TRANSPORTATION RESEARCH SYNTHESIS

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Chloride Free Snow and Ice Control Material

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of Fortin Consulting, Inc.,, MnDOT or LRRB.

OVERVIEW

The City of Burnsville requested that the Local Road Research Board (LRRB) 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. Rock salt is the most common deicer used for winter maintenance in Minnesota. It is affordable to purchase, and is usually an effective winter maintenance tool, but it causes damage to lakes, rivers and groundwater.

According to the most recent ground water report by the Minnesota Pollution Control Agency (MPCA), approximately 1/3 of the Twin Cities Metro Area wells tested exceed the state chronic standard for chloride[1]. Only 1% of tested wells outside of the Twin Cities Metro Area exceeded the state secondary drinking water standard or the chronic standard for chloride. The EPA does not have a Primary Drinking Water Standard for chloride but it does list chloride under the Secondary Drinking Water Standards (SDWA). The contaminant levels set under the secondary standards are primarily for aesthetics. For chloride, the secondary maximum contaminant level (SMCL) of 250 mg/L seeks to prevent a salty taste in drinking water.

The water quality criteria under the Clean Water Act for surface waters are different than the drinking water standards. Water quality criteria are based on impacts to the health of aquatic organisms. Shingle Creek was Minnesota's first surface water to be put on the impaired waters list for high chlorides. Successive 303(d) lists issued by the MPCA contain more lakes and rivers listed for chloride impairments. To reverse this growing trend in chloride impairments, it is important to find new ways to maintain safety on roadways while reducing chloride use in a cost effective manner.

With the growing concern around increasing chloride levels in Minnesota's water, the question was asked: "What are the alternatives to rock salt and what are their environmental impacts, performance characteristics and cost benefits?" Cost and benefits must be part of the discussion around the use of salt versus alternatives. Costs to consider include economic, safety, mobility, implementation requirements, infrastructure damage, and environmental impacts. This is a very complex issue which requires more study.

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 the advisory team expressed through the contract and at the first team meeting that the report should include 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, based on the decisions of the advisory team.

Research Area 1:
Non-Chloride Deicers

Research Area 2:
Task 2a – Permeable Road Surfaces
Task 2b – Pavement Texture, Color, Material and Design Elements

Research Area 3:
Public Awareness, Driver Education, Winter Speed Limits, Tire Technology, Transit Options

Fortin Consulting, Inc. (FCI) performed an internet literature review, worked with MnDOT Research Services and Library, and conducted email and phone interviews to gather information.

Research Area 1: Non-chloride Deicers

A wide view 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.

FOCUS

Chlorides are a family of inorganic deicers that are currently most frequently used. The most common is Sodium Chloride (NaCl) which works best at average temperatures of 15°F to 32°F. Magnesium Chloride ($MgCl_2$) and Calcium Chloride ($CaCl_2$) work at colder temperatures in the -20°F to 32°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.

Acetates are a family of non-chloride organic 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 so at a variety of pavement temperature ranges. KAc works at the coldest temperature range of the acetates the -20°F to 32°F range. None of the acetates work at extremely cold pavement temperatures (below -20 degrees Fahrenheit). Unlike rock salt they are not corrosive to steel;e however, they do react with and corrode zinc (galvanized steel)[2] 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 an inorganic metal ion and an organic acetate ion. The metal ion (e.g. calcium, potassium, sodium) will remain in the water, while the acetate ion will continue to biodegrade. In the biodegradation process oxygen is consumed creating an oxygen demand that can harm fish. Since acetates decompose they don't accumulate or persist long term in the water (years).

Formates are a family of non-chloride organic deicers of which the most common are sodium formate (CHO_2Na) and potassium formate (CHO_2K). 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°F to 32°F. They have been shown to have minimal effects on steel. The formate (CHO_2) component of these materials biodegrades in water. As they biodegrade, dissolved oxygen is consumed, 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.[3]

Urea ($CO(NH_2)_2$) is a non-chloride organic deicer that melts ice best in the 15°F to 32°F temperature range. Urea has not been shown to be corrosive to steel. Urea will biodegrade in water, this process uses dissolved oxygen. Urea uses the largest amount of dissolved oxygen of any of the non-chloride deicers and has been shown to consume more dissolved oxygen than Propylene Glycol.[4] Urea is a nitrogen fertilizer that has been extensively studied in Minnesota agriculture. Excess nitrogen has been found to pollute ground water and surface water, contributing to plant and algae growth. Since urea biodegrades in water, it consumes dissolved oxygen. Urea will not accumulate long term in lakes, rivers, and streams.

Glycerol/Glycol products are a family of non-chloride organic deicers that have mostly been used at airports. They melt ice at cold temperatures in the -20°F to 32°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.Glycerol/Glycol products do not accumulate long term in the lakes, rivers and streams, because they biodegrade in water, creating an oxygen demand.

Succinate products are a family of non-chloride organic deicers that are not widely used but with interest could be locally manufactured where there is a market demand. Because they are a liquid, shipping costs are high unless the product is manufactured locally. Potassium succinate ($C_4H_4O_4K_2$) is a liquid deicer and the most commonly used of the succinates. Potassium succinate is comparable to potassium acetate because it melts ice at the same temperature range the -20°F to 32°F range and is similar in price. Succinates biodegrade in water consuming dissolved oxygen in the process. Succinates do not accumulate long term in the water. The US headquarters for research and development of potassium succinate is located in Plymouth Minnesota. [5]

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 but add anti-corrosion or anti-caking properties to the deicer. Organic additives do not accumulate in water but biodegrade instead, consuming dissolved oxygen in the process. Some additives may contain nutrients that can stimulate algae growth.

Abrasives (sand) do not melt ice or snow. Sand can be used to improve traction on top of snow or ice at any temperature range and is often used during very cold temperatures when deicers are ineffective in melting ice and snow. Sand is 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 over time sand will accumulate on the bottom of rivers, lakes, ponds and streams. Sand can be removed from surface water bodies through dredging.

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 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 and therefore 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

Deicer Category	Material	Environmentally Harmful (Yes/No)	Melts Ice (Yes/No)
Acetates	Potassium Acetate	Yes	Yes
	Sodium Acetate	Yes	Yes
	Calcium Magnesium Acetate	Yes	Yes
Formates	Sodium Formate	Yes	Yes
	Potassium Formate	Yes	Yes
Urea	Urea, Urea/ammonium nitrate	Yes	Yes
Glycerol/Glycol	Glycerol	Yes	Yes
	Ethylene Glycol	Yes	Yes
	Propylene Glycol	Yes	Yes
Succinate	Potassium Succinate	Yes	Yes
Additives	"Beet Juice"	Yes	No
	Molasses	Yes	No
	Distiller's Solubles	Yes	No
	Corn Syrup	Yes	No
Abrasives	Sand	Yes	No
Chlorides	Sodium Chloride	Yes	Yes
	Sodium Chloride liquid	Yes	Yes
	Calcium Chloride	Yes	Yes
	Magnesium Chloride	Yes	Yes
Explanation of Column		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?
References		6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23

Table 2: Common form of deicers and waste factor

Deicer Category	Material	Common Form Used (Liquid/Solid)	Low Waste (Yes/No)
Acetates	Potassium Acetate	Liquid	Yes
	Sodium Acetate	Solid	No
	Calcium Magnesium Acetate	Solid	No
Formates	Sodium Formate	Solid	No
	Potassium Formate	Liquid	Yes
Urea	Urea	Solid	No
Glycerol/Glycol	Glycerol	Liquid	Yes
	Ethylene Glycol	Liquid	Yes
	Propylene Glycol	Liquid	Yes
Succinate	Potassium Succinate	Liquid	Yes
Additives	"Beet Juice"	Liquid	Yes
	Molasses	Liquid	Yes
	Distiller's Solubles	Liquid	Yes
	Corn Syrup	Liquid	Yes
Abrasives	Sand	Solid	No
Chlorides	Sodium Chloride	Solid	No
	Sodium Chloride	Liquid	Yes
	Calcium Chloride	Liquid	Yes
	Magnesium Chloride	Liquid	Yes
Explanation of Column		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.
References		24 25 26 27 28 29 30 31 32 33 34	35 36 37 38 39 40 41 42 43 44 45

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)
Acetates	Potassium Acetate	Yes	Yes	No
	Sodium Acetate	Yes	No	No
	Calcium Magnesium Acetate	Yes	No	No
Formates	Sodium Formate	Yes	Yes	No
	Potassium Formate	Yes	Yes	No
Urea	Urea	Yes	No	No
Glycerol/Glycol	Glycerol	Yes	Yes	No
	Ethylene Glycol	Yes	Yes	No
	Propylene Glycol	Yes	Yes	No
Succinate	Potassium Succinate	Yes	Yes	No
Additives	"Beet Juice"	No	No	No
	Molasses	No	No	No
	Distiller's Solubles	No	No	No
	Corn Syrup	No	No	No
Abrasives	Sand	No	No	No
Chlorides	Sodium Chloride	Yes	No	No
	Sodium Chloride liquid	Yes	No	No
	Calcium Chloride	Yes	Yes	No
	Magnesium Chloride	Yes	Yes	No
Explanation of Column		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.		
References		[46] [47] [48] [49] [50] [51] [52] [53] [54] [55] [56]		

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

Deicer Category	Material	Price Estimates		Large Scale Availability
			(per lane mile)	(Yes/No)
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	Unknown
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. 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		57 58 59 60 61 62 63 64 65 66		67 68 69 70 71 72 73

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

Deicer Category	Material	Biodegrades in water (Yes/No)	Accumulates in Water (Yes/No)	Uses up oxygen in the water (Yes/No)	Stimulates algae and aquatic plant growth (Yes/No)
Acetates	Potassium Acetate	Yes	No	Yes	No
	Sodium Acetate	Yes	No	Yes	No
	Calcium Magnesium Acetate	Yes	No	Yes	No
Formates	Sodium Formate	Yes	No	Yes	No
	Potassium Formate	Yes	No	Yes	No
Urea	Urea	Yes	No	Yes Highest of all	Yes
Glycerol/Glycol	Glycerol	Yes	No	Yes	No
	Ethylene Glycol	Yes	No	Yes	No
	Propylene Glycol	Yes	No	Yes	No
Succinate	Potassium Succinate	Yes	No	Yes	No
Additives	"Beet Juice"	Yes	No	Yes	Yes
	Molasses	Yes	No	Yes	Yes
	Distiller's Solubles	Yes	No	Yes	Yes
	Corn Syrup	Yes	No	Yes	Yes
Abrasives	Sand	No	Yes	No	No
Chlorides	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
Explanation of Column		When a chemical breaks down into other chemicals over time (biodegrades)	Is the material persistant?	(BOD/COD) When chemicals breakdown in the water, they often use dissolved oxygen.	Some products contain nutrients such as nitrogen & phosphorus.
References		74 75 76 77 78 79			80 81 82 83 84

Table 6: Deicer pollutant removal, corrosive to steel

Deicer Category	Material	Easily removed from water (Yes/No)	Ponds remove this pollutant (Yes/No)	Corrosive to Steel (Yes/No)
Acetates	Potassium Acetate	No	No	No
	Sodium Acetate	No	No	No
	Calcium Magnesium Acetate	No	No	No
Formates	Sodium Formate	No	No	No
	Potassium Formate	No	No	No
Urea	Urea, Urea/ammonium nitrate	No	No	No
Glycerol/Glycol	Glycerol	No	No	No
	Ethylene Glycol	No	No	No
	Propylene Glycol	No	No	No
Succinate	Potassium Succinate	No	No	No
Additives	"Beet Juice"	No	No	No
	Molasses	No	No	No
	Distiller's Solubles	No	No	No
	Corn Syrup	No	No	No
Abrasives	Sand	Yes	Yes	No
Chlorides	Sodium Chloride	No	No	Yes
	Sodium Chloride liquid	No	No	Yes
	Calcium Chloride	No	No	Yes
	Magnesium Chloride	No	No	Yes
Explanation of Column		Can be removed by a known process and using a straight-forward, affordable procedure.	Can stormwater ponds or rain gardens effectively remove from water?	Will this product by itself be corrosive to steel?
References		85 86 87 88 89 90	91	92 93 94 95 96 97

RESEARCH AREA 1: DISCUSSION

There are many deicing products marketed and used today that perform well and improve traction on winter roads, parking lots and sidewalks. There are no chemicals currently marketed and used in winter maintenance that do not impact lakes, rivers and wetlands. There is no "perfect answer" as far as product selection. The tables above show a broad view summary of the functionality and the benefits 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, and they are sold in different forms and at various price ranges.

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

A brief discussion of pros and cons for deicing products can take any path. Organic deicers and additives, generally speaking, are much less persistent in the water than chlorides. Organic deicers can be more immediately dangerous for the water because they break down quickly and decompose, using up the oxygen in the water creating low dissolved oxygen conditions 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 do chlorides.

More thorough research should be done to understand the advantages and disadvantages of the succinates. Very little accessible information exists on this product, especially for use as a deicer, when compared to the other products.

Research Area 2: Permeable Road Surfaces and Pavement Texture (color, material options that could provide better melting or traction)

INTRODUCTION

A significant amount of research exists on various pavement types and designs that may reduce need for deicing chemicals. This has been a topic of research since at least 1970, and there have been field studies on some of the possible options. Additionally, engineering universities are currently studying the possibilities of nanotechnology and thermal designs. The goal of this research section is to look across the field of research and present useable information about pavement options in an easy-to-use and understandable format, and to summarize the major avenues that have been explored, and to present basic information on both newer and older possibilities.

FOCUS FOR RESEARCH AREA 2 A & B

- Section 2A focuses on permeable road technology and provides an overview of the current understanding of its utility. There is also a discussion 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 an overview of the major possibilities that have been considered.

SECTION 2A: Permeable Pavements

There are three common categories of pervious pavement: 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. Section 2A will not look into the specific design considerations of using permeable pavements. It will look at the feasibility and durability of using full-depth permeable pavements in the Minnesota climate, and will focus the potential for reducing road chemical use. Permeable pavement will be the term used in the discussion, including both PC and PA as sub-types.

How permeable pavements work

Permeable pavements are pavements that allow water to pass through and infiltrate into the soil below or the flow is directed to holding basins for controlled discharge to stormwater systems. Traditional pavement is impermeable; water flows off roadway surfaces into stormwater systems. Permeable pavements have become more common as a stormwater runoff rate control 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.

Permeable pavements 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 permeable pavement larger void space and increased traction. Permeable pavements on average have void space of 15–25% compared to conventional pavements at 5–10%.[98] Below the permeable pavement's 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 to be absorbed more slowly into the soil.

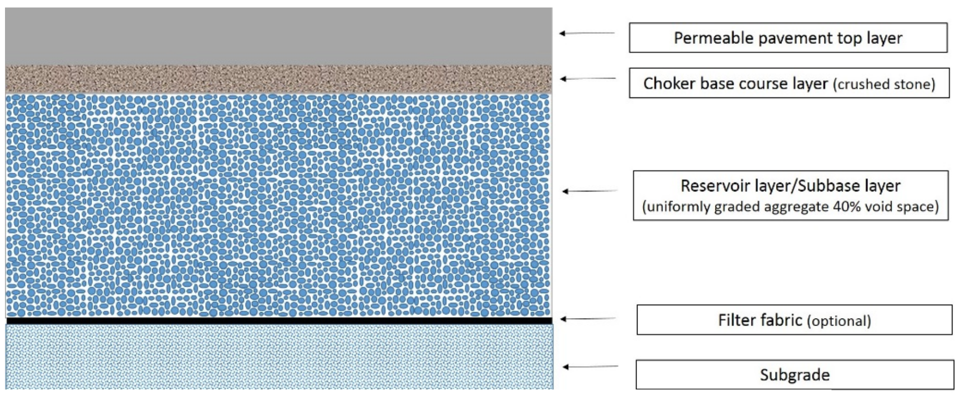


Figure 1: Permeable pavement layers

Depending on soil conditions, an outlet pipe connected to a stormwater drainage system may be needed to allow excess water out of the system. Permeable pavements capture the first flush of rainfall (the first 30 minutes of rainfall collect most pollutants) 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.[99]

Since the water is penetrating more directly into the ground instead of being directed into storm drains and ditches, permeable pavement provides a possible way to reduce chloride loading to surface water. However, deicing salts are not fully removed or retained in soil and can travel into shallow groundwater.[100] Permeable pavements have been researched in Europe. Danish and Netherlands research shows that there is less clogging of the pavement voids on high speed roads because of the cleaning action of high speed vehicles; however, if regular cleaning (water blasting and vacuuming) is not done regularly the voids become clogged.[101] There are also examples of trials on high speed roads in the United States, including a stretch of State Route 87 in Arizona.[102] Experts caution the use of permeable pavements on high speed roads because small rocks can break loose, striking vehicles or windshields and the roughness can cause increased wear on tires.[103]

Maintenance Considerations

Sand should not be used on permeable pavement for winter maintenance because it will clog the pavement voids. The University of New Hampshire has compiled a set of Winter Maintenance Guidelines for Porous Pavements based on their research.[104] Regular vacuum sweeping and occasional power washing can help maintain the permeability of these pavements. Mechanical brush sweepers are not a recommended practice on permeable pavement of any type.[105] This grinds material down into the pore structure.

Porous Asphalt

Porous asphalt has been used in Europe since the 1980's and the experience has been mixed. The Netherlands have used permeable pavement on roads since 1986 and have studied the advantages and disadvantages of porous asphalt in particular. The biggest problems they see are with durability and the need for additional salt applications in freezing rain. In the United States, porous asphalt has been used in Westchester, Pennsylvania, and several Mid-Atlantic States. More recently, cold region states have looked into porous asphalt and its performance.[106]

In Europe, application and study of permeable pavement was begun 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 permeable pavement because of durability problems and reduced lifespan. France's National Road Administration has also stopped using permeable pavement for the same reason. Germany does not recommend PA for areas where there are 50 or more days of snow and ice.

Black ice formation on porous asphalt has been a problem in many of the European countries.[107] [108] Black ice has also been observed at times by the City of Burnsville, Minnesota, on a parking lot.[109] European countries found pre-wet salts to work well for preventing or removing black ice, but note that the permeable pavement requires an increase in salt use of 30-50% per year. Germany also noted that frequent salting, every 60–90 minutes, was necessary during some events to avoid black ice problems and compaction. The need for increased salting is thought to be a result of the applied salt washing into the open graded surface instead of remaining on the surface and active in preventing ice formation.

The Danish Road Institute (DRI) is looking into the use of larger salt grains to keep salt on the surface of the road longer. DRI cautions that "porous asphalt should not be applied to short stretches of road." The concern is that drivers could be taken by surprise to suddenly drive on a different type of asphalt or differing levels of snow/ice cover on the roadway. In all of the countries, clogging has been observed within the first few years and cleaning is an important maintenance practice.[110] [111]

Research conducted by the University of New Hampshire on parking lots shows that PA can perform well in northern climates. Freeze-thaw temperature cycles did not compromise the structural integrity. The PA exhibited greater frictional resistance than conventional asphalt and did not experience the refreeze that conventional asphalt did. Snow melted on the parking lot and drained well even at cold temperatures. The study observed that with regular plowing minimal salt was needed unless freezing rain created icy conditions In a direct time comparison of melting properties, the porous asphalt required 50-75% less salt than conventional asphalt and can become clear of ice and snow faster.

Minnesota Department of Transportation (MnDOT) has also done research into porous asphalt. They constructed test cells on a low volume road test circuit (not open for public travel) in 2008-2009. The 3-year study did not look specifically at salt use. They did not salt the test road segments. Researchers observed that there was increased frictional resistance in the porous asphalt cells. Snow appeared to melt faster, particularly when sunshine reached the pavement, and even when there was very low ambient air 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 pervious pavement 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 showed raveling and some increased rutting in the top 1 inch of pavement, but no cracking or other significant distress.[112] [113]

The Shingle Creek Watershed Management Commission and the City of Robbinsdale, Minnesota, collaborated to study permeable asphalt in a pair of city street intersections. The 2, 150 foot test sections were constructed on the approach to stop sign-controlled intersections. Observations were recorded for three winter seasons and the intersections are still in use as permeable asphalt sections.

No salt was applied to the permeable test sections in Robbinsdale. It was observed that snow on the permeable pavement sections melted more slowly than on salted conventional asphalt, but faster than unsalted conventional asphalt. The test sections did not refreeze and achieved similar net bare pavement, but it took more time, from a few to several hours. Temperature sensors 17-inches below the surface showed an insulating capacity which allowed infiltration even in temperatures below 32 degrees. It was observed that the porous asphalt was durable, after 3 seasons the test sections showed no rutting and minimal wear, and no snowplow damage. If placed where turning would occur, there is concern over increased wear and aggregate loss in the turn radius.[114]

Pervious Concrete studies

The use of porous concrete goes back to Mexico City in the early 1900's where it was used to allow for recharge of the groundwater aquifer.[115] The University of New Hampshire, in the same study on parking lots referenced above, also looked at pervious concrete. The study found that pervious concrete did not have the same capacity for increased skid resistance or salt reduction as porous asphalt. 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 permeable pavements functioned 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, 2011/2012 less salt was needed on the permeable surface; however, it was an unseasonably warm winter with less snowfall than Toronto's average winter.[116]

MnDOT has also studied pervious concrete in a parking lot and driveway at the MnRoad Test Facility. In the three year performance report, they state there were changes in surface distress from the first year to the third year including a longitudinal crack, severe raveling, and spalling at joints. They also observed that there can be a reduced amount of freeze-thaw cycles in the pervious concrete. They do not use salt on the pervious concrete cells, only plow.[117]

The City of Shoreview, Minnesota installed a nearly one mile section of pervious concrete roadway in a residential neighborhood in 2009. They do not apply any deicing chemicals to this section of roadway and use the same equipment for clearing snow as on all other low volume roads. They have not observed greater damage caused specifically from plowing. Shoreview has observed that melting is more closely related to air temperature than ground temperature.

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 observed no significant cracking since. They have encountered some spalling and/or aggregate loss concentrated in two places. In the all-pervious intersection there is aggregate loss in the wheel paths. Another intersection shows spalling where a high volume county highway intersects with the pervious surface. This spalling is located only on the first 50 feet of pervious pavement, the portion adjacent to the county highway. Deicing salt is applied to the intersecting highway. Based on their observations, Shoreview staff believes that the spalling is caused by the deicing chemicals that drain onto the permeable pavement.[118] It is unknown whether they did any follow up investigations on the actual cause.

Pervious Pavement 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. 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.[119] Besides basic construction costs, there are different maintenance costs to consider depending on the site. Sweeping or vacuuming is important to keep permeable pavements clear of debris such as sand, leaves, and other materials that will clog the pores of the pavement. At the Shoreview installation, the city sweeps every 6 weeks.[120] At the Shingle Creek intersection site, sweeping occurs a few times a year.[121]

Upcoming Research

Clear Roads, a national research consortium focused on rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews, currently has a study underway on Understanding the Chemical and Mechanical Performance of Snow and Ice Control Agents on Porous or Permeable Pavements.[122] Expected to be completed in August 2014, it has not yet been published as of January 2015.

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 and deicing
Initial Cost*	Medium	High
Maintenance Cost*	Low	Medium-High
Extra Stormwater system Required	Yes	No
Extra Maintenance Considerations	No	Regular vacuuming
Expected lifespan	Asphalt: 20+ years Concrete: 35+ years †	Unknown
Patch	As needed	Up to 10% area
High Speed Roads	Yes	No
Low Speed Roads	Yes	Yes
Major Concerns	Pot holes, cracking, hydroplaning, deicing chemicals	Cost, pavement life, clogging, overloading, turning movement, groundwater

* [123]

† [124]

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 on these pavements. In general the research is inconclusive, it suggests that pervious pavements may be able to withstand the demands of a Minnesota winter including freeze-thaw cycles but there are concerns with the overall long term integrity of these pavements and impact on roadway deicing and black ice formation. There are positive attributes to pervious pavements including reduced refreeze of water on the surface, reduced standing water, lowered reflection off the road, reduced road spray and hydroplaning in wet conditions.[125] Major concerns include compaction, black ice, and overall long term durability of the pavement. In Europe increased salt required to melt snow and ice has been observed; however, in the New Hampshire study possible salt reductions of up to 77% have been observed providing that plowing was performed regularly.[126] In the Shoreview trial the permeable roadway was not salted at all, a 100% reduction.

Caution must be taken if deicing agents are used on permeable pavement. Deicing salts are highly soluble and are not filtered out through the top soil layers in permeable pavement design, therefore can provide a direct conduit for chemicals into shallow ground water.

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, crumb rubber 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 chemical use reduction.

Reducing road widths (impermeable area reductions)

By reducing the amount of impermeable surface, we have less area that requires chemical treating in the winter. Reducing road widths is a common component of green infrastructure planning. In addition to reducing road widths, best practices include minimizing the use of cul-de-sacs 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 possible reduction in chemical requirements.

Reducing the amount of impervious surface that must be deiced is a step that could move transportation departments into a better position to meet goals being set by watershed management organizations and the MPCA. The American Association of State Highway and Transportation Officials (AASHTO) as well as the Institute of Transportation Engineers (ITE) both give recommendations on road widths.[127] [128] MnDOT has included flexible design standards within their design criteria. The Federal Highway Administration (FHWA) has specifically encouraged the protection of natural resources through flexibility in highway design standards.[129]

Pros and Cons:

+ Possible reduction in need for deicing chemical
+ Reduces stormwater volume
+ Little changes needed in maintenance equipment or training
+ Design tools currently available

- Slow phase in
- Need to prove/accept that narrower roads will accommodate other concerns

Reducing Snow Drift and Compaction

Modifications can be made to roadway design or to adjacent areas that could potentially yield some chemical reductions. These elements can reduce drift and subsequent compaction. When compaction occurs, underbody scrapers must be employed to “cut through” the resulting ice and ruts.[130] [131] These design elements are not new. However; providing areas to plant living snow fences or place structural snow fences can require the purchase of additional right of way. While snow fences are potential solutions, with a solid history of implementation, they may not be the easiest in every situation and their use can limited by many factors.

Other roadway elements which may reduce chemical 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 use of alternatives to solid concrete barriers that will allow snow to blow across a road and not create a snow trap, 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.

Pros and Cons:

+ Possible reduction in the need for salt
+ Little 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 (easier in rural areas vs urban)

Color

Anecdotal observations have been made by plow operators that sections of new asphalt lose snow or ice cover faster than older sections.[132] Trials of porous asphalt and pervious concrete have suggested that the asphalt has a faster melting rate due to the color difference.[133] [134] Maintaining a darker asphalt surface through the use of surface treatments or materials could improve the speed of melting whether chemicals are applied or not.

Pros and Cons:

+ 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
- Frequent reapplication of fog seal or chip seal to maintain dark color
- Fog sealing can result in reduced traction under certain conditions
- Chip seals on high-speed roads can result in broken windshields and headlights

Pavement roughness and grooving

In 1993, a study funded by the 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 reduced 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.[135]

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.

In addition to simply using rougher material for surfacing, there are other means to achieve "roughness". One example is a patent that was filed in 2003 for magnetic roadway covers which would allow for variable roughness during icy conditions (below freezing).[136]

Airports require extensive grooving of runways for better traction and drainage. A comprehensive evaluation of grooving, or texturization, of runway surfaces for these benefits was undertaken by NASA's Technology Utilization Program in 1993.[137] 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. In 1966, to determine if grooving highways would be beneficial, a curved section of highway in California was selected for testing because of its high frequency of wet pavement accidents. The two years of tests resulted in a 98 percent reduction of accidents due to improved traction in wet conditions.[138] In winter conditions, better drainage could decrease re-freeze and grooving or texturization could provide better traction.

High friction surface treatments (HFST) are another means of improving traction by increasing roughness.[139] HFST are types of overlays that can be added post-construction. Other overlays are discussed in detail in the next section. HFST aggregate treatments have been used in the field with some success, particularly in high-risk areas.[140] [141] They do however wear down relatively quickly and may have to be reapplied.

Pros and Cons:

+ Possible reduction in the need for chemicals
+ Readily available methods to achieve surface roughness
+ Likely no changes needed in maintenance equipment or training

- Slower phase in
- Choosing the best approach to surface roughness involves other factors
- More expensive initially
- Possibly reduced wear life
- Shorter life on plow cutting edges

Pavement Overlays

Overlays change the characteristics of the top layer of a roadway surface. These overlays may reduce the need for deicing chemicals by limiting ice adhesion through increased surface roughness and/or 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. A test in Minnesota on Highway 8 in the late 1980's showed no benefit[142] and other reports also document little to mixed improvement in anti-icing.[143 144] 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. Durability issues were also seen.[145 146 147] In Connecticut, two test sections were removed within months of installation due to a dramatic increase in accidents.[148]

SafeLane is an epoxy aggregate overlay marketed as an anti-icing and anti-skid product. It is designed to absorb anti-icing or de-icing chemicals and release them when needed. In 2010 MnDOT undertook a study and produced a research bulletin on SafeLane.[149] 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 a reduction in accidents during a 5-year bridge study and at an airport application site.[150 151] A study at Detroit's metropolitan airport showed a 50% reduction in deicing chemical use after runways were coated with SafeLane.[152] The economics of SafeLane need to be more thoroughly investigated, as installation costs varied significantly in the reports examined, as did the wear life.

Other coatings have been suggested as possible solutions to reduced traction during snow and ice events. One example is the "smart anti-icing overlays" touted by the Keewenah Research Center-Michigan, which may prevent moisture incursion into the roadway surface and improve traction during winter conditions. These overlays were most effective above 20 degrees F.[153] A literature review of overlays is available through a 2003 report by the Keewenah Research Center and Michigan Technological University.[154] Placing porous asphalt or permeable concrete on top of a conventional surface has also been explored as a method to minimize water retention at the surface and possibly decrease the need for salt.[155] This is also known as open grade friction course (OGFC) or permeable friction course (PFC). It should be noted that in some cases greater quantities of deicers may be needed on these surfaces as the chemical moves away from the surface down into the voids and doesn't remain at the surface where it's needed. [156]

Pros and Cons:

+ Possible reduction in the need for chemicals
+ Readily available products, can be added to existing roadways

? Unknown whether changes needed in maintenance equipment or training

- Those with embedded chemicals are potentially dangerous
- More expensive initially
- Potentially reduced wear life
- More expensive to maintain if regular reinstallation is required

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.[157] 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 on the products 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.[158] 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.[159] This study was supported by the FHWA's National Research and Innovative Technology Administration (RITA).

Pros and Cons:

+ Possibly a reduction in the need for chemicals
+ Research is closer to field trials than some other innovations

- No comprehensive review of research available for product selection
- Expected to be more expensive for installation
- Very short wear-life
- Unknown changes to other winter maintenance techniques

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. Recent literature discusses this technology, but nothing was found in the public domain that talks about products actually being field tested for roadway use. 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 for 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 at warmer temperatures and adhesion to –22F. Below that temperature, adhesion was still greatly diminished. They plan to commercialize this for applications that include roads.[160]

Pros and Cons:

+ Possible reduction in the need for chemicals

- No product currently proven to work on roadways
- Expected to be more expensive upfront,
- No information on wear life
- Plowing may need to be done with different equipment

Chunk Rubber Asphalt Concrete

Rubber particles have long been included in various road surface recipes. Such pavements were created to use up discarded tires, increase surface friction of roadways and provide some limited flexibility to the roadway surface. These blends are most commonly called crumb rubber modified (CRM) mixtures. Researchers noted the deformability of the CRM roadway surfaces and a Strategic Highway Research Program (SHRP) study was undertaken on the ice disbonding possibilities of this material.[161] PlusRide is the CRM formulation that was examined.

Starting with the PlusRide composition, researchers varied the size of the rubber, amount of rubber and void space. 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.[162] 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 and the experience in Minnesota and other states with field trials has been mixed with respect to improved winter maintenance.[163]

Pros and Cons:

+ Possible reduction in the need for chemicals
+ Relatively inexpensive material

? Unknown changes needed in maintenance equipment or training

- May have shorter wear-life than conventional roadway surfaces therefore more expensive
- May not perform as well in cold climates
- Steel threads may puncture tires

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.[164] 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 an option even in Canada and Nebraska.[165] 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.[166]

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 on roadways but currently this has been studied only on other, non-wearing surfaces such as airplane and building components.[167]

Pros and Cons:

+ Possible reduction in the need for chemicals
+ Possibly less overall operating expense

- 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

Solar

Two approaches to the use of solar energy for keeping roadways clear of ice and snow 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.[168] 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 has been trialed in several locations worldwide. In Switzerland, it was found not to be economically viable in areas with significant snowfall and lengthy winter conditions.[169]

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 crowd-sourced funding and federal grants. Solar Roadways states that the material is strong enough for heavy vehicle traffic.[170] The installation on parking lots or roadways is envisioned to include charging stations for electric cars, and integrated street lighting.

Pros and Cons:

+ Possible reduction in the need for chemicals
+ Generates power for other uses

- May need substantial 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 deicing chemicals is promising but in its infancy. In national studies on winter maintenance and road salt usage, looking specifically at pavement alternatives has not previously been researched.[171] An NCHRP Synthesis published in 2013, briefly explored the current options, and its contents include some additional citations for the pavement alternatives discussed here.[172]

The 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 in this report, have traditional implementation pathways but the effectiveness and long term costs are unknown.

RESEARCH AREA 2 A & B: RECOMMENDATIONS FOR FUTURE STUDY

A 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 quantify the cost/benefit as well as environmental impacts.

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 that could potentially reduce salt use.

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

Research Area 3: Public awareness, tire technology, winter speed limits, driver education, reduced road use

INTRODUCTION

The first two sections of this report examined possible changes that public works departments could make to potentially reduce the amount of deicing chemicals needed. This section looks at five ways for the public to be involved in the goal of reduced chloride use during snow events. This section 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 salt use reductions, raise public awareness, and encourage safe driving behavior.

Many people believe that there are more fatal crashes during the winter. Crash data shows, however, that fewer lives are lost during the winter than in the summer. Fatal crashes occur mostly in the summer months and are due primarily to illegal or unsafe speed, failure to yield right of way, and driver inattention or distraction. "Road surface conditions where crashes occurred were usually good. For fatal crashes, 76% were on dry roads, 10% were on wet roads, and 12% were on snowy or icy roads." Winter crashes like their summer counterparts; occur primarily due to driver error. 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 five sections presented here reveal potential options to reduce the use of deicing chemicals.

PUBLIC AWARENESS

Minnesota has a history of working on public awareness around safe winter driving and the impacts of using road salt on our transportation infrastructure and environment. MnDOT is very active prior to and during the snow and ice season. It partners with the Department of Public Safety (DPS) on snow and ice messages. The intent is to get drivers to slow down and drive according to the road conditions. The annual campaign could expand on the environmental impact of deicers as well. MnDOT uses video and infographics on the website www.dot.state.mn.us/workzone/ and via social media to help explain things such as black ice, blow ice, effective deicer temperatures and associated chemical use.

MnDOT has produced many YouTube videos that highlight winter maintenance issues. MnDOT staff frequently presents at the annual Road Salt Symposium, reaching out to leaders in environmental protection and transportation on ways to maintain mobility and apply chemicals in the most effective and responsible manner.

In 2007, Clear Roads provided its member states with all the material necessary for a safe winter driving campaign: video, radio spots, signage, etc.[173] This material is primarily focused on safer driving and does not discuss the need for reduced chloride use. Some states, such as Wisconsin and New York, have used pieces of the Clear Roads "Ice and Snow, Take it Slow" winter safety portfolio and added salt reduction concerns to this basic information. The media campaigns have included videos on YouTube as well as some TV spots. Colorado and Maine are two states actively employing safer winter driving campaigns that connect to the use of less salt.

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.[174] 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.[175] [176]

MnDOT, the Minnesota Local Technical Assistance Program (LTAP) and the MPCA have contributed to the overall level of awareness on salt usage through training for maintenance professionals, and other initiatives such as MPCA's Salt Dilemma display. The display is shown at the state fair and also travels around the state. The MPCA has reached out through social media to share information about the environmental impacts of road salt.

The Clear Roads study, "Developing and Evaluating Safe Winter Driving Messages," provides some insights into how better to utilize media for public outreach and could be used by all agencies. 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.

> Other things to think about while driving in winter weather:
>
> - *Cold Temps* - Once temperatures get down into the teens, salt is less effective. This is because salt takes longer to work, and refreezes at a faster rate when temperatures fall below 20 degrees. 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.

Several public works departments and MnDOT maintenance shops were asked about the relationship each had with their corresponding public safety departments. Those that met yearly to discuss winter maintenance practices had a better working relationship than those who didn't meet.[177] [178] [179] An open dialog appears to reduce the pressure from law enforcement placed on maintenance departments regarding chemical applications during storm events and provides an understanding to law enforcement of how anti-icing and de-icing chemicals work.

For all agencies working to educate the public on road salt use, here are some tools and ideas:

- Add additional information about the public's role in helping to reduce the need for salt, and perhaps using the Clear Roads images and research on how best to reach the public.
- Educate more people on this connection between their behaviors and the amount of salt needed in winter maintenance.
- Continue to reach out to community's first responders/law enforcement, which also need to be provided with information on winter maintenance.

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 those practicing during the winter time. Overall, the curriculum appears to be limited in what it conveys to new drivers about following distance and speed changes relevant to ice and snow conditions. There is no reminder to access road condition information from MnDOT or to consider other methods of transportation when conditions are dangerous.[180] There is much more that could be taught to new drivers about the effect of road conditions and driver behavior on maintenance operations in the winter.[181]

In addition to on-line information, there are companies which specifically teach winter driving skills, even to the extent of having "skid pads" for practice driving on ice. MnDOT maintenance, some trucking companies and the military require such knowledge of their drivers, and have developed programs on winter driving. Some insurance companies give rate reductions to those who have taken winter driving courses.[182]

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 disproportionally involved in winter crashes.[183] In all age categories, the first snow day accounts for a significant number of a winter's crashes.[184]

WINTER SPEED LIMITS

Minnesota State Statute 169.14 defines maximum speed limits for each road type to be lawful "where no special hazard exists". All state highways have a speed determined on the basis of an engineering and traffic investigation. The investigation considers 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.[185] Subdivision 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.[186] In Minnesota illegal/unsafe speed was the number one reason for crashes in 2013. [187]

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.[188] As road conditions change due to winter weather, it is up to drivers to adjust to appropriate speeds. Behaviors vary when drivers encounter adverse weather based on their experience and risk tolerance. Some drivers may decrease their speeds while others may maintain or even increase their speeds.[189]

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.[190]

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.[191] (It is unclear what the severity of that winter was.) 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.[192]

Minnesota currently uses advisory close loop VSL signs on I-35W and I-94 to adjust the advisory speed according to traffic. Based on a study done on the area, "Drivers may use the advisory speed to gauge downstream congestion and prepare themselves for encountering upcoming shockwaves."[193]

Changeable message signs (CMS) are another method being used to display warnings or advisories about weather conditions to alter driver behavior in order to be more cautious in adverse weather conditions. Using variable speed limit signage or existing changeable message signs to inform drivers of road conditions may decrease drivers' speeds and may in turn reduce crashes.

TIRE TECHNOLOGY

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 within various types and brands.[194] [195] [196]

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.[i] Minnesota State Statute 169.72 prohibits the use of studded tires except in very limited conditions. It is permissible to use chains of reasonable proportions when required for safety. The use of chains may be less practical where snowy and icy roads occur regularly.[197] [198]

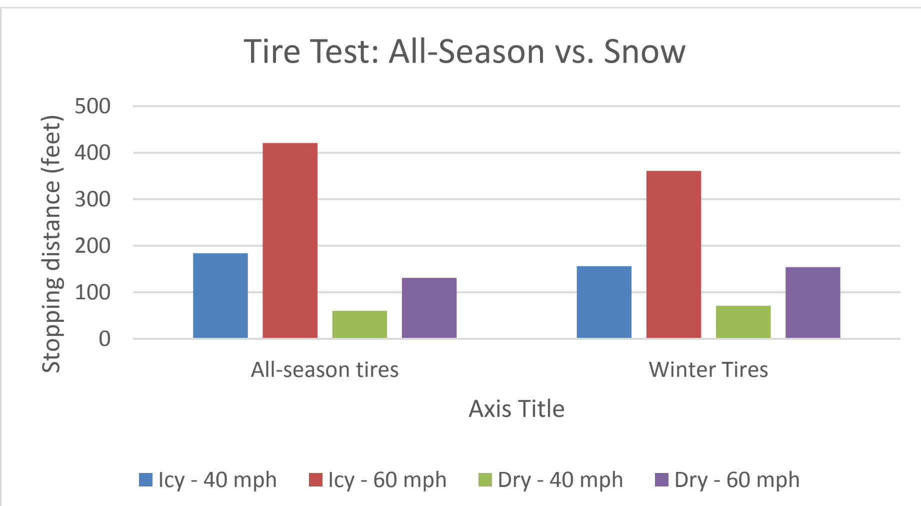
Studded tires were introduced in the United States in the 1960's. In the 1990's improvements were made to studded tires by Scandinavian countries to try to make them less damaging to pavement. These are the tires primarily used today. A study conducted by the Oregon Department of Transportation found that studded tires increased wear on roads by 315%. There is a shift toward lightweight studs, which reduce wear by approximately 50%.[199] Other problems with studded tires includes: Rutting which can cause tramlining which is hydroplaning on accumulated water in the ruts, excessive road spray, and premature damage to pavement markings.[200] 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. Japanese and Finnish studies concluded that restriction of studded tires reduced infrastructure costs, but that these savings were outweighed by the costs of injury crashes and increased road salting/sanding costs.[201]

Winter tires were developed 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 perform well in winter road conditions. Winter tires, sometimes referred to as snow 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.[202] 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 the pros and cons of different tires.

Tire	General Description	Allowed in Minnesota [203]	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
Chains	Chains attach to existing tires to add traction	X *	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.[204]



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,[205] 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.[206]

Snow is more easily removed than ice or compacted snow. If maintenance departments do not have to deal with a significant amount of compacted snow, they can reduce the amount of salt used to restore traction on roadways. Salting of roadways is most effective when done at a slow speed, 25 mph or less, to reduce scatter. Significant traffic and parked vehicles can decrease the ability of maintenance departments to clear snow and ice. Employers and transit officials can help to provide better conditions for public works to perform critical snow removal tasks 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.[207]

> 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 could 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.[208] [209] Many government agencies in Washington D.C., for example, use "telework" as an option during snow events that might otherwise significantly impact productivity.[210] Any company that wants to reduce its environmental impact could consider this approach.

Another way to take drivers off the road while maintenance workers are plowing is to improve mass transit options in the Twin Cities. This could 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 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.[211] Other regions with public transit options promote them during storm events in hopes of reducing the vehicle load on the roadways.[212] Research shows that 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.[213]

Discussion for Research Area 3

There are many avenues open to public participation in the effort to reduce road salt use. Of the five options addressed in Research Area 3, none requires new technology to institute change and none offer a solution by alone. A combination of approaches is necessary to reduce chemical usage.

Organizations such as MnDOT and MPCA are well-equipped to do the public outreach on the many concerns around winter driving safety and road salt. Local governments can take the same messages and distribute them to local audiences. More public education is needed to start to engage the citizenry in the important issue of winter driving and the use of road salt. There are metrics for public outreach being used on MnDOT projects and market research that could also be used to gauge the success of a salt usage /safe driving campaign.[214] One way to design such a campaign might be to couple the current MnDOT winter public awareness campaign with the Clear Roads toolkit on Winter Safety public awareness campaigns and MPCA's educational resources on road salt.

If we consider productivity in a larger context, we see that allowing for better initial snow removal can result 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. Working from home is also an option that should be discussed with larger businesses and school districts. The goal would be to reduce road parking or road traffic during key clean-up times. Fewer cars driving on the road causing compaction can improve mechanical removal.

Improved drivers training programs or educational events may 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 have 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 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 could have value.

RESEARCH AREA 3: RECOMMENDATIONS FOR IMPLEMENTATION

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 reduce road salt use. A media campaign with video outreach is recommended for reaching a large enough portion of the public to have the desired effect.

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

The campaign could include a collaborative effort to reduce the number of drivers on the road during snow removal operations. This could allow for more efficient winter maintenance, with less salt, and a faster return to better driving conditions.

- Work with mass transit authorities to increase capacity during winter events
- Work with employers to keep employees working from home during these times
- Educate the public on their options for winter mass transit, working from home or working variable shifts

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