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MARYLAND DEPARTMENT OF TRANPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

PERFORMANCE OF ULTRA-THIN BONDED WEARING COURSE (UTBWC) DURING WINTER SNOW ICE EVENTS IN MARYLAND

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FINAL REPORT

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16. Abstract

Ultra-Thin Bonded Wearing Course (UTBWC) pavement surfacing was developed as a preventative maintenance option to extend pavement life. Despite the successful applications of UTBWC in various states, feedback from winter maintenance crews indicates icing accumulation on some UTBWC surfaces in Maryland during winter storms, and thus current salting practices may need to be revisited. Similar concerns have been identified by other states, and thus safety benefits under snow and ice conditions recently have been in question. However, other non-UTBWC locations seem to have no issues. The scope of this study was to investigate how prevalent the problem is in Maryland, to assess the performance of UTBWC surfaces, and whether any issue is dependent on specific weather and/or winter treatment maintenance. Objectives of this research were thus to: (i) determine how prevalent the problem is in Maryland; (ii) assess the performance difference of UTBWC surfaces compared to non-UTBWC surfaces as reported by SHA Districts; (iii) determine whether any issue is dependent on precipitation type, rate of fall or volume; (iv) examine whether volume of salt or other treatment affects performance, and, (iv) provide potential recommendations for improving their performance.

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Chapter 1 Introduction

Ultra-Thin Bonded Wearing Course (UTBWC) pavement surfacing was developed as a preventative maintenance option to extend pavement life. Despite the successful applications of UTBWC in various states, feedback from winter maintenance crews indicates icing accumulation on some UTBWC surfaces in Maryland during winter storms, and thus current salting practices may be insufficient. Similar concerns have been identified by other states, and thus safety benefits under snow and ice conditions recently have been in question. However, other UTBWC locations seem to have no issues. Thus, the objective of this study was to investigate how prevalent the problem is in Maryland, to assess the performance of UTBWC surfaces, and whether any issue is dependent on specific weather and/or winter treatment maintenance.

1.1 Study Objectives & Scope of Work

The objectives of this research were to: (i) determine how prevalent the problem of insufficient salt practices is in Maryland; (ii) assess the performance difference of UTBWC surfaces compared to adjacent non-UTBWC surfaces as reported by SHA Districts; (iii) determine whether any issue is dependent on precipitation type, rate of fall or volume; and, (iv) examine whether volume of salt or other treatment affects performance. To achieve these objectives the following tasks were undertaken:

Task 1. Project management: continuous interaction and coordination with State Highway Administration (SHA) engineers and division staff were kept throughout the project duration. This included discussion on plans to carry out the research, which included surveys and expert feedback, data collection and analysis as outlined below, and continuous feedback on the project progress and research findings.

Task 2. Literature review & expert feedback: An extensive review was conducted to examine (i) past and current practices of UTBWC in Maryland and other states and investigate (ii) the effects and experiences of how UTBWC snow and ice affect performance. The research team, with support from SHA staff, conducted interviews and solicited information and feedback regarding experience with ice and snow control on UTBWC pavements. This task provided: an overview of the history and success of UTBWC in

Maryland; an assessment of the winter maintenance methods and impact on UTBWC sections according to the District staff responsible for such activities; an overview of other state's experience with such sections; and assessment of data availability for analysis of Task 3.

Task 3. Assessing UTBWC performance in Maryland: Objective of this task was to determine how prevalent the problem is in Maryland; assess the performance difference of UTBWC surfaces as reported by division staff in regard to non-UTBWC surfaces; assess whether any issue is dependent on specific weather conditions, and/or wither treatment practice. To achieve these objectives, the research team with support and close coordination with SHA staff and District personnel identified all UTBWC sites in Maryland, collected and examined material and UTBWC mixture inputs, site and location specific data, reported winter maintenance practices, and weather and traffic volume data

Task 4. Final Report: Based on the analysis and findings of the above tasks, the research team prepared this final project report as outlined next and including the summary, conclusions and recommendations as discussed and reviewed with SHA staff throughout the regularly scheduled project meetings.

1.2 Background (Literature Review)

While the project focus was on the UTBWC in Maryland, the project team conducted a literature review of such sections elsewhere for lessons learned and identifying potential recommendations for dealing with performance issues. Such review also helped identify the content and extent of the surveys conducted with SHA division staff responsible for winter maintenance of UTBWC sections in Maryland. A summary of such findings is briefly presented next.

Adoption of pavement preservation treatments can effectively improve the pavement conditions and protect the underlying pavement, which defers the need for rehabilitation or reconstruction of the pavements. Thus, pavement preservation treatments maintain structural integrity and extend the life and serviceability of the pavements which will ultimately result in improved safety, reduced cost and decreased environmental impact (Wegman et al., 2018). Ultra-Thin Bonded Wearing Course (UTBWC) is an exclusive pavement preservation treatment process which consists of a heavy application of polymer-modified emulsion followed by an ultra-thin gap-graded hot mix asphalt (HMA) (Figure 1.1). There are three different gap graded types of HMA that can be used in UTBWC as shown in Table 1.1 (NovaChip® Midland Asphalt). Types B and C have been most commonly used. In Maryland, Type B has been most commonly used. It should be noted that there are no air voids specifications for UTBWCs, but they are generally considered porous, and measurements indicate that the air voids range from 5% to 20% (Akin et al., 2020).

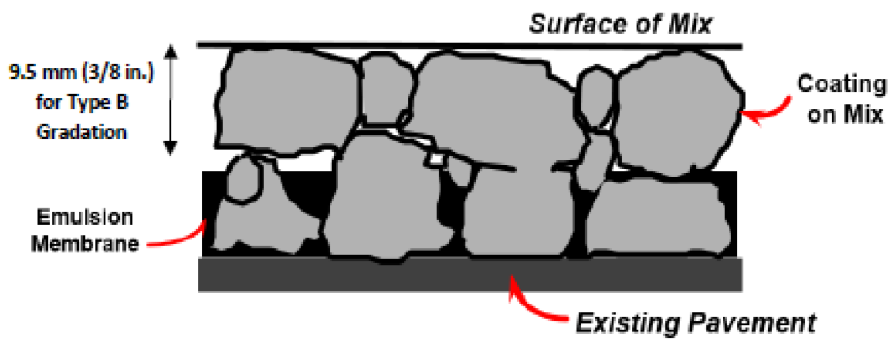

Figure 1.1 UTBWC Schematic example (after MnDOT)

Table 1.1 Gradations of UTBWC

Gradations	Aggregate size	Final thickness	Applications
Type A	1/4 inch	1/2 inch	Residential applications with light traffic counts
Type B	3/8 inch	5/8-7/8 inch	Residential and metropolitan settings with moderate truck traffic
Type C	1/2 inch	5/8-7/8 inch	Heavy highways with high traffic count

UTBWC was first developed in the late 1980s in France, and it was introduced to the United States in 1992 under the name of NovaChip®. After that, some UTBWC projects were implemented in Texas, Alabama, Mississippi, Pennsylvania, and Minnesota. Hanson (2001) did a review of UTBWC performance in Pennsylvania which shows that it provides a surface with excellent macro texture qualities, good aggregate retention, and excellent bonding of the very thin surfacing to the underlying pavement. Nationwide research has also shown that UTBWC application provides a smooth surface, while addressing raveling, low-severity top-down cracking, and oxidation (Newcomb, 2009). Minnesota Department of Transportation (DOT) evaluated the performance of the UTBWC surface on US-169 by collecting and analyzing the pavement condition data and comparing the performance with the control section (Ruranika & Geib, 2007; Ahmed, 2009). It was observed that UTBWC courses were durable and appropriate for pavements in need of major rehabilitation. A comprehensive study was conducted by Ji et al (2015), which monitored and analyzed the in-situ performance of UTBWC surfaces based on the pavement condition data such as pavement condition rating (PCR), structural number (SN) and international roughness index (IRI) and compared the data with control sections. The study revealed that UTBWC can be considered as a low-cost preventive maintenance treatment which improves the functional and structural condition of roadways and extends the pavement's service life.

The advantages of UTBWC are summarized below (Ahmed, 2010):

- Reduce deterioration caused by traffic, weathering, raveling, and oxidation
- Reduce traffic noise
- Provides good skid resistance
- Sealing small cracks
- Speedy application during construction
- Immediate opening to traffic
- 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

Despite these advantages, UTBWC winter performance and maintenance have been in question. When used in colder climates, UTBWC tends to freeze more rapidly and retain snow and ice for a longer period of time. For instance, there were observations in Minnesota that UTBWC was causing ice and snow build-up in the wheel paths on some sections, which required increased treatment frequency and additional amount of material to achieve a clear and dry surface (Wegman, D. & Sabouri, M., 2018). Akin et al. (2020) conducted an interview to identify the problems with permeable friction courses (PFC, including UTBWC). The survey responses indicate that these surfaces perform differently during winter conditions than dense graded pavements (DGPs). In this study, the following disadvantages of PFCs during winter conditions were also noted.

- Freeze sooner and for a longer period of time than DGPs.
- Surface dries slower due to moisture trapped in the voids that is “pumped” to the surface by traffic, which can lead to icing when adjacent DGPs are dry.
- Sanding is not recommended to improve friction because of the potential to clog PFCs.
- May require higher application rates of deicers or more frequent application of de-icing chemicals.
- May require more frequent application of deicers and for a longer duration than DGPs.
- Snow and ice tend to stick to PFCs sooner because the surface is generally cooler, and snow and ice remain longer because salts have dissipated from the pavement surface.
- Preventative salting (anti-icing) is not as beneficial because the salt penetrates the void structure; however, this is less problematic in highly trafficked areas or if larger salt grains are used.
- Icing problems can occur in the transition zones between PFCs and DGPs due to a lack of deicers being carried over by traffic.

UTBWC Winter Maintenance

For winter maintenance, different methods are used prior to and during a winter storm. Some typical methods used are as follows (Board, 2016; Wegman et al., 2018; Onyango et al., 2022):

Anti-icing: This is a proactive method; it involves the application of liquid chemicals to the roadway before a winter storm to prevent ice from bonding to the pavement. One of the benefits of anti-icing is the reduction of the amount of time required to restore the roads to bare pavement. Anti-icing can be performed before the storm during a regular shift, and this may offer cost savings over de-icing (in material, personnel, and equipment). In other cases, pre-treatment of roads before a winter storm may be performed with solid materials. However, the application of an anti-icing procedure requires precise weather forecasts since the material may be washed away if rain comes first, or wasted if forecasts are wrong (Board, 2016).

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. This method can either be used as a complement to the plowing method to help make the process easier and more effective, and/or as an independent approach for getting the bare pavement goals. The best practice for de-icing methods to improve effectiveness is by using prewetted deicers.

Pre-wetting: This involves the addition of brine or other liquids to granular materials to help jump-start the melting process. Pre-wetting can be applied to the spinner, in the pile, or by adding brine in the spreader box. The benefits that come with this method include achieving faster melting, decreasing material use, and, because it is in a semi liquid state, helping to prevent material scatter.

Snow Plowing: The removal of snow and ice from the roadway by mechanical means. Plowing is typically complemented with the addition of de-icing chemicals. For some conditions, it may be necessary to plow the roadway while adding sand or other abrasives. Plowing alone may have no environmental impacts from chemical use, but the trade-off is less effective snow removal, lower levels of service, and potentially a higher risk to public safety.

A variety of winter maintenance materials are available to control snow and ice. Table 1.2 is a summary of the commonly used winter maintenance materials as reported in terms of materials, their uses, attributes, and environmental impacts by the Local Road Research Board, Minnesota DOT (Board, 2016).

Many studies showed that snow and ice accumulate differently on open graded friction course (OGFC) pavements, which have been used across the United States since the 1950s, to improve the surface frictional resistance of asphalt pavements than on traditional fine dense graded pavements (Huber, 2000). This is potentially because the open-graded rough (popcorn like) texture of OGFC surfaces tends to accumulate ice and snow. Several DOT operations forces have expressed a need for improved methods for snow and ice removal on porous pavements, where traditional methods are not as effective (Huang et al., 2019). The larger voids content of OGFC provides an insulating effect, resulting in lower temperatures within the pavement layer compared with traditional pavement surfaces. Also, studies have shown that when the temperature of an OGFC drops below freezing, it will stay below freezing longer than regular dense HMA pavements and thus results in delayed thawing (Yildirim et al., 2006). Although UTBWC is considerably thinner and less porous than OGFC, the open-graded surface is rough enough to accumulate snow and ice. Some of OGFC winter maintenance practices, which have been thoroughly studied and implemented, may also be applicable to UTBWC winter maintenance (Onyango et al. 2022).

Based on such review, the following components were considered with SHA staff for possible inclusion in the survey with HMA winter maintenance staff for reporting and documenting the District's experience in Maryland:

- Overall assessment of winter performance of UTBWC sections in Maryland.
- Current winter maintenance practices and materials for UTBWC and traditional HMA pavements in Maryland.
- Whether snow and ice accumulate quicker on UTBWC than traditional HMA.
- Whether UTBWC requires more frequent winter maintenance.
- Whether specific maintenance methods and anti-icing materials are, or can be, beneficial in the snow and ice removal process for UTBWC, such as prewetting, rock salt (NaCl), or other specific practices.

Table 1.2 Winter maintenance materials (Board, 2016)

							
	Abrasives	Solid Rock Salt	Salt Brine	Magnesium Chloride	Calcium Chloride	Acetates	
		(NaCl)		$(MgCl_2)$	$(CaCl_2)$	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	- 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)	- Excellent melting capacity - Lower cost compared to other chemicals - Clear roads of snow and ice	- 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	- 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	- Better cold temperature performance than rock salt - Reduced amount of product used	- Non-corrosive	- Non-corrosive - Often used on bridge anti-icing systems
Negative Attributes	- 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	- Corrosion - Impacts on roadside and waterways - Pavement deterioration - Corrosion to vehicles and infrastructure	- Corrosion - Impacts on roadside and waterways - Corrosion to vehicles and infrastructure	- Pavement deterioration - Corrosion - Material cost is higher than rock salt - More corrosive than sodium chloride	- Pavement deterioration - Corrosion - Material cost is higher than rock salt - More corrosive than sodium chloride	- Expensive	
Environmental Impacts	- 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	- Entry into waterways - Impact to roadside soil, vegetation	- Entry into waterways - Impact to roadside soil, vegetation	- Entry into waterways - Impact to bridge infrastructure - Leaching/run-off from stockpiles	- Entry into waterways - Impact to roadside - May mobilize heavy metals in soil releasing them into the water	- Their decomposition consumes dissolved oxygen, resulting in lower oxygen levels in water.	

1.3 Organization of the Report

This final research project report is organized in the following sections. Chapter 1 includes the introduction, study objectives and scope of work, background information on performance of UTBWC sections and organization of the report. Chapter 2 presents the assessment of UTBWC's winter performance in Maryland, including SHA's District survey responses and relevant conclusions. Chapter 3 includes a description of the data and analysis for identifying meaningful and prevailing factors affecting UTBWC winter performance. Chapter 4 summarizes the overall study results and findings and project recommendations for UTBWC winter maintenance in Maryland.

Chapter 2 Assessment of UTBWC's Winter Performance in Maryland

To solicit input from Maryland District's on winter performance of UTBWC sections, a survey was prepared with SHA staff and distributed to maintenance personnel responsible for such activities. The survey questionnaire is included in Appendix A. The research team collected and analyzed the survey responses and feedback. Overall, twenty-seven responses were collected for the SHA Districts with UTBWC sections. The replies provided feedback on section location, issues encountered with snow and ice accumulation, winter maintenance practices, materials and effectiveness, and an overall assessment of the performance of UTBWC sections. Details of the survey results are provided next.

2.1 Survey Responses

Thirty-three UTBWC sections are identified in six Districts (Figure 2.1) in Maryland. District 2 has the most UTBWC sections while District 3 has none. Responses for twenty-seven sections (82%) were received as shown in Table 2.1. Out of these sections, fourteen responses (52%) indicated that UTBWC sections have experienced moderate to severe snow and ice issues, while the remaining thirteen (48%) showed the same winter performance as adjacent non-UTBWC sections. In this study, snow and ice issues were defined as snow and ice buildup on the UTBWC surface requiring greater maintenance effort and ice control material rates. From the survey responses, it should be noted that most of the UTBWC sections in District 1 were paved recently (2021), and the respondents were not able to provide reliable responses due to lack of winter storm experience on these sections.

Figure 2.1 Maryland Districts

Table 2.1 UTBWC in Maryland & survey responses

District	County	Route	RNUM	Direction	Begin MP	End MP	Winter performance
1	DO	MD	14	Both	8.47	10.80	No issues
1	DO	MD	16	Both	7.35	9.53	No issues
1	DO	MD	16	Both	19.64	24.41	No issues
1	DO	MD	331	Both	11.94	13.82	No issues
1	DO	MD	392	Both	0.00	0.08	No issues
1	SO	MD	388	Both	0.11	2.38	No issues
1	SO	MD	667	Both	9.04	10.40	No issues
1	SO	MD	667	Both	12.65	17.61	No issues
1	WO	MD	575	Both	0.08	2.64	No issues
2	CE	MD	272	Both	9.44	10.95	-
2	CE	MD	781	Both	0.00	0.80	-
2	CO	MD	302	Both	1.47	2.56	-
2	CO	MD	404	E	1.19	4.76	-
2	CO	MD	404	W	1.23	1.35	-
2	CO	MD	404	W	4.57	4.76	-
2	KE	MD	213	Both	16.61	17.87	Moderate
2	QA	MD	213	Both	8.50	9.08	Moderate
2	QA	MD	302	Both	0.00	3.70	Moderate
2	QA	MD	404	E	0.00	0.52	Moderate
2	TA	MD	33	Both	18.14	20.83	Moderate

2	TA	MD	404	E	1.02	5.77	Moderate
2	TA	MD	404	W	1.02	1.15	Moderate
2	TA	US	50	E	4.70	7.81	Moderate
2	TA	US	50	E	19.95	24.42	Moderate
4	BA	MD	30	Both	0.39	4.97	Severe
4	BA	MD	130	Both	0.31	1.74	Moderate
5	CA	MD	2	Both	2.83	7.99	Moderate
5	CA	MD	2	Both	14.64	18.71	Moderate
6	AL	MD	36	Both	24.30	29.39	No issues
6	AL	MD	61	Both	0.35	1.83	No issues
6	WA	IS	70	W	11.19	12.23	No issues
7	HO	IS	70	W	13.13	19.39	Severe
7	HO	MD	100	Both	3.66	7.40	No issues

Figure 2.2 shows the geographical locations of the UTBWC sections. The map was developed in ArcGIS based on the global positioning system (GPS) coordinates of the start and end-points of the UTBWC sections (i.e., each point represents either the start or the end of a UTBWC section). The sections were color coded to reflect reported winter maintenance issues as reported by District personnel (i.e., red colored sections represent sections where severe issues were encountered, yellow represents moderate issues, while green indicates no winter maintenance issues reported). Figure 2.3 presents the locations of UTBWC sections along with the highway network in Maryland. It can be observed that most of the UTBWC sections are located in the east portion of the state. The location of the UTBWC sections in combination with local climatic data (i.e., temperature, precipitation or snow accumulation) were analyzed and discussed in the follow-up section for pertinent conclusions in regard to their performance.

2.2 Winter Performance of UTBWC Sections

One of the objectives of the study was to explore how prevalent the snow and ice issues are in Maryland. Respondents were asked to identify whether snow and ice issues occur on the UTBWC pavement sections during snow or winter storm events. The responses are summarized in Figure 2.4. More than half (14 out of 27) of the respondents indicated that snow and ice issues exist on UTBWC sections. While most of these sections experienced moderate issues, two sections (MD 30 and IS 70 in Howard County) reported severe issues (road shut down for safety until further maintenance performed).

Figure 2.5 shows the satisfaction rating of the UTBWC winter performance. Respondents were asked to rank the winter performance from 0 to 5, with 5 being the most satisfied. The majority (9 out of 15) respondents are fairly satisfied with UTBWC winter performance, while two respondents are concerned about snow and issues.

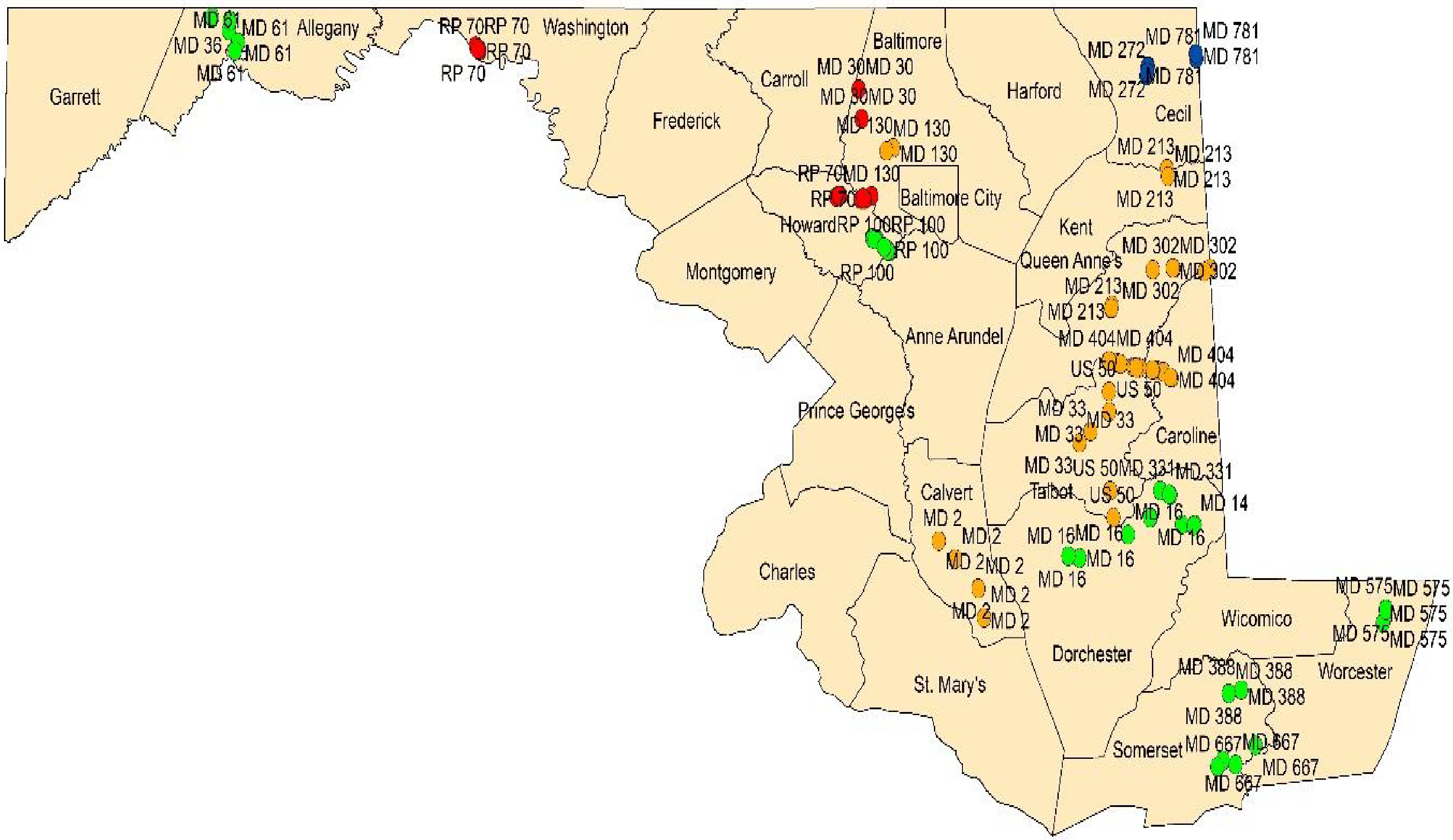

Figure 2.2 Geographical locations of UTBWC pavements in Maryland

Note: Red - severe issues; Yellow - moderate issues; Green - no issues; Blue - No responses from Districts

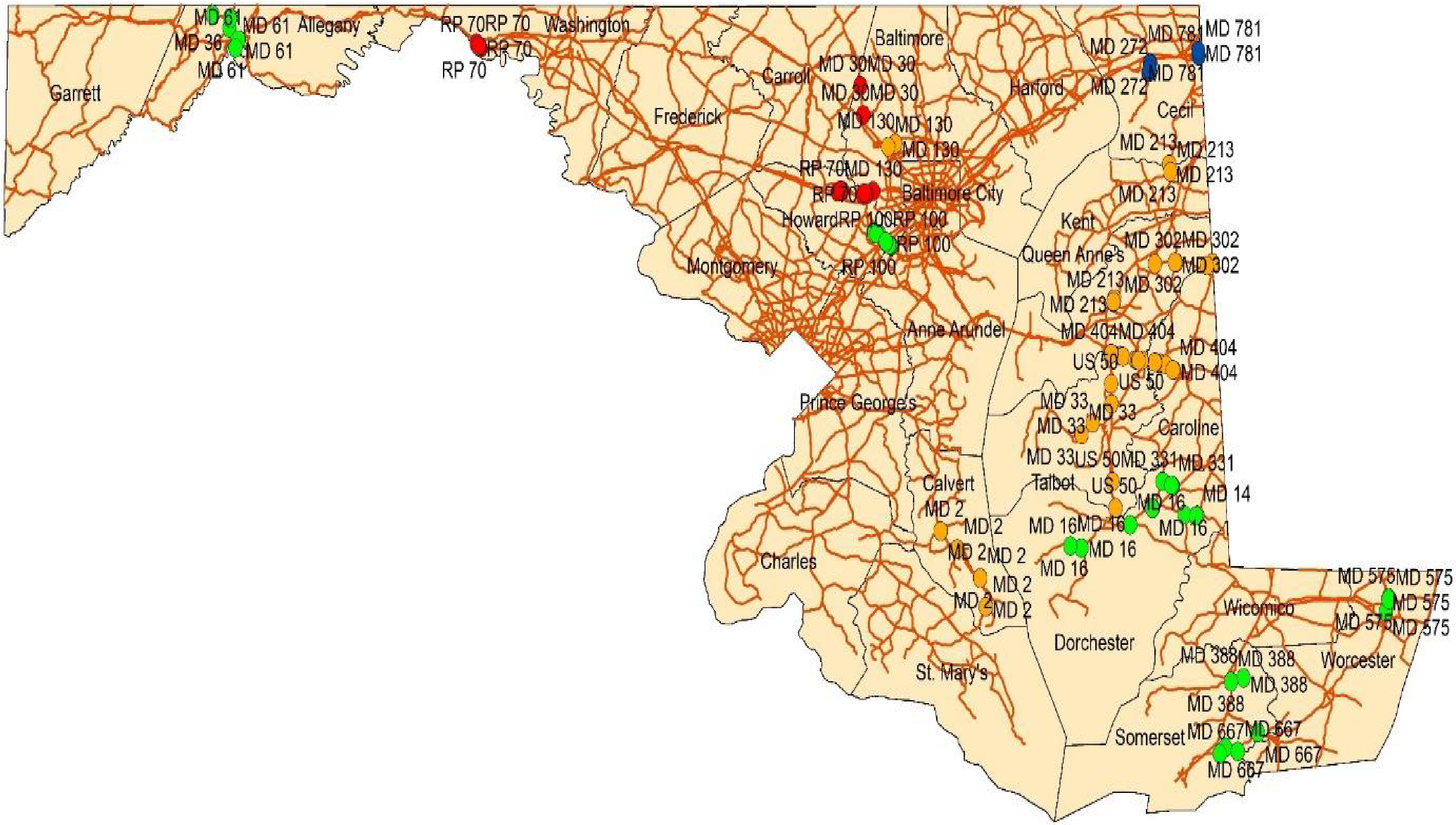

Figure 2.3 Geographical locations of UTBWC pavements with highway network

Note: Red - severe issues; Yellow - moderate issues; Green - no issues; Blue - No responses from Districts

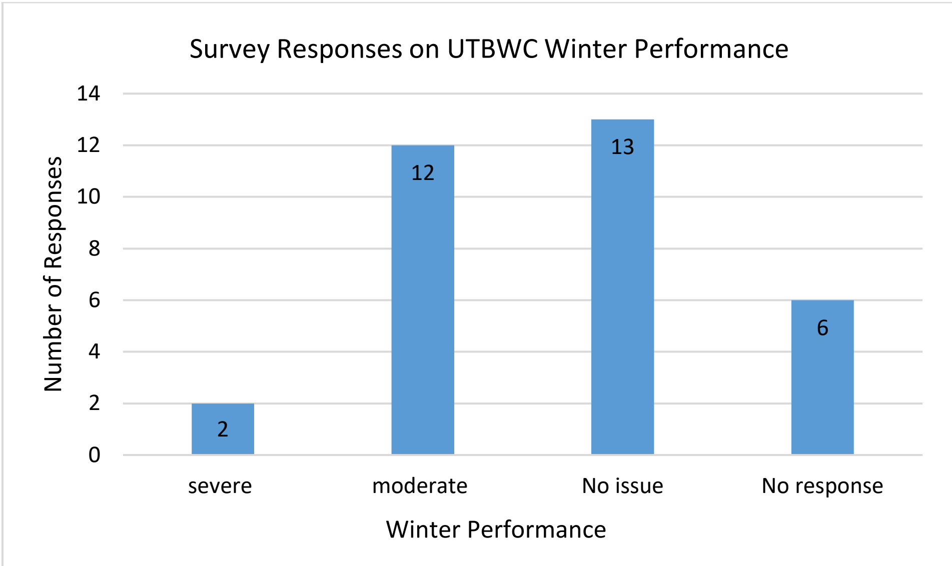

Figure 2.4 Survey responses on UTBWC winter performance

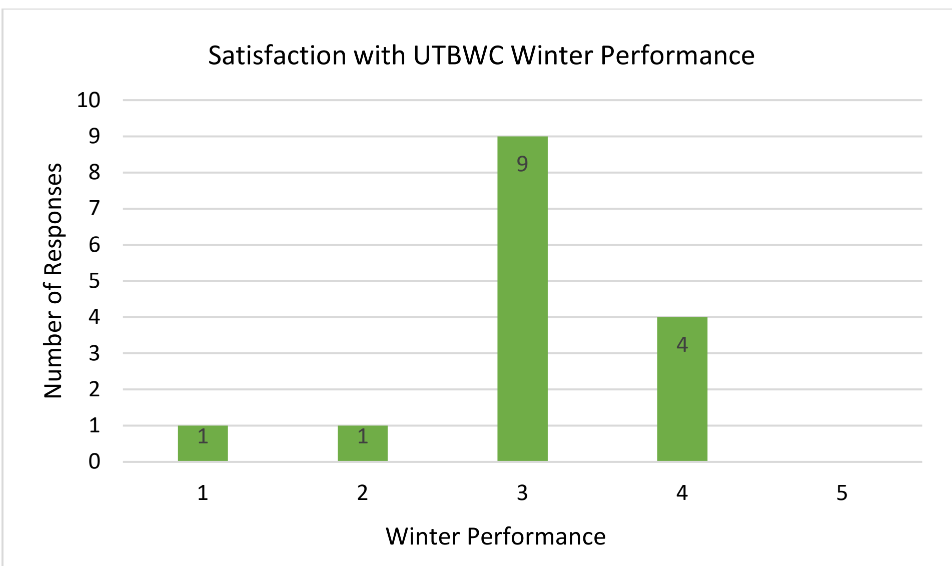

Figure 2.5 Satisfaction with UTBWC winter performance (0-5)

Note: 15 responses

2.3 Winter Maintenance Treatment and Materials

The survey participants were asked to identify the effectiveness of alternative winter maintenance methods and materials that are considered for use in UTBWC sections. Various winter maintenance techniques were evaluated by the respondents and were ranked in terms of their effectiveness (i.e., rated with 1 as ineffective, to 5 as very effective). The median effectiveness response is presented in Table 2.2. The most common winter maintenance technique reported is snow plowing followed by anti-icing, de-icing, prewetting, and sanding. In terms of effectiveness, the median shows that snow plowing is the most effective technique with a median effectiveness of 4, followed by anti-icing, de-icing and prewetting. Sanding was only applied on one UTBWC section (US 50). Although sanding appears to be effective, it is not commonly used in Maryland for winter maintenance. Thus, further field assessment is needed to identify whether such technique is effective for UTBWC winter maintenance sections in Maryland.

Table 2.2 Current winter maintenance techniques and effectiveness

Winter maintenance techniques	Effectiveness*	UTBWC sections
De-icing	2	4
Anti-icing	2	23
Snow plowing	4	27
Prewetting	1.5	2
Sanding	4	1

Note: *median response

In terms of materials used for winter maintenance, solid rock salt (100%) and salt brine (85%) are the most used (Figure 2.6). Abrasives were used on two UTBWC sections and only one section was treated with magnesium chloride. In the survey responses, some respondents provided the application rates and feedback on the effectiveness of these materials. Such information is summarized in later sections.

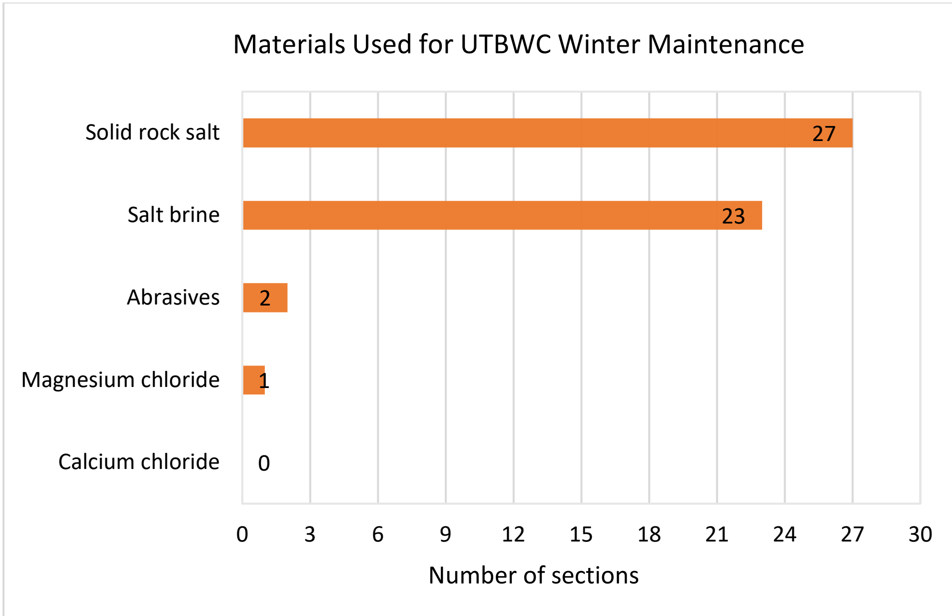

Figure 2.6 Materials used for UTBWC winter maintenance

2.4 Effectiveness of Current/Standard Winter Maintenance Procedures

While there are no specific procedures or guidelines for UTBWC winter maintenance in Maryland, the survey questionnaire asked whether standard winter practices were sufficient for treating these sections. As shown in Table 2.3, fourteen respondents indicated that the standard winter maintenance practices were effective. Six respondents mentioned that the standard winter maintenance was not sufficient to address snow or ice issues on the UTBWC in their Districts. Two responses indicated that UTBWC had to be treated more frequently and with more materials to address snow events.

Table 2.3 Effectiveness and sufficiency of standard winter maintenance on UTBWC

	Number of responses
Effective	14
Not effective	6
Effective with increased application rates	2
No response	11

2.5 Application Rates and Alternative Pre-Treatments

The questionnaire also asked respondents to identify the material application rates and alternative pre-storm treatments used on UTBWC sections. Table 2.4 summarizes the feedback. For those UTBWC that experienced snow and ice issues (e.g., MD 213, MD 33, MD 30 etc.), increased application rate and frequency were considered to address winter weather events. In some cases, the application rate and frequency had to be increased by three times (i.e., MD 30, MD 130 and IS 70). Some respondents indicated that salt brine pre-treatments were applied, but they appeared not to be effective.

2.6 Reported Issues with UTBWC in Maryland

The main winter maintenance challenges reported by respondents are summarized below:

District 1

- The UTBWC sections of roadway are new and have not had the proper time or winter weather to form honest opinions on winter performance.

District 2 (MD 213)

- During colder than normal weather UTBWC causes ice to build-up in the wheel paths on some sections of the roadway.
- UTBWC roadways have the tendency to accrue wind-blown snow.
- Open-graded components of UTBWC surfaces may require additional de-icing material compared to conventional HMA surfaces.
- Tree canopy and open field areas where wind blows snow across roadways experience more snow and ice issues.
- Additional salt/sand mix and additional staff and equipment are needed to plow. MD 33, MD 404, and US 50.
- Roads stay colder.
- The water from the median runs across the road since there are no drains in the median in that area which road is colder, so it turns to ice.
- Light snow will stick into the road.

Table 2.4 Winter maintenance materials and treatments rates for UTBWC in Maryland

District	County	Route	RNUM	Winter performance	Winter treatment application rates	Alternative pre-storm treatments
1	DO	MD	14	No issues	NA	NA
1	DO	MD	16			
1	DO	MD	331			
1	DO	MD	392			
1	SO	MD	388	No issues	Rock salt 300 lbs per lane mile (same treatment as dense graded sections)	None
1	SO	MD	667			
1	WO	MD	575	No issues	Salt 300 lbs per lane mile (same as other sections)	None
2	KE	MD	213	Moderate	33% percent increase in treatment	Salt brine
2	QA	MD	213	Moderate	NA	NA
2	QA	MD	302			
2	QA	MD	404			
2	TA	MD	33	Moderate	Double winter treatment rates (material and application)	pre-treatment doesn't not increase effectiveness
2	TA	MD	404			
2	TA	US	50			
4	BA	MD	30	Moderate to severe	Solid rock salt not effective at freezing temperature or below.	
4	BA	MD	130			

					Salt brine is used at higher rate (2 to 3 times higher material and applications)	None
5	CA	MD	2	No issues	NA	NA
6	AL	MD	36	No issues	Same treatment as other sections. 50/50 mix and up to 450lbs treatment per lane mile	Salt brine
6	AL	MD	61			
7	HO	IS	70	Severe	Increased application rate and frequency of salt (depending on the winter event, in some case up to 3-5 times)	Pre-storm application of salt brine, not effective
7	HO	MD	100	No issues	Same as other sections	Anti-icing

District 4 (MD 30 & MD 130)

- Had to put an additional liquid salt brine truck to help with ice melt to keep the road from icing over.
- UTBWC does not allow moisture/water to stay on the surface, thus this is needed for rock salt, but the surface doesn't hold any treatment long, so more treatments are needed.
- Winter maintenance of these sections takes 2-3 times the resources than other sections.
- After two winters, the road is unraveling and causing potholes.

District 7 (IS 70)

- Frequent freezing of the pavement compared to the other sections
- This section of roadway needs frequent attention, which then disrupts snow removal efforts on I-70.

- Normal winter maintenance strategies for UTBWC are NOT effective.
- Problems are consistent regardless of wind and temperatures.
- Few potholes developed.
- There is a need for excessive amounts of salt to manage this area during winter storms.
- Under current conditions, UTBWC eliminated the constant need to patch the failing pavement surface prior to the placement of UTBWC.

MD 30 Core Testing Data

The core testing data for the UTBWC on MD 30 was collected from Maryland (MD) SHA materials division. Tables 2.5 and 2.6 show the volumetric parameters measured from the core samples including G_{mm}, G_{mb} and air voids (AV). As mentioned in the literature review, UTBWC mixtures generally have higher air voids than conventional HMA mixtures, which can potentially cause pavement temperature to drop more rapidly and thus retain snow and ice for a longer period of time. It should be noted that the air voids of the core samples from MD 30 are significantly higher than the design value (10.2%). Meanwhile, severe winter maintenance issues are reported on this specific section.

Table 2.5 UTBWC core testing data from MD 30 southbound

Sample #	Sample size	G_{mb}	G_{mm}	% AV
1	4"	2.168	2.549	14.5
2	4"	2.205	2.549	15.0
3	4"	2.204	2.549	15.7
4	4"	2.151	2.549	15.7
5	4"	2.154	2.549	15.8
6	4"	2.154	2.549	16.1
7	4"	2.169	2.549	14.8
8	4"	2.175	2.549	14.7

9	4"	2.164	2.549	13.7
10	6"	2.166	2.549	15.5
11	6"	2.171	2.549	14.5
12	6"	2.170	2.549	14.9

Table 2.6 UTBWC core testing data from MD 30 northbound

Sample #	Sample size	G_{mb}	G_{mm}	% AV
14	4"	2.168	2.547	14.9
15	4"	2.205	2.547	13.4
16	4"	2.204	2.547	13.5
17	4"	2.151	2.547	15.5
18	4"	2.154	2.547	15.4
19	4"	2.154	2.547	15.4
20	4"	2.169	2.547	14.8
21	4"	2.175	2.547	14.6
22	6"	2.164	2.547	15.0
23	6"	2.166	2.547	14.9
24	6"	2.171	2.547	14.8
25	6"	2.170	2.547	14.8

Chapter 3 Methodology and Data Analysis

This chapter presents the analysis based on the data available for the UTBWC sections and the survey responses. The steps of the analysis are presented in Figure 3.1 and included: literature review and Maryland UTBWC survey responses; geographic information system (GIS) mapping and visualization; multivariate analysis; and analysis findings. The following sections describe the pertinent data preparation, geospatial analysis, and multivariate analysis.

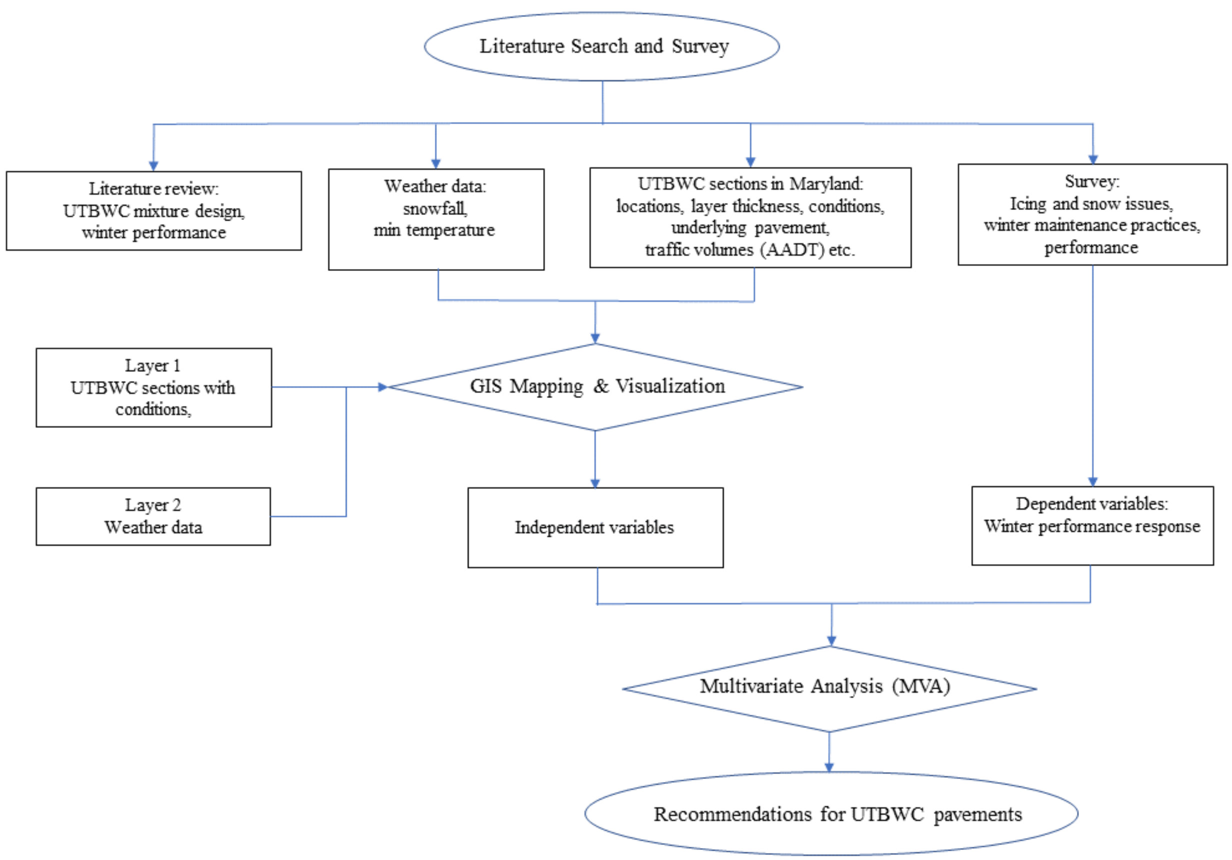

Figure 3.1 Study methodology & analysis

3.1 Weather Data for UTBWC Section Locations

As shown in Figure 3.1, weather data (such as minimum temperature and snow accumulation), were collected in order to (i) develop GIS mapping, (ii) conduct statistical analysis, and (iii) examine the prevailing factors affecting UTBWC winter performance. In this study, two types of weather data were collected. These included location specific data, which is obtained from weather stations and datasets in formats that can be imported into GIS and create weather maps. The following sections describe how weather data were collected and prepared for the analysis.

The location of specific data was obtained from the Northeast Regional Climate Center (RCC). Figure 3.2 shows the weather stations in Maryland from Northeast RCC. For a specific UTBWC location (Figure 2.2), the nearest weather station was identified. For example, as shown in Figure 3.3, the nearest weather station to UTBWC section on MD 30 is the station in Reisterstown. Once the nearest station was identified, specific weather data such as minimum temperature, snowfall, and precipitation were obtained. It should be noted that the data can be obtained in terms of daily, monthly, seasonal, yearly, or hourly values. Figure 3.4 shows an example of daily temperatures from the station located in Reisterstown. In this study, seasonal (i.e., winter season from December to February) minimum temperature and seasonal snow accumulation data were collected for years 2021 and 2022, since most of the UTBWC sections were paved in the about the past five years. The location specific data were used to conduct statistical analysis reported in later sections.

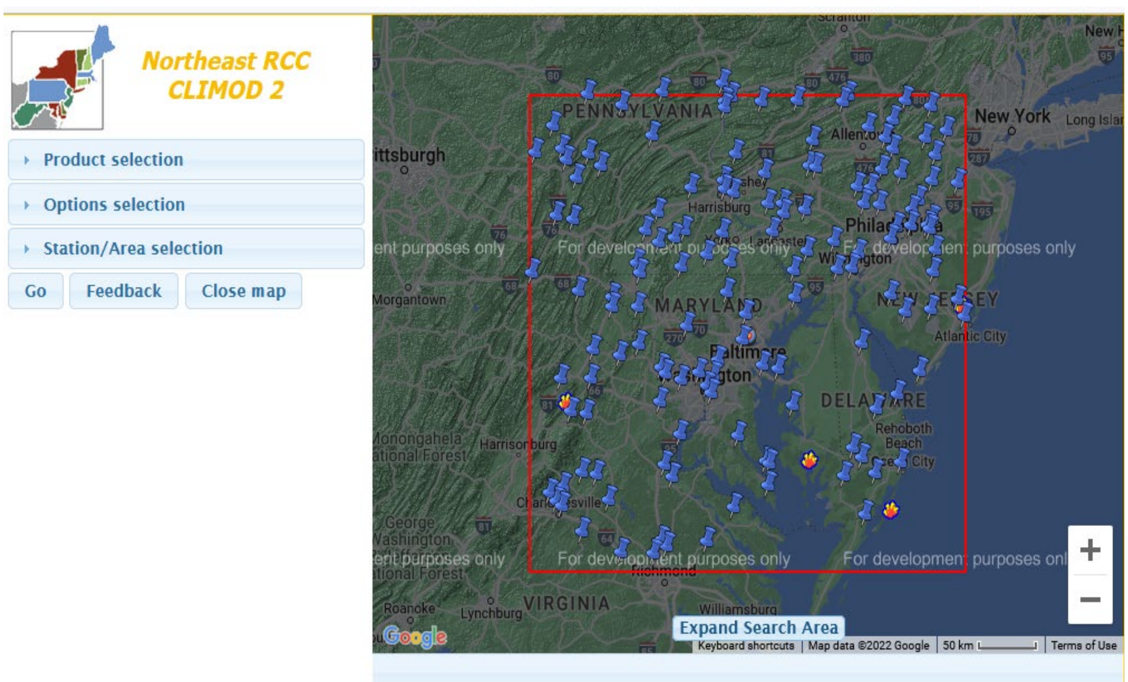

Figure 3.2 Weather stations in Maryland from Northeast RCC

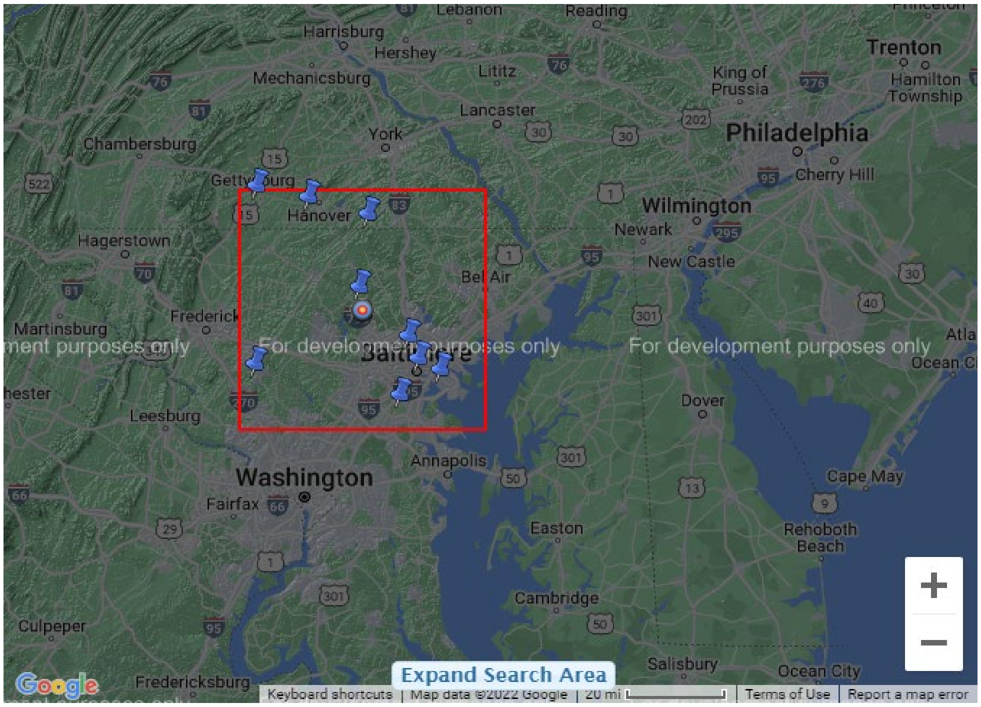

Figure 3.3 Nearest weather station (Reisterstown, MD) to UTBWC section on MD 30

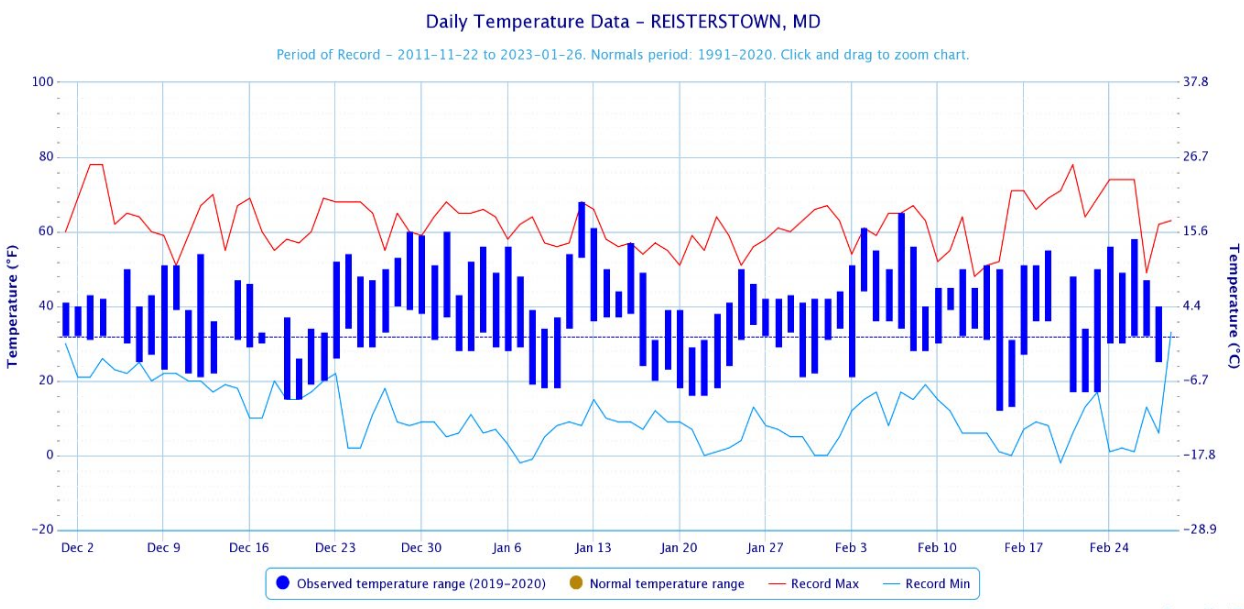

Figure 3.4 Example of Daily temperature data for MD 30

In addition to location-specific weather data, Applied Climate Information System (ACIS) data were collected from the National Oceanic & Atmospheric Administration (NOAA) database. ACIS climate data consists of in-situ observations collected from a variety of federal, regional, state, and local weather and climate networks. The advantage of the ACIS data is that they can be imported to GIS and interpolated to weather maps. This type of data is referred to as raster data. For example, Figure 3.5 represents ACIS total snowfall interpolated to a 5km-by-5km gridded map. ACIS data were primarily used to create weather maps. These weather layers were added on top of the UTBWC geographical location maps in GIS (i.e., geospatial analysis) to examine weather snow and issues occurring in certain areas with lower temperatures and higher snowfall.

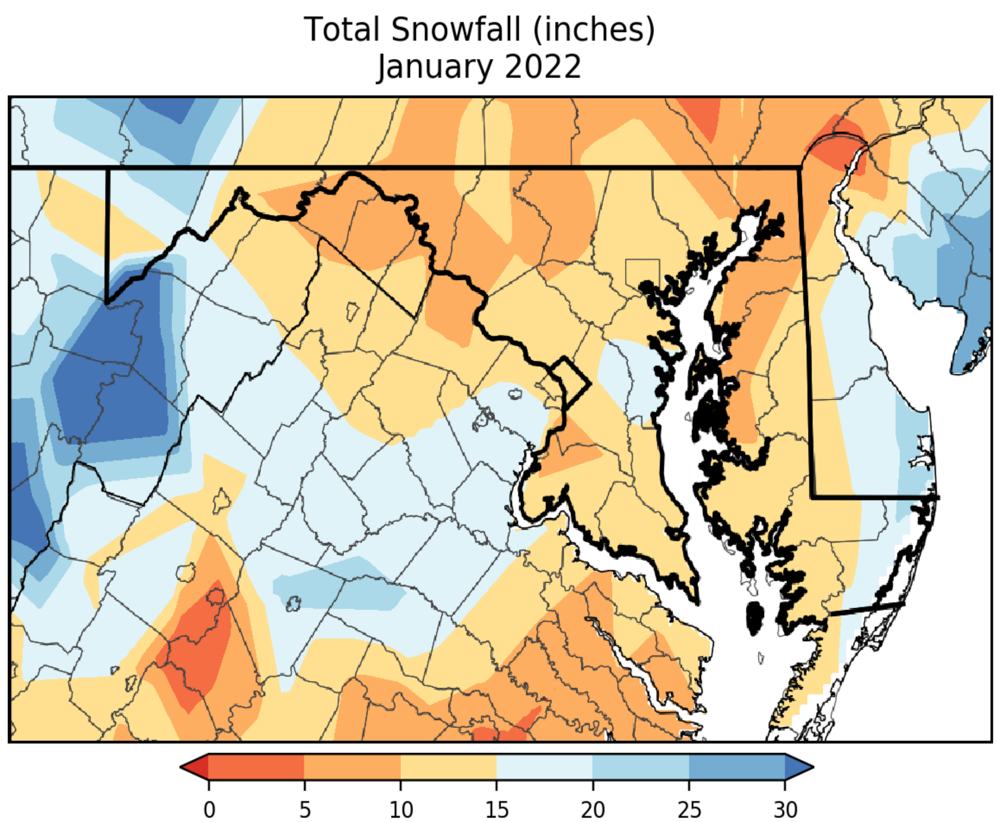

Figure 3.5 Total snowfall map for January 2022 (source NRCC)

3.2 Geospatial Analysis

Geospatial analysis involves applying various spatial analysis techniques to derive insights from the data. Some common techniques include spatial querying, spatial statistics, interpolation, network analysis, proximity analysis, and overlay operations. In this study, an overlay operation in ArcGIS was used to superimpose the survey response and weather data to identify any relationships between them. Overlay analysis represents the composite map by the combination of attributes and geometry of datasets. Attribute data is non-spatial information associated with geographic (i.e., spatial) data. For instance, the survey responses and weather data (i.e., min temperature and snow accumulation) are attributes, while geographic locations of UTBWC sections are spatial data which are represented by latitude and longitude coordinates.

The overlay operation was conducted in ArcGIS. Firstly, a vector dataset was prepared which includes the latitude and longitude coordinates of the start and end locations of the UTBWC sections. The survey responses were added to the dataset as an attribute. The dataset was imported to ArcGIS for attribute manipulation. As mentioned in section 2.1, the UTBWC sections were labeled with different colors based on the survey responses. Then, an overlay operation was conducted by adding an additional layer of weather data. Figures 3.6 to 3.9 show the results of the overlay analysis using the seasonal minimum temperature and seasonal snow accumulation from 2020 to 2021 and 2021 to 2022. From Figures 3.6 and 3.7, no clear relationship was observed between temperature and UTBWC winter performance. For instance, UBTWC sections in colder regions (e.g., MD 61 and MD 36) did not report any snow issues, while sections in milder conditions (e.g., MD 33, MD 213 and MD 30) appeared to have moderate to severe snow issues. Similarly, no noticeable relationship was observed between snow accumulation and UTBWC winter performance. However, it must be stressed that the consequence of the selected interpolation of weather is that values obtained for each climatic grid cell represent an 'average' daily condition, and thus do not necessarily represent meteorological conditions at a specific weather station location. Therefore, it is equally important to consider location-specific weather data directly obtained from the nearest weather stations.

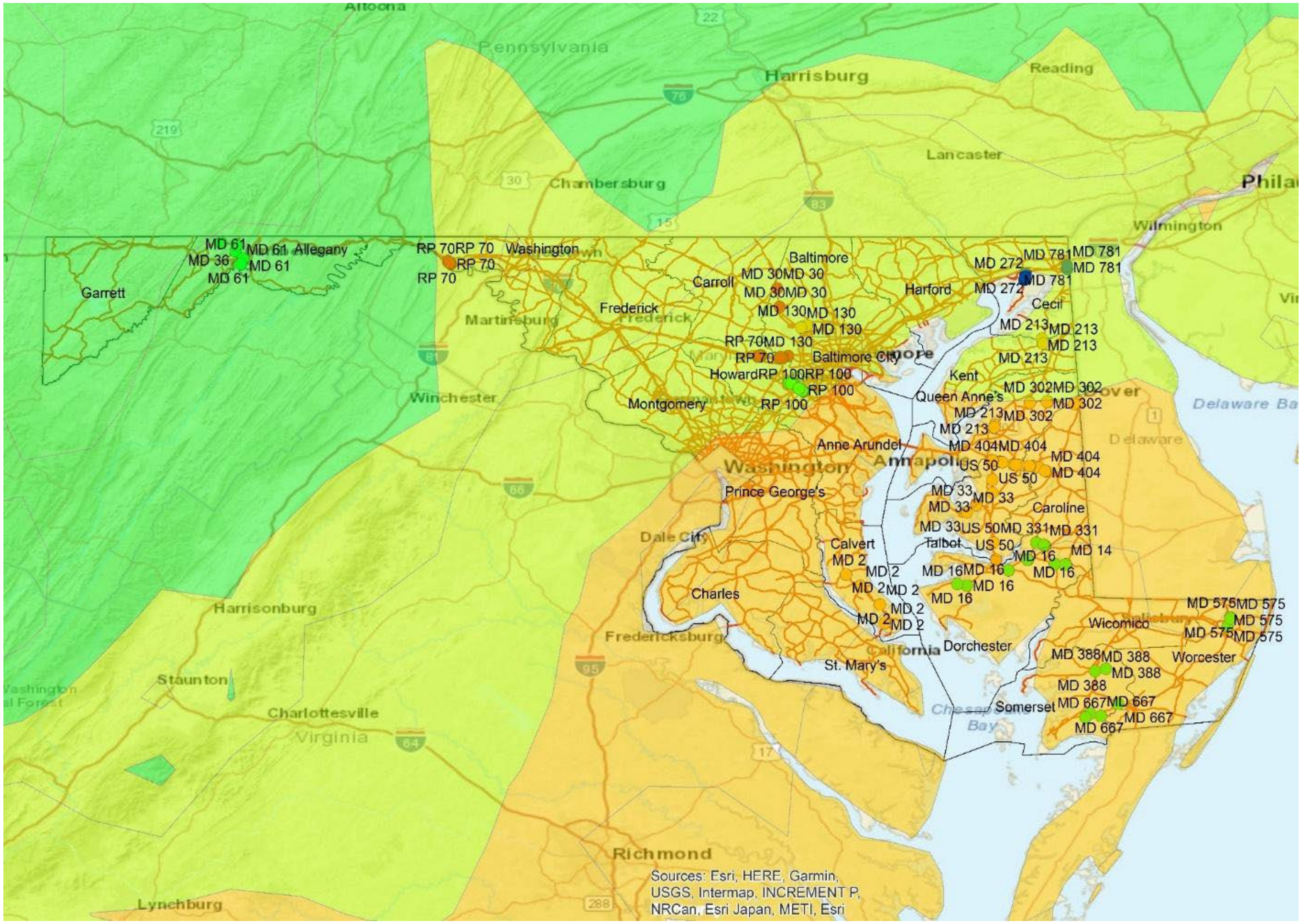

Figure 3.6 Seasonal minimum temperature 2021-2022
Note: T1 orange: 20-22°; T2 light green: 18-19°; T3 green: 16-17°

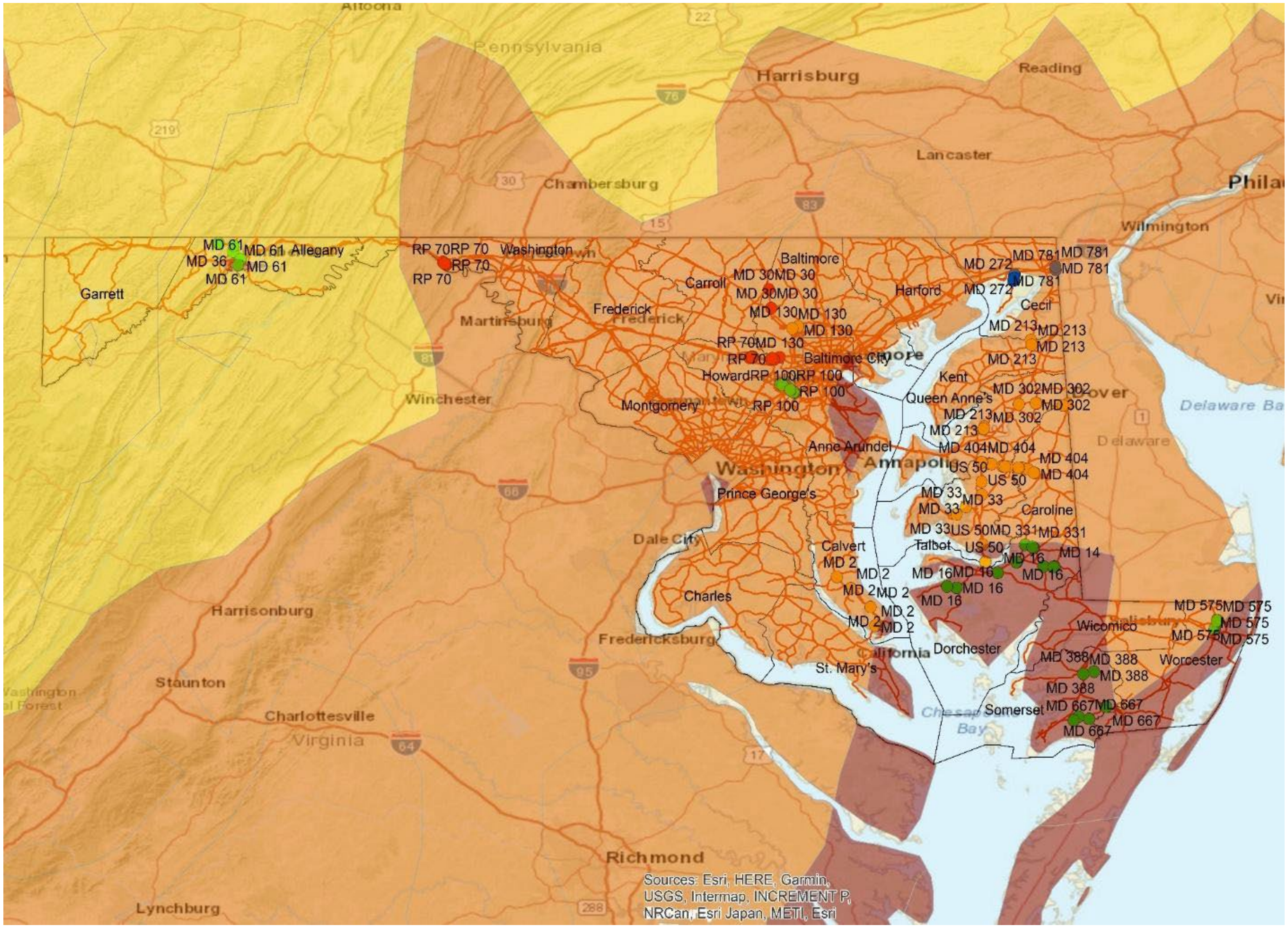

Figure 3.7 Seasonal minimum temperature 2022-2023
Note: T1 dark brown: 29-30°; T2 light brown: 26-28°; T3 yellow: 23-25°

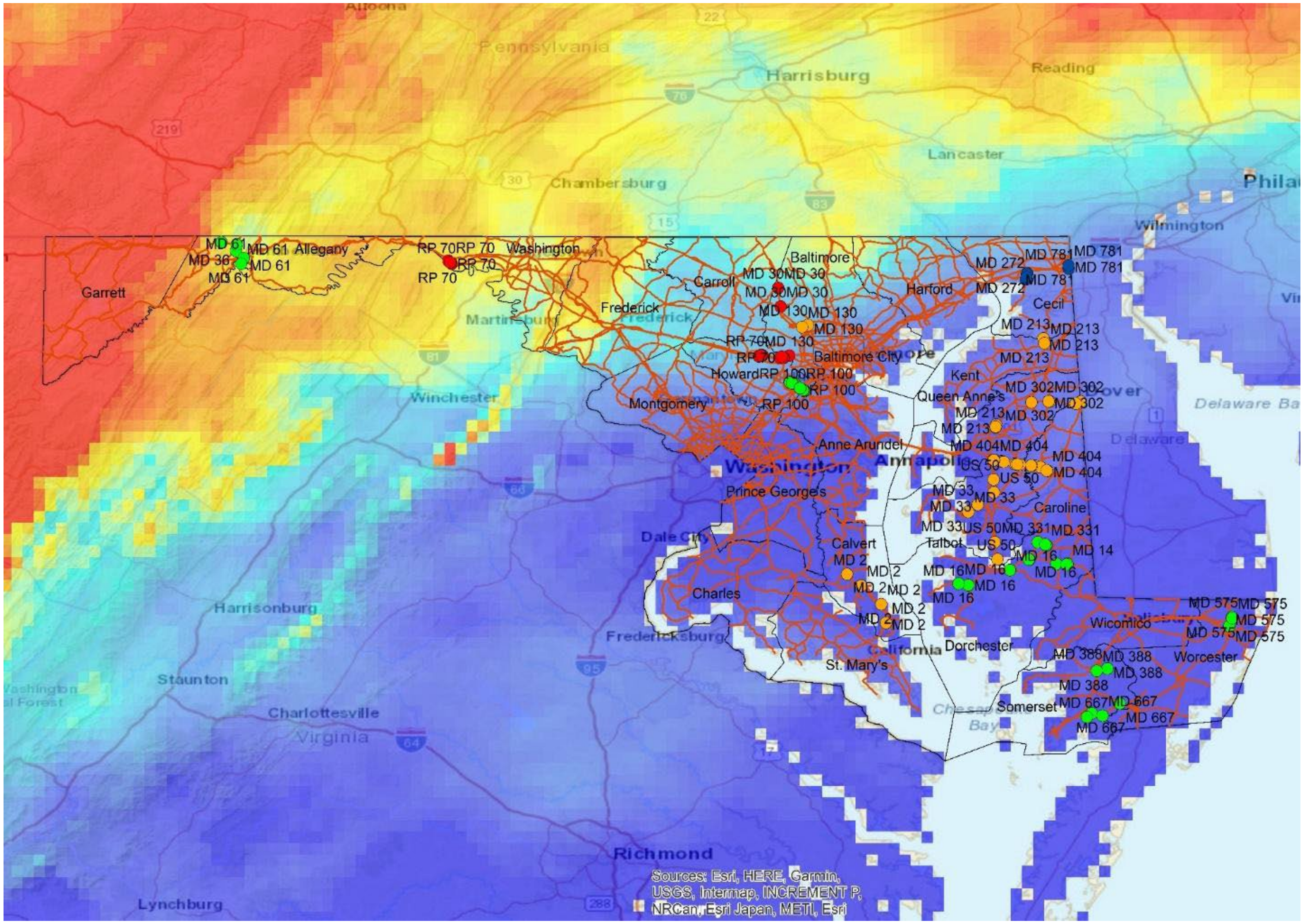

Figure 3.8 Seasonal snow accumulation 2020-2021

Note: L1 purple: 2-6 in; L2 celeste: 6 in-1 ft; L3 yellow/orange: 1-2 ft

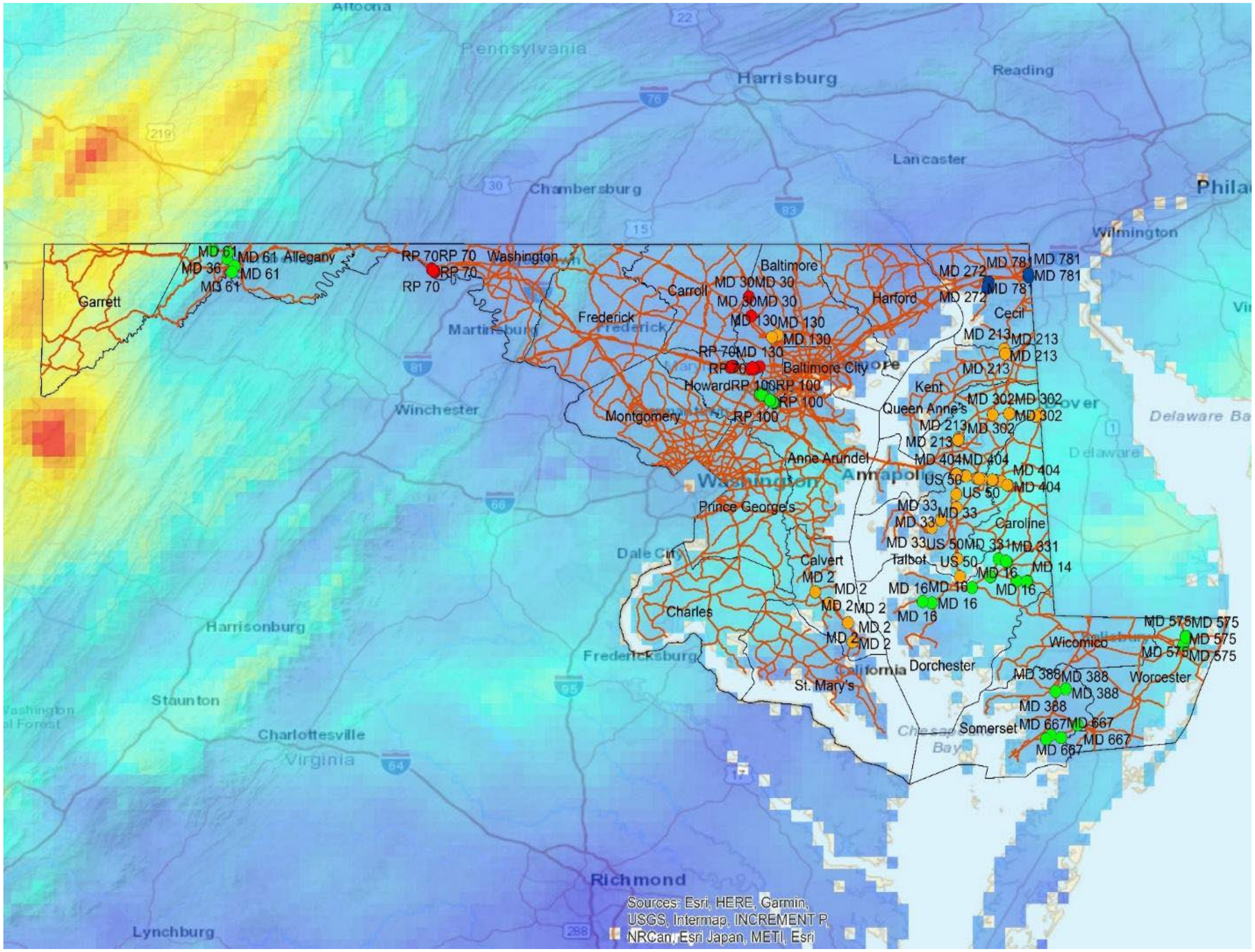

Figure 3.9 Seasonal snow accumulation 2021-2022

Note: L1 (e.g., IS70, MD30, MD130 etc.) 6 in-1 ft; L2 (MD 61 and 36, MD213, MD404 etc.) 1-2 ft

3.3 Statistical Data Analysis

3.3.1 Introduction

Generalized linear models (GLMs) were considered to examine the complex interplay of various predictors (e.g., temperature, snow accumulation, mixture, traffic volume, etc.) and their impact on winter performance. GLM is an advanced statistical modeling technique formulated by John Nelder and Robert Wedderburn in 1972. It is an umbrella term that encompasses many other models, which allows the response variable, y, also known as dependent variable, to have an error distribution other than a normal distribution. The models include linear regression, logistic regression, and Poisson regression. GLMs are flexible and powerful class of statistical models that extend the framework of linear regression to handle a wide range of response variables and error distributions. They provide a unified approach for analyzing data that do not meet the assumptions of traditional linear regression models, such as normally distributed errors or continuous response variables. GLMs allow to model various types of response variables, including binary, count, and categorical.

Linear regression is not suitable for this study because the response variable (i.e., winter performance) is not continuous but categorical. Therefore, logistic regression was employed to model the relationship between the response and predictors. Logistic regression is a process of modeling the probability of a discrete or categorical response given a set of input variables. It does not need many of the key assumptions of linear regression that are based on ordinary least squares algorithms – particularly regarding linearity, normality, homoscedasticity, and measurement level. The most common logistic regression model is a binary response (i.e., a parameter that can have two values typically represented as 0 and 1, corresponding to the absence or presence of an event, in this study either an issue or no issue with UTBWC performance). Multinomial logistic regression can model scenarios where there are more than two possible discrete responses (e.g., no issue, moderate issue and severe issue). In this study, the analysis focused on binary logistic regression because there were very few severe events (i.e., 2 observations with severe issues as shown in Table 2.1). However, ten events per response variable is a widely advocated minimal criterion for sample size considerations in logistic regression analysis.

3.3.2 Odds Ratio and Logistic Function

Logit Function and Odds

Logistic regression assumes that the logit transformation of the dependent variable has a linear relationship with the independent variables, and estimates the probability of occurrence of an event, such as performance issues or no issues with UTBWC section, based on a given dataset of dependent variables. It also helps determine which independent variables are more significant in estimating the dependent variable. Since the outcome is probability, the dependent variable is bonded between 0 and 1. In logistic regression, this is achieved by applying a logit transformation on the odds, which are the ratio of the probability that an event will occur to the probability that it will not occur. If the probability of an event occurring is p, the probability of the event not occurring is (1-p). Then the corresponding odds is a value given by:

$$Odds\ (of\ an\ event) = \frac{p}{1-p} \tag{3.1}$$

Such logit transformation of odds is also commonly known as the log odds, or the natural logarithm of odds. This logistic function is represented by the following formula:

$$logit(y) = \ln(Odds) = \ln\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_k x_k \tag{3.2}$$

Where: p is the probability of interested outcome and x is the independent variable; α and β are the coefficients of logistic regression.

Maximum likelihood is commonly used to estimate the β coefficients in a logistic model. This method evaluates different values of beta, β, through multiple iterations to optimize for the best fit of log odds. These iterations produce the log likelihood function, and logistic regression seeks to maximize this function to find the best parameter estimate. Once the optimal coefficient (or coefficients if there is more than one independent variable) is found, the conditional probabilities for each observation can be calculated, logged, and summed together to yield a predicted probability. For a binary classification, a probability less than 0.5 will predict 0 while a probability greater than 0.5 will predict 1. After the model has been computed, the goodness of fit is used to evaluate how well the model predicts the dependent variable, as explained in a follow-up section.

3.3.3 Logistic Regression Analysis

Since the purpose of the logistic regression analysis is to infer whether the winter performance issue is dependent on any of the independent variables, a reasonable number of samples is required for attaining adequate statistical power. As mentioned, ten events per variable (EPV) is a widely advocated minimal criterion for sample size considerations in logistic regression analysis. However, in this study, the number of observations (n =33) is not enough to derive the statistics that represent the parameters if all the independent variables in Table 3.1 were to be considered. Thus, it is important to select a subset of variables. A stepwise logistic regression analysis was conducted to build an accurate and parsimonious model.

Three performance matrices were computed to evaluate the goodness of fit of the models including deviance, deviance Chi-Square test, and Akaike information criterion (AIC). The larger difference between null deviance and residual deviance leads to larger Chi Squared statistic and thus smaller p value, which provides evidence against the intercept-only model in favor of the current model. AIC was used to compare the fit of different logistic regression models. A drop in AIC indicates that the model provides a better fit to the data.

To determine whether the association between the response (i.e., dependent variable) and each independent variable in the model is statistically significant, Chi-Square test of independence was used (i.e., p values associated with each independent variable in Tables 3.5 to 3.6). The null hypothesis is that there is no relationship between the two variables meaning that the independent variable is not statistically significant in predicting the dependent variable. Usually, a significance level (denoted as α or alpha) of 0.05 is used, which indicates a 5% risk of concluding that an association exists when there is no actual association. If the p-value is less than or equal to the significance level (i.e., 0.05), it can be concluded that there is a statistically significant association between the response variable (i.e., dependent variable) and the independent variable.

Tables 3.5 and 3.6 shows some examples of the developed logistic regression models and their performance. To be mentioned that Table 3.5 was the initial regression analysis based on limited data (as clarified in this Table) and used to assess how traditional lineal regression may be related to binomial logistic regression. However, the later was the focus of the analysis due to the data characteristics discussed (i.e, categorical versus numerical and correlations).

The backward elimination process was employed in which the algorithm starts with a model that includes all variables and iteratively removes variables until no further improvement is made. Since multicollinearity exists among independent variables, the correlated variables were removed in the first logistic model (i.e., logit #1 in Table 3.6 as example). A total of 10 variables were considered in the first model. A p value of 1.845e-11 associated with the Chi Square statistic of deviance indicates a good statistical fit. However, the p values associated with independent variables were computed to be 1, which indicates that a complete separation occurred. This is potentially because one of the independent variables, such as “sufficiency,” perfectly predicts the dependent variable. The variable sufficiency was extracted from the survey responses. The responses indicated that the current winter maintenance practices are not sufficient for all UTBWC sections that have winter performance issues.

In next step, variables were removed iteratively and then checked model performance. After the variable “sufficiency” was removed, the complete separation issue was resolved, for instance, logit model # 4, Table 3.6. The Chi-Square test of independence (i.e., p values associated with independent variables) indicates that vertical acceleration (VA) ($p = 0.001432$ which is less than 0.05) is the only variable that is statistically significant in predicting the dependent variable. Annual Average Daily Traffic (AADT) appear to be more significant than treatment, IRI and snow accumulation. To improve the model, the independent variables with larger p values were removed. For example, in logit #6, both p value and AIC decreased compared to model #4, and thus model #6 indicates an improved model performance. However, the Chi-Square test of independence still shows VA is the only significant variable. After a stepwise back elimination process, the best model was obtained when VA and AADT were included as independent variables. A p value of 0.000363 for VA indicates a significant relationship exists between VA and winter performance of UTBWC sections. However, it should be noted that this conclusion was drawn based on a limited number of samples. Other variables could also have a significant impact on the winter performance, but more samples are needed to produce the statistic which is able to be inferred from larger populations.

Goodness of fit

Deviance is one of the measures of goodness of fit for logistic regression. The null deviance shows how well the response is predicted by the model with only an intercept. The residual deviance shows how well the response is predicted by the model when selected independent variables are included. The difference between null deviance and residual deviance should be chi squared distributed with n (n = df of null - df of model) degrees of freedom. Thus, we can check the goodness of fit based on the p-value for the chi square distribution. The smaller the p-value associated with a specific independent variable, the higher the importance of the variable. Other means of checking goodness of fit include Hosmer-Lemeshow methods, receiver operating characteristic (ROC) curves, classification table (confusion matrix), and model validation via prediction of out of sample data.

AIC (Equation 1) was also used to evaluate the goodness of fit and select a model. AIC statistics are a measure of relative (a way to compare regression models) goodness of fit. If there is a drop in AIC by adding or reducing more predictor variables, it is evidence that the latter model provides a better fit to the data. AIC also considers model complexity. AIC statistics determine the relative information value of the model using the maximum likelihood estimate and the number of parameters (independent variables) in the model.

$$AIC = 2K - 2\ln(L) \qquad (3.3)$$

K is the number of independent variables used and L is the log-likelihood estimate.

3.3.4 Data Preparation

Independent variables

Table 3.1 summarizes the independent variables considered for logistic regression analysis. These variables include mixture inputs, construction methods, weather inputs, traffic volume, pavement conditions, and variables extracted from survey response. It can be observed that some variables are categorical such as mix method, treatment, underlying pavement, and variables extracted from survey response. Dummy variables were created to represent these categorical data. For instance, a code of 1 is used if the mixture was a hot mix and 0 if the mixture was a warm mix with refinery process. Similarly, two weather related variables were considered including seasonal minimum temperature and seasonal snow accumulation. Location-specific data from the nearest weather stations were used. Four variables were extracted from the survey response to determine whether any issue is dependent on winter maintenance practices. A master database was prepared consisting of the collected data for these variables. The data for

UTBWC sections with “both” direction in Table 2.1 was duplicated to represent the two sections in opposite directions. The duplicate records better represent the underlying effects, so the regression algorithm may provide stronger relationship between effects.

Table 3.1 Considered independent variables

Type	Independent variables	Data type
Mixture	Mix method	Categorical, 0 warm mix, refinery processed, additive: 1 hot mix
	G_{mb}	Numerical
	AV%	Numerical
Construction	Treatment	Categorical, 0 UTBWC; 1 Mill UTBWC
	Underlying pavement	Categorical, 0 flexible, 1 composite
Weather	Snow accumulation	Numerical, seasonal snow accumulation (2021-2022)
	Min temperature	Numerical, seasonal minimum temperature (2021-2022)
Traffic	AADT	Numerical
Pavement conditions	IRI	Numerical, condition year of 2021
	RUT	
	FCD	
	SCD	
	SKID	
	Anti-icing	

Survey (extracted from survey response)	Snow plowing	Categorical, winter maintenance practice on UTBWC sections and their effectiveness, 1-5 with 1 being not effective at all and 5 being very effective.
	Sufficiency of current winter maintenance procedures	Categorical, 0 being insufficient, 1 being sufficient
	Application rate	Categorical, whether increased application rate was considered; 0 normal rate, 1 increased rate

3.3.5 Correlation Analysis

Correlation among independent variables in logistic regression models can cause problems such as multicollinearity, leading to unstable and unreliable estimates of the regression coefficients. Furthermore, this can also result in a high variance in the estimates and lead to overfitting. Multicollinearity is particularly problematic when the two highly correlated independent variables are included in the same regression model. This is because their individual effects on the dependent variable are difficult to disentangle, and thus it becomes challenging to determine the unique contribution of each independent variable. As a result, the regression coefficients for each independent variable may become unstable and unreliable. Therefore, correlation analysis was conducted to identify any correlation among independent variables. Table 3.2 shows the Pearson correlation coefficients among mix method, G_{mb}, air voids (AV%) and treatment. As expected, a strong correlation exists between G_{mb} and AV%. Multicollinearity was also identified among the mix method, G_{mb} and VA%. As shown in Table 3.3, five pavement condition indices were considered, and correlation may likely exist among these variables based on domain knowledge. Table 3.3 shows the correlation coefficients between the pavement condition indices. Multicollinearity was observed among IRI, FCD, and SCD. The correlation among variables from survey responses was also examined and presented in Table 3.4. Correlation was observed only between sufficiency and application rate. The correlation coefficient between seasonal minimum temperature and snow accumulation was calculated to be 0.9285536, which indicates that the two variables are highly correlated. To address the issue of highly correlated independent variables, the most common method is to remove one of the independent variables from the model.

Table 3.2 Correlation coefficients between mix method, G_{mb}, VA and treatment

	Mix method	G_{mb}	VA	Treatment
Mix method	1.0000000	-0.8843046	0.9193322	0.3353468
G_{mb}	-0.8843046	1.0000000	-0.9218131	-0.4288669
AV%	0.9193322	-0.9218131	1.0000000	0.2872821
Treatment	0.3353468	-0.4288669	0.2872821	1.0000000

Table 3.3 Correlations between pavement condition indices

	IRI	RUT	FCD	SCD	SKID
IRI	1.00000000	0.0576818	0.7606831	0.7361368	-0.09285516
RUT	0.05768180	1.0000000	0.1235889	0.2323502	-0.10299780
FCD	0.76068312	0.1235889	1.0000000	0.9461643	-0.16113126
SCD	0.73613675	0.2323502	0.9461643	1.0000000	-0.14285200
SKID	-0.09285516	-0.1029978	-0.1611313	-0.1428520	1.00000000

Table 3.4 Correlations among survey response variables

	Sufficiency	Anti-icing	Snow plowing	Application rate
Sufficiency	1.0000000	-0.4239922	0.4380923	0.7745967
Anti-icing	-0.4239922	1.0000000	-0.2317249	-0.3217204
Snow plowing	0.4380923	-0.2317249	1.0000000	0.3998222
Application rate	0.7745967	-0.3217204	0.3998222	1.0000000

Table 3.5 Initial regression analysis and variables

<table>
<tr><th>Regression Analysis</th><th>Independent variable(s)</th><th>Dependent variable (s)</th><th>Smallest p</th><th>Conclusions</th></tr>
<tr><td rowspan="4">Multinomial Logistic Regression</td><td>Temp,
Snow
Mixture</td><td rowspan="4">1, 2, 3 *</td><td>0.155
(mixture)</td><td rowspan="4">Snow and temperature correlated

Small sample size (few severe cases)</td></tr>
<tr><td>Temp
Mixture</td><td>0.175
(temp)</td></tr>
<tr><td>Snow
Mixture</td><td>0.1863
(mixture)</td></tr>
<tr><td>Mixture</td><td>0.181</td></tr>
<tr><td rowspan="2">Binomial Logistic Regression</td><td>Snow acc
Min_temp</td><td rowspan="2">0, 1 **</td><td>0.104
(Snow acc)</td><td>Snow and temperature are correlated</td></tr>
<tr><td>Snow acc
mixture</td><td>N/A</td><td></td></tr>
</table>

	Min_temp mixture		N/A	Predicted probabilities are either 0 (not occurred) or 1 (occurred)
linear Regression	Min_temp mixture	1,2,3 ***	0.168 (mixture)	independent variables: numerical

Notes:
Performance Issues (dependent variable)
* 1 no issues; 2 moderate; 3 severe (1, 2 and 3 are considered factors)
** Binary Variable: 0 no issues, 1 with issues (moderate or severe)
*** 1 no issues; 2 moderate; 3 severe (1, 2 and 3 are considered numerical numbers)

Independent Variables
Temp: T1, T2 and T3 based on 2021-2022 seasonal average min temperature (Figures 3.1 to ???)
Snow: L1, L2 and L3 based on 2021-2022 seasonal snow accumulation (Table 1)
Mixture: Mixture No. as shown in Table 1

Snow_acc: actual seasonal snow accumulation (2021-2022) for each section
Min_temp: actual minimum temperature (2021-2022) for each section

3.4 Logistic Regression Analysis

The follow-up analysis includes an extended search for logistic regression models as shown in Table 3.6. The findings are discussed in a follow-up section.

Table 3.6 Logistic regression model performance

Logistic regression models	Independent variable(s)	p-vale (significance)	Comments	Goodness of fit (model)
	VA	1	Warning: fitted probabilities numerically 0 or 1 occurred	Null deviance: 8.8473e+01 on 63 degrees of freedom
	C. Treatment	1		
	Snow accumulation	1		

Logit model #1	AADT	1	Possible reasons: 1. too many predictor variables with too few data, 2. There is a predictor that completely separates the dependent variable (i.e., sufficiency).	Residue deviance: 3.7130e-10 on 49 degrees of freedom p-value for chi square: 1.845e-11 AIC: 30
	IRI	1		
	SKID	1		
	Anti icing	1		
	Snow plowing	1		
	Sufficiency	1		
	Underlying pavement	1		
Logit model #2	VA	1		Null deviance: 8.8473e+01 on 63 degrees of freedom Residue deviance: 3.7130e-10 on 50 degrees of freedom p-value for chi square: 7.152e-12 AIC: 28
	Treatment	1		
	Snow accumulation	1		
	IRI	1		
	SKID	1		
	Anti icing	1		
	Snow plowing	1		
	Sufficiency	1		
	VA	1		Null deviance:

Logit model #3	Treatment	1		8.8473e+01 on 63 degrees of freedom Residue deviance: 3.7130e-10 on 51 degrees of freedom p-value for chi square: 2.659e-12 AIC: 26
	Snow accumulation	1		
	IRI	1		
	Anti icing	1		
	Snow plowing	1		
	Sufficiency	1		
Table 3.7 Logistic regression model performance (continued)				
Alternative Variables reduction				
Logit model #4	Intercept	0.000453		Null deviance: 88.473 on 63 degrees of freedom Residual deviance: 11.153 on 58 degrees of freedom p-value for chi square: 4.309e-13 AIC: 23.153
	VA	0.001432		
	Treatment	0.806230		
	IRI	0.783149		
	Snow accumulation	0.826693		
	AADT	0.341282		
	Intercept	0.000308		Null deviance:

Logit model #5	VA	0.000751		88.473 on 63 degrees of freedom
	Snow accumulation	0.522229		
	C. Treatment	0.407935		Residual deviance: 12.101 on 60 degrees of freedom p-value for chi square: 3.065e-14 AIC: 20.101
Logit model #6	Intercept	0.000540	Comparing model #5 and 6, both residual and AIC decrease. AADT appears to more significant than Treatment	Null deviance: 88.473 on 63 degrees of freedom Residual deviance: 11.317 on 60 degrees of freedom p-value for chi square: 1.873e-14 AIC: 19.317
	VA	0.000812		
	AADT	0.238134		
	Snow accumulation	0.806222		
	Intercept	0.000132		Null deviance: 88.473 on 63 degrees of freedom
	VA	0.000271		

Logit model #7	Treatment	0.401860		Residual deviance: 12.514 on 61 degrees of freedom AIC: 18.514 p-value for chi square: 4.659e-15 AIC: 18.514
Table 3.8 Logistic regression model performance (continued)				
Logit model #8	Intercept	0.000161	Comparing models #7 and 8: AADT has second smallest p-value among all independent variables.	Null deviance: 88.473 on 63 degrees of freedom Residual deviance: 11.375 on 61 degrees of freedom p-value for chi square: 2.826e-15 AIC: 17.375
	VA	0.000363		
	AADT	0.193249		
	Intercept	0.000142		Null deviance:

Logit model #9	VA	9.02e-05	Comparing models #8 and #9: Model #8 better with a slightly lower residual deviance.	88.473 on 63 degrees of freedom Residual deviance: 13.395 on 62 degrees of freedom p-value for chi square: 7.49e-16 AIC: 17.395
Logit model #10 (demo)	VA	1	Sufficiency caused complete "separation."	
	Sufficiency	1		

Chapter 4 Study Findings & Recommendations

4.1 Summary findings of UTBWC Performance in Maryland

The objectives of this research were to investigate how prevalent the winter performance issues are in Maryland, provide an overall assessment analysis of the UTBWC winter performance in the state, and identify recommendations for appropriate monitoring, managing, salting, and snow removal for UTBWC.

4.1.1 Overall Assessment of UTBWC performance in Maryland

The survey results show that more than half of the reported UTBWC sections experienced moderate to severe winter performance issues such as accumulation of snow and ice formation. The surface temperature of UTBWC is expected to be lower than that of conventional HMA sections eventually due to higher air voids. Subsequently, ice and snow may accumulate faster, freeze quicker, and melt slower on UTBWC sections compared to conventional HMA surfaces. Therefore, higher winter maintenance may be required in terms of materials and treatment frequency for UTBWC. Some District maintenance personnel reported addressing UTBWC snow and ice issues by increasing winter maintenance application rates. Based on the survey responses and feedback from SHA staff, there are no in-place training and/or established guidelines for snow and ice control specifically for UTBWC sections. Thus, for the sections that issues were encountered, winter maintenance personnel attempted to increase the application rate and material to address winter performance issues. Beyond winter performance issues, these sections have performed well as reported regarding pavement conditions. The survey responses indicated that UTBWC extends the pavement's service life. Due to higher mixture air void content, UTBWCs are very effective in displacing moisture from the pavement surface and thus may reduce traffic accidents during wet conditions.

4.1.2 Effectiveness of Current Winter Maintenance Strategies from MD Districts Personnel

The survey responses indicated that the current winter maintenance practices often do not sufficiently address the snow and ice issues that are encountered on UTBWC sections. In summary, snow plowing is the most common winter maintenance practice in Maryland, and in most cases has proven to be effective for UTBWC sections. However, the survey responders reported that additional staff and equipment are needed to increase the frequency of plowing to address a winter event. Anti-icing procedures are also used to prevent snow and ice from bonding to the pavement. De-icing has been applied to a much lesser degree (i.e., applied on only four UTBWC sections). The predominant material used by MDSHA for de-icing roadways during snow events is rock salt. However, it has been found that the UTBWC pavement surfaces are significantly more difficult to maintain ice-free using rock salt. UTBWCs require more frequent applications of rock salt and still tend to be icier than adjacent dense graded sections. Salt brine was applied by some Districts as an alternative pre-storm treatment, but it has been considered ineffective against ice forming. In conclusion, alternative winter maintenance practices and guidelines need to be explored to identify possible best practices for UTBWC sections in Maryland.

4.1.3 Summary & Findings based on Data Analysis

The geospatial analysis indicated that the snow and ice issues may not be dependent only on temperature and/or snow accumulation. This has been proven by the fact that snow and ice issues are not observed on UTBWC surfaces (e.g., MD 61 and MD 36) in colder regions (i.e., Allegory County) with higher snowfall accumulation. In other words, winter weather is a necessary but not sufficient condition to cause winter performance issues. The logistic regression showed that mixture air voids appear to be a significant variable regarding winter performance. Additionally, the feedback from SHA material divisions indicated that there is no specification for gap-graded requirements of UTBWC projects. The voids of the UTBWC mixtures varies considerably, for instance, the AV ranges from 7% to 13% for the mixtures used in Maryland. Thus, a relationship between air void content of UTBWC mixtures and increased snow and ice issues is expected. Greater air voids result in lower pavement temperature, which allows water and snow to become trapped more easily and freeze faster than other pavement surfaces. The higher open void structure also creates conditions for snow and ice to bond to the pavement. It should be noted that the logistic regression analysis was conducted with a very limited number of observations. More data is needed to further validate the analysis and conclusions.

4.2 Study Recommendations

There is a consensus between the experience of other agencies (literature review) and the survey responses from the Maryland Districts on the expected difference in performance between

UTBWC and dense graded pavements in terms of snow accumulation, formation of ice, and the need for more intensive use of salt and de-icing operations. Thus, the following recommendations for winter maintenance of UTBWC sections are provided herein based on the study analysis and findings.

4.2.1 Recommendations for potential improvements of Winter Maintenance of UTBWC

Snow plowing: It is recommended to increase resources and dedicated equipment for more frequent plowing on historically troubled UTBWC sections. UTBWC may be more easily damaged by snowplows than dense graded pavements, and compacted snow tends to bond more on UTBWC sections. To reduce damage to pavement surfaces, shoes should be used to keep plow blades just above the pavement surface or rubber-edged blades.

Anti-icing: Anti-icing procedures involve a combination of liquid, dry solid, and pre-wetted chemicals applied at appropriate times, considering temperature, amount of moisture, and traffic conditions. A comprehensive guideline developed by the Federal Highway Administration (FHWA) for anti-icing is included in Appendix B. Precise timing for anti-icing procedures is critical. A maintenance team should be ready to apply chemicals soon after sufficient precipitation has fallen to activate the anti-icing materials, but before snow or ice bonds to the pavement. Anti-icing is recommended if temperatures are above 20°F. Pre-wetted salts and chemicals are recommended to improve effectiveness. If liquid solution such as salt brine is used, it is recommended to use fan spray nozzles instead of stream spray for liquid anti-icing. It also helps to spread more uniformly and provide better adhesion to the road surface. Additionally, more liquid anti-icing is expected as UTBWC surfaces displace water/moisture more easily. Liquid material application and pre-wetted solid deicers are recommended to prevent formation of ice.

De-icing: De-icing of UTBWC sections during and after a storm is recommended even if anti-icing is applied. Anti-icing with a planned transition to de-icing on UTBWC sections during a storm event can increase effectiveness and reduce clean-up effort at the end of the storm.

Alternative Winter Treatment and Materials: Materials used for UTBWC winter maintenance in Maryland were mainly solid rock salt (NaCl), and salt brine. Only one section reported the application of calcium chloride (CaCl2). Generally, higher salt and brine application rates should be expected on UTBWC surfaces. When the temperature is below 20°F, it is recommended to add additives to standard salt brine, such as calcium chloride ($CaCl_2$) with recommended rates of 10%, and other alternative products. When ice is formed on a pavement surface, a high dosage of $CaCl_2$ may be applied for treatment. Fan nozzles should be used for liquid applications to ensure uniform application. Since sanding was applied only in one UTBWC section providing satisfactory results, further field assessment is needed to identify whether such technique is effective in Maryland.

Statewide Guidelines & Training: A statewide manual on winter maintenance of UTBWC sections is recommended to be developed and implemented for the state of Maryland. The FHWA recommendations (Appendix B) may be used as an initial guide and further fine-tuning based on Maryland experience from its implementation. More training with snow and ice control procedures should be implemented for operators to improve efficiency with controlling snow and ice. Training by commercial product vendors of equipment and materials on their usage could also help to improve winter maintenance performance and reduce costs.

4.2.2 Suggested Monitoring Procedures for Winter Maintenance of UTBWC

To provide effective and efficient winter maintenance operations for Maryland, the following monitoring procedures are recommended:

Monitor Pavement Temperature: The proper timing and application of winter maintenance alternatives requires a real time monitoring of pavement temperature, as well as weather monitoring conditions. While atmospheric conditions may be obtained from weather stations in the vicinity of UTBWC sections (as attempted in this study), Road Weather Information Systems, RWIS, may be used with pavement surface sensors (i.e., able to provide real data on both temperature and moisture monitoring). Other options may be the use of infrared sensors and imaging fixed at location, and/or on winter maintenance equipment for real time monitoring of temperature and moisture. This will help to monitor and adjust winter maintenance treatment as operations take place.

Effectiveness of Current & Alternative Winter Treatments: Assessment of the effectiveness of the current winter treatment, and thus determination of appropriate adjustments in winter maintenance techniques and frequency, is also critical for improving performance. Thus, alternative treatments need to be assessed for local conditions and materials.

Winter Maintenance Database & Historical Performance: Since UTBWC winter performance is affected from many variables not often easily quantified, the availability of a database with historical records will be beneficial to identify potential issues and parameters not initially considered or encountered in setting up the proper winter maintenance for each section. The availability of historical records will reveal such issues as well as comparable performance analysis of alternative treatments.

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Appendix A

MD SHA Project

Performance of Ultra-Thin Bonded Wearing Course (UTBWC) During Winter (snow, ice) Events in Maryland

Survey Questionnaire documenting UTBWC experience in Maryland

<u>Project Objectives - Introduction</u>

The scope of this study is to review how well UTBWC sections perform in Maryland and identify prevalent issues. Objective of this questionnaire is to "Survey Experts opinion in Maryland" collecting and documenting the experience of winter maintenance experts in Maryland including the following:

The survey includes three sections: The first section, Part A, helps to identify whether there are snow and ice issues with UTBWC sections and how prevalent and serious these issues are compared with traditional HMA pavements; The second section, Part B, is related to the winter maintenance practices in Maryland; while the third section, Part C, is associated with the performance of UTBWC.

1. **<u>Please complete a survey for each UTBWC section in your District.</u>**
2. *<u>Forward completed survey to Prof. Dimitrios Goulias, University of Maryland, leading this study:</u>* *dgoulias@umd.edu*

Name:____

Job Responsibility: ____

email:______________________________Phone: __________________________

Part A. UTBWC sections in Maryland

Identify UTBWC pavement section(s) location (complete as needed for each section):

1. Identify specific UTBWC pavement section (complete as needed for each section):

   District #: Route Number - Milepost start- end ______________________________

   (Example: District 4: MD 30 – MP 0.39 to 4.97)

2. Are there snow and ice issues with this UTBWC roadway during snow or winter storm events? (Snow and ice issues are commonly defined as snow and ice buildup on the UTBWC surface requiring greater maintenance effort and ice control materials to address an event)

   □ No issues

- ☐ Moderate
- ☐ Severe (road shut down for safety until further maintenance performed)

3. Are snow and ice control issues greater than adjacent non-UTBWC sections?
   - ☐ Yes
   - ☐ No

Please include any additional comments in regards to the UTBWC sections in your District:

____

____

Part B. Winter maintenance on UTBWC

4. Are standard winter maintenance procedures effective and sufficient for snow and ice control on this section of UTBWC?
   - ☐ Yes
   - ☐ No
5. What winter maintenance techniques(s) do you adopt? (Select all that apply)
   - ☐ De-icing
   - ☐ Anti-icing
   - ☐ Pre-wetting
   - ☐ Snow plowing
   - ☐ Sanding
6. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of de-icing on this section of UTBWC?
   - ☐ 0
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5
7. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of anti-icing on this section of UTBWC?
   - ☐ 0
   - ☐ 1
   - ☐ 2

- ☐ 3
- ☐ 4
- ☐ 5

8. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of pre-wetting on this section of UTBWC?
   - ☐ 0
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5
9. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of the snow plowing on this section of UTBWC?
   - ☐ 0
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5
10. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of sanding on this section of UTBWC?
    - ☐ 0
    - ☐ 1
    - ☐ 2
    - ☐ 3
    - ☐ 4
    - ☐ 5
11. What winter maintenance materials do you use on UTBWC? (Select all that apply)
    - ☐ Abrasives
    - ☐ Solid rock salt
    - ☐ Salt brine
    - ☐ Magnesium chloride
    - ☐ Calcium chloride

- ☐ Acetates
- ☐ Others (please be specific) ____

12. Are there different considerations on winter maintenance between this section of UTBWC and adjacent dense graded pavements?
    - ☐ Yes
    - ☐ No
13. Can UTBWC snow and ice issues been addressed by increasing the volume/frequency of salt or deicers?
    - ☐ Yes
    - ☐ No
14. Is there any extra cost associated with the UTBWC winter snow and ice control?
    - ☐ Yes
    - ☐ No

Please provide feedback on the following questions

15. What winter maintenance materials (as Q12) treatment rates and times are being applied to this section of UTBWC during snow events?

    ____

    ____

    How such winter maintenance materials treatment rates and times compare to non UTBWC adjacent sections?

    ____

    ____

16. What alternative pre-storm treatments have been tried and which is the most effective pretreatment in various situations?

    ____

    ____

17. Are you aware of any other winter maintenance issues on UTBWC?

    ____

    ____

18. Are you aware of snow and ice issues that happen at certain areas of UTBWC sections (e.g., rural, tree canopy, and super-elevation)?

____

____

19. Please identify if current winter maintenance strategies for UTBWC are effective

____

____

20. Are you aware if UTBWC snow and ice problems are prevalent with wind intensity or very cold conditions?

____

____

21. Do you have in place training or specific snow and ice control guidelines for UTBWC pavements?

____

____

What would you recommend for UTBWC winter maintenance?

____

____

Part C. Performance of UTBWC sections

22. On a scale of 0 – 5, how satisfied are you with the performance and effectiveness of this section of UTBWC in properly addressing winter storm events?
    - ☐ 0
    - ☐ 1
    - ☐ 2
    - ☐ 3
    - ☐ 4
    - ☐ 5
23. Are you aware of any performance issues with this section of UTWBC?
    - ☐ Yes
    - ☐ No

    If Yes, please indicate any challenges or issues with UTWBC winter maintenance ______

____

____

On a scale of 0 – 5, how satisfied are you with the performance of this section of UTBWC for extending the life and serviceability of the pavement?

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Please indicate how UTBWC may have affected pavement condition and long-term performance:

____

____

Please feel free to include any additional comments from your experience in regards to the three survey sections on UTBWC performance in Maryland.

____

____

____

Appendix B

Table B1. Weather event: moderate or heavy snowstorm. (FHWA, 2012)

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	pavement surface at time of initial operation	maintenance action	dry chemical spread rate, kg/lane-km (lb/lane-mi)		maintenance action	dry chemical spread rate, kg/lane-km (lb/lane-mi)		
			liquid	solid or prewetted solid		liquid	solid or prewetted solid	
Above 0°C (32°F), steady or rising	Dry, wet, slush, or light snow cover	None, see comments			None, see comments			1) Monitor pavement temperature closely for drops toward 0°C (32°F) and below 2) Treat icy patches if needed with chemical at 28 kg/lane-km (100 lb/lane-mi); plow if needed
Above 0°C (32°F), 0°C (32°F) or below is imminent; *ALSO* **-1 to 0°C (30 to 32°F)**, remaining in range	Dry	Apply liquid or prewetted solid chemical	28 (100)	28 (100)	Plow accumulation and reapply liquid or solid chemical as needed	28 (100)	28 (100)	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 55 kg/lane-km (200 lb/lane-mi) to accommodate longer operational cycles 2) Do not apply liquid chemical onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply liquid or solid chemical	28 (100)	28 (100)				
-4 to -1°C (25 to 30°F), remaining in range	Dry	Apply liquid or prewetted solid chemical	55 (200)	42-55 (150-200)	Plow accumulation and reapply liquid or solid chemical as needed	55 (200)	55 (200)	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 110 kg/lane-km (400 lb/lane-mi) to accommodate longer operational cycles 2) Do not apply liquid chemical onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply liquid or solid chemical	55 (200)	42-55 (150-200)				
-10 to -4°C (15 to 25°F), remaining in range	Dry, wet, slush, or light snow cover	Apply prewetted solid chemical		55 (200)	Plow accumulation and reapply prewetted solid chemical as needed		70 (250)	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 140 kg/lane-km (500 lb/lane-mi) to accommodate longer operational cycles 2) If sufficient moisture is present, solid chemical without prewetting can be applied
Below -10°C (15°F), steady or falling	Dry or light snow cover	Plow as needed			Plow accumulation as needed			1) It is not recommended that chemicals be applied in this temperature range 2) Abrasives can be applied to enhance traction

Table B2. Weather event: frost or black ice. (FHWA, 2012)

PAVEMENT TEMPERATURE RANGE, TREND, AND RELATION TO DEW POINT	TRAFFIC CONDITION	INITIAL OPERATION			SUBSEQUENT OPERATIONS			COMMENTS
		maintenance action	dry chemical spread rate, kg/lane-km (lb/lane-mi)		maintenance action	dry chemical spread rate, kg/lane-km (lb/lane-mi)		
			liquid	solid or prewetted solid		liquid	solid or prewetted solid	
Above 0°C (32°F), steady or rising	Any level	None, see comments			None, see comments			Monitor pavement temperature closely; begin treatment if temperature starts to fall to 0°C (32°F) or below and is at or below dew point
-2 to 2°C (28 to 35°F), remaining in range or falling to 0°C (32°F) or below, *and* equal to or below dew point	Traffic rate less than 100 vehicles per h	Apply prewetted solid chemical		7-18 (25-65)	Reapply prewetted solid chemical as needed		7-18 (25-65)	1) Monitor pavement closely; if pavement becomes wet or if thin ice forms, reapply chemical at higher indicated rate 2) Do not apply liquid chemical on ice so thick that the pavement can not be seen
	Traffic rate greater than 100 vehicles per h	Apply liquid or prewetted solid chemical	7-18 (25-65)	7-18 (25-65)	Reapply liquid or prewetted solid chemical as needed	11-32 (40-115)	7-18 (25-65)	
-7 to -2°C (20 to 28°F), remaining in range, *and* equal to or below dew point	Any level	Apply liquid or prewetted solid chemical	18-36 (65-130)	18-36 (65-130)	Reapply liquid or prewetted solid chemical when needed	18-36 (65-130)	18-36 (65-130)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency 3) It is not advisable to apply a liquid chemical at the indicated spread rate when the pavement temperature drops below -5°C (23°F)
-10 to -7°C (15 to 20°F), remaining in range, *and* equal to or below dew point	Any level	Apply prewetted solid chemical		36-55 (130-200)	Reapply prewetted solid chemical when needed		36-55 (130-200)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency
Below -10°C (15°F), steady or falling	Any level	Apply abrasives			Apply abrasives as needed			It is not recommended that chemicals be applied in this temperature range