# An Investigation of the Impact of Asphalt Mix Types on Predicted Distresses Using the PMED Software

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## Abstract

The specifications for asphalt concrete (AC) mixes and resulting mix designs vary among and within highway jurisdictions. The performance of each mix type depends on materials composition and quality, traffic loads, climatic exposures, etc. The AASHTOWare Pavement ME Design (PMED) software is a comprehensive tool for the design and analysis of pavement structures incorporating various design input parameters including different properties of AC mixes. In this study, design trials were completed using the PMED software v3.0 to investigate the impact of different AC mix types on the predicted distresses in new flexible pavements and the suitability of the PMED software for this impact assessment. The trials included four different AC mixes for the surface AC layer and three different AC mixes for the base AC layer from Manitoba and Ontario. This resulted in design trials for 12 combinations of AC surface and base layers. For each combination, design trials were run for 11 weather stations across Canada, which resulted in a total of 132 design runs for the investigation.

The results from this study indicated that a higher effective binder (i.e., increased VMA) content in surface layer AC mixes results in increased AC layer rutting and bottom-up fatigue cracking (BUFC). A higher density of surface AC layer mixes results in a reduced amount of AC layer rutting and BUFC. The effects of AC mix properties on the predicted top-down fatigue cracking (TDFC) and transverse cracking (TC) were inconsistent and the reason for such inconsistent variations is unclear. The properties of base layer AC mixes have no or minimal effect on the predicted distress, except for the density of base AC layer that show some effect on the predicted BUFC. The predicted total rutting followed the similar trends as the AC layer rutting. Varied climatic exposures has significant or noticeable effect on the predicted distresses. In general, a higher maximum air temperature results in increased rutting in AC layer, a higher mean air temperature results in reduced BUFC and TDFC, a colder air temperature in winter results in increased TC. The predicted International Roughness Index (IRI) depends on predicted total rutting, total fatigue cracking (BUFC plus TDFC) and TC. The freezing index and amount of precipitation have minimal effect on the predicted IRI.


## Introduction

The stiffness of an asphalt mix in terms of structural layer coefficient, layer equivalency or other mechanistic properties is a key parameter for pavement design including AC layer thickness determination. The long-term performance of an AC layer also depends on its structural stiffness such as resilient modulus and dynamic modulus, and flexibility such as tensile strength to withstand rutting and cracking. However, the specifications and quality requirements of AC mixes generally vary among the highway agencies. An agency may also have multiple specifications for AC mixes. For example, an agency may have AC mixes that contain dense graded, open graded or gap graded aggregate gradations. The requirements for physical and volumetric properties including the gradation of aggregates may also vary among AC mixes even they fall under dense graded mixes. The binder used in AC mixes may be one of available many performance or penetration viscosity grade asphalt binders. AC mix additives may include polymer, anti-stripping additives like lime, or warm mix additives, for examples. As a result, the stiffness, flexibility and performance of AC mixes vary widely. An AC mix performance is also influenced by the exposed climate. Therefore, each AC mix should be designed with a balance of stiffness, flexibility, stability and durability with the selection of appropriate mix compositions and properties including gradation and quality of aggregates.

In empirical pavement methods, the total pavement structure requirements are established based on design inputs such as subgrade material stiffness, traffic loads, service quality after construction and the desired service quality at the end of design service life. The thickness of each layer material is then determined based on the stiffness and structural layer coefficient or layer equivalency of each layer material. An example of empirical design approach is the procedure incorporated in the AASHTO 1993 pavement design guide[1], which is still a predominant approach for flexible pavement design. This design approach provides a design (total) structural number (SN) based on subgrade stiffness, design traffic loads and other design inputs for the design of a flexible pavement. The design SN is then converted into the thickness of different layer materials using their structural layer coefficient ($a_i$) values. The $a_i$ value of each material depends on its elastic or resilient modulus ($M_r$), which in turns depends on the composition and properties of that respective material. For example, an asphalt mix with 10% air voids (AV) will exhibit a lower elastic modulus and thereby, a lower $a_i$ value than a mix with 7% AV. This will affect the required thickness of a pavement structure when using the AASHTO 1993 pavement design guide. However, the structural layer coefficients or layer equivalencies used by different highway agencies are generic, which are probably taken from a well-known design guide, a design manual developed by another agency and/or professional judgement of designers (refer to TAC[2] guide for typical values) as opposed to the measured values that are applicable to each local mix design, specifications or construction practices. In addition, the design equations used in empirical methods are developed based on field experience of pavement performance in terms of service quality, which is a composite indicator of ride or service quality. These design methods cannot predict individual distresses in pavements such as surface roughness, rutting in AC, base and subbase layers, transverse cracking, fatigue cracking, etc.

AASHTOWare PMED software, which has been under development and refinement for over two decades, is the newest and most sophisticated tool for the design and analysis of various pavements. It can predict individual distresses in pavements based on numerous design inputs including asphalt mix properties. The software also allows for the modification of design inputs to optimize pavement performance with a balance among the key distresses in pavement. However, despite the robustness of the software in predicting the long-term performance of pavements, Canadian highway agencies are still facing challenges to implement this software. Some concerns include low sensitivity of the predicted distresses due to some key inputs, inconsistencies in predicted distresses, significant variations in predicted distresses between successive software versions, and the inability to come up with a unique set of calibration factors in each jurisdiction. The study presented in this paper attempted to compare the performance of different types of AC mixes in new flexible pavements, in terms of predicted distresses in different climatic exposures across Canada, and to assess the suitability of the latest version of PMED software for pavement design and analysis.

## Background

AASHTOWare PMED software has the option to input project specific or typical physical and volumetric or mechanistic properties of asphalt mixes, and grades or mechanistic properties of asphalt binders for pavement structural design. The software can also be used to analyse the effect of each physical and volumetric or mechanical property and binder grades on pavement performance. The inputs for asphalt mix volumetric and physical properties include air voids, effective asphalt binder content (by volume), asphalt binder content, unit weight, aggregate gradations and asphalt binder grades.

For flexible pavement structures, an agency may use a single AC mix for the required total design thickness of AC layer. Alternatively, two or more AC mixes can be used in different layers to make up the total design thickness requirement. The AC surface layer (or lift) is subject to most intense stresses from traffic loads and climatic exposures, and thereby it experiences the maximum damage and distresses when compared with other AC layers (or lifts) of a pavement structure. When two or more AC mixes are used, AC mixes for the surface layer are generally designed with smaller maximum size and finer gradation of aggregates, and a higher quantity (percentage) of asphalt binder than the underlying AC base layer(s) to provide a dense, impermeable, durable and long-lasting surface. This AC surface layer, with a high percentage of asphalt binder content and finer aggregate gradation, is prone to experience higher amount of rutting than the underlying AC base layer(s). In such case, larger size aggregates with coarser gradations and lower asphalt binder contents than the surface AC layer mix are used in the underlying AC base layers to provide a high resistance to rutting.

The Transportation Association of Canada (TAC) ME Pavement Design Subcommittee (Subcommittee) has been evaluating the AASHTOWare PMED software since 2007. These studies have involved numerous design trials aimed at understanding how different input parameters impact the distress predictions for different pavement types. Several papers have been published at TAC annual conferences to document and share the results of these design trials.

In 2023-2024, the Subcommittee evaluated the effect of in-place compaction (density), voids in mineral aggregates (VMA) and asphalt binder contents on predicted distresses for different climates across Canada. The input value for each of these design parameters were changed independently to evaluate the impact of each variable on predicted distresses[3].This study focused on evaluating the sensitivity and consistency of PMED software predicted distresses in flexible pavement using seven different asphalt mixes from Ontario and Manitoba for surface and base layers with varied mechanical and volumetric properties. The performance of different AC mixes, and AC surface and AC base layer combinations were analysed for different climatic areas across Canada. All other input parameters for AC mixes such as poisons ratio, reference temperature, thermal conductivity and heat capacity remained unchanged to PMED software default values in all design trials.

## Findings from Literature Review

Hot mix asphalt (HMA) or AC is the most widely used material for roadway pavements. The mix design process for HMA targets a balance between constituent materials that will result in a satisfactory field performance. Most highway agencies have developed their own specifications for HMA mixes and their placement to meet certain characteristics as required by each agency. For example, Ontario Provincial Standard Specification[4] has specified the requirements for the materials and construction, and the processes for proportioning and mixing following the SuperPave (SP) and stone matrix asphalt (SMA) mix design methodology. Manitoba Transportation and Infrastructure(MTI)[5] outlined the property requirements for typical HMA mix design using both Marshall and SP methods. According to their Pavement Assessment and Design Manual[6], MTI requires that the design traffic loads (ESALs) and loading type (fast, slow or standing) should be taken into consideration for the selection of HMA mix type, asphalt binder grade and AC layer thickness. Based on a network analysis of rutting of nearly 7000 km of 365 primary highway paving projects, Alberta Transportation and Economic Corridors[7] developed its protocols and criteria to select HMA Mix Types for different climate zones and traffic loadings. The typical mix types are defined by three components that include aggregate criteria, mix design criteria and asphalt binder criteria to service four different applications: high service, medium service, low service and specialty.

PMED software Manual of Practice[8] provides guidance for design inputs to satisfy the desired performance criteria when designing a pavement structure. For example, if alligator cracking (i.e., bottom-up fatigue cracking) needs to be satisfied, then the HMA density should be increased, and air voids should be decreased. Alligator cracking and rutting are also affected by the HMA aggregate sizes.

By using the v3.0 of the PMED software, Ahammed et. al.[3] completed several design trials to assess the effects of in-place compaction, the voids in mineral aggregates (VMA) and asphalt binder content on predicted distresses in HMA pavements in Canadian environments. It was found that predicted distresses were very sensitive to changes in HMA density (air voids), VMA and asphalt binder content:

- A lower density (i.e., increased air voids) resulted in an increase of predicted IRI, total rutting, AC layer rutting, bottom-up fatigue cracking (BUFC) and thermal cracking, but an inconsistent variation of top-down fatigue cracking (TDFC).
- Increased VMA and asphalt binder content resulted in a reduction of predicted IRI, BUFC and thermal cracking, a reduction of predicted TDFC with some inconsistencies and an increase of total and AC layer rutting.
- An increased asphalt binder content was shown to be more helpful in reducing the thermal cracking than a reduced air voids and asphalt binder performance grade.
- The impact of climatic condition on predicted distresses did not seem to align well with the expected or experienced performance of pavements.

Al-Shamsi et al.[9] reported that the prediction from PMED cracking models is consistent with the experimental findings, and that the predicted longitudinal cracking increase significantly with the reduction of VMA.

Numerous studies have explored the effects of volumetric properties of HMA on the pavement performance. For example, Coleri et al.[10] reported that 2% reduction of AV content in asphalt mixes results in 1.5 to 2 times increase in cracking resistance . Tran et al.[11] reported that HMA in-place density (i.e., % compaction) has a significant impact on the performance of flexible pavements, and that inadequate compaction results in a HMA with poor durability, early aging, rutting, raveling, and moisture related stripping due to the ingress of moisture, and other pavement performance issues because of the high amount of VMA and air voids. Their study showed that increasing asphalt mix density by 1% can lead to improvement of fatigue cracking (long-term) and rutting resistance of asphalt pavements by 33.8% and 66.3%, respectively. Based on laboratory testing and PMED software predictions, Mogawer et al.[12] found that a higher HMA density improved fatigue and rutting performance. By examining multiple mix designs, Williams and Foreman[13] reported that VMA has a greater influence on pavement rutting performance than aggregate gradation. As VMA was increased, the rutting performance decreased, and as asphalt binder content was increased, the rutting performance decreased.

After evaluating the performance of 85 SMA projects in USA, the National Center for Asphalt Technology[14] noted that SMA is a rut-resistant AC mixture for use in high traffic conditions because of better stone-on-stone contact of aggregates than other dense-graded HMA. SMA mixtures also appeared to be more resistant to cracking probably due to relatively higher amount of asphalt binder contents than other dense-graded HMA.

## Scope, Objective and Significance

The design trials completed in this study included four AC mix types for the surface layer and three AC mix types for the base layer. The selected AC mixes represent typical mixes used on Manitoba and Ontario provincial highways and roads. Manitoba AC mix types included in this study were Bit. B, SP12.5, and SP19.0 while Ontario AC mix types included in this study were SP12.5, SMA12.5, SP19.0 and SP25.0. The design trial matrix consisted of 12 combinations of AC surface and base layers, which were run for 11 weather stations across Canada. These resulted in a total of 132 design runs for this study. All other PMED inputs remained unchanged.

The objectives of this study were examining the impacts of using different AC mix types in the surface and base layers of a new flexible pavement structure on PMED software predicted distresses. Instead of varying each design input parameters separately in each design trial, this study aimed to evaluate the combined impacts of different mix designs and specifications to compare their relative performance in varied climatic conditions across Canada. The study also aimed to assess the suitability of the latest version of PMED software, in terms of accuracy, consistency and practicality of results, for the above specified assessments. The objective of this paper is the present the details of design trials, trial results, analysis and summary/findings. The information presented in this paper may help different agencies and other interested individuals in assessing the suitability of the current version of the PMED software for flexible pavement design and analysis.

## Software Versions and General Design Inputs

All participants utilized the PMED software version 3.0 with the global calibration coefficients for all design trials. The general design inputs are summarized in Table 1. The design inputs for different trial runs include mix properties from seven different AC mixes that are typically used in Manitoba and Ontario. Design trials also included different climatic data from 11 weather stations across Canada. Details of the climatic data and asphalt mix properties are presented in the next sections.

Table 1. General input parameters for design trials

| Item | | Value Used |
|---|---|---|
| Climate Data | | MERRA-2 from 11 weather stations across Canada |
| Truck Traffic | | Two-way 7,500 trucks/day (3,000 trucks/day on the design lane of a four-lane divided highway) and 2% annual growth rate |
| Vehicle Class Distribution and Axle Load Spectra | | Manitoba Level 1 |
| Design Life | | 20 years |
| Initial IRI | | 0.9 m/km |
| Design Reliability | | 90% |
| HMA Properties | | Seven asphalt mixes with varied physical and volumetric properties. All other design input parameters such as poisons ratio, reference temperature, thermal conductivity and heat capacity remained unchanged to software default values in all design trials |
| Asphalt Binder | | PG 64-34 in both AC surface and AC base layers |
| Pavement Structures | AC Surface Layer | 50 mm thick |
| | AC Base Layer | 150 mm thick |
| | Base Layer | 200 mm thick granular base (MB GBC-I) with an annual representative Mr value of 225 MPa |
| | Subbase Layer | 300 mm thick crushed rock (MB CR-M50) subbase with an annual representative Mr value of 200 MPa |
| Subgrade | | MB high plastic clay (AASHTO A-7-6) with an annual representative Mr value of 35.0 MPa |

## Selected Weather Stations and Summary of Climate Data

MERRA-2 climate data from 11 weather stations across Canada with varied climatic input parameters were selected for the design trials presented in this study. Figure 1 shows the geographic location of the weather stations.

The red dots indicate relatively warmer climates while the blue dots indicate relatively colder climates in Canadian context. Table 2 presents the list of weather stations and the summary of the key climatic parameters. It should be noted here that some of the climatic parameters (such as minimum air temperature, frost depths and annual number of wet days) in the MERRA-2 climate database seem to be unreasonable as they do not match with actual observations.

Figure 1. Geographic locations of weather stations across Canada

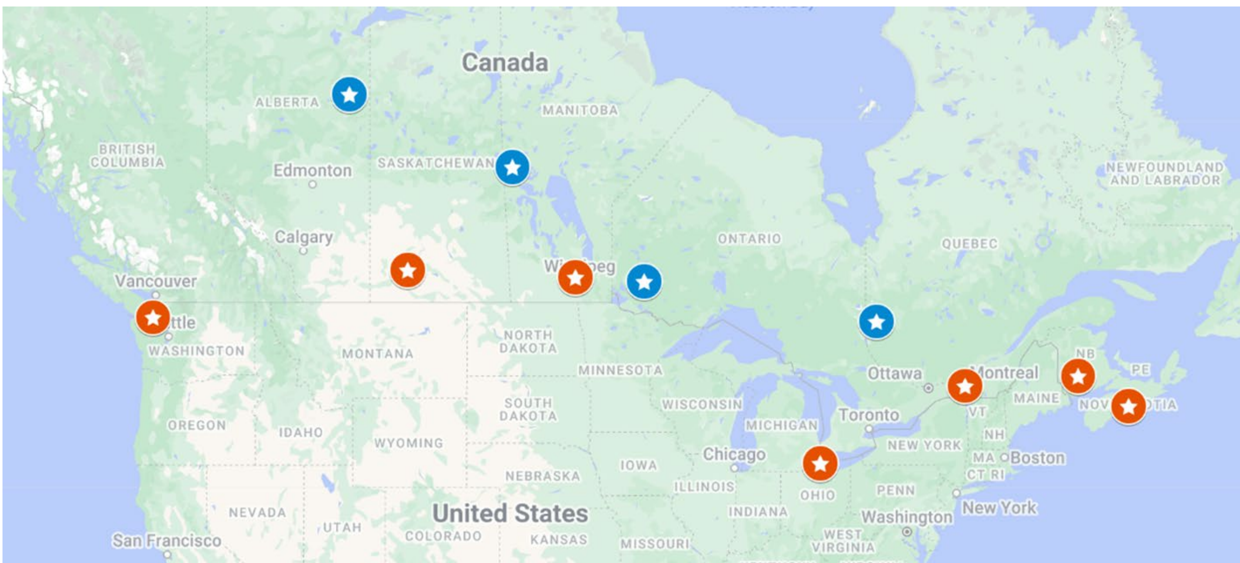



Table 2. List of weather stations and summary of key climatic parameters over the design life

| Weather Station | Annual Air Temp. (°C) | | | PPT (mm)* | # of Wet Days* | FI (°C-days)* | FD (m)* | # of F-T Cycles* |
|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Mean | | | | | |
| Victoria, BC | -15.4 | 29.4 | 10.9 | 1502 | 332 | 11 | 0.5 | 7.2 |
| Fort McMurray, AB | -47.1 | 36.9 | 0.2 | 630 | 337 | 2081 | 4.4 | 66.5 |
| Swift Current, SK | -42.1 | 37.9 | 4.9 | 451 | 274 | 999 | 2.0 | 108.6 |
| Winnipeg, MB | -45.9 | 38.3 | 3.5 | 605 | 302 | 1754 | 3.2 | 67.6 |
| The Pas, MB | -48.1 | 37.9 | 0.5 | 590 | 329 | 2357 | 7.5 | 58.9 |
| Wheatley, ON | -21.7 | 31.6 | 9.6 | 1092 | 304 | 301 | 2.0 | 52.0 |
| Waldhof, ON | -48.9 | 33.6 | 1.3 | 858 | 335 | 2131 | 4.1 | 56.8 |
| Rouyn, QC | -45.7 | 31.1 | 2.0 | 1226 | 350 | 1794 | 2.7 | 67.3 |
| Montreal, QC | -41.5 | 36.7 | 6.2 | 1379 | 326 | 1100 | 2.2 | 70.8 |
| Fredericton, NB | -36.2 | 31.8 | 5.0 | 1389 | 345 | 1028 | 1.6 | 81.2 |
| Halifax, NS | -20.1 | 27.1 | 7.3 | 1647 | 340 | 315 | 1.1 | 70.0 |

**Mean Annual Values; PPT = Precipitation; FI = Freezing Index; FD = Frost Depth; F-T = Freeze-Thaw*

## Trial Matrix and Varied Design Inputs

The specifications for AC mixes differ widely across Canada and elsewhere. The uses of AC mix type can also differ depending on the depth of AC layer. For example, a dense, watertight and wear resistance AC mix with small maximum aggregate size (≤12.5 mm), fine graded aggregates and high asphalt binder content is often used in the AC surface layer. Alternatively, stronger rut-resistant AC mixes with large maximum aggregate size (>12.5 mm), coarse graded aggregates and low asphalt binder contents are typically used in the AC binder (intermediate) and base layer.

Considering the importance of AC mix properties on pavement performance, design trials were conducted for each of the selected weather stations by changing the asphalt mix physical and volumetric properties based on local specifications and mix design data. The AC surface layer included Manitoba Bit. B and SP12.5, and Ontario SP12.5 and SMA12.5 mixes. The AC base layer included Manitoba SP19.0, and Ontario SP19.0 and SP25.0 mixes. Design trials for each surface layer AC mix included each of the base AC layer mixes. These led to 12 of combinations design trials for each weather station and a total of 132 design trials for 11 weather stations across Canada. The summary of AC mix properties is presented in Table 3. Table 4 presents the design trial matrix for each weather station.

Table 3. Physical and volumetric properties of selected AC mixes

| AC Mix | Gradation- Passing Sieve (%) | | | | Density (kg/m$^3$) | Asphalt Binder Content (%) | Void in Mineral Aggregates (%) | Air Voids Contents (%) | Effective Binder Contents (%) |
|---|---|---|---|---|---|---|---|---|---|
| | 19.0 mm | 9.5 mm | 4.75 mm | 0.075 mm | | | | | |
| MB Bit. B | 100.0 | 79.0 | 62.0 | 4.1 | 2301 | 4.8 | 17.0 | 6.9 | 10.1 |
| MB SP12.5 | 100.0 | 80.6 | 52.6 | 2.8 | 2276 | 4.8 | 17.2 | 6.9 | 10.3 |
| ON SP12.5 | 100.0 | 83.2 | 54.0 | 4.0 | 2460 | 5.0 | 18.8 | 7.0 | 11.8 |
| ON SMA12.5 | 100.0 | 73.1 | 29.7 | 9.3 | 2530 | 5.7 | 21.6 | 7.0 | 14.6 |
| MB SP19.0 | 95.3 | 67.9 | 51.8 | 3.0 | 2294 | 4.5 | 16.6 | 6.9 | 9.7 |
| ON SP19.0 | 96.9 | 72.5 | 52.8 | 3.9 | 2460 | 4.7 | 18.2 | 7.0 | 11.2 |
| ON SP25.0 | 89.1 | 63.3 | 49.3 | 3.8 | 2469 | 4.0 | 17.4 | 7.0 | 10.4 |

Table 4. Design trial matrix for different AC mixes

| Design No. | AC Surface Layer | AC Base Layer |
|---|---|---|
| 1 | MB Bit. B | MB SP19.0 |
| 2 | MB SP12.5 | MB SP19.0 |
| 3 | ON SP12.5 | MB SP19.0 |
| 4 | ON SMA12.5 | MB SP19.0 |
| 5 | MB Bit. B | ON SP19.0 |
| 6 | MB SP12.5 | ON SP19.0 |
| 7 | ON SP12.5 | ON SP19.0 |
| 8 | ON SMA12.5 | ON SP19.0 |
| 9 | MB Bit. B | ON SP25.0 |
| 10 | MB SP12.5 | ON SP25.0 |
| 11 | ON SP 12.5 | ON SP25.0 |
| 12 | ON SMA 12.5 | ON SP25.0 |

The results from these design trials were then used to assess the impact of varied AC surface and AC base mix specifications on the predicted distresses in different climatic conditions. The suitability of the PMED software in predicting pavement performance and surface distresses as practically expected or experienced was also assessed.

## Results, Analysis and Discussion

The summary of predicted distresses for different climatic areas are presented in Tables 5a, 5b and 5c. Figures 2 through 7 show the values and trends of different distresses predicted by PMED software for different AC mix types, and combinations of AC surface and base layers for the selected weather stations. It should be noted that there are overlaps of trendlines between weather stations due to no or negligible difference in predicted distresses between those stations. The results/trends and analysis of each distress type are discussed below.

Table 5a. Predicted distresses: Victoria

| Weather Station | Design No. | AC Mix Types and Layer Combinations | IRI (m/km) | Rut Depths (mm) | | | BUFC (%) | TC (m/km) | TDFC (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | AC Layer | UBGL-SG | | | |
| Victoria, BC | 1 | MB Bit. B/MB SP 19.0 | 2.33 | 11.02 | 5.32 | 5.70 | 31.70 | 40.97 | 14.25 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.37 | 11.53 | 5.80 | 5.73 | 34.77 | 40.97 | 14.75 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.36 | 11.49 | 5.75 | 5.74 | 34.67 | 40.97 | 14.69 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.41 | 12.24 | 6.47 | 5.77 | 38.66 | 40.97 | 14.36 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.26 | 11.13 | 5.41 | 5.72 | 18.77 | 40.97 | 14.25 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.29 | 11.63 | 5.87 | 5.76 | 21.46 | 40.97 | 14.75 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.29 | 11.58 | 5.82 | 5.76 | 21.40 | 40.97 | 14.69 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.32 | 12.27 | 6.48 | 5.79 | 24.71 | 40.97 | 14.36 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.27 | 10.78 | 5.09 | 5.69 | 23.23 | 40.97 | 14.25 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.30 | 11.29 | 5.58 | 5.71 | 25.97 | 40.97 | 14.75 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.30 | 11.25 | 5.53 | 5.72 | 26.00 | 40.97 | 14.69 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.34 | 11.95 | 6.20 | 5.75 | 29.38 | 40.97 | 14.36 |

*UBGL-SG = Unbound Granular (Base and Subbase) Layers and Subgrade*

Table 5b. Predicted distresses: Fort McMurray, Swift Current, Winnipeg, The Pas and Wheatley

| Weather Station | Design No. | AC Mix Types and Layer Combinations | IRI (m/km) | Rut Depths (mm) | | | BUFC (%) | TC (m/km) | TDFC (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | AC Layer | UBGL-SG | | | |
| Fort McMurray, AB | 1 | MB Bit. B/MB SP 19.0 | 2.85 | 17.18 | 11.31 | 5.87 | 68.28 | 40.98 | 14.89 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.91 | 18.27 | 12.37 | 5.90 | 72.29 | 40.98 | 15.66 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.91 | 18.21 | 12.31 | 5.90 | 72.29 | 40.98 | 15.57 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.99 | 19.87 | 13.93 | 5.94 | 77.5 | 40.97 | 15.13 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.68 | 17.43 | 11.54 | 5.89 | 45.29 | 40.98 | 14.89 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.74 | 18.51 | 12.58 | 5.93 | 48.86 | 40.98 | 15.66 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.73 | 18.46 | 12.53 | 5.93 | 48.86 | 40.98 | 15.57 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.81 | 20.09 | 14.12 | 5.97 | 53.51 | 40.97 | 15.13 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.74 | 16.80 | 10.95 | 5.85 | 54.82 | 40.98 | 14.89 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.80 | 17.89 | 12.00 | 5.89 | 58.75 | 40.98 | 15.66 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.80 | 17.85 | 11.96 | 5.89 | 58.95 | 40.98 | 15.57 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.88 | 19.50 | 13.57 | 5.93 | 64.07 | 40.97 | 15.13 |
| Swift Current, SK | 1 | MB Bit. B/MB SP 19.0 | 2.30 | 9.76 | 4.06 | 5.70 | 23.14 | 42.34 | 15.04 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.31 | 9.90 | 4.17 | 5.73 | 23.93 | 41.38 | 15.88 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.31 | 9.92 | 4.19 | 5.73 | 24.17 | 41.50 | 15.77 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.34 | 10.52 | 4.76 | 5.76 | 27.44 | 40.98 | 15.38 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.29 | 9.63 | 3.92 | 5.71 | 9.30 | 41.45 | 15.05 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.30 | 10.01 | 4.27 | 5.74 | 11.47 | 41.34 | 15.88 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.30 | 10.03 | 4.28 | 5.75 | 11.71 | 41.43 | 15.77 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.31 | 10.63 | 4.85 | 5.78 | 14.83 | 40.98 | 15.38 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.28 | 9.36 | 3.68 | 5.68 | 12.78 | 41.44 | 15.05 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.29 | 9.74 | 4.03 | 5.71 | 15.39 | 41.34 | 15.88 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.29 | 9.76 | 4.05 | 5.71 | 15.55 | 41.43 | 15.77 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.31 | 10.36 | 4.63 | 5.73 | 19.01 | 40.98 | 15.38 |
| Winnipeg, MB | 1 | MB Bit. B/MB SP 19.0 | 2.37 | 10.05 | 4.32 | 5.73 | 27.70 | 48.97 | 15.05 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.40 | 10.47 | 4.71 | 5.76 | 30.38 | 47.77 | 15.88 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.40 | 10.48 | 4.72 | 5.76 | 30.52 | 48.84 | 15.77 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.44 | 11.16 | 5.37 | 5.79 | 34.11 | 41.26 | 15.38 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.33 | 10.18 | 4.43 | 5.75 | 14.97 | 48.40 | 15.05 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.35 | 10.59 | 4.81 | 5.78 | 17.55 | 47.27 | 15.88 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.35 | 10.61 | 4.83 | 5.78 | 17.71 | 48.29 | 15.77 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.36 | 11.28 | 5.46 | 5.82 | 21.03 | 41.23 | 15.38 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.33 | 9.88 | 4.16 | 5.72 | 19.27 | 48.37 | 15.05 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.34 | 10.30 | 4.55 | 5.75 | 21.97 | 47.22 | 15.88 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.35 | 10.32 | 4.57 | 5.75 | 22.11 | 48.23 | 15.77 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.38 | 10.99 | 5.22 | 5.77 | 25.45 | 41.22 | 15.38 |
| The Pas, MB | 1 | MB Bit. B/MB SP 19.0 | 2.39 | 10.23 | 4.48 | 5.75 | 29.53 | 40.99 | 15.08 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.42 | 10.69 | 4.91 | 5.78 | 32.19 | 40.99 | 15.89 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.42 | 10.70 | 4.92 | 5.78 | 32.40 | 41.00 | 15.79 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.46 | 11.43 | 5.62 | 5.81 | 36.09 | 40.97 | 15.41 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.34 | 10.36 | 4.60 | 5.76 | 16.62 | 40.99 | 15.08 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.36 | 10.82 | 5.02 | 5.80 | 19.27 | 40.99 | 15.89 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.36 | 10.83 | 5.03 | 5.80 | 19.48 | 41.00 | 15.79 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.38 | 11.50 | 5.72 | 5.78 | 22.76 | 40.97 | 15.41 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.34 | 10.05 | 4.32 | 5.73 | 21.13 | 40.99 | 15.08 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.36 | 10.52 | 4.76 | 5.76 | 23.78 | 40.99 | 15.89 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.36 | 10.53 | 4.76 | 5.77 | 23.91 | 41.00 | 15.79 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.40 | 11.26 | 5.46 | 5.80 | 27.28 | 40.97 | 15.41 |
| Wheatley, ON | 1 | MB Bit. B/MB SP 19.0 | 2.35 | 10.25 | 4.53 | 5.72 | 28.63 | 40.97 | 14.89 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.38 | 10.67 | 4.92 | 5.75 | 31.36 | 40.97 | 15.67 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.38 | 10.67 | 4.91 | 5.76 | 31.49 | 40.97 | 15.58 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.43 | 11.31 | 5.52 | 5.79 | 35.33 | 40.97 | 15.13 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.31 | 10.38 | 4.65 | 5.73 | 15.80 | 40.97 | 14.89 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.33 | 10.80 | 5.02 | 5.78 | 18.50 | 40.97 | 15.67 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.33 | 10.79 | 5.01 | 5.78 | 18.72 | 40.97 | 15.58 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.35 | 11.41 | 5.59 | 5.82 | 22.06 | 40.97 | 15.13 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.31 | 10.06 | 4.36 | 5.70 | 20.26 | 40.97 | 14.89 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.33 | 10.49 | 4.75 | 5.74 | 23.03 | 40.97 | 15.67 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.33 | 10.49 | 4.74 | 5.75 | 23.14 | 40.97 | 15.58 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.36 | 11.10 | 5.33 | 5.77 | 26.57 | 40.97 | 15.13 |

*UBGL-SG = Unbound Granular (Base and Subbase) Layers and Subgrade*

Table 5c. Predicted distresses: Waldhof, Rouyn, Montreal, Fredericton and Halifax

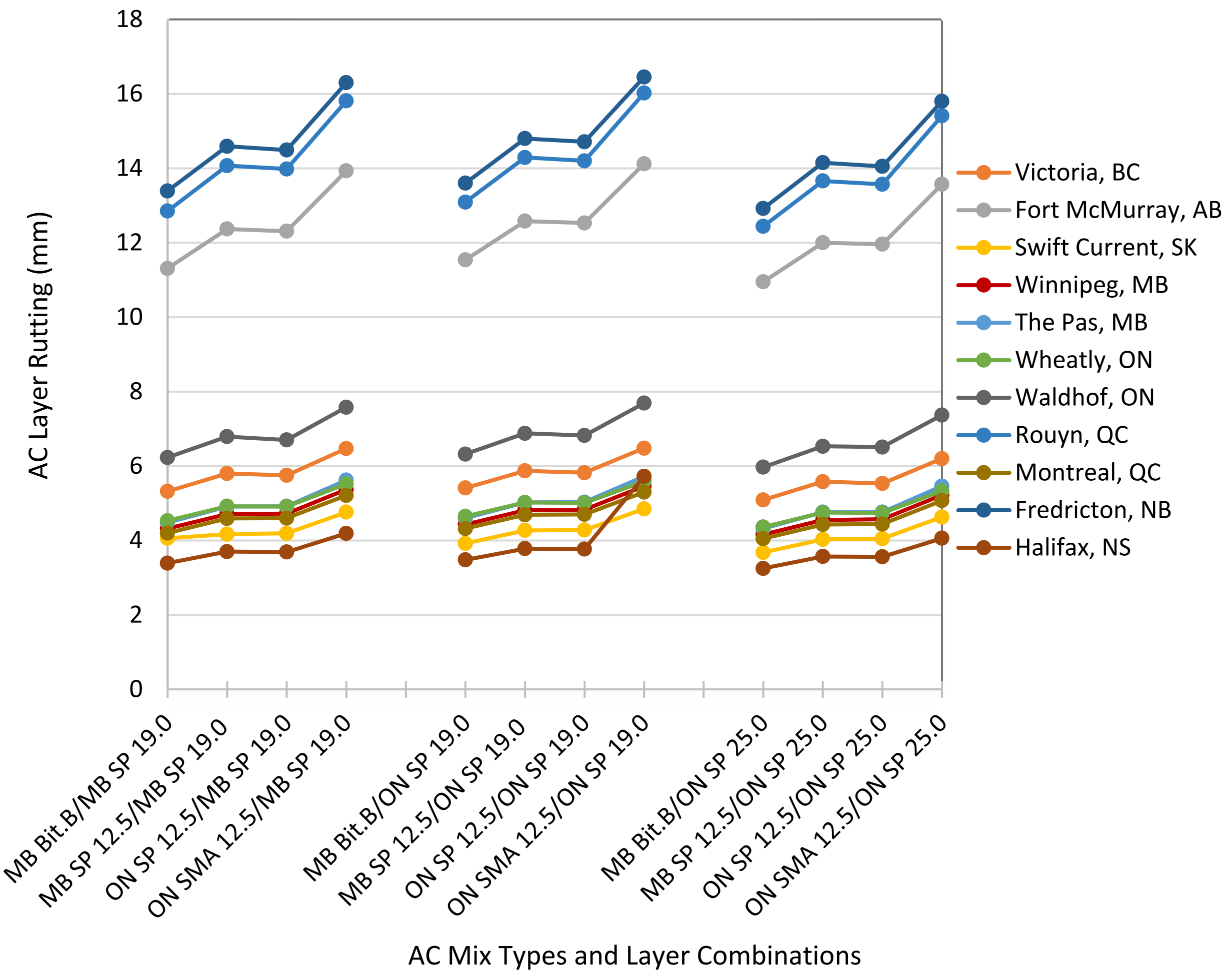
| Weather Station | Design No. | AC Mix Types and Layer Combinations | IRI (m/km) | Rut Depths (mm) | | | BUFC (%) | TC (m/km) | TDFC (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | AC Layer | UBGL-SG | | | |
| Waldhof, ON | 1 | MB Bit. B/MB SP 19.0 | 2.51 | 11.97 | 6.23 | 5.74 | 38.23 | 41.02 | 15.04 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.55 | 12.57 | 6.79 | 5.78 | 41.59 | 41.02 | 15.88 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.55 | 12.49 | 6.70 | 5.79 | 42.00 | 41.02 | 15.73 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.62 | 13.40 | 7.58 | 5.82 | 47.54 | 40.97 | 15.35 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.42 | 12.09 | 6.32 | 5.77 | 24.25 | 41.01 | 15.04 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.45 | 12.68 | 6.88 | 5.80 | 26.73 | 41.01 | 15.88 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.45 | 12.63 | 6.82 | 5.81 | 27.02 | 41.02 | 15.73 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.49 | 13.54 | 7.69 | 5.85 | 30.17 | 40.97 | 15.35 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.44 | 11.70 | 5.97 | 5.73 | 29.02 | 41.01 | 15.04 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.47 | 12.29 | 6.53 | 5.76 | 31.82 | 41.01 | 15.88 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.47 | 12.28 | 6.51 | 5.77 | 31.95 | 41.02 | 15.73 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.52 | 13.17 | 7.37 | 5.80 | 35.55 | 40.97 | 15.35 |
| Rouyn, QC | 1 | MB Bit. B/MB SP 19.0 | 2.94 | 18.72 | 12.85 | 5.87 | 70.19 | 40.98 | 14.95 |
| | 2 | MB SP 12.5/MB SP 19.0 | 3.00 | 19.97 | 14.07 | 5.90 | 74.39 | 40.98 | 15.69 |
| | 3 | ON SP 12.5/MB SP 19.0 | 3.00 | 19.89 | 13.98 | 5.91 | 74.79 | 40.98 | 15.61 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 3.09 | 21.76 | 15.81 | 5.95 | 80.00 | 40.97 | 15.17 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.76 | 18.97 | 13.09 | 5.88 | 46.82 | 40.98 | 14.95 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.82 | 20.21 | 14.29 | 5.92 | 50.48 | 40.98 | 15.69 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.82 | 20.13 | 14.20 | 5.93 | 50.89 | 40.98 | 15.61 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.91 | 21.99 | 16.02 | 5.97 | 55.83 | 40.97 | 15.17 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.82 | 18.29 | 12.44 | 5.85 | 56.54 | 40.98 | 14.95 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.89 | 19.54 | 13.66 | 5.88 | 60.66 | 40.98 | 15.69 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.89 | 19.46 | 13.57 | 5.89 | 61.36 | 40.98 | 15.61 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.97 | 21.33 | 15.41 | 5.92 | 66.48 | 40.97 | 15.17 |
| Montreal, QC | 1 | MB Bit. B/MB SP 19.0 | 2.42 | 9.95 | 4.20 | 5.75 | 28.63 | 77.23 | 15.03 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.44 | 10.36 | 4.59 | 5.77 | 31.47 | 68.73 | 15.89 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.44 | 10.38 | 4.60 | 5.78 | 31.59 | 70.10 | 15.73 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.47 | 11.02 | 5.21 | 5.81 | 35.33 | 43.05 | 15.36 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.38 | 10.09 | 4.32 | 5.77 | 15.94 | 73.66 | 15.03 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.39 | 10.49 | 4.69 | 5.80 | 18.63 | 66.05 | 15.89 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.39 | 10.51 | 4.70 | 5.81 | 18.84 | 67.12 | 15.73 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.39 | 11.14 | 5.30 | 5.84 | 22.11 | 42.86 | 15.36 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.37 | 9.78 | 4.05 | 5.73 | 20.29 | 73.39 | 15.03 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.39 | 10.20 | 4.43 | 5.77 | 23.03 | 66.05 | 15.89 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.39 | 10.21 | 4.44 | 5.77 | 23.21 | 67.01 | 15.73 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.41 | 10.86 | 5.07 | 5.79 | 26.57 | 42.84 | 15.36 |
| Fredericton, NB | 1 | MB Bit. B/MB SP 19.0 | 3.01 | 19.29 | 13.39 | 5.90 | 78.50 | 40.97 | 14.83 |
| | 2 | MB SP 12.5/MB SP 19.0 | 3.07 | 20.52 | 14.59 | 5.93 | 82.40 | 40.97 | 15.54 |
| | 3 | ON SP 12.5/MB SP 19.0 | 3.07 | 20.44 | 14.49 | 5.95 | 82.90 | 40.97 | 15.48 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 3.15 | 22.29 | 16.30 | 5.99 | 87.50 | 40.97 | 14.98 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.83 | 19.52 | 13.60 | 5.92 | 54.32 | 40.97 | 14.83 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.89 | 20.76 | 14.80 | 5.96 | 58.35 | 40.97 | 15.54 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.89 | 20.67 | 14.71 | 5.96 | 58.85 | 40.97 | 15.48 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.98 | 22.47 | 16.45 | 6.02 | 63.97 | 40.97 | 14.98 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.89 | 18.81 | 12.92 | 5.89 | 64.67 | 40.97 | 14.83 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.96 | 20.06 | 14.15 | 5.91 | 69.18 | 40.97 | 15.54 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.96 | 19.98 | 14.05 | 5.93 | 69.78 | 40.97 | 15.48 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 3.04 | 21.77 | 15.80 | 5.97 | 74.99 | 40.97 | 14.98 |
| Halifax, NS | 1 | MB Bit. B/MB SP 19.0 | 2.31 | 9.10 | 3.39 | 5.71 | 21.27 | 40.97 | 15.01 |
| | 2 | MB SP 12.5/MB SP 19.0 | 2.34 | 9.45 | 3.70 | 5.75 | 24.06 | 40.97 | 15.80 |
| | 3 | ON SP 12.5/MB SP 19.0 | 2.34 | 9.44 | 3.69 | 5.75 | 24.17 | 40.97 | 15.74 |
| | 4 | ON SMA 12.5/MB SP 19.0 | 2.37 | 9.98 | 4.19 | 5.79 | 27.57 | 40.97 | 15.32 |
| | 5 | MB Bit. B/ON SP 19.0 | 2.31 | 9.21 | 3.48 | 5.73 | 9.40 | 40.97 | 15.01 |
| | 6 | MB SP 12.5/ON SP 19.0 | 2.33 | 9.55 | 3.78 | 5.77 | 11.59 | 40.97 | 15.80 |
| | 7 | ON SP 12.5/ON SP 19.0 | 2.33 | 9.55 | 3.77 | 5.78 | 11.73 | 40.97 | 15.74 |
| | 8 | ON SMA 12.5/ON SP 19.0 | 2.38 | 11.55 | 5.72 | 5.83 | 22.76 | 40.97 | 15.41 |
| | 9 | MB Bit. B/ON SP 25.0 | 2.31 | 8.95 | 3.25 | 5.70 | 12.79 | 40.97 | 15.01 |
| | 10 | MB SP 12.5/ON SP 25.0 | 2.32 | 9.30 | 3.57 | 5.73 | 15.41 | 40.97 | 15.80 |
| | 11 | ON SP 12.5/ON SP 25.0 | 2.32 | 9.29 | 3.56 | 5.73 | 15.65 | 40.97 | 15.74 |
| | 12 | ON SMA 12.5/ON SP 25.0 | 2.33 | 9.83 | 4.06 | 5.77 | 19.12 | 40.97 | 15.32 |

*UBGL-SG = Unbound Granular (Base and Subbase) Layers and Subgrade*

**AC Layer Rutting**

Figure 2 shows that MB Bit. B mix with finer gradation, slightly higher density and slightly less effective binder content exhibits less rutting in the AC layer than the MB SP12.5 mix in each climatic area. ON SP12.5 mix with a slightly finer gradation, higher density and higher effective binder content results in a similar amount of rutting as the MB SP12.5 mix. ON SMA12.5 mix with coarser gradation, but with significantly higher fines content, higher density and effective asphalt content provides significantly higher rutting in AC layer as compared to other mixes.

Figure 2. Trends of predicted AC layer rutting




In general, a coarser AC mix with larger aggregate sizes, a higher fraction of coarse aggregates and/or a smaller fraction of fines, a denser AC mix and a mix with lower optimum asphalt binder content are expected to provide better resistance to rutting. However, although SMA mixes contain a high amount of fines and asphalt binder, they exhibit a high resistance to rutting due to better quality of aggregates used and more stone-to-stone contacts than the conventional dense AC mixes. The trends of predicted distresses, as shown in Figure 2, indicate that PMED software is unable to account for the benefit of superior quality AC mixes when Level 3 inputs are used.

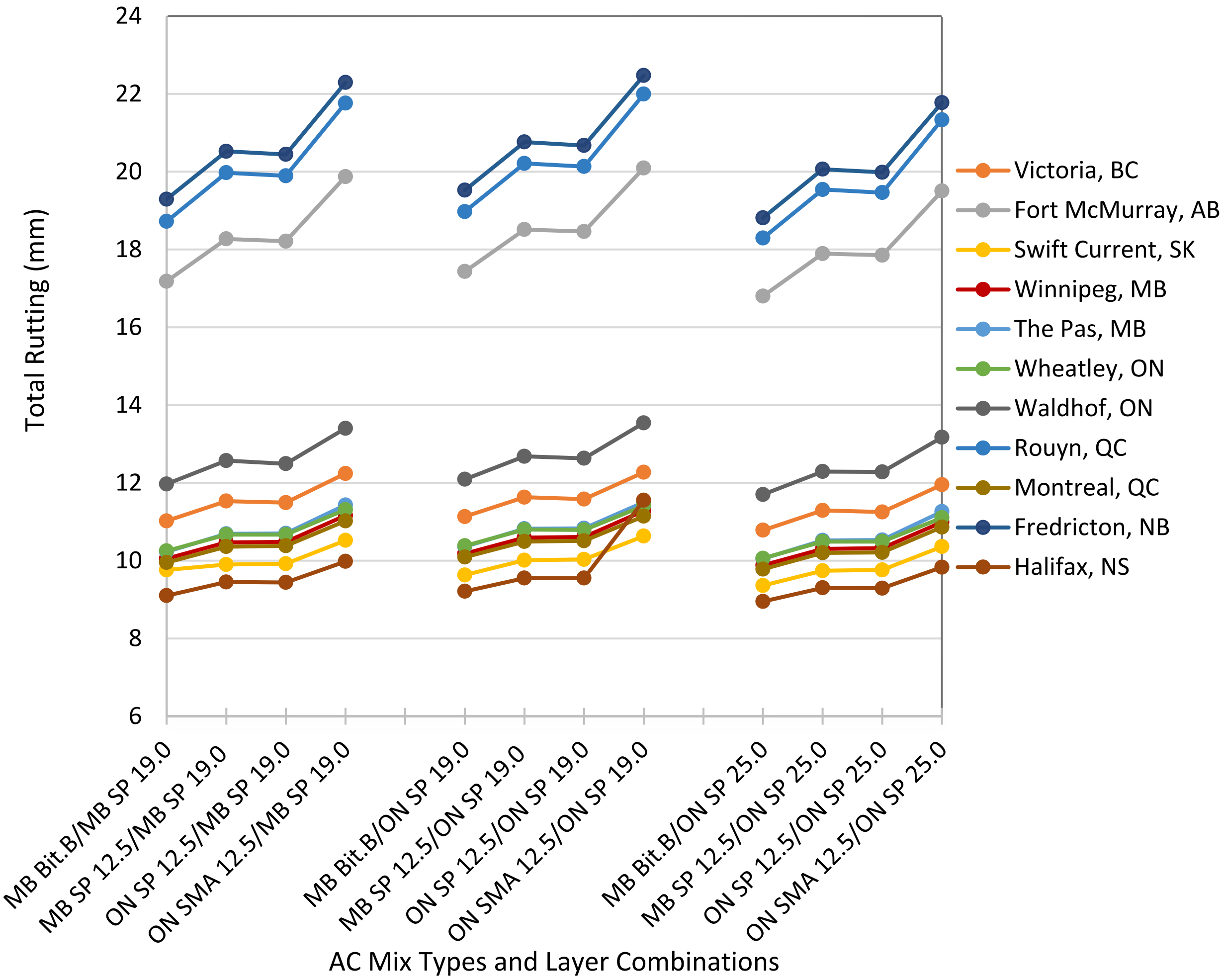
Similar trends are observed whether MB SP19.0, ON SP19.0 or ON SP25.0 mixes are used in the AC base layer. The predicted rutting values with ON SP19.0 as an AC base layer are similar, with slight differences between climatic areas, to MB SP19.0. ON SP19.0 mix has a slightly finer gradation, higher density and higher effective binder content than MB SP19.0 mix. The predicted rutting values in AC layers with ON SP25.0 as an AC base layer are lower than MB SP19.0 and ON SP19.0. ON SP25.0 mix has larger maximum size aggregate, coarser gradation, higher density and lower effective binder content than MB SP19.0 and ON SP19.0 mixes.

Based on the assessment presented above, the effective asphalt binder content, and thereby, VMA (as air voids contents were almost same at 6.9-7.0% for all mixes) and density (unit weight) seem to have some effect on the predicted rutting in AC layer. Higher effective binder content (i.e., increased VMA) increases rutting in AC layer and higher density reduces rutting. The trends in Figure 2 show that variation of climatic condition has a significant effect on the predicted rutting in AC layer. A statistical analysis (using MS Excel) with different combinations of AC mix properties of both surface and base AC layers and climatic parameters indicated that only the maximum air temperature (thereby, maximum pavement temperature) is a statistically significant variable at about 90% confidence level for AC layer rutting within the scope of design trials. A higher air temperature results in increased rutting in AC layer, which is a logical trend. However, this trend was not observed in some climatic areas such as Fredericton and Rouyn.

## Predicted Total Rutting

Figure 3 shows the trends of total rutting i.e., total permanent deformation of pavement structures in different climatic areas for different AC mixes and combinations of AC surface and base layers. The trends of predicted total rutting are similar to AC layer rutting. The total rutting in granular aggregate base and subbase layers and subgrade remains constant, ranging from 5.7 to 6.0 mm, regardless of AC mix types, combinations of surface and base AC layers, and climatic conditions. Since the input parameters for subgrade, granular subbase and base layers remained unchanged in all design trials, such prediction seems reasonable. A statistical analysis showed that the minor variations of total rutting in unbound base, subbase and subgrade are still strongly correlated with the amount of AC layer rutting. This may indicate that a higher amount of rutting in AC layer would cause a higher amount of rutting in underlying support layers and subgrade.

Figure 3. Trends of predicted total rutting

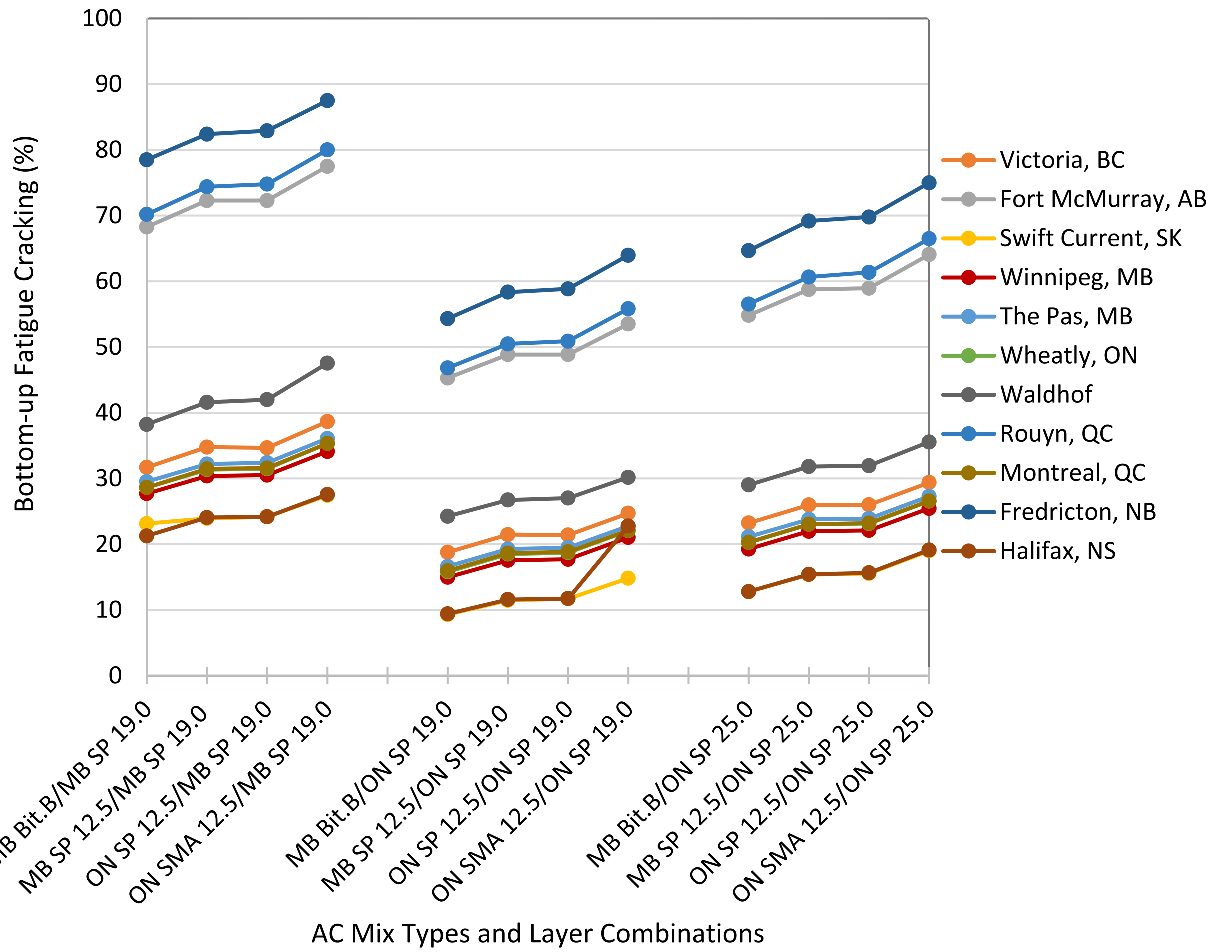



## Bottom-up Fatigue Cracking (BUFC)

Figure 4 shows that MB Bit. B mix with finer gradation, slightly higher density and slightly less effective binder content exhibits a lower amount of BUFC in AC layer than the MB SP12.5 mix in each climatic area. The trends of predicted BUFC resemble the predicted rutting. Such results could be questionable. A softer mix that experiences a higher amount of rutting is expected to reduce the amount of fatigue cracking because of its increased flexibility. ON SP12.5 mix, with slightly finer gradation, higher density and higher effective binder content, results in a slightly higher amount of BUFC as compared to the MB SP12.5 mix. ON SMA12.5 mix with coarser gradation, but with significantly higher fines content, higher density and higher effective asphalt content, results in significantly higher amount of BUFC in AC layer as compared to MB SP12.5 and ON SP12.5 mixes.

Similar trends of predicted BUFC are observed whether MB SP19.0, ON SP19.0 or ON SP25.0 mixes are used in the base AC layer. However, the predicted amounts of BUFC with ON SP19.0 are lower than MB SP19.0. Since ON SP19.0 mix has slightly finer gradation, higher density and higher effective binder content than MB SP19.0, the lower amounts of BUFC with ON SP19.0 AC base seem to be reasonable. The predicted BUFC with ON SP25.0 are higher than MB SP19.0 and ON SP19.0. Since ON SP25.0 mix has larger maximum size aggregate, coarser gradation, higher density and lower effective binder content, a higher amount of BUFC with ON SP25.0 AC base seems to be reasonable.

Figure 4. Trends of predicted bottom-up fatigue cracking



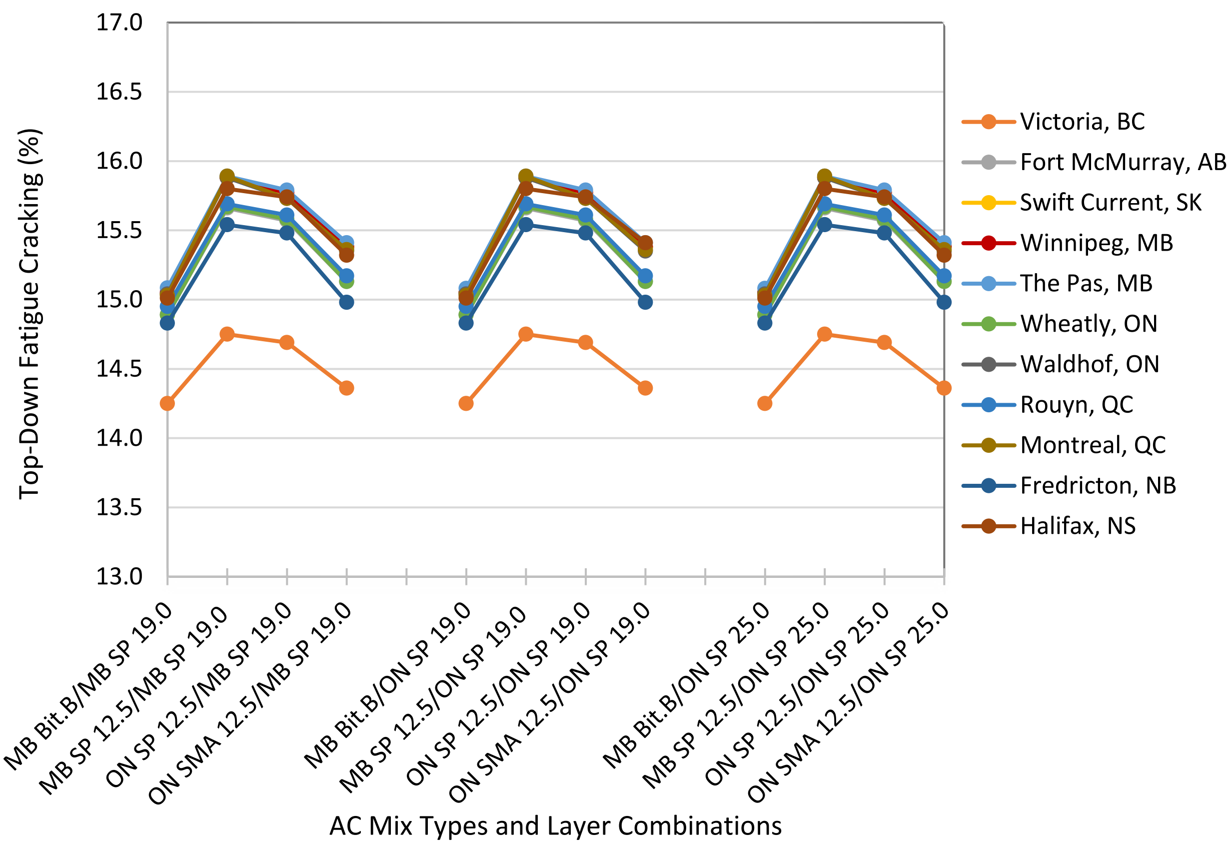

Based on the assessment presented above, effective asphalt binder content and density (unit weight) seem to have some effect on the predicted BUFC as well. A higher effective binder content (i.e., increased VMA) in the surface AC layer results in an increase in BUFC. A higher effective binder content in the base AC layer results in a reduction of BUFC, and a higher density in both surface and base AC layers results in a reduced amount of BUFC. The trends in Figure 4 show that variation of climatic condition also has significant effect on the predicted BUFC. A statistical analysis with different combinations of AC mix properties of both surface and base AC layers and climatic parameters indicated that only two variables, out of those included in this study, are statistically significant at different confidence levels: the mean air temperature (thereby, mean pavement temperature) at 95% confidence level and the effective binder content in AC base layer at 90% confidence level. A higher air temperature results in reduced BUFC, which is a logical trend. However, this trend was not observed in some climatic areas such as Fredericton, Rouyn and Fort McMurray. Air voids content in AC mixes was not a significant factor because it remained constant at (6.9-7.0%) for all AC mixes.

**Predicted Top-down Fatigue Cracking (TDFC)**

Figure 5 shows the trend of predicted TDFC in AC layers. MB Bit. B mix with a finer gradation, slightly higher density and slightly less effective binder content exhibits a lower amount of TDFC than the MB SP12.5 mix in each climatic area. ON SP12.5 mix with slightly finer gradation, higher density and higher effective binder content results in a lower amount TDFC than the MB SP12.5 mix. ON SMA12.5 mix with coarser gradation, but with significantly higher fines content, higher density and higher effective asphalt content, provide a further drop in TDFC compared to MB SP12.5 and ON SP12.5 mixes. The reason for such trends is unclear.

Figure 5 also shows that the predicted TDFC is unaffected by the properties of AC base layer. Variation of climatic exposures has some influence on the predicted TDFC. A statistical analysis with different combinations of AC mix properties of surface layer and climatic parameters indicated that only the mean air temperature (thereby, mean pavement temperature) is statistically significant at about 90% confidence level for varied TDFC among the varied input parameters used in these design trials. A higher air temperature results in reduced TDFC, which is a logical trend. Air voids content in AC mixes was not a significant factor probably because it remained constant at (6.9-7.0%) for all AC mixes.

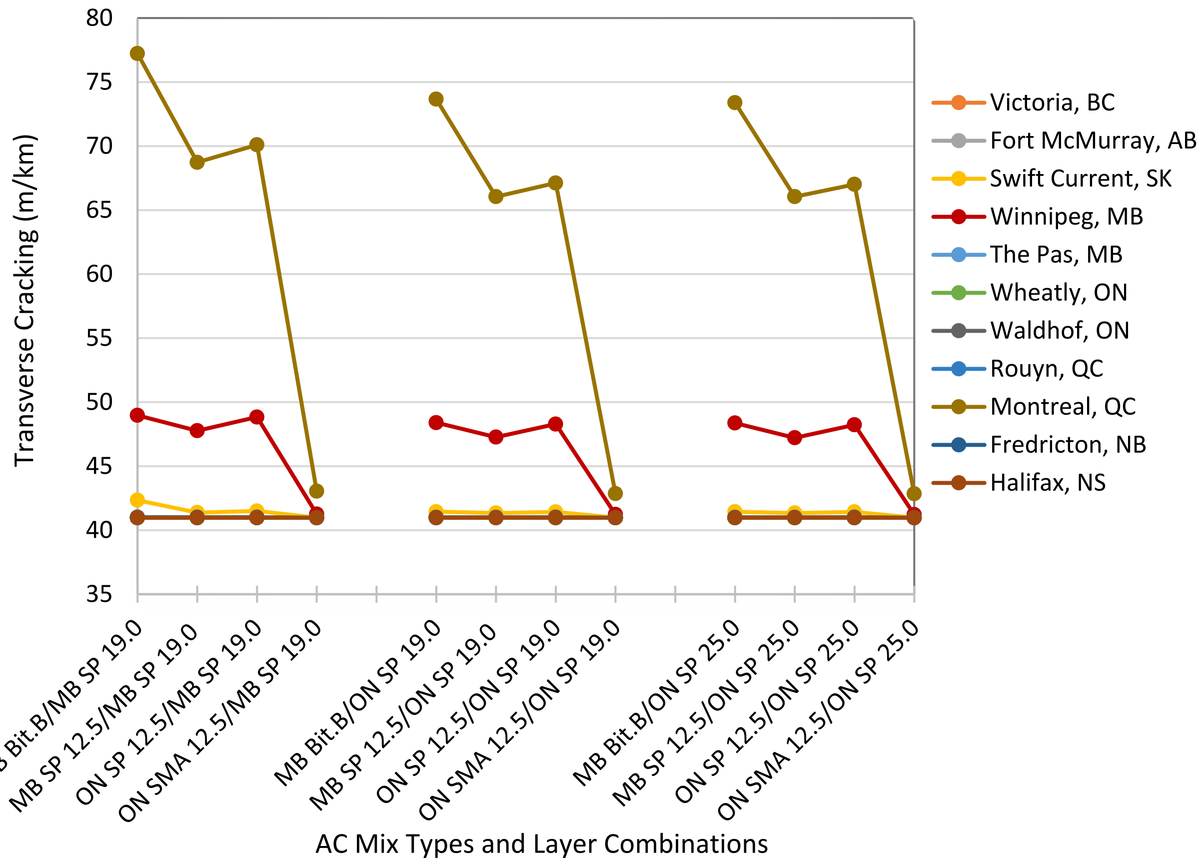
Figure 5. Trend of predicted top-down fatigue cracking




**Predicted Transverse Cracking (TC)**

Figure 6 shows MB Bit. B mix with slightly higher density and lower effective binder content (same percentage of asphalt content) exhibits a higher amount of TC than the MB SP12.5 mix in three climatic areas (Montreal, Winnipeg and Swift Current). ON SP12.5 mix with higher density and effective binder content results in a slight increase in the amount of TC as compared to the MB SP12.5 mix in those climatic areas. ON SMA12.5 mix with higher density and higher effective asphalt content (higher asphalt content) results in significant drop in the amount of TC in AC layer as compared to MB SP12.5 and ON SP12.5 mixes in those climatic areas. The reason for such opposing trends is not clear. The predicted TC remains unchanged or shows negligible variations in other climatic areas. Although the weather in The Pas is colder than in Winnipeg, there are some variations of TC in Winnipeg between surface AC mixes, but no variation for The Pas, which does not reflect the actual field performance.

Figure 6. Trends of predicted transverse cracking



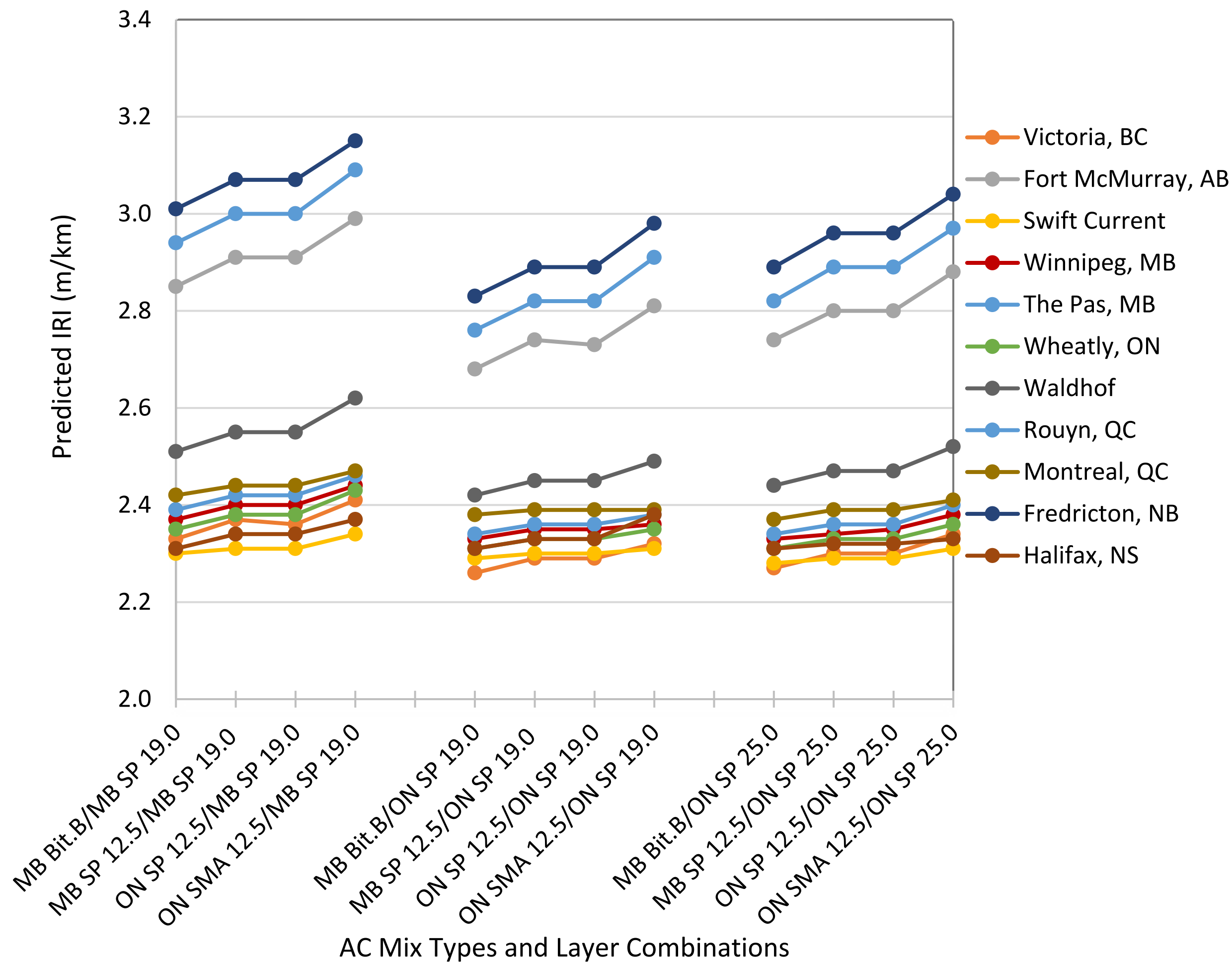

Similar trends of predicted TC are observed whether MB SP19.0, ON SP19.0 or ON SP25.0 mixes used in the AC base layer. No variation, or a minor, but inconsistent variation (with up and down) of predicted TC are observed among varying AC base layers in the affected climatic areas, except for MB Bit. B mix. MB Bit. B has a small drop in TC when changing AC base layer from MB SP19.0 to ON SP19.0, but there is no noticeable change when switching to ON SP25.0 as an AC base layer in those affected areas. The reason for such variation is unclear.

A statistical analysis with different combinations of AC mix properties of both surface and base AC layers and climatic parameters indicated that only the minimum air temperature (thereby, minimum pavement temperature), among the varied input parameters used in these design trials, is statistically significant at about 90% confidence level for the varied amount of TC. A colder air temperature results in increased TC, which is a logical trend.

## Predicted IRI

Figure 7 shows the trends of predicted (calculated) IRI for different climatic areas. Since IRI depends on the predicted rutting, thermal cracking, total fatigue cracking and site factors, it was not possible to assess the impact of individual input parameters of AC mixes. A statistical analysis for the predicted IRI encompassing all the relevant variables (i.e., predicted rutting, thermal cracking, fatigue cracking, freezing index and precipitation), that are included in the IRI prediction model, was conducted to determine the statistically significant variables. The gradation and plasticity of subgrade soils were excluded from this statistical analysis because they remained unchanged in all design trials. This analysis has shown that the predicted total rutting has the most significant influence on the predicted (calculated) IRI followed by the total fatigue cracking (BUFC plus TDFC) and predicted transverse cracking. The freezing index and amount of precipitation have minimal effect on the predicted IRI.

Figure 7. Trends of predicted IRI



## Summary and Conclusions

The specifications for AC mixes, including the quality of materials, vary among highways agencies and within a jurisdiction. The AC mix type can also vary between surface and underlying layers. An AC mix can perform differently in different climatic areas. AASHTOWare PMED software is a modern and sophisticated pavement design and analysis tool. However, it's implementation in Canada is hindered due to some unexpected outcomes and inconsistency between software versions. This study attempted to assess the suitability of the latest version of PMED software in predicting the performance of varied AC mixes in different climatic conditions across Canada. Design trials were completed for four different AC mixes for surface layer and three different AC mixes for base layer in 11 different climatic areas. Based on the assessment and analysis of results from design trials, the following conclusions can be drawn:

1. A higher effective binder content (i.e., increased VMA) results in increased rutting. A higher density results in a reduced amount of AC rutting. The variation of climatic condition has significant effect on the predicted rutting in AC layer. However, only the maximum air temperature had a statistically significant effect at about 90% confidence level on the AC layer rutting. A higher air temperature should increase rutting in AC layer, which is a logical trend. However, some inconsistencies were observed for some weather stations.
2. The trends of predicted total rutting are similar to AC layer rutting. The total rutting in pavements were about 5.7 to 6.0 mm higher than the AC layer rutting.
3. A higher effective binder content in the surface AC layer results in an increase in BUFC while a higher effective binder content in the base AC layer results in a reduction of BUFC. A higher density in both surface and base AC layers results in a reduced amount of BUFC. Variation of climatic condition has significant effect on the predicted BUFC. The mean air temperature is statistically significant at 95% and the effective binder content in AC base layer is statistically significant at 90% confidence levels for explaining the variation of BUFC.
4. There are inconsistent effects of surface layer AC mix properties on the predicted TDFC. The predicted TDFC was unaffected by the properties of base layer AC mixes. Varied climatic exposures have some influence on the predicted TDFC. Only the mean air temperature was statistically significant at about 90% confidence level for varied TDFC.
5. The predicted TC remains unchanged or shows negligible variations in most climatic areas, except for Montreal (QC), Winnipeg (MB) and Swift Current (SK). The effect of surface layer AC mix properties on the predicted TC in these three areas were inconsistent. There is no effect of base layer AC mixes on the predicted TC, except for minor drop with MB Bit. B mix and ON SP19.0 combination. The reason for such variation is unclear. Only the minimum air temperature is statistically significant at about 90% confidence level for the varied amount of TC.
6. The predicted IRI is mostly dependent on the predicted total rutting, total fatigue cracking (BUFC plus TDFC) and TC. The freezing index and amount of precipitation have minimal effect on the predicted IRI.

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