easy to use and understandable format.

Currently, there is also a large amount of literature being generated, particularly at engineering universities, on the possibilities of nanotechnology and thermal designs. The goal of this research synthesis is to summarize the major avenues that have been explored, and to pull out basic information on these that may be useful at the present moment. The information included here is not meant to provide engineering directives, but to allow transportation managers to examine possibilities. With all changes to roadways, safety should be considered. That aspect is not quantified here.

### **RESULTS FOR RESEARCH AREA 2 A & B**

There are two sections of research presented here. Section 2A focuses on permeable road technology and provides an overview of the current understanding of its utility. There is also a summary of permeable road sections installed in Minnesota. Section 2B touches on a multitude of other pavement options and lists some of the positive and negative issues around each. This is not meant to be an exhaustive list of the options but an overview of the major possibilities that have been considered.

#### **SECTION 2A: Permeable Pavements**

This section of the report will look at pervious pavements (PP) as an alternative way to reduce salt use for winter maintenance. There are three common categories of PPs: 1) pervious concrete (PC), 2) porous asphalt (PA), and 3) permeable interlocking concrete pavers. Permeable interlocking pavers are not discussed in this report because they are not suitable for road use. They have not held up well to vehicle traffic and snow removal [1]. This synthesis will not look into the specific design considerations of using PA or PC. There are references for design. [2, 3, 4] It will look at the feasibility and durability of using full-depth pervious pavements in the Minnesota climate and salt saving potential.

## How permeable pavements work

Permeable pavements (PP) are pavements that allow water pass through and infiltrate into the soil below. Traditional pavement is impermeable; water flows off roadway surfaces into stormwater systems. Permeable pavements have become popular as a stormwater best management practice. In this capacity, permeable pavements have been used as a way of reducing runoff in wet climates and the water quality degradation that can be associated with runoff. Studies have also shown PP to offer potential safety and noise benefits. Reduced standing water reduces overall reflection off the roadway, as well as decreasing road spray and hydroplaning in wet conditions. Studies have also shown permeable surfaces to absorb tire and engine noise. [5]

PPs include a layered subgrade system. This is shown in Figure 1. The top pavement has fewer of the fine particles that normally would make the surface smooth. This gives PP larger void space and increased traction. Pervious pavements on average have void space of 15 – 25% compared to conventional pavements at 5 – 10%. [6] Below the PP top layer, there is a layer fine grade material for structural integrity. Water flows through to a stone reservoir layer that is made up of larger uniform rock and has about 40% void space. This third layer allows water time to be absorbed into the soil. Depending on soil

conditions, an outlet pipe connected to a stormwater drainage system may be needed to allow excess water out of the system. PPs capture the first flush of rainfall (the first 30 minutes of rainfall collect most pollutants)

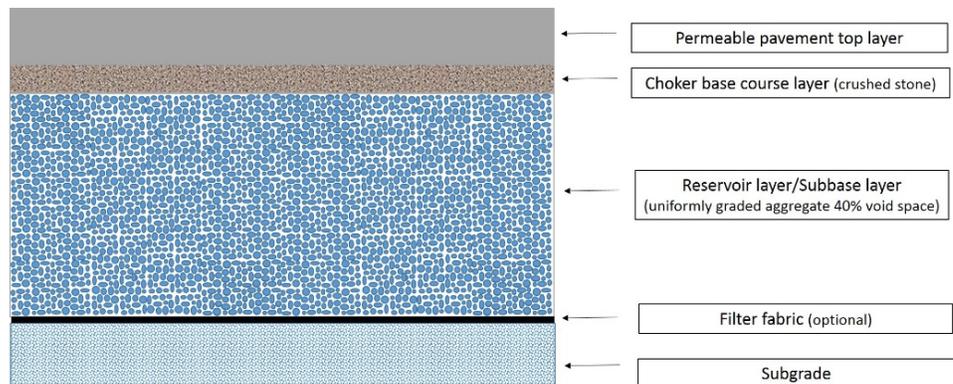


Figure 1: Permeable pavement layers

and allow it to absorb into the ground. The soil is being used as a natural filtration system to treat this polluted runoff. This also helps replenish ground water supplies. [7]

Since the water is penetrating into the ground instead of being directed into storm drains and into the lakes, rivers and streams, PPs provide a possible way to reduce chloride loading to surface water. However, the runoff will migrate into groundwater systems, and deicing materials such as sodium and chloride are not well attenuated in soil. Some percentage will travel into shallow groundwater. [8] According to the article *Chloride Released from Three Permeable Pavement Surfaces after Winter Salt Application*, as noted in the Journal of the American Water Resources Association, chloride levels in shallow groundwater exceeded the USEPA acute standard (860 mg/l) for aquatic life immediately following snow events. Chloride was detected in the water year round at the locations monitored. [9]

Permeable Pavements can be used on high speed roads, this has been done in Europe. Danish and Netherlands research shows that there is less clogging on high speed roads because of the cleaning action of high speed vehicles. [10] There are also examples of high speed roads in the United States, including a stretch of State Route 87 in Arizona. There are cautions from experts on high speed roads because small rocks can break loose, striking vehicles or windshields and cause increased wear on the roads. [11]

### **Maintenance Considerations**

Sand should not be used for winter maintenance because it will clog the pavement and reduce the permeability. Removal of snow can occur like any other pavement. The University of New Hampshire has compiled a set of Winter Maintenance Guidelines for Porous Pavements based on their research. [12] Regular vacuum sweeping and occasional power washing can help maintain the permeability of pavements. Mechanical brush sweepers are not a recommended practice on permeable pavement of any type. [13] This grinds material down into the pore structure. Public awareness of how the pavement works can be important to maintaining the effectiveness of the pavement. Signs should be posted to indicate the stormwater function and maintenance requirements. [14]

### **Porous Asphalt**

Porous asphalt has been used in Europe since the 1980's. The Netherlands have used PA roads since 1986 and have studied the advantages and disadvantages of porous asphalt in their country. The biggest problems they see are with freezing rain. Porous asphalt has been used since the 1970's in European countries as well as in Westchester, Pennsylvania, and several Mid-Atlantic States. More recently, cold region states have looked into porous asphalt and its performance. [15]

In Europe began application and study of PA in the 1970's for noise and spray reduction purposes on high speed roads. In Denmark porous asphalt is used on both high speed and low speed roads. Switzerland is no longer in favor of PA because of durability problems and reduced lifespan. France's National Road Administration has stopped using PA. Germany does not recommend PA for areas where there are 50 or more days of snow and ice. Monitored test sections in Denmark have shown that in winter the temperature of the road surface drops 1 to 2 degrees C faster than conventional asphalt. France found that PA fell to frost point about 30 minutes before conventional pavement. Black ice formation has been a problem in Denmark, Germany, The Netherlands, France, and Italy. [16, 17] It has also been observed by the City of Burnsville, Minnesota on their parking lot in early hours of the morning. [38] In Europe they have found pre-wet salts to work well, but requires an increase in salt use of 50%. Germany also noted that increase was due to need for more frequent salting, every 60 – 90 minutes to avoid black ice problems and compaction. Increased salt use is also thought to be a result salt washing into the open graded surface. The Danish Road

Institute (DRI) is looking into the use of larger salt grains to help with keeping salt on the surface of the road longer. According to DRI “Porous asphalt should not be applied to short stretches of road, as the winter maintenance technique has to be adapted, and the road users will be taken by surprise suddenly to drive on a different type of asphalt.” In all of the aforementioned countries, clogging has been observed within the first few years and cleaning is an important maintenance practice. [16, 17]

According to research done by at the University of New Hampshire on parking lots, PA can perform well in northern climates. Freeze-thaw temperature cycles do not compromise its structural integrity. It exhibits greater frictional resistance than conventional asphalt and did not experience the refreeze that conventional asphalt did, since snow melted on the roadway and drained well even at cold temperatures. The study observed that with regular plowing, salt was only needed for events when freezing rain occurred. In a direct time-wise comparison of melting properties, PA required 50 – 75% less salt than conventional asphalt to produce better and safer surface conditions. [18]

Minnesota Department of Transportation (MNDOT) has also done research into PA. They constructed test cells on a low volume road test circuit in 2008-2009. The 3-year study did not look specifically at salt use. They do not salt the test road segments. Researchers observed that there was increased frictional resistance in PA cells. Snow appeared to melt faster, particularly when sunshine reached pavement, and even when there was very low ambient temperatures and frozen subsurface conditions. Based on three temperature sensors placed at different depths in the pavement, the study showed that frost went only 40% as deep in the PA as compared to conventional asphalt. Over the 3-year study, it showed that the road did lose some permeability, but not enough to make the cells ineffective. The pavement did show raveling in the top 1 inch of pavement. Increased rutting over the standard asphalt cell also occurred, but no cracking or other significant distress. [19, 20]

The Shingle Creek Watershed Management Commission and the City of Robbinsdale, Minnesota, collaborated to study PA in a pair of city street intersections. The test sections are 150 feet of road leading up to a stop sign controlled intersection. It was hoped that the PA would provide a surface with good friction for people to stop. The goals of the study were to see if PA is an effective means to reduce the need for salt, to determine if porous asphalt can hold up to the rigors of a city street, to determine maintenance requirements, and look at water quality and quantity benefits. The study lasted three winter seasons.

No salt was applied to the permeable test section. It showed that snow on PA melted more slowly than on salted conventional asphalt, but faster than unsalted conventional asphalt. The PA sections did not refreeze and achieved similar net bare pavement, but it took more time, from a few to several hours. Increased solar radiation had positive effects on the melting of both the porous and conventional pavements. Temperature sensors 17” below the surface showed an insulating capacity which allowed infiltration

even in subfreezing temperatures. It was observed that PA was durable, there is no rutting and minimal wear, and no snowplow damage after the three winters. [21] In applications where turning would occur, there is concern over increased wear and aggregate loss in the turn radius. [22]

### **Pervious Concrete studies**

The use of porous concrete goes back to Mexico City in the early 1900's where it was used to recharge the groundwater aquifer. [23] The University of New Hampshire, in the same study on parking lots referenced above, also looked at PC. The study found that PC did not have the same capacity for increased skid resistance or salt reduction as PA. The study found that shading was a contributing factor to snow melt, which could be due to the lighter color of PC. This causes the pavement to reflect more solar radiation and as opposed to absorbing the radiation like PA. One possible benefit of lighter colored PC is that it could help reduce the urban heat effect. It can also help prevent increases in water temperature due to surface water. [24]

Researchers in Toronto looked at the performance of permeable pavements in cold regions, with the purpose of stormwater management. Several parking lots were constructed, including one of pervious concrete. The study found pervious pavements to function well in freezing temperatures. No significant surface slumping or heaving was observed and high permeability was maintained through the three year study. In reference to salt savings, it was noted that in the final winter season less salt was needed on the permeable surface. It was a warmer than average winter with less snowfall, however. [25]

MNDOT has also studied PC. In the two year performance report, they state that the surface ratings of the cells meet MnDOT requirements for "good" pavement and have good friction values. They also have observed that there can be a reduced amount of freeze-thaw cycles in the PC. They do not use salt on the PC cells, only plow. It was noted that increased melting versus conventional pavement was not seen, while it had been with PA. [26]

The City of Shoreview, Minnesota installed a nearly one mile section of PC roadway in a residential neighborhood in 2009. The low volume roadway is holding up well. They do not apply any deicing chemicals to the roadway and use the same method of clearing snow as on all other low volume roads. They have not observed greater damage caused specifically from plowing. No salt is used on the pavement. Shoreview has observed that melting is more closely related to air temperature than ground temperature. It is also suspected that increased sun exposure is helpful in snow melting, although the neighborhood has heavy tree coverage, so Shoreview has little experience in this area.

Shoreview has experienced only minor problems with cracking, spalling, and aggregate loss. They have one transverse crack that occurred within 12 months of construction which they do not believe has to do with curing. They have had none since. They have

encountered some spalling and/or aggregate loss concentrated in two places. In the all-pervious intersection there is aggregate loss that resemble wheel paths. Second, there is aggregate loss where the nearby high volume county highway drains to the pervious surface. This spalling is caused by the concentration of deicing chemicals which drain into the first 50 feet or so adjacent to the highway. [27, 28]

## **Cost**

There are several factors that can influence the cost of permeable pavements that are site specific. The proximity, availability, and cost of gravel and pavement supplies can change the cost of the project. The slope and type of soil are important factors. Clay soils may need additional base material or stormwater discharge considerations. Stormwater management, whether or not there is existing stormwater structure, permeable pavements are in and of themselves a stormwater management technique. [29]

The demand of the market, availability of product and knowledgeable contractors can also contribute to the cost of a project. The City of Chicago began the Green Alley Program installing pervious pavements in alleyways in 2006. One year later, the price of pervious concrete dropped from \$145 per cubic yard to \$45 per cubic yard, while the cost of ordinary concrete was \$50 per cubic yard. [30] Besides basic construction costs, there are slightly different maintenance costs to consider. Sweeping is an important step to keep permeable pavements clear of debris such as sand, leaves, and other items that will clog to pores of the PP. At the Shoreview installation, the city sweeps every 6 weeks. [31] At the Shingle Creek intersection site, sweeping happens a few times a year. [32]

## **Upcoming Research**

Clear Roads, a pooled research fund, currently has a study underway on Understanding the Chemical and Mechanical Performance of Snow and Ice Control Agents on Porous and Permeable Pavements. The report is due out in August 2014. [33]

## Tables and Graphs

This table lays out some of the important considerations that go into comparing conventional and permeable pavements.

Table 1: Comparison of Conventional and Permeable Pavements

Pavement Type	Conventional Pavement	Permeable Pavement
Refreeze	Yes	Inconclusive
Salt needed	Yes	Mixed results
Winter Maintenance	Plowing, deicing	Plowing
Initial Cost*	Medium	High
Maintenance Cost*	Low	Medium
Extra Stormwater system Required	Yes	No
Extra Maintenance Considerations	No	Regular vacuuming
Expected lifespan	Asphalt: 20+ years Concrete: 35+ years <sup>†</sup>	Unknown
Patch	As needed	Up to 10% area
High Speed Roads	Yes	No
Low Speed Roads	Yes	Yes
Major Concerns	Pot holes, cracking, hydroplaning, chlorides	Cost, pavement life, clogging, overloading, turning movement, groundwater

\* [34]

<sup>†</sup> [35]

## Discussion for Research Area 2A

There has been some research done on pervious pavements in colder climates in both the United States and Europe, but there has been very little research done specifically looking at salt reduction. In general, research suggests that pervious pavements are able to withstand the demands of a Minnesota winter, including freeze-thaw cycles and plowing. The additional application of pervious pavements on roads in Minnesota could be feasible. New Hampshire studies show a possibility of salt reduction up to 77% [36] and, in Minnesota, the permeable roadways are not salted at all, a 100% reduction.

However, caution must be used when applying salt to permeable surfaces, as deicing salts are highly soluble and do not filter out through the soil layers, allowing them to reach groundwater easily. The expectations of citizens may have to change if other installations in Minnesota take the same approach and do not salt at all as full melting may take longer without salt. [37] There are many positive attributes to pervious pavements including reduced refreeze of waters on the road, reduced standing water, lowered reflection off the road, reduced road spray and hydroplaning in wet conditions, and reduced tire and engine noise. [38]

## **SECTION 2B: Other Pavement Options**

The options touched upon in this section are: reducing road widths, road design to reduce snow drift, color, pavement roughness or grooving, pavement overlays, hydrophobic materials, nanotechnology, flexible pavement, conductive concrete and solar use. These options were selected as those being most represented in the literature and possessing potential for some degree of salt use reduction. There are other options that may be emergent and, looking at the need for salt reduction in a holistic manner, may arise from sources other than traditional chemical and transportation organizations.

### **Reducing road widths (impermeable area reductions)**

By reducing the amount of impermeable surface, we have less area that requires salting in the winter. Reducing road widths is a common component of green infrastructure planning. Green infrastructure planning is a strong movement in the US and abroad to use design elements in city planning that improve sustainability. This includes the reduction of stormwater and pollutants carried by it. There are several best practice guides for city planners to use if they wish, and these address many of the concerns around safety that transportation decision-makers might raise when considering such changes to roadways [1,2,3,4,5]. In addition to reducing road widths, best practices include minimizing the use of culs-de-sac and, if they are necessary, reduction of their radii, and/or inclusion of a pervious island. These changes would result in an overall reduction of impervious surfaces and a direct reduction in salting requirements to keep such surfaces clear during the winter.

Reducing the amount of impervious surface that must be deiced is a simple step that will move the transportation industry into a better position to meet the goals being set by local government and the MPCA. Reduction in impervious area could be driven by use of the recommendations from the American Association of State Highway and Transportation Officials (AASHTO) on road widths, and working to ensure that local standards do not exceed those for roadway width. Many local standards exceed these recommendations [5,9]. The Minnesota Department of Transportation (MnDOT) has included flexible design standards within their own design criteria. For highways, the Federal Highway Administration (FHA) has specifically encouraged the protection of natural resources through flexibility in highway design standards [8].

- + Proven reduction in need for salting
- + Reduces stormwater as well as salting
- + Little to no changes needed in maintenance equipment or training
- + Design tools available
  
- Slow phase in
- Need to prove/accept that narrower roads will work

## **Reducing Snow Drift**

Easy modifications can be made to roadway design or the design of adjacent areas to yield a significant amount of salt reduction. These are practical and simple elements that can reduce drift and subsequent compaction. When compaction occurs, more road salt must be employed to “cut through” the resulting ice and ruts [2,10]. These design elements are not new, but the connection between such practices and the goal of salt use reduction has not been made clear so far. Salt reduction numbers are available for some of these modifications<sup>1</sup>, while others must be assumed from the observed reduction in snow drift and/or compaction. Less compaction means a reduction in applied salt.

Elements which can reduce salt use include: improved drainage so water does not stand on roadways and freeze, wide ditches that allow plows to push the snow clear of the shoulder, the proper use of snow fences, the elimination of “accidental” snow fences such as solid lane barriers that drop snow onto the roadway, and the careful consideration of elevations for roads that are parallel, to reduce uneven snow deposition. Many green infrastructure planning guides discuss these issues in depth.

- + Proven reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + Design tools and real-life experience available for snow fencing and other changes
  
- Slower phase in, as elements are added to existing and new roads
- May be limits in various roadway settings for these elements to be incorporated

## **Color**

It has frequently been noted by plow operators and those doing field tests that sections of new asphalt lose snow or ice cover faster than other sections [11]. Trials of porous asphalt and pervious concrete have suggested that the asphalt has a faster melting rate due to such a color difference [12, 13]. It is a fact that greater reflection of sunlight will reduce heating of surfaces. Using darker asphalt could be a method of improving the reduction of compacted snow and black ice, and speeding the process of deicing when salting must be done.

- + Possible reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + Readily available methods to achieve darker roadways
  
- Slow phase in
- Other issues drive composition choice for roadways, including heating effect in urban areas

### **Pavement roughness and grooving (physical):**

In 1993, a study funded by a Strategic Highway Research Program showed that increasing the surface roughness yielded better removal of ice from the roadway surface. Ice formation is slowed and adhesion is less when surfaces are rougher. Roughness beyond a certain point, however, leads to difficulties in achieving contact between the plow blade and the ice, and decreases the net gain in performance [14]. Roughness also increases road noise and can affect tire wear.

Numerous studies of roughness additives such as ground glass, carbonates, and other aggregates have been done in the US and internationally to evaluate traction in wet conditions or for noise studies. There are also many studies that have looked at the physics of ice adhesion under varying surface texture profiles. Studies that evaluate grooving and roughness factors together, specifically for winter conditions, are lacking. The use of SafeLane (an overlay product discussed in the next section) for airports involves this consideration, and the work that is being done to evaluate the combination could be a benchmark for roadway implementation [15].

In addition to simply using rougher material for surfacing, there are other means to achieve “roughness,” ones which may not have the same drawbacks. Just one example is a patent was filed in 2003 for magnetic roadway covers which would allow for variable roughness during icing conditions (below freezing) [16]. Some other approaches could be explored as well, such as putting in grooving that is offset to the drive lanes [17].

Airports require extensive grooving of runways for better traction and drainage. A comprehensive evaluation of grooving, or texturization, of roadway surfaces for these benefits was undertaken by NASA’s Technology Utilization Program in 1993 [18]. The need for extra safety on shuttle runways led to an evaluation of grooving and grinding for runways at commercial airports. This idea was then extended to roadways. Multi-year studies showed a dramatic decrease in automobile accidents due to improved traction in wet conditions [18]. In winter conditions, better drainage could decrease re-freeze issues and the grooving or texturization could provide better traction.

High friction surface treatments (HFST) are another means of improving traction by increasing roughness [19]. These aggregate treatments have been used in the field with great success, particularly in high-risk areas. SafeLane is essentially a HFST with

an anti-icing “storage” potential. HFST are also a type of overlay, in that it can be added post-construction. Overlays are discussed in detail in the next section.

- + Proven reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + Readily available methods to achieve surface roughness
  
- Slower phase in
- Choosing the best approach to surface roughness involves other factors
- More expensive initially, and possibly reduced wear life

### **Pavement Overlays: benefit from less ice formation/bonding, or improves effectiveness of added chemicals**

Overlays change the characteristics of the top layer of a roadway surface. These overlays may reduce ice adhesion through increasing surface roughness and/or through better retention of applied anti-icing chemicals, or even through the inclusion of anti-icing chemicals in the overlay itself. The pros and cons of surface roughness were discussed above. This section focuses primarily on overlays that have embedded chemicals or some unique chemical feature.

Verglimit is calcium chloride encapsulated in linseed oil. This is blended into the wearing surface of the roadway. The calcium chloride will attract moisture and is supposed to create a moisture/chloride layer that prevents icing. This product has been around for decades. A test in Minnesota on Highway 8 in the late 1980’s showed no benefit [19] and other reports also document little to mixed improvement in anti-icing [21, 22]. There is commentary suggesting significant road traffic is necessary to obtain an anti-icing effect. Verglimit surfaces can actually be more slippery than conventional roadway surfaces under light traffic conditions and snowfall and durability issues were also seen [22,23,29]. In Connecticut, two test section were removed within months of installation due to a dramatic increase in accidents [23].

SafeLane is an epoxy aggregate surface that is marketed as anti-icing and anti-skid. Its manufacturer indicates, and some studies bear out, that a reduction in frost and black ice results from the use of SafeLane. It is meant to absorb anti-icing or de-icing chemicals and release when needed. In 2010, MnDOT undertook a study and produced a research bulletin on SafeLane [24]. It stated that SafeLane was effective in improving traction and it demonstrated anti-icing effects. However, the study also noted that it was subject to rapid wear from tire action and plowing. Two Michigan Technological University reports, released that same year, reported excellent reduction of accidents during a 5-year long bridge study and at an airport application site [15, 25]. A study at Detroit’s metropolitan airport showed a 50% reduction in deicing chemical use after runways were coated with SafeLane [26]. The economics of SafeLane need to be more thoroughly investigated, as reported installation cost varied significantly in the reports examined, as did the wear life.

Other coatings have been put forth as possible solutions to snow and ice accumulation on roadways. Just one example is the “smart anti-icing overlays” touted by the Keewenaw Research Center-Michigan as preventing moisture incursion into the roadway surface and improving traction during winter conditions [27]. One fairly comprehensive literature review of overlays is available through a 2003 report by the Keewenaw Research Center and Michigan Technological University [28]. Putting porous asphalt or permeable concrete on top of conventional roadway has also been explored as an overlay method that would minimize water retention at the surface and decrease the need for salt [29]. This also known as open grade friction course (OGFC) or permeable friction course (PFC) and this can be used, with some adjustments in installation and maintenance, even in northern states [45].

- + Possible reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + Readily available products, can be added to existing roadways
  
- May be negative interaction with weather conditions
- More expensive initially, reduced wear life

#### **Hydrophobic Material Overlay (water resistance):**

Substantial research in this area dates to the 1970s but seems largely untracked. Hydrophobic materials are thin coatings that resist water and are applied onto existing roadways. An EPA funded study in 1976 identified two coating materials that “showed considerable promise” by significantly reducing ice adhesion [30]. The products did not reduce traction and the cost was noted as similar to the use of road salt. The main drawback was the wear-life. The products needed to be re-applied every 1-2 months whereas the goal was to only have to apply once per season. Further study was recommended but more recent information was not found.

At the University of Pittsburgh’s Swanson School of Engineering, other hydrophobic coatings were studied more recently and found to have anti-icing potential, however, the correlation between surface roughness and the hydrophobicity was not defined. So it is unclear which combination of factors produces the best result [31]. These coatings were combinations of polymers and nanoparticles. The use of nanotechnology is discussed more fully in the next section. A 2013 study from Wisconsin centers on creation of icephobic cement-like composites which incorporate nano-fibers into the aggregate mixture and produces a “super hydrophobic” coating [32]. This study was supported by the FHWA’s national Research and Innovative Technology Administration (RITA), showing that this is being considered at the national level.

- + Possible reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- No comprehensive review of research available for product selection
- Expected to be more expensive for installation
- May have very short wear-life

### **Nanotechnology (working at molecular level to change features):**

Nanotechnology techniques can range from embedded characteristics (as in a coating) to etching of nano-structures on the surface of conventional roadway surfaces.

At many engineering schools there is a strong interest in using the emerging possibilities of nanotechnology to prevent ice adhesion. Lots of recent literature discuss this technology, but nothing was found in the public domain that talks about products actually being field tested for roadways. Roadways are mentioned in multiple articles as a major application that is being considered. There is ample evidence that various nanotechnology approaches work well for airplane “skins,” or use on roof tiles and other surfaces that do not require traction for vehicles and/or do not support vehicle weight.

Harvard University has a group that developed a coating effective in preventing ice formation to -30 C. Below that temperature, adhesion was greatly diminished. They plan to commercialize this for applications that include roads [33].

- + Possible reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + No need for chemical deicing or anti-icing
- No product currently proven to work on roadways
- Expected to be more expensive upfront, no information on wear life

### **Flexible Pavement**

Rubber particles have long been included in various road surface recipes. Such flexible pavements were created to use up discarded tires, increase surface friction of roadways and provide some limited flexibility to the roadway surface. There are multiple ways to create roadways by incorporating these rubber parts; these blends are most commonly called crumb rubber modified (CRM) mixtures. PlusRide is the formulation that was examined in a FHA study for ice disbonding possibilities [34].

This study showed that the use of relatively large rubber particles and less small aggregate were able to shed or crack off thin ice under vehicle traffic [35]. This material has been called Chunk Rubber Asphalt Concrete (CRAC). Some problems have been seen with rutting and other deformation of this material under high traffic loads.

- + Possible reduction in the need for salt
- + Little to no changes needed in maintenance equipment or training
- + Relatively inexpensive material
  
- Likely to be inexpensive
- May have shorter wear-life than conventional roadway surfaces
- May not perform as well in colder climates

## **Conductive Concrete**

Conductive concrete contains a certain ratio of conductive material to concrete. The materials used are commonly steel and carbon. This allows a current to flow through the concrete when a source of electricity is applied. The current flow, and subsequent heating, has been shown to prevent ice adhesion on bridge decks and in some roadway studies [36]. Conductive concrete is lighter and less dense than traditional concrete; it can work well as an overlay or sandwiched between two layers of conventional concrete.

Some assessments find the cost of installation and operation to be roughly two-thirds that of conventional concrete and conventional winter roadway maintenance, and have shown it to be a viable option even in Canada and Nebraska [37]. As with pervious concrete or porous asphalt, care must be taken to design areas with conductive concrete so that issues don't arise at the intersections with conventional roadway. Clear Roads funded a synthesis report in 2007 on the various conductive concrete projects done in the US and abroad [38]

Pulse electro-thermal deicers (PETD) are a variation of conductive concrete. PETD uses very brief bursts of electricity through an interface in order to prevent ice bonding to the surface. There may be some application for this in roadway maintenance but currently this has been studied only on other, non-wearing surfaces [39].

- + Possible reduction in the need for salt
- + Possibly less expensive than conventional roadway surfaces
  
- May have shorter wear-life than conventional roadway surfaces
- May need changes to winter maintenance equipment
- Needs input of electricity
- Expected to be more expensive to install, wear life is uncertain

## **Solar**

Two approaches to the use of solar energy for keeping roadways safe during winter were found most commonly in the literature. The first involves storing solar energy in a geo-thermal heat sink during the summer and drawing upon this supply to heat the road in the winter [40]. As direct heating of roadways was excluded from this Research Topic area by the LRRB, this possibility was not researched further. Use of solar arrays

to directly power conductive concrete trialed in several locations worldwide. In Switzerland, it was found not to be economically viable in areas with significant snowfall and lengthy winter conditions. [41]

The second type of application of solar energy that might have a reasonable place in roadway deicing is that pioneered by Solar Roadways in Idaho. Solar panels are joined together to create the roadway itself, and these solar cells use the sun's energy to generate sufficient heat to melt ice and snow off the surface. Solar Roadways has done some limited field trials of this technology and appears poised to run larger scale testing with its crowd-sourced funding and federal grants. Solar Roadways states that the material is strong enough for heavy vehicle traffic [42]. The installation on parking lots or roadways is envisioned to include charging stations for electric cars, and integrated street lighting.

- + Possible reduction in the need for salt
- + Generates power for other uses
  
- May need changes to winter maintenance equipment
- Much more expensive to install, wear life is uncertain

## **RESEARCH AREA 2 A & B: DISCUSSION**

The possibility of using other pavement options to decrease the reliance on road salt is promising, and such solutions have mostly been overlooked in chloride reduction conversations. In national studies on winter maintenance and the road salt issue, looking specifically at pavement alternatives was not previously researched [43]. An NCHRP Synthesis published in 2013, however, did spend a page reviewing the current options, and its contents include some additional citations for the pavement alternatives discussed here. [44].

The heavy emphasis on winter maintenance best practices is important, however, the use of chlorides cannot be reduced beyond a certain point unless changes are also made to the roadways, or other transportation alternatives are pursued. Some of the methods to reduce the use of chloride, as discussed here, have straightforward implementation pathways and are not excessively expensive. It appears that few at the local level are really looking at using them in the near term [45]. Within the context of road salt economics, many of these pavement options are less costly overall than the current use of deicers for winter maintenance [46].

## **RESEARCH AREA 2 A & B: RECOMMENDATIONS FOR FUTURE STUDY**

A federally-funded research synthesis study should be completed on pavement overlays, including hydrophobic options and emerging nanotechnology.

## **RESEARCH AREA 2 A & B: RECOMMENDATIONS FOR FIELD STUDY**

Evaluation of porous asphalt and pervious concrete should be done on road test sites in cold weather states such as Minnesota to quantify potential salt savings. Testing should be designed to look at the many factors that might affect the proper implementation of these for salt reduction.

## **RESEARCH AREA 2 A & B: RECOMMENDATIONS FOR IMPLEMENTATION TRIALS**

City, county and state transportation departments should increase the use of snow fencing, and reduce road widths, where appropriate. Both are existing technologies proven to reduce salt use.

A variety of pavement overlays and grooving patterns should be trialed in Minnesota, to examine possible reductions in salt use. Testing should be designed to look at the many factors that might affect the proper implementation of these for salt reduction.

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## Research Area 3: Winter speed limits or other winter driving changes

### INTRODUCTION

The first two sections of this report examined possible changes that the maintenance industry can make to reduce the amount of chloride going into the state's water. This section looks at five ways for the public to be involved in the goal of reduced chloride use during winter maintenance activities. The report looks at these topics: public awareness of the issues, tire technology, winter speed limits, winter driver education and reduced road use during an event. In the recommendations, we highlight those options which would most likely yield significant salt use reductions without reducing the level of safety provided to the driving public.

A key component of this entire research section revolves around level of service (LOS). The level of service that car commuters expect on roadways in 2014 is different than that expected in the 1950s or even the 1980s. Improvements in technology have allowed the winter maintenance industry to increase the LOS to the point at which most citizens expect bare pavement within hours after a storm event. The most common arguments for an elevated level of service are based on public safety and economic impacts, but these are not completely valid.

The public safety argument rests on the assumption that there are more crashes during the winter, taking more lives. Crash data shows, however, that fewer lives are lost during the winter than in the summer. Severe crashes that take lives occur mostly in the summer months and due primarily to inattention and speed. Winter crashes like their summer counterparts, occur primarily due to driver error. It is lower speed crashes that are higher in the winter months; these result in property damage but lower rates of significant injury.

A review of crash data indicates that improving education and training for inexperienced drivers could decrease winter crashes. Public awareness campaigns can likewise remind all drivers to use additional caution when roads are impacted by weather. The trend in driving crashes is toward an increase from inattention and speed rather than road conditions due to weather.<sup>2</sup>

In the Snowbelt states there is the common misconception that snow and ice make for the most dangerous roads.

The statistics show that during the period 1995 to 2008, an annual average of 190,100 crashes occurred on road conditions described as icy pavement, with 680 annual deaths. That's a rate of 358 deaths per 100,000 crashes. The rate for conditions described as snow/sleet: 387. For snow/slushy pavement: 369. During the same period, the rate for crashes that weren't described as weather-related was about twice as high, about 727.<sup>3</sup>

Wet roads actually take more lives and contribute to more crashes than snowy roads.<sup>4</sup> The awarding of a driver's license must be understood to include the responsibility to drive appropriately for the conditions, whether it be from snow or rain.

In the public discussion, the highest possible level of service is argued for based on perceived economic losses that may stem from a "shutdown" of the urban areas during winter events. This argument fails to take into account the reality of driver safety and the ways that productivity can be accomplished outside of the office building. If traffic is on the road during crucial plowing windows, then the period of time over which commuters suffer crashes and economic impact is likely to be greater than a few hours from a delayed start to the work day. Public maintenance organizations need to have the necessary time and conditions to do thorough physical removal if we are to become able to use less salt. Much of the difficulties from ice and snow compaction are caused due to incomplete physical removal prior to heavy traffic on the roadways.

The five sections presented here reveal options to drive down the use of salt without altering the overall safety of the roadways during the winter, and to minimize as much as possible the changes to economics during a storm event. By collaborating with efforts by public maintenance agencies, citizens in the Snowbelt states can protect their water resources, while remaining as safe and economically competitive as they were prior to any such changes.

## **PUBLIC AWARENESS**

Minnesota needs more public awareness around safe winter driving and the impacts of road salt on our transportation infrastructure and environment. A campaign should include awareness of safe winter driving techniques and transit options that citizens can use to avoid driving during storm events and cleanup. Colorado and Maine are two states actively employing safer winter driving campaigns.<sup>5</sup> In 2007, Clear Roads provided its member states with all the material necessary for a safe winter driving campaign: video, radio spots, signage, etc.<sup>6</sup> Some states, such as Wisconsin and New York, have used pieces of the Clear Road winter safety portfolio and added to this basic information. The media campaigns have included videos on YouTube as well as some TV spots.

The Minnesota Department of Public Safety has public seminars on preparing for winter each November, and winter driving is one of the offerings each year.<sup>7</sup> MnDOT holds open houses on road projects so that citizens may learn about the proposals and offer comments. Cities, both in Minnesota and elsewhere, also use this approach to get buy-in from the public and have found it effective in reducing complaints about winter maintenance efforts.<sup>8</sup> The piece that is missing is the connection to the environmental degradation from road salt. The MPCA has contributed to the overall level of awareness on the salt issue through its certification training for public maintenance, and other initiatives such as its Road Salt display which is available at the state fair and travels around the state. The agency has also reached out through media multiple times to share information about the environmental impacts of road salt.<sup>9</sup>

In Minnesota, the public's responsibility for safe traveling was touched upon in the 2013-2014 MnDOT Snow and Ice budget video. This is a video that is posted to the MnDOT website as an overview of each past winter season. In the future, media efforts by state and local agencies could have more emphasis on the "do not travel if you don't need to" message. There is a general perception in Minnesota that we are not limited by winter conditions, even in our ability to travel safely during winter events. Winter maintenance organizations take pride in their role as part of this culture. This can result in a feeling that they must do "whatever we need to do [to keep the public traveling as usual]"<sup>10</sup>

Unfortunately, most average citizens have not been reached by their states' safe winter driving campaigns, much less by the building concern over road salt and the environment. A Clear Roads study, "Developing and Evaluating Safe Winter Driving Messages," could provide some insights into how better to utilize media for such outreach.<sup>11</sup> It is vitally important that the public understand how safe driving techniques and road salt use are intertwined if the need for road salt is to be reduced. Development of videos for use on television and/or the web could play a key role, particularly in reaching younger audiences.

As an example, below is an excerpt from Michigan's DOT website, in which education about appropriate salt use is coupled with encouragement to motorists to drive for the conditions. MDOT is a user of the Clear Roads' "Ice and Snow, Take it Slow!" campaign, which was mentioned earlier.

### **Keys to Winter Driving**

Driving in Michigan can be very challenging during the winter months. Ice, snow, wind and below-freezing temperatures often combine to make winter weather driving a difficult undertaking.

MDOT is committed to keeping Michigan roads as safe as possible during these winter months. Winter maintenance crews are maintaining roads and bridges as conditions require. MDOT urges motorists to do their part and follow these simple steps when driving in winter weather:

- Always wear a safety belt when in a vehicle, and be sure children are properly buckled as well
- Slow down when visibility is low and/or when road conditions are snowy or icy – **in Ice and Snow Take it Slow!**
- Give snowplow drivers plenty of room to plow and salt/sand the roads – **Snowplows Need Room to Groom!**
- Be extra cautious on bridges because they can be icy when roadways are dry
- Accelerate and brake slowly and avoid abrupt steering maneuvers, especially when merging or changing lanes
- Don't pump anti-lock brakes
- Remember, don't text and talk while driving

Other things to think about while driving in winter weather:

- *Treacherous Temps* - Once temperatures get down into the teens, salt can be ineffective. This is because salt takes longer to work, and refreezes at a much faster rate when temperatures fall below 20 degrees. As a result, driving on road surfaces that have been salted can be more dangerous than driving on roads that have been plowed, but not salted. [Here's more info on how salt works in winter conditions](#) . When extreme cold temperatures occur, plow drivers often use sand more than salt to provide traction.
- *Watch the Slush* - Look at the slush being thrown by passing vehicles. If slush is thrown to the side of the wheels and splashing, the salt is still working. If the slush begins to stiffen and is thrown directly behind the wheels, the salt is losing effectiveness and icy conditions may begin to develop.

MnDOT also has information on winter driving on its website. Adding additional information about the public's role in helping to reduce the need for salt, and perhaps using the Clear Roads images, might educate more people on this connection between their behaviors and the amount of salt needed in winter maintenance.

In addition to involving the general public at a higher level, a particular sub-set of the public, a community's first responders, also need to be provided with information on the priorities of winter maintenance. Several cities and the MnDOT were asked about the relationship each had with the corresponding police and other first responders. Those that had positive things to say were those that met yearly with these groups to inform them about winter maintenance and to set up a strong working relationship.<sup>12</sup> This appears to reduce the pressure that is felt by some maintenance organizations from first responders and opened up the conversation so that first responders understand how anti-icing and de-icing work and what effective measures are for given conditions.

## **WINTER DRIVER EDUCATION**

The driving instruction provided to new drivers in Minnesota does not address winter driving techniques in much detail. Real world practice will vary dramatically for those doing their behind-the-wheel training during the summer months versus during the winter time. Overall, the curriculum appears to be very limited in what it conveys to new drivers about following distance and speed changes, and proper vehicle control in winter driving scenarios.<sup>13</sup> There are, however, private companies which specifically teach these skills, even to the extent of having "skid pads" for practice when the weather doesn't provide for real life experience. Transportation companies and the military require such knowledge of their drivers, and have developed certification programs on winter driving. Insurance companies give rate reductions to those who have taken winter driving courses.<sup>14</sup>

Crash data supports the idea that winter driving is a skill, acquired over time and with practice. Older drivers (65+) are involved in fewer crashes in the winter than would be anticipated from their overall rate although this number must always be reflective of actual miles driven during storm events. Older drivers may choose to drive less when conditions are poor, which is often the response requested of all drivers by public safety and transportation officials. The youngest drivers (18-25 years old) are disproportionately involved in winter crashes.<sup>15</sup> In all age categories, the first snow day accounts for a significant number of a winter's crashes.<sup>16</sup>

## **WINTER SPEED LIMITS**

Minnesota state statute 169.14 covers speed limits, zones, and radar. The law defines maximum speed limits for each road type to be lawful "where no special hazard exists".<sup>17</sup> They are set based on road type, location and type of access points, sufficient length of roadway, existing traffic control devices, crash history, traffic volume, sight distances, and test drive results speed study.<sup>18</sup> Subsection 1 states that drivers have the "duty to drive with due care". This means that when weather and road conditions worsen, as may happen in the winter, it is the drivers' legal responsibility to slow down and otherwise adjust to the conditions.<sup>19</sup> In Minnesota illegal/unsafe speed was the number one reason for crashes in 2013.<sup>20</sup>

An Institute of Transportation Engineers study found that most of the measured speeds are faster than the speed limit on roadways with posted speed limits of 45 mph or lower. On roads with the posted speed limit of 55 mph or more, about half the measured speeds are above the posted speed limit.<sup>21</sup> As road conditions change due to winter weather it is up to drivers to adjust to appropriate safe speeds. Behaviors vary when drivers encounter adverse weather based on experience and risk tolerance. Some drivers may decrease their speeds while others may maintain or even increase their speeds.<sup>22</sup>

One way that drivers could be encouraged to slow down in bad weather is through the use of a technology called variable speed limit (VSL) systems. This is a system that uses electronic signs to change the speed limits according to factors that can include darkness, traffic conditions, atmospheric conditions, weather, emergencies, and other conditions that could affect driver safety. The speed limits can either be regulatory – enforceable by law, or advisory – recommended, not enforceable.

There are currently weather related VSL systems in place around the United States as well as in several European countries including Finland, France, Germany, Sweden and The Netherlands. These systems respond to weather conditions such as rain, fog, snow, and wind. They are most often used on stretches of road that are known to encounter inclement weather and have higher crash levels than expected. The FHWA has compiled a set of guidelines for the use of variable speed limit systems in wet weather.<sup>23</sup>

Wyoming installed VSL signs along the Elk Mountain corridor, on interstate I-80, in 2009. Overall they have observed speed reduction of 3.4 to 6.4 mph for every 10 mph of speed reduction on the VSL signs beyond slowing attributed to weather conditions. The winter after the implementation of the system had the lowest reported crash frequency and crash rates compared with the previous 10 winters. Washington State DOT (WSDOT) currently has several VSL systems in place on the following roadways: I-5 Northbound into downtown Seattle, I-90 between the City of Bellevue and Seattle, SR 520 between the City of Bellevue and Seattle, US 2 over the Stevens Mountain Pass, and I-90 over the Snoqualmie Mountain Pass. A study conducted by the University of Washington found that on average vehicle speeds were reduced up to 13%. The study also noted that signs were most effective when the speed was lowered by smaller increments.<sup>24</sup>

Minnesota currently uses advisory close loop VSL signs on I-35W and I-94 to adjust the speed limit according to traffic. Based on a study done on the area, "Drivers may use the advisory speed limit to gauge downstream congestion and prepare themselves for encountering upcoming shockwaves."<sup>25</sup>

Changeable message signs (CMS) are another method that can be used to display warnings or advisories about weather conditions to alter driver behavior in order to be more cautious in weather conditions. Using variable speed limit signage or existing changeable message signs to decrease drivers' speeds could in turn reduce crashes or allow roads with a lower level of service to be safely traversed.

## **TIRE TECHNOLOGY**

Many crashes occur when cars lose control or cannot stop quickly enough in snowy and icy conditions. This is caused by loss of traction between tires and the road surface. Many cold weather regions require the use of studded tires, winter tires, or chains on tires throughout the snowy season. This increases the traction a car has in winter driving conditions, making snowy and icy roads safer to drive on without requiring bare pavement conditions. Without the need for bare pavement conditions, less salt will be needed.

There are many different types of tires: summer tires, winter tires, all-season tires. Each has unique characteristics to give better handling ability in different conditions. This is accomplished by changing the rubber composition or tread patterns. Each type of tire has its own advantages and disadvantages. When it comes to tire performance in winter conditions, there have been studies to compare the performances of various types and brands.

Most states and countries have laws pertaining to studded tires. These include full allowance of studded tires, studded tires permitted only with lightweight studs, seasonal restrictions, or full bans on studded tires.<sup>[1]</sup> There are similar rules for chains which are placed on tires to give added traction. Chains are sometimes required on certain

stretches of road such as in mountain passes or in certain weather conditions. This may be less practical where snowy and icy roads occur regularly.<sup>26</sup>

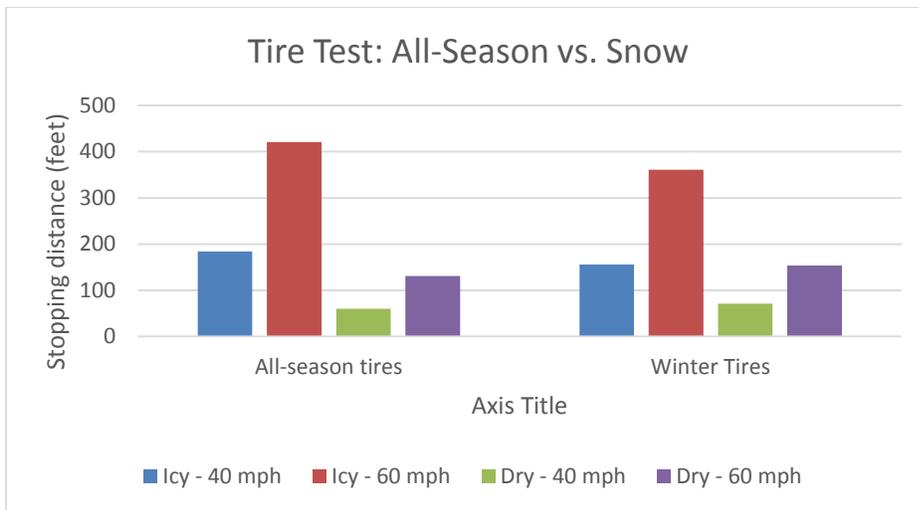
Studded tires were introduced in the United States in the 1960's. In the 1990's improvements were made to studded tires by Scandinavian countries to try to make them less damaging to pavement. These are the tires primarily used today. A study conducted by the Oregon Department of Transportation found that studded tires increased wear on roads by 315%. There is a shift toward lightweight studs, which reduce wear by approximately 50%.<sup>27</sup> Rutting can cause tramlining, hydroplaning on accumulated water in the ruts, excessive road spray, and premature damage to pavement markings.<sup>28</sup> Many state agencies, provinces, and countries have completed studies to quantify the costs associated with studded tire wear, finding that millions of dollars of damage is caused by studded tires each year. Japan and Finland studies concluded that restriction of studded tires reduced infrastructure costs, but that these savings were outweighed by the costs of safety and road salting/sanding costs.<sup>29</sup>

Winter tires were developed in the late 1980's as an alternative to studded tires. Studies in Alaska and Washington compared studded tires, winter tires, and all-season tires. All-season tires do not fare well in winter road conditions. Winter tires are designed to grip the road when it is icy and snow packed, even at very cold temperatures. They skid less on corners than studded tires. Studded tires are slightly more effective on ice near temperatures of freezing, but any other circumstance appears to favor winter rubber tires.<sup>30</sup> All tires pollute the air and water as they break down. However, winter rubber tires and studded tires wear down more rapidly than all-season tires. Winter tires have the advantage of not causing accelerated wear on roads. The chart below summarizes pros and cons of different tires:

Tire	General Description	Allowed in Minnesota <sup>31</sup>	Compared to All-Season Tires in Winter Conditions							
			Shorter Stopping Distance	Better on Curves	Effective on high speed roads	Increased Road Wear	Requires change of tires	Tires wear faster	Breakdown causes air/water pollution	
Studless / Winter	Softer rubber, tread pattern with wider grooves and narrow slits at the edge for better grip in snowy and icy road conditions even at cold temperatures	X	X	X	X			X	X	X
Studded	Tires with studs, often metal that stick out of the rubber to give added traction		X	X	X	X	X	X	X	X
Chains	Chains attach to existing tires to add traction	X <sup>*</sup>	X	X		X				

\* Allowed "of reasonable proportion... when required for safety because of snow, ice, or other conditions tending to cause a vehicle to skid"

A comparison of winter and all-season tires showed stopping distances of cars under icy and dry road conditions going different speeds. The results are shown in the chart below.<sup>32</sup>



Having good tires--whether they are winter, studded, or all season--that do not have worn treads, can help with stopping and skidding on winter roads. However, any vehicle with any type of tire will take longer to stop in icy or snowy conditions versus dry

conditions. When roads are snowy, slushy, or icy, drivers must leave more room for stopping between their car and the car in front of them and drive at lower speeds. It may be helpful to have winter specific tires, but it is still important for drivers to drive appropriately for the road conditions.

## **REDUCE ROAD USE IN WINTER OR DURING STORM EVENTS: EMPLOYER AND TRANSIT OPTIONS**

Removing drivers from the roads during storm events and clean-up could substantially improve the mechanical removal of snow and ice. Research has already shown that drivers self-select out of travel at a notable rate,<sup>33</sup> but much less so if the trip(s) are work-related. “[If] fewer folks are out on the road...injuries and fatalities that might occur in really, really bad weather are lower simply because there's not as many people out there taking chances,” according to Eric Rodgman, an analyst with the university's Highway Safety Research Center.<sup>34</sup>

Plows work best at slower speeds, and snow is more easily removed than ice from snow compaction under traffic loads. If organizations do not have to deal with a significant amount of compacted snow, they can reduce the amount of salt used to restore roadways. Salting of roadways also is most effective when done at a slow speed, to reduce scatter. The presence of additional vehicles can make plow drivers feel pressured to do their work at a speed greater than optimal.

Traffic, parked vehicles and speeding drivers decrease the ability of the maintenance organizations to clear snow and ice, and contribute to the overall number of crashes during the winter. Winter crashes are not always due to winter conditions, but are caused by secondary issues such as speed, insufficient following distances, and obstructions from traffic flow or parked vehicles. Employers in the metropolitan area and transit officials can provide better conditions for public works to do snow removal by promoting mass transit, car-pooling or work from home options.

In Great Britain, the Royal Society for Prevention of Accidents encourages employers to have a winter driving policy for their staff who drive for work purposes.<sup>35</sup>

Central to the policy will be the question of whether, when conditions are very severe, journeys need to be undertaken at all. Of course, the best thing to do in extremely bad weather is to stay off the roads altogether and, to this end, firms should ensure that their drivers take heed of any warnings - either from official external sources or from within the firm - not to continue their journeys.

If employers assisted storm clean-up efforts by staggering start times, allowing employees to have work at home options, or otherwise supported fewer employees driving at the typical “rush hour,” the overall snow and ice removal process would yield better results. This could lead to a reduction in the amount of salt used. Removing just

1% of the normal commuters from the traffic stream can reduce as much as 20% of congestion, depending on the variables in play.<sup>36</sup> Many of the government agencies in Washington D.C., for example, use “telework” as an option during snow events that might otherwise significantly impact productivity.<sup>37</sup> The State of Minnesota, as a large employer in the Twin Cities Metropolitan Area, could model this approach for the other large companies.

Another way to take drivers off the road while maintenance workers are plowing is to improve mass transit options in the Twin Cities. This can be done by building more commuter railways, by targeting bus routes for early plowing, or making public transit more attractive during storm events through subsidizing the cost and/or adding more capacity. In New Jersey, system cross-honoring is typically used during storms to keep commuters off the road. Cross-honoring allows a ticket holder on any form of public transport to use that on the other types, such as using a bus pass for the light rail line.<sup>38</sup> Other regions with public transit options promote them during storm events in hopes of reducing the vehicle load on the roadways.<sup>39</sup> Research shows the people respond more willingly to changes induced by a temporary alteration in transportation option and are also then more likely to make permanent choices based on their perceptions during that time.<sup>40</sup>

### **Discussion for Research Area 3**

There are many avenues open to public participation in the effort to reduce road salt use. The five options addressed here are those that the LRRB identified as promising. None of the approaches require new technology or particularly difficult pathways to instituting change; none of the approaches offer a solution by themselves. A combination of approaches are necessary to reduce road salt.

Organizations such as MnDOT and MPCA are well-suited to explaining the many concerns around winter driving safety and road salt to the public. Smaller organizations can take the same messages and distribute them to the local audience. More public education campaigns are needed to start to engage the citizenry in the important issue of winter driving and reduced use of road salt. One way this could be done is to couple the Clear Roads toolkit on Winter Safety public awareness campaigns with MPCA’s educational resources on road salt

If we consider productivity in a larger context, we see that allowing for better initial snow removal results in a better economic outcome for employers and employees. State and local officials can start the conversation with large employers and other organizations to discuss transit plans such as light rail, buses or other public transportation options. The goal would be to reduce road parking or road traffic during key clean-up times. Fewer cars driving on the road and compacting the snow will improve mechanical removal.

An additional cost that is relevant to this study is the potential loss in economic gain due to a degradation of natural resources from road salt overuse. Tourism is a key component of Minnesota’s economy. If road salt is overused, we may jeopardize the

ability to draw tourists and to maintain the quality of outdoor living that is so ingrained here. Several communities in Minnesota have already responded on the local level to long-term trend analysis of chlorides in their surface waters.

Improved drivers training programs or educational events may work to improve the skill and knowledge of Minnesota's winter drivers. For new drivers, the state could require that driving instruction for those requesting a license would have an increased emphasis on and practice of winter driving skills. Government and private business has teamed up on other safety issues such as child safety seats and fire safety with great success. The same approach could be taken with winter driving safety and skills. Topics could include the use of winter tires, safer following distances and knowledge of state advisory notices. The information would then be delivered to an audience wider than just new drivers.

In the five research areas examined in this section, multiple opportunities to reduce road salt use were found. In our recommendations, we have highlighted those which appear to have the potential for the greatest positive impact on road salt use compared to the inputs necessary. Any of these areas would have value. The advisory group felt that a concerted effort among agencies to support the message of salt overuse as a public issue is vital.

### **RESEARCH AREA 3: RECOMMENDATIONS FOR IMPLEMENTATION**

1. A public awareness campaign should be initiated to highlight the hazards of winter driving and the public's responsibility to be part of the solution to the road salt issues. A media campaign with video outreach is recommended for reaching a large enough portion of the public to have the desired effect. Staff involved in winter maintenance activities should also include their own public outreach as one of their winter maintenance tasks.

These are the key issues such a campaign should highlight:

- Environmental damage from road salt
  - Driver responsibility to drive with due care
  - Preparing your car for winter
  - Safety around plows
2. A collaborative effort to keep parked cars off of the road and drivers off of the road during critical winter maintenance operations should be instituted by working with mass transit authorities to increase capacity during these times, and by working with employers to keep employees working from home during these times. By educating the public on their options for winter mass transit or working from home or working variable shifts, winter maintenance organizations could help reduce the number of vehicles on the road during plowing. This could allow for more efficient winter maintenance, with less salt, and a faster return to better driving conditions.

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