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Ultra-Thin Bonded Wearing Course (UTBWC) Snow, Ice, and Wind Effects

Prepared by Braun Intertec Corporation

Ultra-Thin Bonded Wearing Course (UTBWC) pavement surfacing was introduced to Minnesota in 1999 under the brand name, “NovaChip”. It was developed as a preventative maintenance option to extend pavement life by placing a thin open/gap-graded hot mix asphalt (HMA) lift over a polymer-modified asphalt emulsion. The open/gap-graded aggregate also provides superior safety benefits under wet pavement conditions but safety benefits under snow and ice conditions recently have been in question.



Image downloaded from www.fhwa.dot.gov

The objective of this Transportation Research Synthesis (TRS) was to investigate UTBWC snow, ice, and wind effect through performing a literature review and conducting interviews and information solicitations regarding experience with ice and snow control on UTBWC pavements. In addition, the available field instrumentation and/or laboratory testing that can be utilized on UTBWC test sections to address findings from this TRS were introduced.

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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. This TRS does not represent the conclusions of either the authors or MnDOT.

Introduction

Several MnDOT UTBWC projects and their pavement performance attributes have been studied during the 2000s. However, winter maintenance practices and activities have not been identified as factors on these projects. Some MnDOT District Maintenance forces have recently observed that in-service UTBWC surfaces can increase time demands and/or the amount of deicing materials to achieve a clear and dry pavement surface. These observations are summarized as follows:

- There have been observations that UTBWC is causing ice build-up in the wheel paths on some sections.
- The rough (popcorn like) texture of UTBWC surfaces has a tendency to accumulate wind-blown snow.
- The rough texture and open-graded characteristics of UTBWC surfaces may require additional deicing material compared to conventional HMA surface, thus allowing accumulated snow to melt at the surface and form a bond with the underlying pavement.
- Once a bond of ice/frozen slush has formed achieving a bare pavement surface requires increased plow time and deicing chemicals necessary as compared to conventional mixes or sealcoated surfaces.
- Various deicing methods such as prewetting and early application have been tried to address this situation without finding a means to consistently address the phenomenon in all Districts of MnDOT.

UTBWC History

In 1986, Pierre Bense of the French Roads Administration (Laboratoire Centrale des Ponts et Chaussées, LCPC) proposed the NovaChip® process in LCPC's newsletter. Screg Routes (now a subsidiary of Colas, Inc.) partnered with the government lab in developing the process, with the first machinery feasibility tests in 1988 and numerous experimental projects placed in France in 1989. After a period of development, the process was fully commercialized under the name as Euroduit® in France in 1990, as SafePave® in the United Kingdom, and as NovaChip® in the rest of the world. In 1991, the NovaChip process was awarded the first place prize for Innovative Technology by the French Road Federation.

The Societe Internationale Routiere (SIR), a Screg subsidiary, commercializes the process internationally. By the end of 1992, 14 million square yards had been placed throughout the world, with projects in Sweden, Norway, Finland, the U.K. Ireland, Germany, Belgium, the Netherlands and the U.S. The first projects were placed in Australia in 1993 and Japan in 1996. By 1997, almost 40 million square yards had been placed around the world. A U.S. patent was obtained in 1990 for the process, including the materials, process, and equipment used for placement. The first projects in the U.S. were constructed under the supervision of Screg in Texas and Alabama in 1992, and New Jersey, New York, and Pennsylvania in 1993. Favorable technical reports and publications on these projects were written by the National Center for Asphalt Technology, the Texas Transportation Institute, the Garden State Parkway authority, and the Pennsylvania Department of Transportation. As of 2003, the first U.S. projects were still exhibiting excellent performance. Screg licensed the NovaChip process to Midland Asphalt Company in parts of New York, All States Asphalt in New England, and to Shore Slurry Seal, Inc. for the rest of the U.S. During this period, numerous projects (a total of 6 million square yards) were placed in New England, New York, Pennsylvania, New Jersey and Texas by the licensees and Shore's sublicensees Russell Standard Corporation and Bay Construction.

In 1998, Koch Materials Company acquired Shore's license for the NovaChip® process in the U.S. Koch Pavement Solutions® technologists adapted the process for U.S. streets, roads, and highways. Koch developed a special NovaBond™ emulsion to optimize construction and bonding performance, wrote new aggregate specifications to make the best use of materials available in the U.S. while maintaining system performance, and used performance-graded binders for the hot mix for local climates and longer durability. Koch also worked with

equipment manufacturers to continuously improve equipment performance, construction quality, and worker safety. With the help of numerous quality contractors throughout the U.S., Koch spread the process to more than 40 states to provide a long-lasting surface treatment to its customers. As of 2003, Koch had been responsible for more than 40 million square yards in the U.S.

In 2007, Koch Pavement Solutions® sold its pavement systems business including NovaChip® to SEM Materials® who continued to market the product in the United States. In 2009, the product was acquired by Road Science LLC®. Upon patent expiration, the NovaChip® brand name was often replaced by the category name of Ultra-Thin Bonded Wearing Course (UTBWC) which it is often referred to at the present time.

Literature Review

In recent years, pavement preservation treatments have been sought as an effective tool to restore pavement surface conditions and protect the underlying pavement, which can defer the need to rehabilitate or reconstruct the pavements. As a result, pavement preservation maintains structural integrity and extends the service life of the pavements which leads to great cost savings.

UTBWC is one of these pavement preservation treatments in which a relatively thick polymer-modified emulsion membrane is sprayed onto the existing pavement surface, then immediately covered with a thin course of open-graded hot mix asphalt (HMA) with a spray paver. In Minnesota, UTBWC has three gradations; Type A (4.75 mm [#4]), Type B (9.5 mm [3/8 in.]), and Type C (12.5 mm [1/2 in.]). Type B has been the most commonly used. A schematic of UTBWC is illustrated in Figure 1.

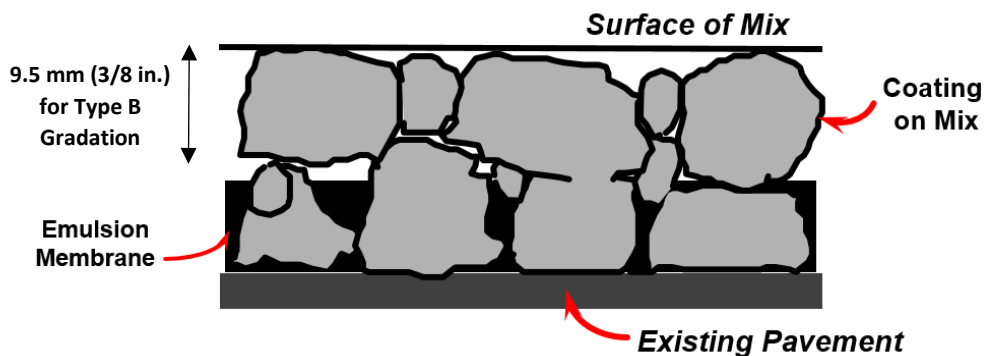


Figure 1. UTBWC schematic

The polymer modified membrane seals the existing pavement surface and provides high binder content at the interface of the existing pavement and the open-graded HMA in one pass. The open-graded HMA is made from high-quality aggregate to restore and retain friction. The open surface texture reduces noise and back spray as it allows water to flow through the surface laterally to the shoulder.

After UTBWC introduction to the USA in the 1990s, some projects were done in Alabama, Mississippi, and Texas. A review of UTBWC applications in Pennsylvania revealed that this method can significantly improve ride quality by comparing the International Roughness Index (IRI) before and after UTBWC application. Also, the study of five projects in Pennsylvania, Texas, and Alabama showed that UTBWC provides a surface with excellent macro texture qualities, good aggregate retention, and excellent bonding of the very thin surfacing to the underlying pavement [1].

Another nationwide research has shown that UTBWC reduced deterioration caused by weathering, oxidation, traffic, and provided good skid resistance, reduced rolling noise, hydroplaning, and back spray from the roadway

[2]. Ji et al. conducted a comprehensive monitoring and data analysis using the Pavement Condition Rating (PCR), Structural Number (SN), and IRI for in situ performance evaluation on UTBWC and compared it with control sections. Their study indicated that the overall performance of the UTBWC sections has been very good and it can be considered as a low-cost preventive maintenance treatment that retards deterioration of the pavement, maintains or improves the functional and structural condition of roadways, and extends pavement service life. It can also be utilized to correct rutting and improve smoothness [3].

UTBWC was first introduced to Minnesota in 1999 under the brand name, “NovaChip”. It was done on a US-169 section in a rural area of Minnesota. A study of the US-169 UTBWC was performed in 2007 and showed a promise in pavement surface rehabilitation, and in providing the maintenance engineering with a cost-effective alternative solution [2].

The overall advantages of UTBWC are as follows [4]:

- Slowing down deterioration caused by traffic, weathering, raveling, and oxidation
- Sealing small cracks
- Speedy application during construction
- Immediate opening to traffic
- Tire noise reduction
- High skid resistance
- Reducing splash, back spray, and hydroplaning
- Thinner lift equipment reduces applied weights and is appropriate for areas with overhead clearance, curb reveal, and drainage profiles limitations.

However, in some instances, UTBWC winter maintenance, especially in cold regions, has been a challenge as the in-service UTBWC surfaces have increased time demands and/or the amount of deicing materials to achieve a clear and dry pavement surface. This is mainly due to the open-graded rough (popcorn like) texture of UTBWC surfaces that have a tendency to accumulate ice/frozen slush as well as wind-blown snow. This surface characteristic is similar to Open Graded Friction Course (OGFC) pavements which have been used since 1950 in different parts of the United States to improve the surface frictional resistance of asphalt pavements. OGFC improves wet weather driving conditions by allowing the water to drain through its porous structure away from the roadway. The improved surface drainage reduces hydroplaning, reduces splash and spray behind vehicles, improves wet pavement friction, improves surface reflectivity, and reduces traffic noise.

Even though UTBWC is considerably thinner and less porous than OGFC, the open-graded surface is rough enough to accumulate ice and snow, so some of OGFC winter maintenance practices, which have been thoroughly studied, may also be applicable to UTBWC. Before discussing OGFC winter maintenance practices, it would be beneficial to summarize the typical winter maintenance methods.

Winter Maintenance Methods







Typical winter maintenance methods are as follows [5]:

- Anti-icing: the application of liquid chemicals to the roadway before a winter storm which prevents ice from bonding to the pavement.
- De-icing: the application of chemicals during or after a storm which improves the ability for plows to clear ice and snow from the road by loosening compacted snow and ice.
- Prewetting: the addition of brine or other liquids to granular materials to help jump-start the melting process.

- **Snow Plowing:** the removal of snow and ice from the roadway by mechanical means. Plowing is typically complemented with adding de-icing chemicals. For some conditions, it may be necessary to plow the roadway while adding sand or other abrasives.

A variety of winter maintenance materials are available for local agencies to use to manage snow and ice. Table 1 summarizes the commonly used materials, their uses, attributes and environmental impacts.

Table 1. Winter Maintenance Materials [5]

							
	Abrasives	Solid Rock Salt (NaCl)	Salt Brine	Magnesium Chloride (MgCl ₂)	Calcium Chloride (CaCl ₂)	Calcium Magnesium Acetate	Potassium Acetate
Usage	Mix with salt to provide traction to slippery roads.	Deicing or anti-icing	Prewetting and anti-icing	Deicing, prewetting, and anti-icing	Deicing	Anti-icing	Anti-icing
Typical Form	Sand (paved roads) or gravel (unpaved roads). Mixed with salt (20% to 33% salt).	Solid granular	Liquid	Liquid or solid	Liquid	Liquid	Liquid
Lowest Practical Melting Temperature	Lowest practical melting temperature	15° F	15° F	-10° F	-20° F	20° F	-15° F
Positive Attributes	<ul style="list-style-type: none"> - Provides temporary traction - More effective than chemicals at very low temperatures and for spot traction at targeted locations (hills, curves, bridges, intersections, shaded areas, windblown areas) - Useful alternative in environmental sensitive locations (no salt roads) 	<ul style="list-style-type: none"> - Excellent melting capacity - Lower cost compared to other chemicals - Clear roads of snow and ice 	<ul style="list-style-type: none"> - Prevents snow and ice from bonding to pavement (anti-icing) - Lower cost compared to other chemicals - Reduced granular scatter when used for prewetting - Low cost 	<ul style="list-style-type: none"> - Reduced amount of product used, reduced salt and abrasive use over rock salt - Better cold temperature performance than rock salt - Persists on the road surface, aiding in longer black ice prevention than sodium chloride 	<ul style="list-style-type: none"> - Better cold temperature performance than rock salt - Reduced amount of product used 	<ul style="list-style-type: none"> - Non-corrosive - Often used on bridge anti-icing systems 	
Negative Attributes	<ul style="list-style-type: none"> - Recovery from storms is slower than chemicals when used alone or in combination with only plowing - More plow passes and applications are required than if chemicals are used - Cannot achieve deicing - Requires clean up after winter season 	<ul style="list-style-type: none"> - Corrosion - Impacts on roadside and waterways - Pavement deterioration - Corrosion to vehicles and infrastructure 	<ul style="list-style-type: none"> - Corrosion - Impacts on roadside and waterways - Corrosion to vehicles and infrastructure 	<ul style="list-style-type: none"> - Pavement deterioration - Corrosion - Material cost is higher than rock salt - More corrosive than sodium chloride 	<ul style="list-style-type: none"> - Pavement deterioration - Corrosion - Material cost is higher than rock salt - More corrosive than sodium chloride 	<ul style="list-style-type: none"> - Expensive 	
Environmental Impacts	<ul style="list-style-type: none"> - Abrasives can enter the waterways and clog streams, clog drains, can impact water quality and aquatic species - Straight abrasive use does not pose corrosion issues, but abrasive-salt mixes can cause this issue 	<ul style="list-style-type: none"> - Entry into waterways - Impact to roadside soil, vegetation 	<ul style="list-style-type: none"> - Entry into waterways - Impact to roadside soil, vegetation 	<ul style="list-style-type: none"> - Entry into waterways - Impact to bridge infrastructure - Leaching/run-off from stockpiles 	<ul style="list-style-type: none"> - Entry into waterways - Impact to roadside - May mobilize heavy metals in soil releasing them into the water 	<ul style="list-style-type: none"> - Their decomposition consumes dissolved oxygen, resulting in lower oxygen levels in water. 	

OGFC Winter Maintenance

Many studies have shown that snow and ice accumulate differently on OGFC pavements than on traditional fine dense graded pavements [6-8]. OGFC porous structure does not insulate like a dense-graded structure, therefore, the OGFC surface is typically several degrees cooler than a traditional pavement surface. Also, it has shown that when the temperature of an OGFC drops below freezing, it will stay below freezing longer than regular HMA pavements thus results in delayed thawing [6].

There are a lot of debates on OGFC winter maintenance practices, as often times the behavior of salt and OGFC is not predictable and varies greatly from mix to mix [9]. OGFC has lower thermal conductivity, and therefore consumes more deicing materials. Another important note is that OGFC must be treated with deicers or anti-icers soon after plowing or slush will freeze in the voids of the pavement. Once frozen, the ice layer is much more difficult to remove.

OGFC winter maintenance methods are salting, sanding, de-icing, chemicals, and snow plowing. Salting needs to be done with care as small pieces can clog the pores. Sanding is not very practical either, as it may clog the voids and considerably reduce permeability. Snow plowing needs to be done carefully, as OGFC surface has less resistance to the blade of the snow plow. De-icing chemicals can be used, but at higher rates as the chemicals will drain through the pavement structure. Anti-icing can also be utilized on OGFC, but is very sensitive to timing as ice and snow will be compacted down into the voids structure in the case of late application. OGFC approximately require 25 to 50% more salt and about 30% more anti-icing materials [9]. New Jersey has used liquid magnesium chloride as an anti-icing agent effectively to prevent ice buildup in an OGFC [10]. In Minnesota, there have been cases where the using of magnesium chloride has been detrimental due to residual refreeze.

A study which was done on winter service of porous asphalt in some European countries including Germany, Switzerland, France, and the Netherlands was done in 2012 which suggested that with appropriate monitoring, managing, salting and snow removal, it is possible to service porous pavements in the winter periods. More frequent salting process and 30 to 50% more salt per year is needed for porous pavements than dense pavements. Also, icy surface and black ice can occur on porous pavements which may lead to lane closure or reduced speed [11].

Due to similarities in the surface texture of UTBWC and OGFC, the following notes can be made:

- Both OGFC and UTBWC exhibit the need for increased quantities of de-icing and anti-icing chemicals. UTBWC is expected to require less de-icing materials than OGFC due to tighter HMA structure.
- Even though the use of sand and small aggregates is not recommended for OGFC, it may be used for UTBWC as it is not a permeable layer.
- Snow and ice tend to accumulate quicker on both OGFC and UTBWC, because these mixes cool faster than conventional HMA.
- Snow and ice can form on the surface of both OGFC and UTBWC quicker, because de-icers may not stay on the pavement surface (more critical for OGFC)
- Even though preventive salting is not beneficial to OGFC (due to clogging), it may be used for UTBWC due to the tighter surface structure.
- Both applications must be treated with deicers or anti-icers frequently after plowing or slush will freeze in the voids of the pavement.
- In some instances, prewetting has shown to be beneficial in the snow and ice removal process for UTBWC.

- Living and manmade snow fencing can reduce problems associated with blowing snow over OGFC and UTBWC surfaces.

UTBWC Wind Effect

Blowing snow, which is the snow lifted from the surface by the wind, in addition to reduced visibility, can interact with UTBWC sections. Blowing snow can come from falling snow or snow that already accumulated on the ground but is picked up and blown about by strong winds. From the UTBWC survey, some interviewees reported issues with blowing snow sticking to the UTBWC surface in between winter events requiring more frequent winter maintenance efforts.

The UTBWC blowing snow issues reportedly occur in rural windy environments where the roadway runs in a direction perpendicular to the common wind direction. In these areas, the pretreatment method can handle the initial event to some extent, but often after the event, blowing snow sticks and accumulates on the surface over time requiring more frequent winter maintenance and in some cases safety issues have been observed. Therefore, it is generally recommended to use caution with UTBWC application in areas with the high potential of blowing snow. Several indices can be looked at to identify the areas with the high potential of blowing snow [12]. These indices are discussed below:

1) The mean snow accumulation season (SAS) snowfall

The first index is the mean snow accumulation season (SAS) snowfall. Using this index, the areas with high mean snowfall need to be avoided in UTBWC applications. Figure 2 shows the mean SAS snowfall for the State of Minnesota from 1971 to 2000. As Figure 2 suggests, the northeast region has the highest mean snowfall (70 inches). Also, the mean snowfall gradually decreases from 70 inches in the northwest area to about 20 inches in the southwest area of the State.

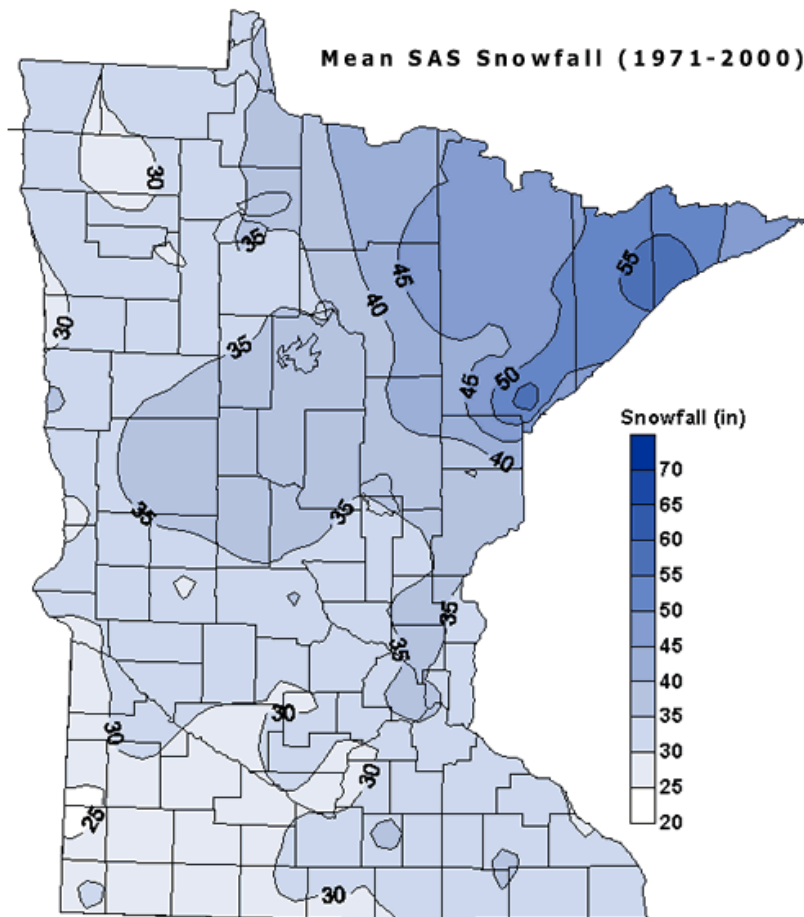


Figure 2. Mean SAS Snowfall (1971-2000) [12]

2) Snow Water Equivalent (SWE)

Blowing snow may be more affected by the density of snowfall rather than its depth. So the Snow Water Equivalent (SWE), which is a common snow density measure, may be a better indicator of blowing snow potential. SWE is the depth of water that would result if the snow mass melted completely, calculated as the ratio of the depth of water to the depth of snow. Higher ratios indicate wetter snow events (high liquid water content) while lower ratios represent drier snow events (low liquid water content). Figure 3 shows SWE for the state of Minnesota. As Figure 3 suggests, SWE is in the range of 0.07 to 0.11 in./in. in the State.

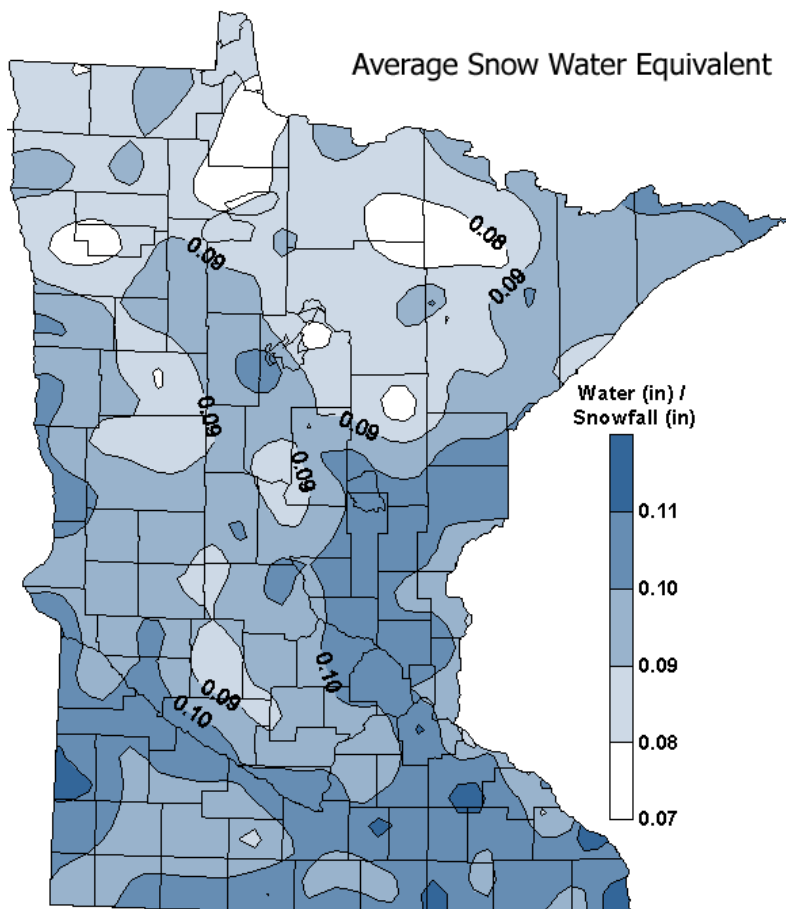


Figure 3. Average Snow Water Equivalent (SWE) for Minnesota [12]

3) The Relocation Coefficient

The relocation coefficient which is defined as the proportion of winter snowfall water equivalent that is relocated by the wind is another index to identify areas with high potential of blowing snow. The relocation coefficient seems to be a better indicator of blowing snow as it considers wind speed, topography, vegetation, and land use which all effect on the amount and severity of the blown snow, while the mean SAS snowfall or SWE are only based on the depth and density of snowfall, respectively.

The relocation coefficient for Minnesota is calculated as part of a research study on snowfall and snowdrift [12] and is shown in Figure 4. As Figure 4 shows, the relocation coefficient changes from 0.1 to 0.7 in Minnesota. It is interesting to note that the topography and land-use characteristics of western Minnesota are such that this area experiences a greater frequency of higher wind speeds, yielding a higher relocation coefficient. Conversely, south-central portions and sites in the forested north have comparatively lower coefficients. Averaging all locations, the relocation factor is 0.35.

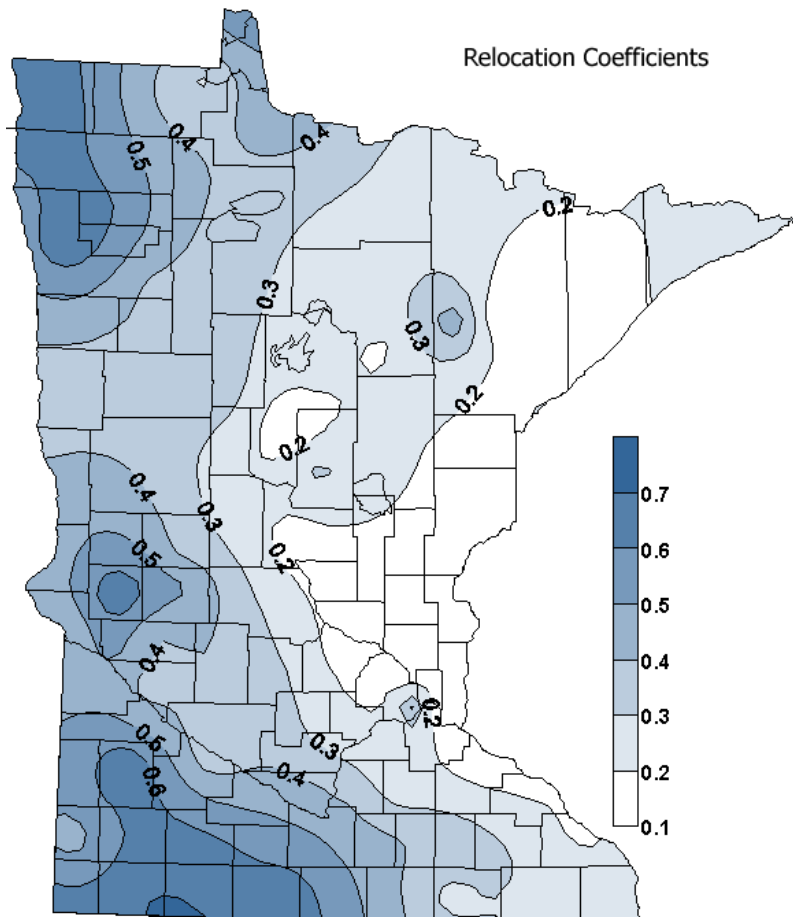


Figure 4. Relocation Coefficients for Minnesota [12]

According to the above discussions, the relocation coefficient is suggested to be used as an indicator for identifying the areas with high potential of blowing snow for UTBWC applications. As a general rule, areas with relocation coefficient of 0.5 or above are recommended to be dealt with caution for UTBWC applications.

In addition to the relocation coefficient, the wind direction that has the greatest snow transport is of importance in determining the areas with high potential of blowing snow. Wind directions of greatest snow transport were identified for several stations in Minnesota as a part of the snowfall and snowdrift study [12] which Figure 5 summarizes the results. Figure 6 presents degrees versus cardinal direction table. It is recommended to use caution in using UTBWC on the sections which are perpendicular to the wind direction of greatest snow transport in each area.

MnDOT UTBWC Sections

Many UTBWC sections were identified in Minnesota. Tables 2 summarizes UTBWC sections in Metro area. Figure 7 shows the approximate locations of these sections on the map.

Table 2. UTBWC Sections in Metro Area

Route	County	Direction	Year	R.P.		Length (miles)	Pavement Type	Remarks
				Begin	End			
I-35	Chisago	SB	2012	133+0.031	147+0.729	14.698	BOB	--
I-35	Chisago	NB	2012	132+0.936	147+0.729	14.793	BOB	2.5" MILL & 4" OL (2011)
I-35	Chisago	NB	2015	157+0.000	163+0.168	6.168	BOC	CONC (1987), CPR (2008)
I-35E	Ramsey	SB	2010	103+0.433	107+0.076	3.643	BOB	5" MILL & OL (2008)
I-35E	Ramsey	NB	2010	103+0.433	107+0.076	3.643	BOB	5" MILL & OL (2008)
I-35W	Hennepin/ Dakota	SB & NB	2009	2+0.845	9+0.113	6.268	BOC	--
I-394	Hennepin	WB	2016	0+0.000	6+0.248	6.248	BOB	--
I-394	Hennepin	EB	2016	0+0.000	6+0.313	6.313	BOB	--
I-494	Dakota	WB	2004	65+0.018	70+0.642	5.624	BOB	--
US 10	Anoka	WB	2013	223+0.985	224+0.804	0.819	BOB	2" MILL & UTBWC (2013)
US 10	Anoka	EB	2013	223+0.985	224+0.804	0.819	BOB	2" MILL & UTBWC (2013)
US 10	Anoka	WB	2013	224+0.804	229+0.560	4.756	BOB	2" MILL & UTBWC (2013)
US 10	Anoka	EB	2013	224+0.804	229+0.560	4.756	BOB	2" MILL & UTBWC (2013)
US 10	Anoka	WB	2016	229+0.560	230+0.802	1.242	BOB	1.5" MILL & 3" OL (2009)
US 10	Anoka	EB	2016	229+0.560	230+0.620	1.06	BOB	MICRO-MILL & UTBWC (2016)
US 10	Anoka	WB	2016	230+0.802	232+0.000	1.198	BOB	MICRO-MILL & UTBWC (2016)
US 10	Anoka	EB	2016	230+0.620	232+0.357	1.737	BOB	MICRO-MILL & UTBWC (2016)
US 52	Dakota	SB	2015	116+0.710	120+0.237	3.527	BOC	BOB (2010)

Route	County	Direction	Year	R.P.		Length (miles)	Pavement Type	Remarks
				Begin	End			
US 52	Dakota	NB	2015	116+0.709	120+0.237	3.528	BOC	BOC & UTBWC (2010)
TH 5	Washington	WB	2013	194-0.968	195+0.859	1.827	BOC	CRACK/SEAT & 4" OL (2004)
TH 5	Washington	EB	2013	194-0.968	195+0.859	1.827	BOC	CRACK/SEAT & 4" OL (2004)
TH 5	Washington	EB & WB	2013	195+0.859	196+0.086	0.227	BOB	ROUNDBABOUT (2010)
TH 5	Washington	EB & WB	2013	196+0.086	199+0.300	3.214	BOC	MICRO-MILL & UTBWC (2013)
TH 5	Washington	SB & NB	2013	199+0.300	200+0.480	1.18	BOB	RECON (2009)
TH 5	Washington	NB	2015	200+0.480	201+0.318	0.838	BOB	RECON (1997)
TH 5	Washington	SB	2015	200+0.480	201+0.318	0.838	BOB	RECON (1997)
TH 36	Ramsey	EB & WB	2016	2+0.000	2+0.734	0.734	BOB	--
TH 36	Ramsey	EB	2012	8+0.481	10+0.350	1.869	BOB	--
TH 36	Ramsey	WB	2012	8+0.481	10+0.350	1.869	BOB	--
TH 47	Anoka	SB/EB	2013	34+0.220	34+0.952	0.732	BOB	BIT (1993), OL (2005)
TH 47	Anoka	WB/NB	2013	34+0.220	34+0.952	0.732	BOB	BIT (1993), OL (2005)
TH 47	Anoka	SB & NB	2014	24+0.140	34+0.220	10.08	BOB	5/8" UTBWC (2013)
TH 55	Dakota	EB	2015	217+0.947	220+0.313	2.366	BOB	--
TH 55	Dakota	WB	2015	217+0.947	220+0.313	2.366	BOB	--
TH 55	Dakota	EB & WB	2015	217+0.442	217+0.947	0.505	BOB	MILL & OL W (2004)
TH 55	Dakota	EB & WB	2015	211+0.146	217+0.442	6.296	BOC	BOC (2009)
TH 55	Dakota	EB	2015	211-0.164	211+0.146	0.31	BOC	BOC W (2010)
TH 55	Dakota	WB	2015	211-0.164	211+0.146	0.31	BOC	BOC W (2010)
TH 55	Hennepin	WB	2005	184+0.628	186+0.452	1.824	BOB	--

*Description of the abbreviations:

WB: Westbound, **EB:** Eastbound, **NB:** Northbound, **SB:** Southbound, **BOB:** Bituminous pavement, **BOC:** Bituminous over concrete pavement, **OL:** Overlay, **CONC:** Portland Cement Concrete Pavement, **CPR:** Concrete Pavement Restoration **RECON:** Reconstruction, **W:** Widening

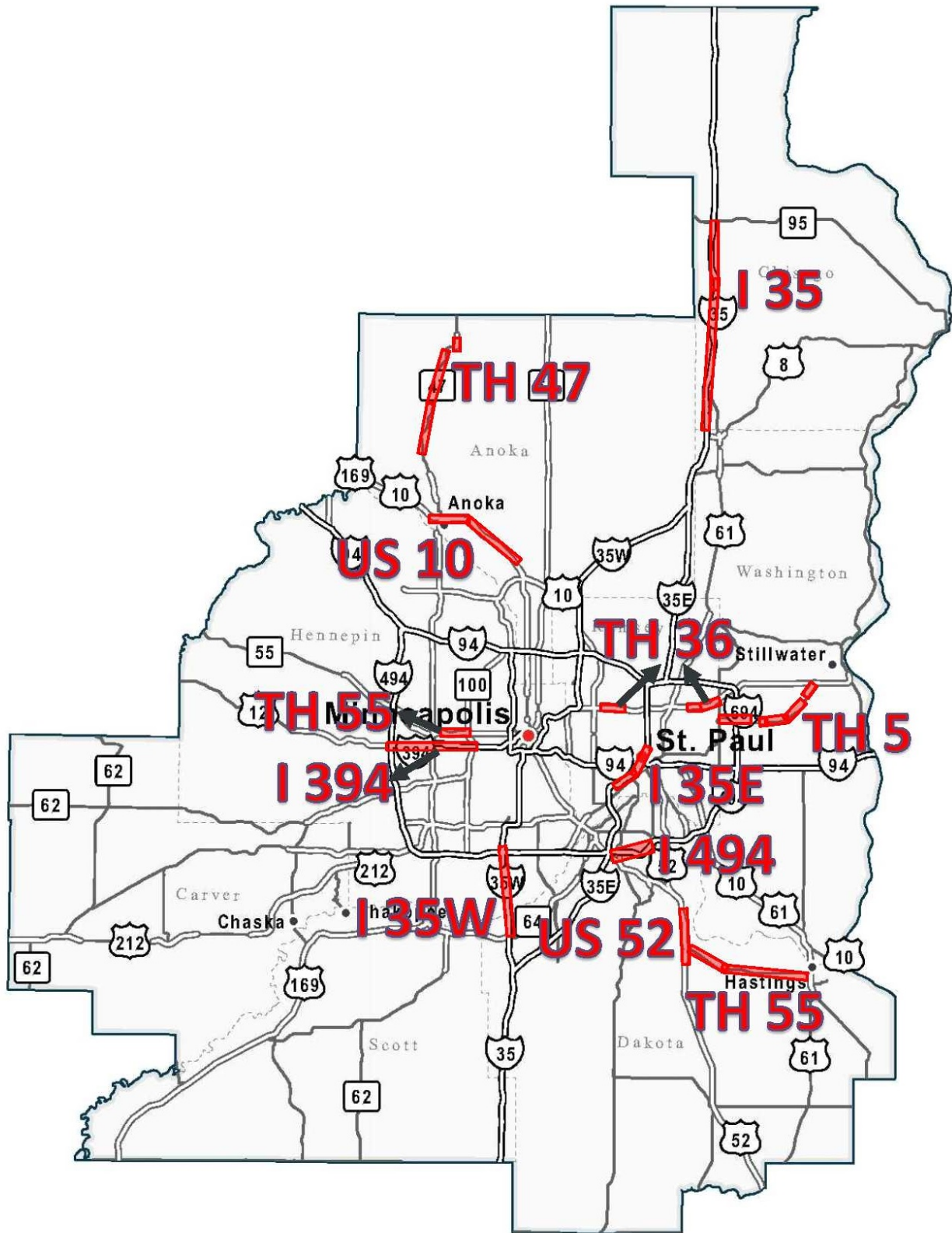


Figure 7. UTBWC Section in Metro Area

Table 3 summarizes non-Metro UTBWC sections in Minnesota. Figure 8 shows the approximate locations of these sections on the map.

Table 3. UTBWC Sections in Non-Metro Areas

Route	County	Direction	Year	R.P.		Length (miles)	Pavement Type	Remarks
				Begin	End			
I-94	Douglas	WB	2012	102+0.688	109+0.001	6.313	BOC	--
US 10	Becker	EB	2012	47+0.263	56+0.144	8.881	BOB	--
US 10	Morrison	WB/SB	2014	116+0.275	131+0.267	14.992	BOB	--
US 10	Morrison	EB/NB	2014	116+0.275	131+0.130	14.992	BOB	AGG SEAL (2009)
US 10	Benton	WB	2014	177+0.341	178+0.583	1.242	BOC	3/4" MILL & UTBWC (2014)
US 10	Benton	EB	2014	177+0.341	178+0.583	1.242	BOC	3/4" MILL & UTBWC (2014)
US 12	Meeker	SB & NB	2013	100+0.541	100+0.777	0.236	BOC	CONC W (1973)
US 169	Mille Lacs	NB	2009	180+0.845	185+0.300	4.455	BOB	--
TH 15	Watonwan	SB	2013	32+0.392	33+0.699	1.307	BOC	CRACK/SEAT W & 3" OL (2012)
TH 15	Watonwan	SB	2013	36+0.547	38+0.584	2.037	BOC	CRACK/SEAT W & 3" OL (2012)
TH 15	Watonwan	NB	2013	32+0.392	38+0.584	6.192	BOC	CRACK/SEAT W & 3" OL (2012)
TH 15	Sibley/ Nicollet	SB & NB	2013	60+0.077	76+0.570	16.493	BOC	BOC W (2012), UTBWC & CHIPSL (2013)
TH 15	McLeod	SB & NB	2015	100+0.989	101+0.528	0.539	BOC	--
TH 169	Sherburne	SB & NB	2012	158+0.177	168+0.982	10.805	BOC	--
TH 22	Meeker	SB & NB	2013	142+0.965	143+0.080	0.115	BOC	CONC W (1973)
TH 23	Benton	EB	2014	207+0.378	208+0.919	1.541	BOC	3/4" MILL & UTBWC (2014)
TH 23	Benton	WB	2013	207+0.378	208+0.919	1.541	BOC	3/4" MILL & UTBWC (2014)

*Description of the abbreviations:

WB: Westbound, **EB:** Eastbound, **NB:** Northbound, **SB:** Southbound, **BOB:** Bituminous pavement, **BOC:** Bituminous over concrete pavement, **OL:** Overlay, **CONC:** Portland Cement Concrete Pavement, **CPR:** Concrete Pavement Restoration **RECON:** Reconstruction, **W:** Widening

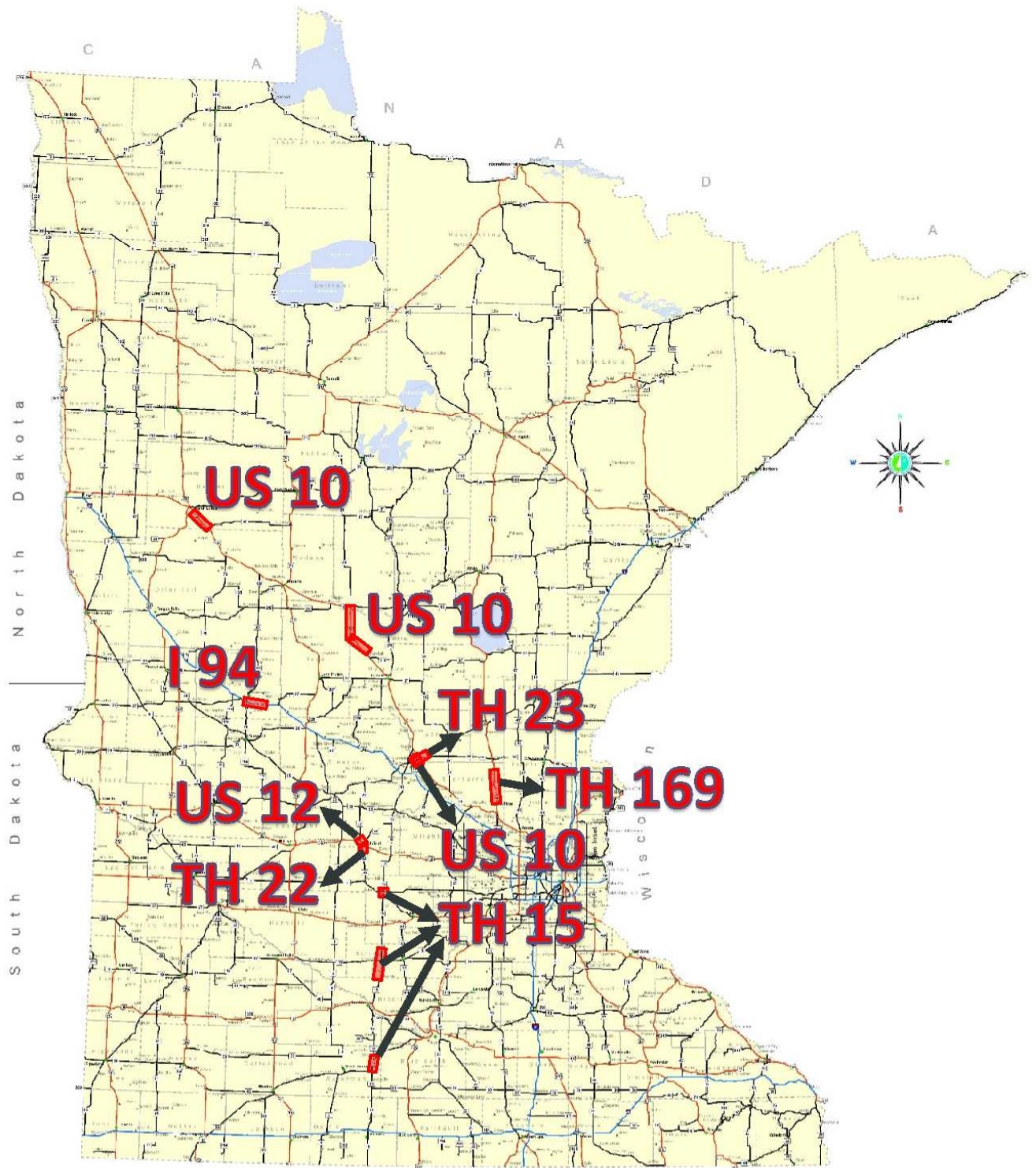


Figure 8. UTBWC Section in Non-Metro Areas

US 169

In order to better understand the performance of UTBWC, the latest performance of US 169 project which was done in 1999 and 2000 near Princeton, MN is evaluated in this section. Two projects were performed on US 169: the first project involved paving lanes between reference post 183 and 185.3 in September 1999 and the second project extended this section from RP 180.845 to RP 183 in August 2000. The section from RP 185.3 to RP 187 was unmodified and has been used as a control section.

An evaluation of this project is previously done by MnDOT in 2007 [2] which indicated an excellent performance of UTBWC after 7 years of service. The project was also performing well in regards to ride quality. The average ride quality index (RQI) on the UTBWC overlay section was 3.2 and the MnDOT Pavement Management System was predicting that the UTBWC overlay section will not reach an RQI of 2.5 for more than 5 years. However, the control section had deteriorated very quickly despite annual maintenance. The ride quality index was 1.9 at the time of rating in 2006, which was well below the rehabilitation trigger value of 2.5. An RQI value of 2.5 is often regarded as the point at which rehabilitation is necessary. As a result, major rehabilitation was recommended to be performed on this section.

Figure 9 shows the most recent RQI from the UTBWC sections and the control section. As this figure shows, the UTBWC sections continued to show excellent performance compared to the control section.

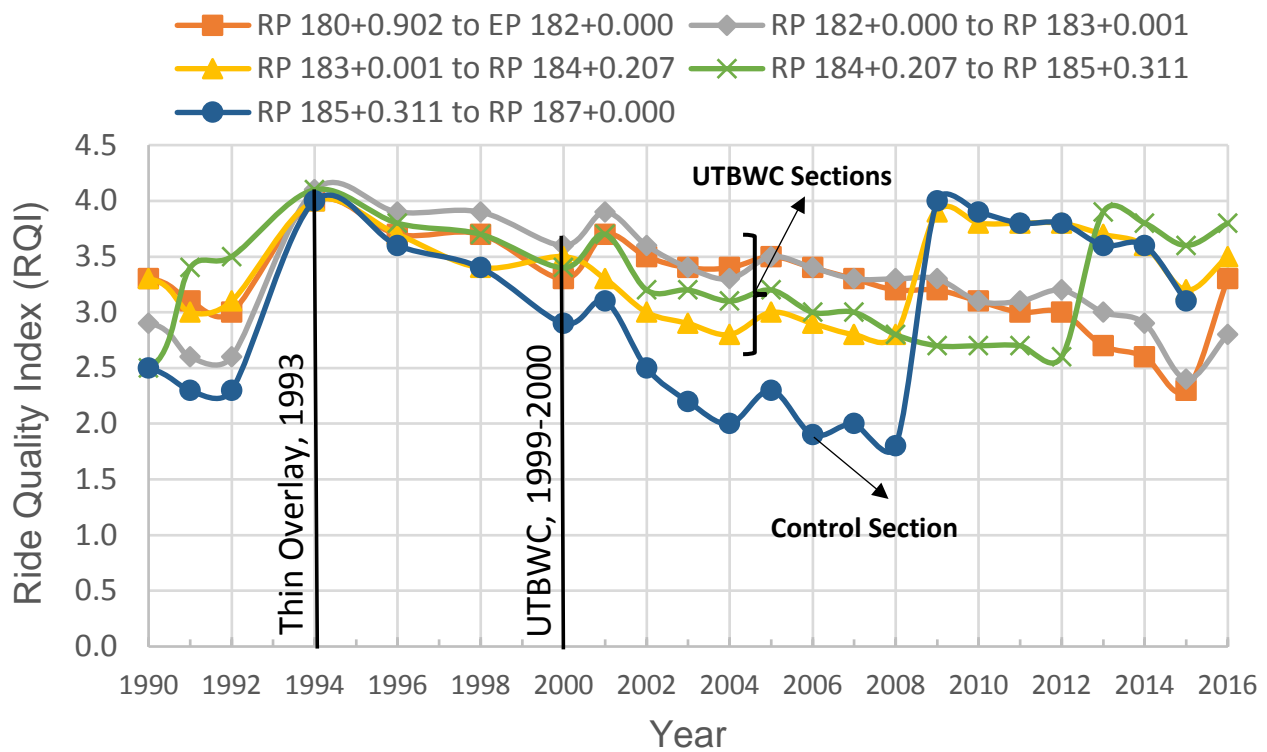


Figure 9. Ride Quality Index (RQI) Performance for UTBWC and Control Sections.

Figure 10 shows the RQI graph for each section along with the maintenance activities that have been performed on these sections. As this graph shows, among the four UTBWC sections, two UTBWC sections from RP 180+0.902 to RP 183+0.001 continued to show excellent performance with only maintenance patching in 2012 and 2016. The UTBWC section from RP 183+0.001 to RP 184+0.207 was milled and overlaid in 2009 (after 10 years of service) and the UTBWC section from RP 184+0.207 to 185+0.301 was milled and overlaid in 2013 (after 14 years of service). The control section (RP 185+0.311 to 187+0.000) was milled and overlaid in 2009 while its RQI value was below 2.5 since 2003. Maintenance patching was also performed on the control section in 2013 and 2016. These results indicate that the reduction in summer maintenance costs far exceed increased winter maintenance costs related to snow and ice control.

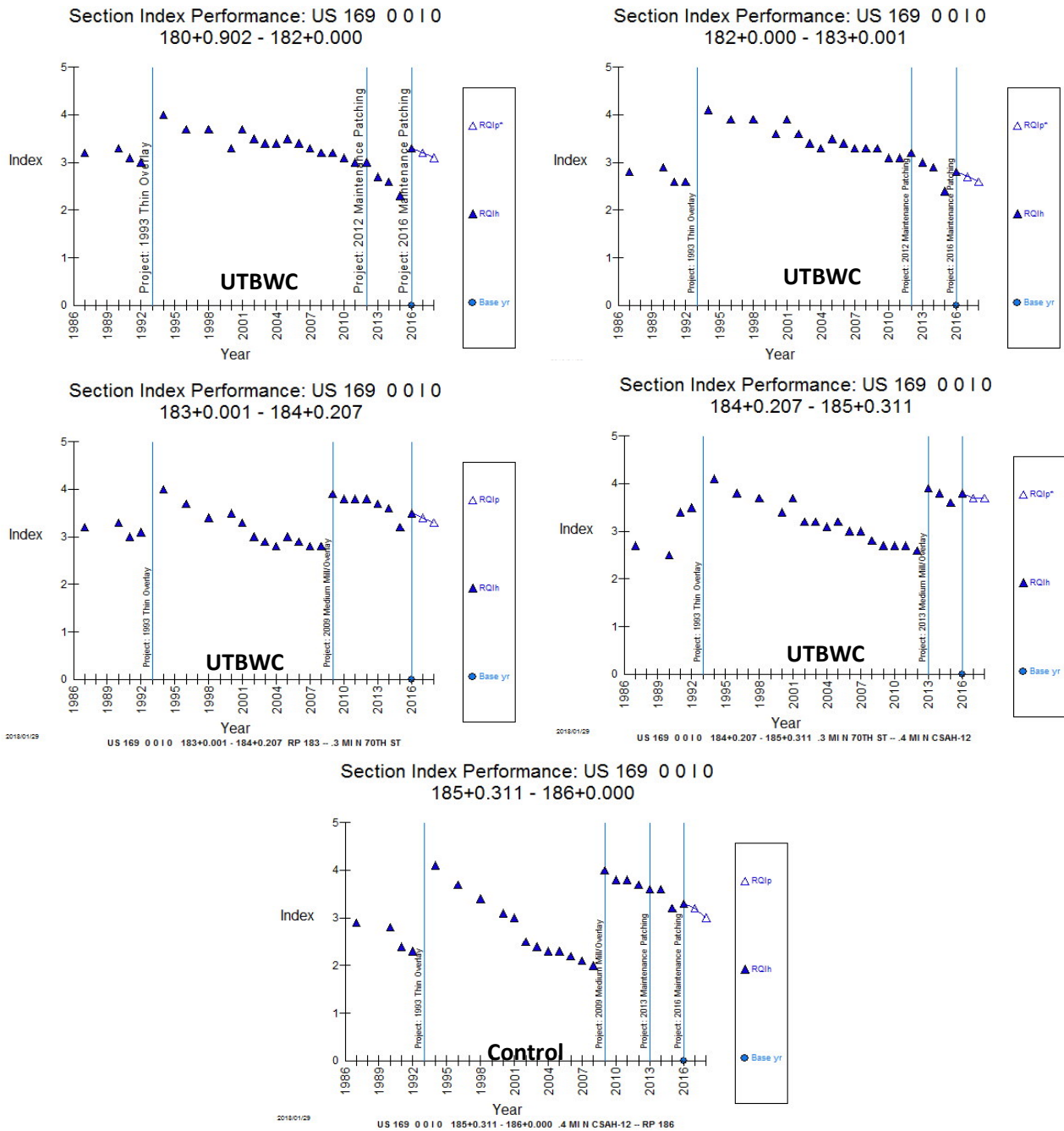


Figure 10. Ride Quality Index (RQI) Performance Plots for All the Sections.

Survey

As part of this research project, Braun Intertec conducted formal interviews and casual information solicitations regarding experience with ice and snow control on UTBWC pavements. Those formally interviewed to provided information are listed below.

- Minnesota Department of Transportation (MnDOT)
 - Perry Collins, District 1
 - Dan Meinen, District 3
 - Dan Whebbe, District 3
 - Darin Nelson, District 3
 - Jamie Hukriede, District 3
 - Rick Frauendienst, District 3
 - Joe Stegmaier, District 4
 - Brad Estochoen, Metro
 - Brian Dodds, Metro
 - Chris Kufner, Metro
 - Curt Turgeon, Metro
 - Dave Janisch, Metro
 - Dave VanDeusen, Metro
 - Gerald Geib, Metro
 - John Garrity, Metro
 - Kevin Kosobud, Metro
 - Paul Nolan, Metro
 - Steve Lund, Metro
 - Sue Lodahl, Metro
 - Tim Clyne, Metro
 - Tom Wood, Metro (now WSB & Associates, Inc.)
 - Mark Panek, District 6
 - Cam Ihrke, District 6
 - Don Nosbisch, District 6
 - Ron Heim, District 6
 - Todd Stevens, District 6
 - Tom Meath, District 6
 - Tom Zimmerman, District 7
 - Cody Brand, District 8
 - Dave Johnston, District 8

- Dakota County
 - Mike Greten
 - Todd Howard

- Wisconsin Department of Transportation (WisDOT)
 - Barry Paye
 - Mike Sproul
 - Ned Grady

- Vermont Agency of Transportation
 - Bob Childs

- Maine Department of Transportation (MaineDOT)
 - Dale Peabody
 - Scott Bickford
- South Dakota Department of Transportation (SDOT)
 - Rick Rowen
 - Joe Feller
- Colorado Department of Transportation (CDOT)
 - Richard Zamora
- Texas Department of Transportation (TxDOT)
 - Robert Lee

The key information and common elements from interviews are provided below.

- UTBWC snow and ice issues reported ranged from no issues to a few significant events where the road was shut down for safety until further maintenance could be performed.
- UTBWC pavements were not constructed in all MnDOT Districts. The interviews conducted focused on those Districts that constructed UTBWC pavement sections.
- Information was also gathered from several other states and a County. Some of this input was related to open-graded mixtures they have used instead of UTBWC.
- MnDOT uses the Koch gradation for UTBWC. This gradation has three types: Type A, Type B, and Type C. The most, if not all, of the UTBWC constructed in Minnesota prior to 2016 has used Koch Type B gradation which is very similar to South Dakota DOT Class S (Type 2) gradation. While SDDOT has used Class S mixtures on several hundred miles across the state, their staff were not aware of any winter maintenance issues on those sections.
- Snow and ice issues were commonly defined as snow and ice buildup on the UTBWC surface requiring greater maintenance effort and ice control materials to address an event. In some cases, there were also issues with blowing snow sticking to the UTBWC surface in between winter events requiring more frequent winter maintenance efforts. These non-event blowing snow issues typically occurred in rural windy environments where the roadway ran in a direction perpendicular to the common wind direction.
- Additional maintenance cost estimates for UTBWC pavements ranged from none to 4 to 5 times the cost of maintaining adjacent highways with traditional fine dense graded mixture surfaces. Those that reported no additional snow and ice control costs typically utilized a pretreatment of deicing chemical prior to winter events as a standard maintenance procedure.
- Virtually all reported that they were very happy with the performance of the UTBWC and that any extra winter snow and ice control costs are more than offset by extended life and reduced pavement maintenance costs such as crack sealing and pothole patching. A primary desire of some maintenance personnel is to better understand how to best address these pavements for snow and ice control and to better understand the cost differential maintaining UTBWC pavements compared to traditional fine dense graded surfaced roadways.

- Pretreatment is more frequently used in higher traffic metro roadways but has been tried on UTBWC pavements in rural areas. It was reported that in windblown rural UTBWC pavements the pretreatment better handled the initial event, but often after the event, blowing snow sticks and accumulates on the surface over time requiring more frequent winter maintenance and in some cases safety issues.
- Some maintenance personnel reported they have addressed UTBWC snow and ice control by increasing the salt application rate on the open-graded textured surface initially. They reported the textured surface held the additional application rate which in some cases provided benefits in controlling ice buildup.
- Rural areas where blowing snow presents a problem reported the snow sticks to the textured surface more during warm sunny days and less during cold temperatures around 0-5 degrees F.
- One District elected to apply a chip seal over the UTBWC surface to reduce surface texture as a means to address the snow and ice control issue.
- Moisture at the surface seems to freeze faster on UTBWC compared to fine dense graded mixtures. This was an observation on roadways that did not receive pretreatment before a snow and ice event.
- Multiple reported that their snow and ice control issues were greater during the first couple years after placement and then tapered off from that point on. Some attributed that to the open voids filling up with sand during that initial timeframe.
- Other maintenance issues reported were – new plow cutting edges grabbing the surface and that if snow and ice get compacted under traffic there is a stronger bond to the surface which makes it even more difficult to remove.
- NovaChip had 3 different gradations with smaller 3/8", 1/2" and 5/8" top size aggregate with the coarser aggregate being more open. Most of the projects placed used the intermediate gradation. Novachip was also designed as a gap-graded mix (coarse and fine aggregate with little intermediate size aggregates). This design provides a porous surface so rain will quickly drain away reducing surface water and spray enhancing summer roadway safety. Enhanced safety during rain events is offset by extra maintenance required to assure safety during snow and ice events.
- It was reported that many of the Novachip projects had difficulty attaining the gap-graded openness specified. There may be a connection between the openness of the UTBWC mixtures and the increased snow and ice issues. The more open void structure creating conditions for snow and ice to grab and bond to the pavement. This could be a factor in the widespread observations related to snow and ice control.
- The amount of wicking of the underlying emulsion membrane into the UTBWC mix was used as an indicator for the gap grading or openness of the mix. The more open the mix the more emulsion wicks up into the mix creating the bond.
- UTBWC with greater film thickness provides more solar flux allowing for snow and ice to melt faster in sunny conditions. This may also be a contributor to blowing snow sticking to the surface at some times as blowing snow seems to stick better to a wet surface.

- Shaded areas and areas of superelevation were characteristics of road sections that have been shut down during some snow events for safety.
- It was reported that these mixes are “the first to freeze and the last to thaw” and are therefore problematic during rapidly advancing freeze conditions and especially problematic during rapid freeze-thaw cycles (nightly freeze with daily thaw).
- Most issues reported were during deep freeze events when deicing chemicals had little or no effect because of very cold conditions.
- Since UTBWC is designed to allow the water to drain laterally, the designers should either continue the mix across the shoulder or make sure it is placed above the elevation of the shoulder leaving a 3/4 inch drop off so water can properly drain.
- While strategic maintenance can reduce UTBWC snow and ice problems, there is no strategy to make these issues completely go away.
- More training with the Snow and ice control handbook and guide for operators could improve snow and ice control on all pavements. Additional research may be needed to include specialty pavements and guidance for operators in an updated handbook.

Phase II Studies

Currently, it is understood that UTBWC pavement occasionally experiences negative pavement performance attributes in cold weather, requiring additional maintenance (beyond typical treatments) to remedy. Observations indicate a phenomenon of ice build-up, potentially due to the accumulation of wind-blown snow, melting and freezing of that wind-blown snow, and bonding of that frozen ice/slush to the underlying pavement. To maintain safe driving conditions and keep the road surface bare and dry, increased plow time and deicing/anti-icing chemicals (relative to non-UTBWC surfaces) are required; however, the various deicing/anti-icing methods currently employed have not yet provided consistent solutions. In addition, the added costs to address these winter issues have not been quantified and compared within various MnDOT Districts.

Literature review and interviews with knowledgeable parties (discussed in previous sections) yielded commonalities that illustrate general conditions and patterns of the cold weather UTBWC phenomenon, and somewhat effective maintenance methods to prevent and/or mitigate the issue. However, the exact science and nature of the phenomenon, as well as the optimal maintenance program to prevent and/or mitigate it, still remains unknown.

Through project development, the TAP has identified that additional data and cost collection (without any field instrumentation and/or laboratory testing) would be beneficial to the research which will be done under Phase 2 of this project. In Phase 2, field information related to the winter maintenance efforts and costs on UTBWC will be gathered and compared to the standard HMA pavements. Also, the bonded dense graded test sections which were constructed in 2017 will be supplemented with additional test sections in summer of 2018 both of which offer considerable opportunity to gather desired information for this phase of the project.

In addition, data from the following sections of TH 15 will be gathered and evaluated:

- UTBWC Novachip gradation
- UTBWC covered with chipseal

- Fine dense graded (Superpave standard specification) bonded wearing course which was constructed in summer 2017 and will be constructed in summer 2018.

Phase III Studies

In order to better understand the science and nature of the cold weather UTWBC phenomenon, and develop optimal prevention/mitigation methods, it is recommended to study (1) potentially related pavement and weather conditions that could cause and foster the cold weather UTWBC phenomenon, and (2) the effects of maintenance activities on the cold weather UTWBC phenomenon.

These can be done through field instrumentation to monitor the actual conditions. Following (and/or during) the monitoring period, it is recommended to remove UTWBC pavement sections for laboratory testing and analyses to further understand the interrelationships between weather, pavement, and maintenance.

Following (and/or during) the field instrumentation monitoring period, it is recommended that the information collected by the field instrumentation (as well as the information resulting from laboratory testing and analyses) be utilized to complete the following activities and goals:

- Investigate collected data from field instrumentation for patterns between:
 - all other pavement and weather conditions concurrently monitored.
 - maintenance activities and observations, including driving conditions.
 - physical findings from the laboratory analyses.
- Develop parameters for the UTWBC phenomenon in cold weather
 - to assist future decision making regarding UTWBC pavement applications.
 - to assist maintenance activities.
- Develop an optimal maintenance program to prevent and/or address the cold weather UTWBC phenomenon.
 - utilizing numerical thresholds to trigger/regulate maintenance activities.
 - utilizing human-recognized weather and/or pavement conditions (i.e. sunny, windy, slippery, etc.) to trigger/regulate maintenance activities.

UTWBC Field Instrumentation

Field instrumentation – sensors and systems installed on a site or structure to automatically monitor conditions over time – should be implemented in order to study and monitor UTWBC and weather conditions and the effects of maintenance activities on the cold weather UTWBC phenomenon. Specifically, instrumentation should monitor in-service test sections of UTWBC pavement, local weather conditions, and the effects of local maintenance activities. Therefore, beyond automated field instrumentation, it is imperative that all local maintenance efforts and observations of the UTWBC pavements be carefully detailed and logged during the monitoring period.

In order to complete the activities and achieve the potential goals noted above, field instrumentation needs to be selected and implemented such that the data collected is holistic, complete, and accurate. To accomplish the collection of holistic, complete, and accurate data, a variety of and redundant level of field instrumentation would be utilized. Based on research and prior experience, it is recommended that the following field instrumentation program be implemented for each stretch of UTWBC pavement designated for monitoring:

- Monitor one or more UTWBC pavement test sections prone to the phenomenon, and one nearby UTWBC pavement test section with no recorded/anticipated issue. *At each UTWBC pavement test section:*
 - **Install two embedded pavement sensors:** one sensor in the wheel path, one sensor not in the wheel path. The embedded pavement sensors monitor the following conditions:
 - Surface temperature
 - Subsurface temperature (if feasible)
 - Surface condition (presence of water, snow, ice, etc.)
 - Ice/Water depth
 - Friction
 - Salinity
 - Freeze temperature
 - **Deploy one non-contact pavement sensor, or non-contact pavement sensor system:** The non-contact pavement sensors monitor the following conditions:
 - Surface temperature
 - Surface condition (presence of water, snow, ice, etc.)
 - Ice/Water depth
 - Freeze temperature
 - Friction or Grip
 - **Deploy one field camera:** The outdoor observation and surveillance field camera monitors the following conditions:
 - Visible weather conditions
 - Visible road conditions
 - **Deploy one weather station:** The weather station monitors the following conditions:
 - Air temperature
 - Relative humidity
 - Wind speed
 - Wind direction
 - Snow depth
 - Precipitation
 - Barometer
 - Solar Radiation
 - Present Weather (fog, mist, hail, etc.)

*Depending on the proximity of test sections, a reduced amount of weather stations, or weather stations with reduced features, may be satisfactory.
- Along the entire stretch of UTWBC pavement:
 - Log all maintenance activities and details, and other observations including:
 - visible weather conditions (sunny, misty, cloudy, etc.), driving conditions, and special observations (include separate focus at weather station)
 - Log 3-day and 24-hour weather forecasts based off of the closest public weather station

Field Instrumentation Selection

Current field instrumentation technologies are capable of monitoring all of the aforementioned weather, surveillance, and roadway conditions. However, the variety of field instrumentation manufacturers, sensors, and systems, variety of implementation considerations, and ongoing advancement in field instrumentation technologies do not single out one viable option. Regarding the sensors or systems needed, the research was based on the manufacturer and product’s accuracy, reliability, general cost, power draw, ease of installation, relative limitations, and maintenance. The most preferred option(s) within two types of field instrumentation and monitoring systems are discussed below: All-in-one and mix-and-match. For many reasons, in general, it is recommended to select the preferred option of the all-in-one field instrumentation: Vaisala RWS200 Road Weather Station.

All-in-one

There are several instrumentation manufacturers that offer a variety of sensors with a unified monitoring system (“all-in-one”), although not one manufactures every single sensor needed for UTBWC weather and pavement monitoring. Based off of extensive research and conversations with knowledgeable parties, a preferred manufacturer provides a relatively superior and seamless all-in-one system that monitors all of the aforementioned weather and pavement conditions. If selecting an all-in-one solution for field instrumentation, it is recommended to use Vaisala’s RWS200 Road Weather Stations and applicable sensors as shown in Figure 11.

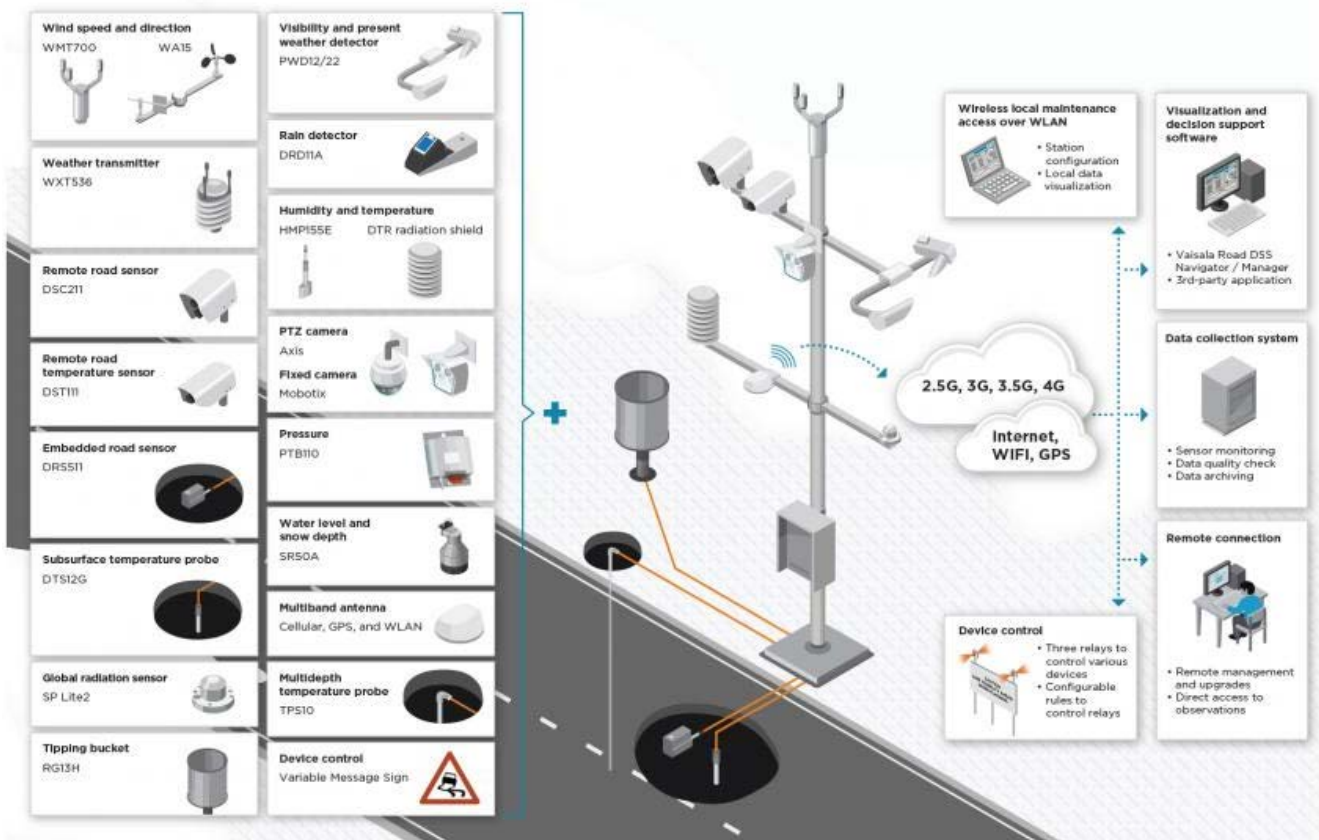


Figure 11. Vaisala RWS200 Road Weather Station

Key benefits of the Vaisala RWS200 all-in-one system are:

- Individual Vaisala sensors are able to measure and monitor all required pavement, visual, and weather conditions; also, the Vaisala sensors have a high level of accuracy and proven reliability.
- MnDOT's Road Weather Information System (RWIS) already utilizes Vaisala technology, thus the integration of each Vaisala RWS200 tower following the monitoring period into the RWIS is readily available. Alternatively, the Vaisala RWS200 (or system components) could be relocated elsewhere.
- One physical tower manages all mounted sensors, datalogger, and antennas, allowing for easier installation and maintenance.
- RWS200 readily connects to all required sensors, servers for remote access data collection, and Vaisala for software updates to handle technological improvements or new sensors not yet available.
- It is easier to add sensors to the RWS200 for a more enhanced setup or remove sensors for a more abbreviated setup.

Key disadvantages to the Vaisala RWS200 all-in-one system are:

- Increased power draw requires system power from the grid, solar panel not customarily available for a larger setup (solar panel may accommodate a more abbreviated setup).
- Relatively expensive.
- The system is particular, and not compatible with many other sensors from other manufacturers.

In order to monitor the aforementioned weather, surveillance, and pavement conditions with an all-in-one solution, the following components should be selected for implementation. For each component, there is a link to its datasheet for quick reference of specifications and details provided by the manufacturer:

System

- RWS200 – Road Weather Station
 - [RWS200 Datasheet](#)
 - [DMU703 Datasheet](#)
 - [PMU701 Datasheet](#)

Weather:

- WXT536 – Weather Transmitter
 - [WXT536 Datasheet](#)
 - Rain Gauge, Wind Speed, Wind Direction, Pressure, Air Temperature, Relative Humidity
- SR50AT – Snow Gauge
 - [SR50AT Datasheet](#)
- SP Lite 2 – Solar Radiation
 - [SP Lite 2 Datasheet](#)
- PWD22 – Present Weather Detection
 - [PWD22 Datasheet](#)

Visual:

- Mobotix M16 – Fixed Camera
 - [Mobotix M16 Datasheet](#)

Pavement:



- DRS511 – Road Sensor
 - [DRS511 Datasheet](#)
 - Surface Temperature, Chemical, Water Amount, Road Condition, Ground Temperature, Freeze Point, Hoar Frost
- DSC211 – Remote Road Surface State Sensor
 - [DSC211 Datasheet](#)
 - Layer Thickness, Level of Grip, Reported Surface States, Visibility
- DST111 – Remote Surface Temperature Sensor
 - [DST111 Datasheet](#)
 - Surface Temperature

Mix-and-Match

There is a wide variety of manufacturers and field instrumentation sensors that monitor weather, surveillance, and pavement conditions. Some manufacturers make a couple sensors very well, while others make a lot, perhaps not so well. Unfortunately, there are not many manufacturers that boast a whole suite of sensors and systems spanning both weather and pavement conditions. Since Vaisala is one manufacturer who does this well, they offer a stark advantage with their all-in-one type of system and approach. However, this does not mean that a reliable field instrumentation program consisting of a wide variety of manufactured sensors and systems doesn't exist. It does exist and will be referred herein as mix-and-match.

Although there is more legwork in the implementation and planning phase, there are plenty of advantages with such a system. Based off of extensive research and conversations with knowledgeable parties, the strong determining factor for the reliability of such a system is that all of the sensors, however possible, connect to one common datalogging system. This obviously means that the datalogger must be able to interface with a wide variety of technologies, and that is likely made by a reputable manufacturer. If selecting a mix-and-match solution for field instrumentation, it is recommended to use Campbell Scientific's CR-1000X datalogging system and related components, and as many Campbell Scientific-manufactured sensors as possible. Figure 12 shows an example of a road weather station and applicable sensors.



Figure 12. Campbell Scientific-based Road Weather Station

Key benefits of the Campbell Scientific-based mix-and-match system:

- Campbell Scientific-based dataloggers are rugged, reliable, and geared toward off-grid monitoring purposes with lower demands on power.
- Ability to more easily integrate highly accurate and reliable sensors from other manufacturers, especially newer technologies still on the forefront.
- Ability to customize the field instrumentation program and setup to exactly what is needed for the investigation with no additional waste or unnecessary items.
- Inherently reduced cost due to the ability to shop around and pick less expensive sensors.
- Campbell Scientific-based sensors are highly accurate and reliable, yet at a much reduced cost relative to other manufacturer sensors.

Key disadvantages to the Campbell Scientific-based mix-and-match system:

- Increased planning and installation efforts to integrate a variety of sensors from other manufacturers.
- Does not readily integrate into the MnDOT RWIS network, thus could be a large expense to not be repurposed at a later date.

- Does not readily integrate with Vaisala sensors.
- If utilizing a solar-powered monitoring system, non-contact pavement sensors with low power draw to accommodate such a system, do not have a high level of accuracy.

In order to monitor the aforementioned weather, surveillance, and pavement conditions with a mix-and-match solution, the following components should be selected for implementation. For each component, there is a link to its Datasheet for quick reference of specifications and details provided by the manufacturer:

System

- CR1000X – Datalogger
 - [CR1000X Datasheet](#)
- MF-1331 GlenMartin Fold Over Tower
 - [MF-1331 Datasheet](#)

Weather:

- RM Young 05103 Heavy Duty Alpine Mechanical Wind Sensor
 - [RM05103 Datasheet](#)
- EE181 – Air Temperature and Relative Humidity Probe
 - [EE181 Datasheet](#)
- CS100 – Barometer
 - [CS100 Datasheet](#)
- SR50AT – Snow Gauge
 - [SR50AT Datasheet](#)
- CS320 – Solar Radiation
 - [CS320 Datasheet](#)
- CS125 – Present Weather Detection
 - [CS125 Datasheet](#)

Visual:

- Campbell Scientific CCFC – Outdoor Surveillance and Observation Camera
 - [CCFC Datasheet](#)
 - Infrared, NDVI imagery

Pavement:

- Lufft IRS31Pro-UMB – Embedded Road Sensor
 - [IRS31Pro-UMB Datasheet](#)
 - Surface Temperature, Chemical, Water Amount, Road Condition, Ground Temperature, Freeze Point, Friction, Ice Percentage
- Lufft NIRS31 – Remote Road Surface State Sensor (for mainline power system)
 - [NIRS31 Datasheet](#)
 - Layer Thickness, Friction, Reported Surface States
- IceSight – Remote Road Surface State Sensor (for offgrid power system)
 - [IceSight 2020e Datasheet](#)
 - Humidity, Air Temperature, Reported Surface States, Surface Temperature

Field Instrumentation Implementation

Evident from the information available for field instrumentation selection, there are a lot of options to choose from. In fact, there were several that were not highlighted. Some have become obsolete over the years, and others are right on the fringe. In a short of the amount of time, innovation can create more attractive or fitting options to the needs of this investigation. For example, MetSense utilizes friction and road condition in 2 dimensions with an integrated visual camera and road surface temperature to better convey the surface conditions over an area (instead of a point or an average), while Lufft recently utilized LED technology, infrared, and photo receivers to better signify surface conditions. As technologies emerge out of their infancy into acceptance, the options for field instrumentation selection increase. In no way are the recommended examples above what shall be employed, they are examples of tried and true technologies that could serve the current needs of the investigation well. As mentioned, there are a wide range of implementation conditions (geography, roadway alignment, obstructions, etc.) that favor one option over the other, or a combination of the both.

During the implementation phase of the field instrumentation program, it is recommended that both recommended options are explored for sourcing (as well as others as appropriate), to demonstrate commitment toward reduced costs, efficiency, and innovative solutions.

UTBWC Laboratory Testing

As it was discussed before, to have a clear and in-depth picture of UTBWC cold weather performance, it would be the best if the field data is paired with laboratory testing and analyses which will help to further understand the interrelationships between weather, pavement, and maintenance.

In case of budget constraints, either the field instrumentation or lab testing can be performed. The main advantage of the laboratory testing over the field instrumentation is the added safety, as the laboratory testing would not need frequent site visits. Also, the lab experiment is much more isolated and therefore, will be much more controllable. The drawback of lab testing is having to obtain fairly big samples (e.g. pavement slabs) from the field which might be challenging. Also, modeling some of the field conditions (e.g. blown snow) in the lab may not be an easy task. Therefore, it is recommended that both paths are followed.

For laboratory testing approach, the pavement samples need to be obtained from multiple sections with different known winter performances in order to be able to compare the testing results and drawing conclusions on the observed differences. Once the pavement samples are obtained, the following experiments can be considered to be performed. Due to the nature of the suggested experiments, samples are required to be in the form of pavement slabs.

- 1) Characterizing surface macro texture profiles using Circular Track Meter (CTM) device. Figure 13 shows the CMT device.

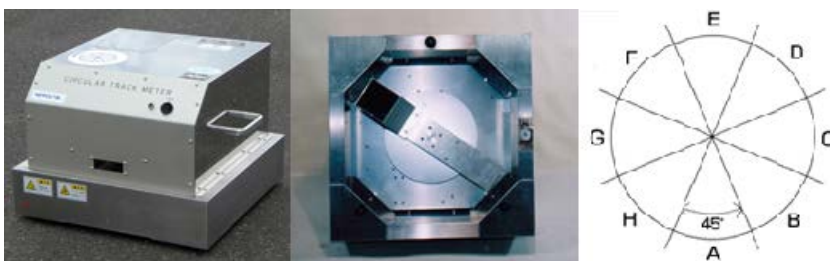


Figure 13. Circular Track Meter (CMT) - Image downloaded from www.nippou.com

CMT measures pavement macro texture in circular area and reports the Mean Profile Depth (MPD) and

the Root Mean Square (RMS). The MPD can be calculated using the following equation in accordance with ISO 13473. Figure 14 presents the MPD.

$$MPD = \left(\frac{1^{\text{st}} \text{ peak level} + 2^{\text{nd}} \text{ peak level}}{2} \right) - \text{average level}$$

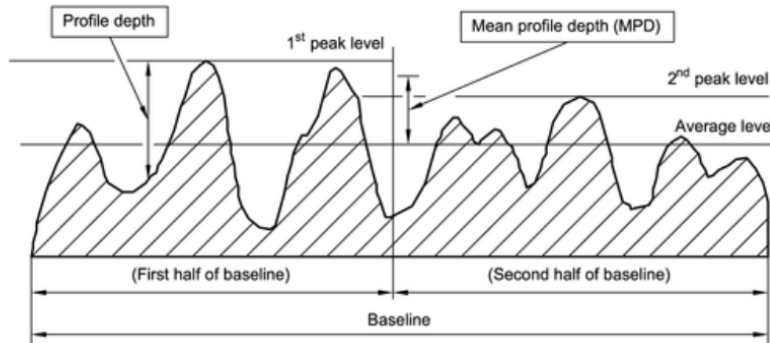


Figure 14. Mean Profile Depth (MPD)

The RMS is the root square value of the deviations which is sometimes used in place of the arithmetic average and can be calculated by the following equation:

$$RMS = \sqrt{\frac{1}{N} \sum y_i^2}$$

- 2) Obtaining frictional characteristics of the surface using Dynamic Friction Tester (DFT). Figure 15 shows the DFT device. Once a specified rotational speed is reached, the bottom disk will be lowered gradually, so the rubber sliders touch the pavement surface. The disk rotational speed will be reduced due to the friction. The frictional coefficient is measured from the amount of reduction in the rotational speed.

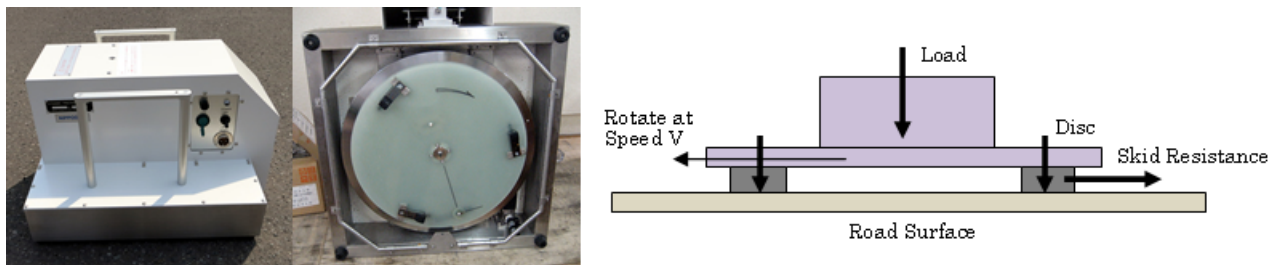


Figure 15. Dynamic Friction Tester (DFT) - Image downloaded from www.nippou.com

- 3) Measuring both the static and dynamic coefficients of friction using Digital Tribometer (Slip Resistance Tester). This device can measure both static and dynamic coefficient of friction with a variety of test sliders in both wet and dry conditions. Figure 16 shows the Tribometer device.



Figure 16. Digital Tribometer – Image downloaded from www.safetydirectamerica.com

- 4) To investigate UTBWC rate of cooling and compare it to the traditional HMA section, temperature sensors can be installed and the samples can be tested in an environmental chamber. At a fixed rate of cooling of the environmental chamber, the samples cooling rates can be measured and compared with the control. The temperature can be measured at the surface of the samples along with multiple locations throughout the depth.
- 5) To investigate how different surface texture can hold ice, the samples can be framed and water of known weight/volume can be added at below zero temperature to build a layer of ice on the surface of the samples. Then the resultant ice depth can be measured and compared. Figure 17 shows a schematic of the framed sample.

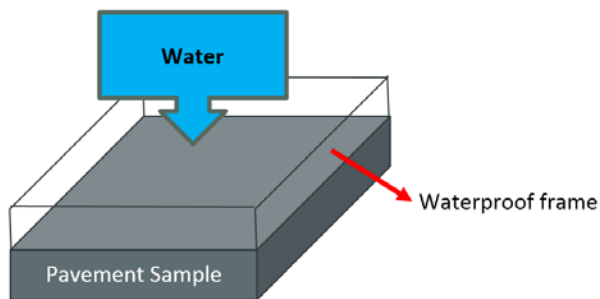


Figure 17. Framed pavement sample

- 6) Once the ice layer is formed on the surface of the pavement slabs, deicing/anti-icing materials can be applied at a pre-specified below zero temperature and the amount of required materials be monitored. The comparisons of the required amounts can show how different sections perform.
- 7) The above experiment can be performed with different deicing/anti-icing materials to find the best-suited product to be used on UTBWC sections.

Obtaining Pavement Slabs

Generally, to run the above-mentioned experiments, pavement slabs with the minimum size of 2 by 2 feet is required. It is very important that the obtained slabs be in perfect shape without any warping and/or edge spalling. From extensive research and conversations with knowledgeable parties, the best approach is to work in the relatively larger area (e.g. 4 by 6 feet), so the diamond cut slab can be pulled out using a forklift as shown in Figure 18.

The paving contractor then needs to patch the area with hot mix asphalt and compact it using a mechanical roller to achieve proper compaction in order to make sure there will be no issues with durability and performance of the patch after the work is done.

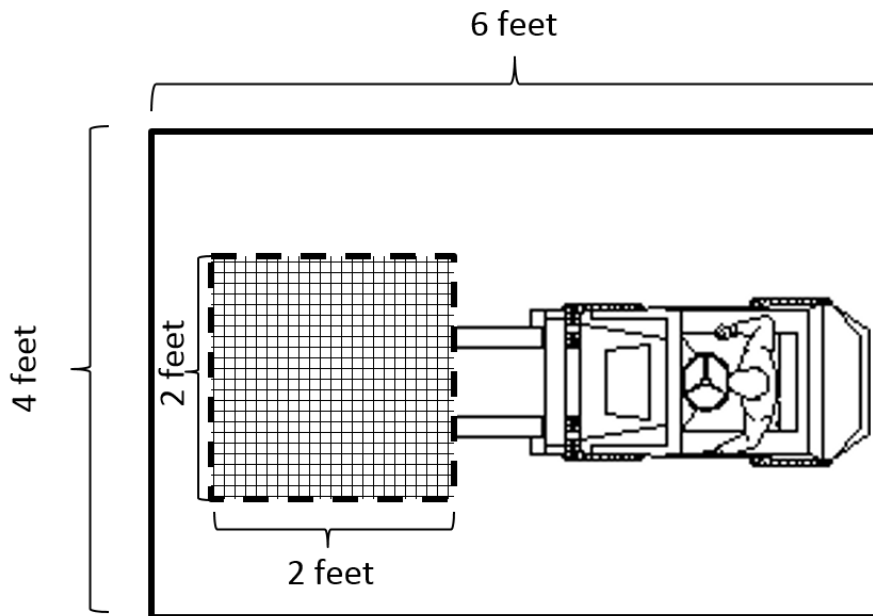


Figure 18. Schematic of Obtaining Pavement Slabs from the Field

Blown Snow Modeling

Modeling blown snow in the lab would require using a walk-in chamber that can maintain below zero temperatures. Two methods of modeling blown snow are discussed here:

- 1) Producing snow using a snow machine:

Shooting the snow that is produced from a snow machine (e.g. a gun snowmaker that is typically used in ski resorts) directly on the samples may not be practical, as snow machine production rates are usually high. A high rate of snow would not allow a proper evaluation of the snow (and ice) accumulation rates. Instead, the snow can be produced and stored in a container. The container then can immediately be placed in a walk-in chamber at a pre-specified temperature and the snow can be blown on the slabs using a fan. Trial experiments need to be run in order to find the best relative locations of the snow container and the fan. A schematic of the experiment is shown in Figure 19. The experiment can be done using different fan speed for modeling different wind speeds. The snow (and ice) accumulation

rates of the sample can be measured and compared in this experiment.

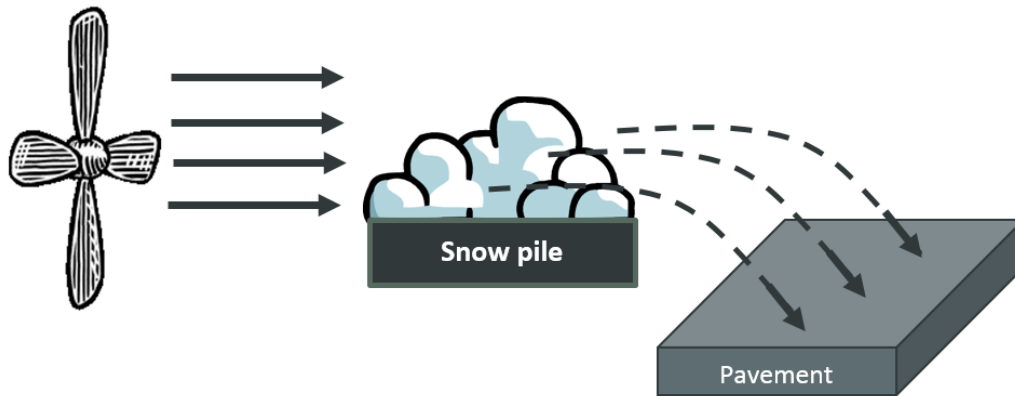


Figure 19. Schematic of blown snow production

2) Producing snow using Koolmist sprays:

On a much lower snow production scale, KoolMist type spray nozzles can be used to produce snow. A trial of this system was performed in a walk-in chamber at 10 F at Braun Intertec which Figure 20 shows the setup. A proper position of the nozzle can blow snow on the surface (rather than falling). Also, a fan can be added to the system to replicate the wind effect better. The simple system shown in Figure 20 could produce $\frac{1}{4}$ inches of snow in only a couple of minutes. Multiple nozzles can be used in the actual experiment to increase the snow production rate, if necessary.



Figure 20. Koolmist Spray System Setup at Braun Intertec

Phase III Work Plan

In this section, the suggested work plan for UTBWC Phase III studies is presented for both field instrumentation and laboratory testing. As it was discussed in the previous sections, to have a clear and in-depth picture of UTBWC winter performance, it would be the best if the field data is paired with laboratory testing and analyses which would help to further understand the interrelationships between weather, pavement, and maintenance. In case of budget constraints, either the field instrumentation or the lab testing can be performed. The advantages and disadvantages of each option are discussed in the previous section.

The first step of the Phase III studies is to select the appropriate test sections. In order to minimize the number of test sections, it is suggested that a minimum of three test sections with the following characteristics be selected:

- 1) UTBWC section – with known good winter performance
- 2) UTBWC section – with known poor winter performance
- 3) HMA section – as the control section

These sections need to be selected after discussions with MnDOT maintenance personnel. To provide easy access to the sites, it is recommended that the sections be selected within the Metro area.

Field Instrumentation Work Plan

Table 4 summarizes the main tasks related to UTBWC field instrumentation and their corresponding duration. Upon implementation of the field instrumentation, remote access to the collected data may not be available or planned for this investigation, although it is strongly recommended. Whether remote access is utilized or not, it is recommended that at least quarterly (or monthly) visits to the monitoring stations be scheduled to not just download the collected data, but to ensure proper system functionality. After collected data is reduced and organized, work can begin toward achieving the field instrumentation goals of investigating for patterns, developing of UTWBC phenomenon parameters, and developing an optimal maintenance program.

As it was discussed before, during the monitoring period, all the actual maintenance activities (i.e. type and amount of deicing and/or anti-icing agents usage, number of plow passes, etc.) and details including visible weather conditions (sunny, misty, cloudy, etc.) needs to be logged to later be included in the analysis. Also, 3-day and 24-hour weather forecasts based off of the closest public weather station need to be logged.

Table 4. UTBWC Field Instrumentation Tasks

Activity Code	Task	Duration (Months)	Comment
F-1	Site selection	1	MnDOT personnel need to be consulted
F-2	Field instrumentation selection (all-in-one or mix-and-match)	1	--
F-3	Purchasing the selected instrumentation	2	--
F-4	Instrumentation installation in test sections	3	One month per site.

Activity Code	Task	Duration (Months)	Comment
F-4-1	Install two embedded pavement sensors per site (one in the wheel path, one not in the wheel path) to monitor: <ul style="list-style-type: none"> • Surface temperature • Subsurface temperature (if feasible) • Surface condition (presence of water, snow, ice, etc.) • Ice/Water depth • Friction • Salinity • Freeze temperature 		Pre and post-installation meetings are required with local MnDOT maintenance personnel to develop an agreeable action plan for maintenance personnel to log observations, weather conditions, and maintenance activities during the data collection period.
F-4-2	Install one non-contact pavement sensor (or sensor system) per site to monitor: <ul style="list-style-type: none"> • Surface temperature • Surface condition (presence of water, snow, ice, etc.) • Ice/water depth • Freeze temperature • Friction or Grip 		
F-4-3	Install one field camera per site to monitor: <ul style="list-style-type: none"> • Visible weather conditions • Visible road conditions 		
F-4-4	Install one weather station per site ⁽¹⁾ to monitor: <ul style="list-style-type: none"> • Air temperature • Relative humidity • Wind speed • Wind direction • Snow depth • Precipitation • Barometer • Solar Radiation • Present Weather (fog, mist, hail, etc.) 		
F-5	Data collection	9 ⁽²⁾	Including one snow and ice season after installation
F-6	Monitoring/Site visits	9 ⁽²⁾	--
F-7	Data Analysis	6	--
F-8	Final report and technical review	5	--

⁽¹⁾Depending on the proximity of test sections, a reduced amount of weather stations, or weather stations with reduced features, may be satisfactory

⁽²⁾Assuming the snow and ice season will happen in a 9-month period

Regarding Table 4, Tasks F-5 and F-6 will happen simultaneously. Also, data analysis (Task F-7) can start about 3 months before the end date of the previous tasks. Figure 21 shows the schedule on a Gantt chart. As this chart shows, Phase III field instrumentation will take about 2 years to complete. It should be noted that this duration is based on 9 months of field data collection and monitoring (Tasks F-5 and F-6) which can be shortened by a few months depending on the actual starting time of the project to include one snow and ice season.

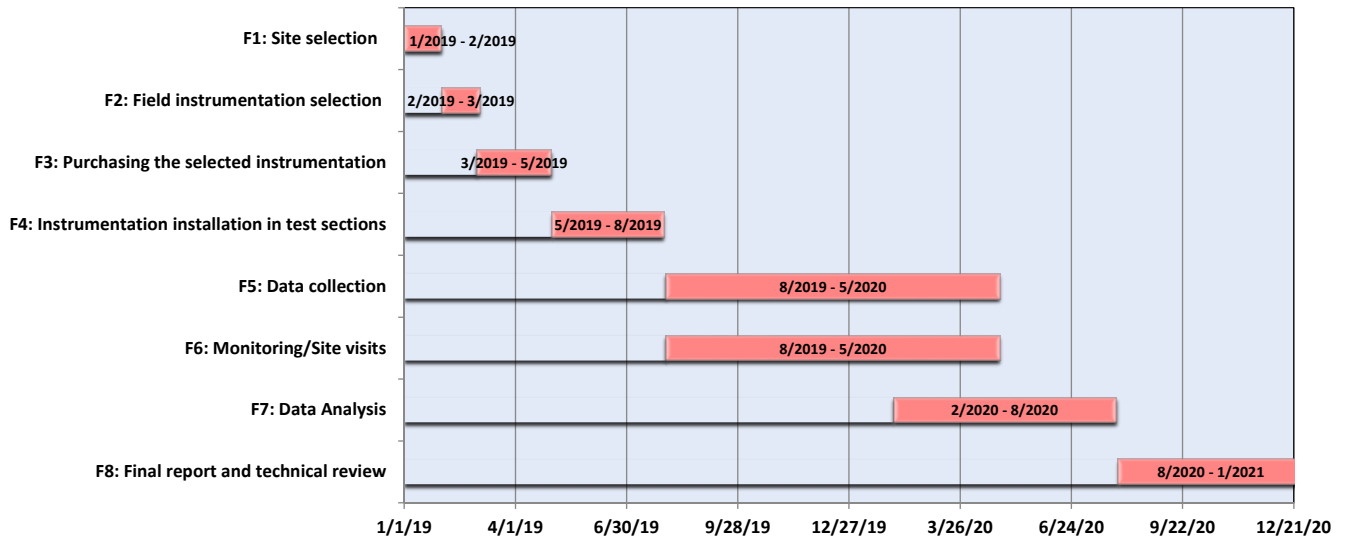


Figure 21. Phase III schedule: Field Instrumentation

Laboratory Testing Work Plan

Table 5 summarizes the main tasks related to UTBWC laboratory testing and their corresponding duration. On each test section pavement slabs of proper size (minimum of 2 by 2 feet) should be obtained, preferably at multiple locations (e.g. 3 locations) along the section. Obtaining three slabs per site would result in a total of 9 slabs for the entire study.

It is recommended that the sampling take place in either spring or fall as in these seasons, the temperature is not too high to cause permanent deformation and warping in the slabs during sampling and shipping, nor too low to encounter frozen base conditions. In any case, the slabs should be handled with care to minimize the warping potential.

All the actual maintenance activities on the test sections and details including visible weather conditions (sunny, misty, cloudy, etc.) need to be logged to later be included in the analysis.

Table 5. Laboratory Testing Tasks

Activity Code	Task	Duration (Months)	Comment
L-1	Site selection	1	MnDOT personnel need to be consulted
L-2	Site visits/Select locations for sample collection	1	--
L-3	Sample collection	3	--
L-4	Laboratory Testing	9 ⁽¹⁾	Approximately one month per slab
L-4-1	Preliminary UTBWC surface characterization using: <ul style="list-style-type: none"> • Circular Track Meter (CMT) • Dynamic Friction Tester (DFT) • Slip Resistance Tester (SRT) 		
L-4-2	UTBWC ice and snow performance by comparing: <ul style="list-style-type: none"> • Cooling rates • Average ice depths • Required amount of deicing and/or anti-icing materials⁽²⁾ 		
L-4-3	Blown snow modeling (using snow gun or Koolmist system) to measure the rates of snow and ice accumulation		
L-5	Data Analysis	6	--
L-6	Final report and technical review	5	--

⁽¹⁾Assuming a total of 9 slabs will be tested.

⁽²⁾Multiple deicing and anti-icing products shall be used.

Regarding Table 5, data analysis (Task L-5) can start about 3 months before the end date of the previous task. Figure 22 shows the schedule on a Gantt chart. As this chart shows, Phase III laboratory testing will take about 22 months to complete.

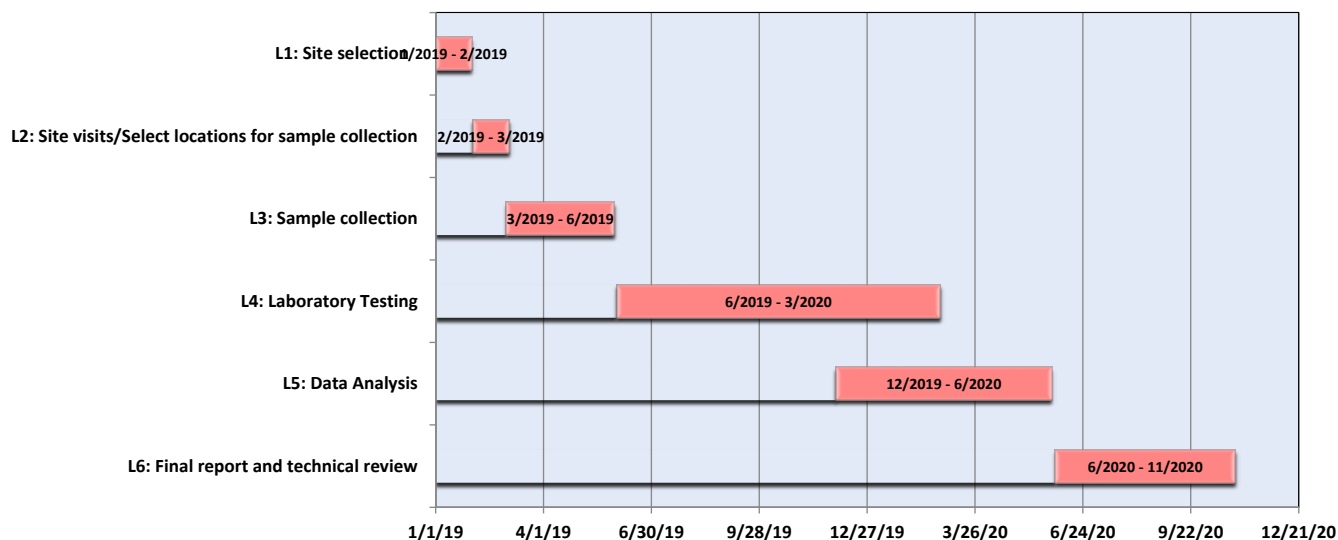


Figure 22. Phase III schedule: Laboratory Testing

Appendix A – Literature Review

Literature Review Resources

[1] Hanson D.I. (2001) “Construction and Performance of an Ultrathin Bonded Hot-Mix Asphalt Wearing Course,” Transportation Research Record, No. 1749, pp. 53-59.

From the abstract: An effective pavement preservation program includes several maintenance strategies that are applied in a cost-effective and efficient manner. Several new technologies have been developed to address these problems. One of the more promising technologies is the use of an ultrathin bonded hot-mix asphalt (HMA) wearing course (UTBWC). It consists of a layer of HMA laid over a heavy asphalt emulsion layer or membrane. The thickness of the ultrathin surface ranges from 9.5 to 19 mm (3/8 to 3/4 in.). The system is placed on a structurally sound rigid or flexible pavement, which may exhibit minor surface distresses. The process was developed in France in 1986 and has been in use in the United States since 1992. Published experimental project reports and inspections of recently completed projects in many locations indicate good performance of the UTBWC. It provides a surface with excellent macro texture qualities, good aggregate retention, and excellent bonding of the very thin surfacing to the underlying pavement.

From the conclusion: Based on a review of the literature, conversations with DOT and industry personnel, and personal inspection of a number of ultra-thin bonded HMA overlays, the following conclusions are drawn:

- The system provides excellent aggregate retention.
- The system has excellent bond to the underlying surface. Delamination of the system from the surface is generally not a problem.
- The ultra-thin bonded HMA wearing course surface has excellent macro texture qualities. Thus, the system will provide a surface with a high level of skid resistance. And, because of its high macro texture surface, it should also provide a surface that will reduce hydroplaning problems.
- Cracks in the existing pavement will reflect through the surface. But, it appears that cracks sealed prior to placement of the UTBWC present no performance problems.

[2] Ruranika M. and Geib J. (2007) “Performance of Ultra-Thin Bounded Wearing Course (UTBWC) Surface Treatment On US-169 Princeton,” St. Paul, Minnesota, USA.

Link: <https://www.lrrb.org/pdf/200718.pdf>

From the conclusion: The field performance of the UTBWC after 7 years is excellent: no weathering or edge deterioration is evident on any of the sections. Furthermore, the UTBWC appears to be adhering to the existing surface well: no raveling is evident. This project is also performing well in regards to ride quality and transverse cracking. The average ride quality index on the UTBWC overlay section is 3.2 and the Mn/DOT Pavement Management System predicts the UTBWC overlay section will not reach an RQI of 2.5 for more than 5 years. The transverse cracks reflecting through the UTBWC overlay are still tight. Ultra-thin bonded wearing courses (UTBWC) appear to be durable: no maintenance costs have been incurred since 1999/2000. However, crack sealing should be considered in the future to extend the life of the overlay. The US-169 control section deteriorated very quickly despite annual maintenance. The ride quality index was 1.9 at the time of rating in 2006, which is well below the rehabilitation trigger value of 2.5. Major rehabilitation should be done on this section.

[3] Ji Y., Nantung T., and Tompkins B. (2015) "Evaluation for UTBWC on SR-11 as Pavement Preservation Treatment: A Case Study," International Journal of Pavement Research and Technology, Vol. 8, No. 4, pp. 267-275.

From the conclusion: This study evaluated the effectiveness of UTBWC as a form of pavement preservation. Based on the analysis of the data, the following conclusions were made:

- The overall performance of the UTBWC sections has been very good. UTBWC can be considered as a low-cost preventive maintenance treatment that retards deterioration of the pavement, maintains or improves the functional and structural condition of roadways, and extends the pavement's service life.
- UTBWC can be utilized to correct rutting and improve smoothness. It is well suited as a preventive maintenance treatment to extend the life of sound pavement. Its function is to increase the PCR and IRI. However, it is not as effective as resurfacing in reducing rutting.
- UTBWC does not increase the structural capacity of the pavement; however, it can rejuvenate the aged pavement surface and appears to slow the progress of reflective cracking.
- Compared to UTBWC, mill and fill can more effectively address rutting, increase ride quality, and show the largest improvement in PCR. Therefore, it can offer the longest functional service.
- With the curves of performance developed in this study, results suggest that the performance life of a treatment is 3 to 4 years for UTBWC and 6 to 8 years for resurfacing.
- The cost analysis indicated that UTBWC is cost-effective if it can provide more than approximately 3.5 years of service life, and resurfacing is cost-effective if it can provide more than approximately 3 years of service life.
- UTBWC effectiveness is influenced by pavement structural capacity, construction, the time at which preservation was performed after pavement deterioration, and traffic volume. If applied properly, UTBWC may show better results and can be considered as an alternative to conventional resurfacing.

[4] Ahmed A.A. (2010) "Ultra-thin Bonded Wearing Course Performance Update, Minnesota," Minnesota Department of Transportation.

From the conclusion: Overall condition of all the UTWBC sections constructed in the summer of 2004 and summer of 2005 in the Twin Cities showed a promising performance up to now with only minor deterioration. Most of the distresses were along transverse and longitudinal joints; this type of distress is common on bituminous overlay on Jointed Plain Concrete pavement.

This product dramatically improved the IRI of all the sections. It showed a good bond both on bituminous and concrete surfaces. All sections revealed no major cracks in 2008 which stop runoff water and deicing chemicals from getting into the pavement. Constant increase of traffic flow on Twin Cities highways and the need for shortening highway lane closure time, UTWBC would give a better choice for pavement engineers when needing to maintain and improve the ride quality of a pavement. A good decision can only be made when the life service of these sections is achieved and compared with the Mn/DOT current pavement maintenance life expectancy and cost.

[5] Local Road Research Board (2016) "Snow and Ice Control Guidebook," Report #2016RIC11.

Link: <http://www.dot.state.mn.us/research/TS/2016/2016RIC11.pdf>

From the introduction: This Snow and Ice Control Guidebook summarizes common snow and ice control tools and serves as an introduction to the field of winter maintenance for operators and managers. Minnesota local agencies perform winter maintenance to keep roads clear for the traveling public. However, agencies must balance public safety, cost, and environmental concerns to effectively manage their winter maintenance policy.

Minnesota cities and counties should retain an up-to-date policy for winter maintenance that specifies desired pavement conditions.

[6] Yildirim Y., Dossey T., Fults K., and Trevino M. (2006) "Winter Maintenance Issues Associated with New Generation Open-Graded Friction Courses," Report Number FHWA/TX-07/0-4834-1. Center for Transportation Research. Austin, TX, 2006.

Link: http://ctr.utexas.edu/wp-content/uploads/pubs/0_4834_1.pdf

From the conclusion: Widespread use of NGOGFCs, however, has been curtailed by their maintenance and performance issues during winter weather conditions. The qualities of NGOGFCs raise special problems in winter maintenance. For example, the lower temperatures and greater air voids of NGOGFCs allow water to become trapped more easily and freeze more quickly than other pavement surfaces. This is known as black ice, and it is a serious road hazard for drivers. Sand and salt are not effective on NGOGFC surfaces. Sand clogs the air voids of NGOGFCs and eliminates their special benefits. Salt drains away too quickly within the open-graded structure of the pavement, proving ineffective against ice. Tire studs and snowplows cause ruts and gouges in NGOGFCs over a shorter period of time. Research and studies have been conducted to solve these special winter maintenance problems with NGOGFCs, including the development and use of de-icing chemical agents, new methods for chemical application, and training of maintenance personnel.

From a survey conducted in 2005, Respondents cited the main disadvantages of using NGOGFCs as being their initial cost of construction, winter maintenance issues, and general maintenance issues. Indeed, results show that NGOGFCs are 22.5 percent more expensive than other dense-graded pavements. Fuel spills were the most reported general maintenance issue by respondents, but respondents did not report any serious problems with raveling, deformation rutting, potholes, fat spots/bleeding, stripping, reflective cracking, thermal cracking, tire stud rutting, gouging/scarring, new construction roughness (IRI), clogging, noise level, or icing. Overall, the respondent districts report satisfactory performance of NGOGFCs.

Anti-icing procedures have proven effective in combating black ice, freezing rain, and light snow. The use of de-icing chemical agents should be used in response to ice and snow that have already bonded with the pavement surface. De-icing procedures require more materials and are not as capable in maintaining safe road conditions as well as anti-icing procedures. Sand should only be used in emergency situations in response to surprise ice or snow events, especially considering that sand may cause clogging and long-term damage to NGOGFC pavements. Other materials other than sand should be considered for providing friction in these circumstances.

[7] Huber G. (2000) "Performance Survey on Open-Graded Friction Course Mixes," NCHRP Synthesis of Highway Practice 284, Transportation Research Board, National Research Council, Washington, D.C., 2000.

Link: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_284.pdf

From the conclusion: In freezing climates open-graded mixtures require a different approach for winter maintenance. Open-graded mixtures tend to be the first section to freeze and the last surface to thaw. For ice and snow removal sand should not be mixed with salt because of the potential to clogging the pores. Without the abrasive action of the sand, ice packs breaks up more slowly. Salt brine soaks into the open-graded mix removing it from the partially dissolved ice. Therefore, open-graded mixes require a more frequent application of salt with less salt applied each time.

[8] Greibe A.P. (2002) "Porous Asphalt and Safety," Proceedings of the Ninth International Conference on Asphalt Pavements, Copenhagen, Denmark.

[9] Federal Highway Administration (2012), "Evaluation of Open-Graded Friction Courses: Construction, Maintenance, and Performance," FHWA Report No. FHWA-SC-12-04.

Link: [https://ntl.bts.gov/lib/46000/46300/46376/SPR_687_Evaluation_of_OGFCs -
_Construction Maintenance and Performance Final Report .pdf](https://ntl.bts.gov/lib/46000/46300/46376/SPR_687_Evaluation_of_OGFCs_-_Construction_Maintenance_and_Performance_Final_Report_.pdf)

From the body: Several winter weather conditions cause concern for OGFC pavements. The phenomenon known as freezing fog, rain falling on a frozen OGFC layer, or simple snow or sleet can be problematic as research shows that OGFC layers have 40-70% the thermal conductivity of a regular HMA pavement. Because of this, OGFCs consume more deicing materials, and OGFCs must be treated with deicers or anti-icers soon after plowing or slush will freeze in the voids of the pavement. Once frozen, the resulting layer of ice is much more difficult to remove from an OGFC layer than from a regular HMA. While the need for salt is generally higher on OGFCs due to salt solution penetrating the void structure, research has shown that as long as traffic volumes remain high, the salt solution will be pumped in and out of the void structure by the traffic diminishing the need for extra salt. This phenomenon has been observed in multiple studies as researchers have noticed higher friction numbers in the travel lane of an OGFC pavement.

[10] Bennert T., Fee F., Sheehy E., Jumikis A. and Sauber R. (2005) "Comparison of Thin-Lift HMA Surface Course Mixes in New Jersey," Annual Meeting of the Transportation Research Board. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C., 2005.

From the body: The predominant method used by the NJDOT for deicing roadways in the winter is the use of rock salt. It has been found that the OGFC pavement surfaces are significantly more difficult to maintain ice-free using rock salt. The OGFC requires more frequent applications of the rock salt and still tends to be icier than adjacent dense graded asphalt (DGA) sections. The OGFC surfaces have been the only surface type that has displayed this problem. The New Jersey Garden State Parkway (NJGSP) is another road authority in New Jersey that contains approximately 1,200 lane miles of HMA, with 100 of the lane miles consisting of OGFC. Unlike the NJDOT however, the NJGSP uses a liquid magnesium chloride for deicing. During winter months, the NJGSP continually measures the OGFC pavement surface temperatures. The measured surface temperatures, along with the weather forecast, allow the NJGSP to pre-treat the OGFC surfaces to avoid icing. The continual monitoring of surface temperature and weather forecasts are necessary because the NJGSP has found that the liquid solution usually washes off the surface if the OGFC has already frozen. However, if pre-treated correctly and timely, the OGFC surface has found to be manageable and can be plowed the same as the DGA sections, although the OGFC usually needs about twice the total application of liquid solution as the DGA.

[11] Danish Road Directorate (2012) "Winter Service of Porous Asphalt; European Experience," Ministry of Transport.

Link:

[http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/498/winter%
20rapport.pdf](http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/498/winter%20rapport.pdf)

From the abstract: 28 km of porous asphalt has been laid in the Bavarian highway network where noise abatement has been needed. Problems with shorter structural lifetime depending on traffic load have been observed. This increases the cost of using porous asphalt. Some problems with clogging have also been observed. 50% extra salt is used and the salting frequency is 60 to 90 minutes. The introduction of a new

“double” salting machine combining wet and dry salting has improved the cost and quality of winter servicing. Speed reduction is sometimes used.

In Switzerland, there are 250 km of porous asphalt on the highways. The national road administration is not in favor of porous asphalt because of durability problems and the reduced lifetime, which increases the cost. Porous asphalt is only used on highway sections where the noise regulation requires noise reduction that cannot be achieved with noise barriers. Extra salt is used.

In France, the national road administration has stopped using porous asphalt. One of the reasons for stopping the use of porous asphalt was the high cost of winter servicing. The pavement type is still used on 200 km by one private highway company presumably because of the reduction in splash and spray and the increase in driver comfort. No information on winter servicing was collected.

In the Netherlands, state policy requires porous asphalt across the whole state highway network to reduce noise, and at present 90% of highways have porous asphalt. The lifetime is a few years shorter than for dense pavements. The contracting sector has considerable experience in porous asphalt. Frost damage has been observed on old porous asphalt in severe winters. Problems with snow in pores and black ice have been observed. Intensive monitoring in winter periods by road staff and sensors and frequent salting are applied. 30 to 40% extra salt is used. Sometimes lanes are closed and sometimes speed reduction is used. The road administration has great experience in the winter servicing of porous asphalt.

[12] Shulski M. and Seeley M. “Climatological Characterization of Snowfall and Snow Drift in Minnesota (for the Design of Living Snow Fences),” MnDOT Agreement No. 74708.

Link: <http://snowcontroltools.umn.edu/background/research/climatology/project/index.html>

From the abstract: Research conducted in the 1960's and 70's by the U.S. Forest Service has shown that snow fences cause blowing snow to deposit on the landscape such that it is stored over the winter season. In the early 1970's, construction for Interstate 80 was completed in eastern Wyoming, however, the highway was subject to numerous drifting problems. Ronald Tabler and others utilized this as an opportunity to apply research results and deploy structural snow fences at problem locations along the interstate and test their effectiveness as snow control measures. It is estimated that these snow fences prevented 35 accidental injuries and cut winter maintenance costs in half for one season. Through these research efforts, detailed guidelines were established by Tabler (1994) outlining the steps necessary for the deployment of snow fences, both structural and living.

The Minnesota Department of Transportation chose to utilize the technique for site specific snow control and one study estimated that there are 4,000 sites, encompassing 1,000 miles, where blowing and drifting snow is problematic (Gullickson 1999). When comparing the cost of snow removal with living snow fences, an average cost/benefit ratio of 17:1 exemplifies the efficiency of this method validating widespread use in Minnesota.

[13] Kluttz R.Q., Jellema E., Woldekidan M.F., and Huurman M. (2013) “Highly Modified Bitumen for Prevention of Winter Damage in OGFCs,” Airfield and Highway Pavement.

From the abstract: Only a few cold winter nights can cause years' worth of raveling damage to a road when stresses due to traffic loads and day to night temperature variations reach the binder's breaking point. Delft University of Technology developed a finite element model, the Lifetime Optimization Tool (LOT), to study this phenomenon by predicting asphalt mix response from asphalt mortar properties. Mortars of long-lasting porous asphalt roads were compared with those from early-failure roads. The study concluded that two factors are critical to prevent winter damage:

- Limited binder stiffness at low temperature, particularly after aging

- Binder stress relaxation at these low temperatures

In a search for improved binder performance, four different highly modified binders were produced by Kraton Polymers Research B.V. Master curves were developed on laboratory-aged binders for viscoelastic properties, and the mortar performance was evaluated at different temperatures and temperature fluctuations using the protocol of the LOT model. The results were compared with literature data of the existing road sections and showed a dramatic improvement in raveling resistance. The SBS polymer-modified binders demonstrated exceptional performance in the winter and at least an equally good performance under summer conditions.

[14] Alvarez A.E., Martin A.E., Estakhri C.K., Button J.W., Glover C.J., and Jung S.H. (2006) "Synthesis of Current Practice on the Design, Construction, and Maintenance of Porous Friction Courses," Report 0-5262-1, Texas Department of Transportation.

Link: <http://tti.tamu.edu/documents/0-5262-1.pdf>

From the conclusion: In general, open-graded mixtures exhibit lower thermal conductivity and reduced heat capacity compared with DGHMA. Elevated air voids contents in OGFC reduce the flow rate of heat through the material. In fact, the thermal conductivity of OGFC can be 40 to 70 percent the magnitude of that for DGHMA, making OGFC operate as an "insulating course" at the surface. As a result of these thermal properties, the surface of OGFC can exhibit temperatures 1 to 2°C (1.8 to 3.6°F) lower than the surface temperature of adjacent DGHMA, producing earlier and more frequent frost and ice formation. Longer periods under such conditions, compared with DGHMA, are thus expected. The time to reach adequate pavement friction values after ice formation has occurred is longer in porous pavement. In fact, formation of black ice and extended frozen periods are currently considered the main problems associated with OGFC maintenance in the United States. Consequently, OGFC requires specific winter maintenance practices. For example, in addition to conventional practices for winter maintenance, the use of pavement condition sensors, meteorological instrumentation, and connecting hardware and software is suggested to monitor the road system and support the decision process involving when and how to treat an OGFC surface. More salt (or deicing agents) and more frequent applications than on DGHMA are required to perform winter maintenance on OGFC and PA. In Texas, deicing agents are currently considered the most effective winter treatment, followed by liquid deicer agents and sand. However, FHWA recommends developing snow and ice control using chemical deicers and plowing and avoiding the use of abrasive materials to improve traction. Spreading of sand to enhance friction and hasten deicing contributes to the clogging of voids, causing a decrease in drainage and noise reduction capabilities, which are considered two of the main OGFC advantages.

Since the deicer can flow into an OGFC instead of remaining at the surface, Oregon DOT has suggested research on organic deicers with higher viscosity and electrostatic charge technology (similar to that employed in emulsified asphalt) to improve bonding of deicers on the surface. Intensive application of liquid deicing salts has allowed Belgium to obtain similar conditions between dense and porous mixtures subjected to snowy weather. Further, higher frequency of application and 25 percent more liquid salting are reported in The Netherlands to address winter maintenance difficulties in PA. Furthermore, the use of liquid chloride solutions was reported in the cold Alpine regions of Italy, Austria, and Switzerland as more effective than the use of solid salt. On the contrary, a Japanese study concluded that fundamental modifications are not required to practice winter maintenance in PA surfaces, since considerable differences between these mixtures and DGHMA were not found. Britain practices preventive salting just before snowfall and more frequent application of salt in comparison with DGHMA. They recommend increasing the amount of salt applied on DGHMA sections that are adjacent to PA segments. This recommendation is due to the reduction in the transfer of salt from the PA to the DGHMA and the differences in response of each material. Additionally, they propose prompt plowing of snow

using plows fitted with rubber edges on the blades (to prevent surface damage). Finally, greater control in the homogeneous application of deicing chemical is required in OGFC, as the traffic has minimal contribution in its distribution over the OGFC surface.

[15] Flintsch G.W. (2004) "Assessment of the Performance of Several Roadway Mixes Under Rain, Snow, and Winter Maintenance Activities," Virginia Transportation Research Council, Report VTRC 04-CR18.

Link: <https://vtechworks.lib.vt.edu/bitstream/handle/10919/46649/04-cr18.pdf?sequence=1&isAllowed=y>

From the abstract: The purpose of this study was to assess the relative functional performance, including skid resistance and splash and spray, of five hot-mix-asphalt (HMA) surfaces and a tinned portland cement concrete highway surface during controlled wet and wintry weather events. The winter maintenance test results were inconclusive, as the various maintenance treatments were unable to significantly improve the functional condition of the road. Under the temperature and precipitation conditions encountered, there were no significant differences in the performance of the different surface mixes tested. However, conditions encountered did not correspond to conditions normally encountered with natural snow. The researcher concluded that at temperatures at and just below freezing, artificial snow might not be appropriate for evaluating the effectiveness of winter maintenance chemicals.

[16] Isenring T., Koster H., and Scazziga I. (1990) "Experiences with Porous Asphalt in Switzerland," Transportation Research Record, Vol. 1265, pp. 41-53.

From the abstract: Particular attention is devoted to the problems of skid resistance, permeability, noise reduction, and behavior under winter road conditions of porous asphalt pavements. For these parameters, the methods of measurement, results, and general conclusions are presented. Conclusions are provided separately for two potential areas of application of porous asphalt: motorways and other roads with fast traffic, and urban roads with slower traffic. Taking into account the different advantages and disadvantages of porous asphalt, experiences obtained so far are generally very positive about the application of porous asphalt to roads with high-speed traffic. When applied in urban areas, different problems appear and initial advantages may be lost within a short time. Also applications in an urban environment cannot take full advantage of the noise-reducing potential when traffic travels at lower speeds. Results from this research project also indicate that a number of conventional surface layers can have favorable acoustic properties; in this field there is potential for further development. Under winter road conditions, porous asphalt surfaces can present the same range of variation of skidding properties as conventional surface layers. However, at a particular moment, there is a difference in the behavior of the two pavement types along the road at the site where the type of surface changes.

[17] Van H.G. and Moraux C. (1990) "Ten Years' Experience of Porous Asphalt in Belgium," Transportation Research Record, Vol. 1265, pp. 34-40.

From the body: Studies and observations made by the BRR have made it possible to draw the following conclusions about the much debated behavior of porous asphalt. Briefly, it can be said that porous asphalt and dense bituminous concrete do not behave differently in snowy weather when spread intensively with deicing salts. If such is not the case, snow may remain longer on porous asphalt because the brine that is formed under traffic can penetrate the voids in this material. However, this difference in snow-clearing behavior has never been the underlying cause of any accidents recorded in Belgium. On the other hand, accidents have happened in icy weather on porous asphalt surfaces while the adjacent pavements were not icy, and vice versa. Ice simulation tests have shown that the comparison for skid resistance is sometimes favorable to porous asphalt and sometimes to dense surfacing, depending on ice conditions.

[18] Camomilla G., Malgarini M., and Gervasio S. (1990) "Sound Absorption and Winter Performance of Porous Asphalt Pavement," Transportation Research Record, Vol. 1265, pp. 1-8.

From the conclusion:

Conclusions Regarding Winter Performance:

- In conditions of intense cold and sharp frosts, the porous pavement presents several disadvantages
- Preventive treatment given the granulometric characteristics of salts currently used is not particularly effective, but certainly not useless
- Ice removal treatment can perhaps be more effective using liquid chloride solutions
- The passage of the snow plow blade compresses and presses the snow into the pores of the porous asphalt, and subsequent traffic brings to the surface part of the snow in the form of semi-liquid slush which easily freezes under low temperatures.
- Attention must be given to the problems which arise at the transition points between the normal pavement and the porous asphalt pavement, because of the different behavior of the two mixes.

Given current knowledge, and pending results of more detailed studies, the following winter operations are advisable:

- In the case of porous asphalt pavements, it is necessary to provide strong preventive treatments consisting of almost three times the amount of salt used for normal pavement.
- To facilitate accurate dosing on the part of the salt spreader operator, it is useful to post signs at the beginning and end of the porous asphalt sections.
- It is necessary to alert staff in ample time to ensure immediate and rapid snow removal operations before the snow can penetrate to depth, and
- Once the snow plows have cleared the snow, it is necessary to proceed immediately with successive and repeated treatments with reduced quantities of NaCl.

Research should be continued to devise new specifications for both preventive treatments (granulometric characteristics of the salts) and ice removal treatments.

[19] Beyene M.A., Meininger R.C., Gibson N.H., Munoz J.F., and Youtcheff J. (2016) "Forensic Investigation of the Cause(s) of Slippery Ultra-Thin Bonded Wearing Course of an Asphalt Pavement: Influence of Aggregate Mineralogical Compositions," International Journal of Pavement Engineering, 17(10), pp. 887-900.

From the abstract: The cause(s) of slippery ultra-thin bonded wearing course (UTBWC) of an asphalt pavement was investigated. Petrographic analysis showed that the aggregate used in the UTBWC is mainly limestone with an average acid-insoluble residue of 5.1%. Coefficient of friction tests were performed both on a comparative UTBWC from Virginia with a different aggregate mineralogy (VA-UTBWC) and on slabs extracted from the slippery UTBWC pavement overlay. The tests clearly showed that the slippery UTBWC overlay sharply declined throughout the polishing process, consistent with the aggregate mineralogical composition and its low amount of acid-insoluble residue. In contrast, the comparative VA-UTBWC mix showed a gradual increase and then decrease in friction with continued polishing. This investigation clearly showed that the cause of the slippery asphalt pavement problem of the road is mainly attributed to limestone aggregate polishing.

[20] Amjadi R., Merritt D., and Sherwood J. (2015) "Gaining Traction on Roadway Safety," Accident Reconstruction Journal. 25(4), pp. 55-59.

From the abstract: This article reports on a study conducted by the Federal Highway Administration and 17 volunteer states, the Evaluations of Low-Cost Safety Improvements Pooled Fund Study, Phase IV. The study focuses on the use of crash data to measure safety performance of pavement treatments. It intends to both examine the effect of pavement surfaces on safety and determine whether various low- and no-cost surface treatments impact safety performance on wet asphalt. The treatments evaluated include hot mix asphalt (HMA) overlay, open graded friction courses (OGFC), chip seal, microsurfacing, slurry seal, diamond grinding and ultra thin bonded wearing course (UTBWC). The results do not reveal that one particular treatment performs significantly better than another. However, some potential differences in benefits among treatments are found to exist and almost all treatments show some benefit for wet road crashes on all road types.

[21] Hencken J., Haas E., Tulanowski M., and Bennert T. (2014) "Pavement Noise Analysis of Pavement Preservation Techniques in New Jersey," American Society of Civil Engineers, pp. 702-710.

From the abstract: The NJDOT is increasing the use of micro surface and chip seal earlier in the pavement life cycle to economically extend the service life of a pavement, to promote a high level of pavement condition index (PCI) throughout the state network, to provide functional benefits such as increased skid resistance, reduced splash and spray, and noise reduction. To determine if noise reduction is attainable using these surface treatments, it was important to first measure the associated noise levels generated and determine how they compare to traditionally used thin-lift overlays. A tire/pavement noise evaluation was conducted utilizing the On-Board Sound Intensity Method (OBSI) on micro surface and chip sealed sections that were placed on state-maintained roads as test sections to compare to noise levels included in the NJ noise database for ultra-thin bonded wearing course (Novachip), High Performance Thin Overlay (HPTO), Stone Mastic Asphalt (SMA) and Asphalt Rubber Open Graded Friction Course (AROGFC). The rank order noise level of thin-lift overlays from quietest to loudest ascertained from this study was AROGFC, SMA, HPTO, Novachip, and then micro surface.

[22] Xuefeng N. (2011) "Selection and Performance Evaluation on Tack Coat Oil Used in Ultra Thin Wearing Course," American Society of Civil Engineers, pp. 1963-1969.

From the abstract: The ultra-thin wearing course is a kind of preventive maintenance technology with excellent performance, and many advantages have been found including high wear resistance surface, low traffic noise, improved skid resistance, good waterproof performance and so on. In this paper, grinding tests were carried out to study the performance of four types of emulsified asphalt which were chosen to be used in step-constructed ultra-thin wearing course. Based on the results of grinding tests, three types of emulsified asphalt were selected and their bond properties were studied using direct shear tests. Test results show that low-grade emulsified asphalt possesses better bond properties and can be used to effectively prevent the damage of tack coat caused by construction vehicles. Thus low-grade emulsified asphalt is the preferred material to be used in step-constructed ultra thin wearing course.