A Comparative Analysis of PMED Software Predicted Distresses Using Level 1 and Level 3 Inputs of Asphalt Mix Properties

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Abstract

There are three quality levels (Levels 1 to 3) of design inputs in the AASHTOWare Pavement ME Design (PMED) software for asphalt concrete (AC) mixes. Level 1 inputs, obtained through comprehensive laboratory tests, are recommended for the most reliable outcomes. Level 2 inputs, derived from a limited number of laboratory tests, provide less reliable outcomes than Level 1. Level 3 inputs, consisting of typical physical properties, are considered to provide the least reliable results. However, obtaining Level 1 input data is challenging for the PMED software users because of the required resources including technical expertise and time to perform the required tests. As a result, Level 3 inputs for AC mixes are generally used.

To compare the outcomes from Level 1 and Level 3 inputs, design trials were completed in this study with inputs from five asphalt mixes containing 0 to 40% reclaimed asphalt pavement (RAP) and 11 weather stations across Canada. Analyses of these trial results indicate that Level 1 inputs predict lower IRI values in warmer and higher IRI values in colder climates than Level 3 inputs. Level 1 inputs have no impact on the predicted thermal cracking (TC) in colder climates but show some impacts in warmer climates. In contrast, Level 3 inputs result in some variation in TC in colder climates while having no impact in warmer climates. Level 1 inputs result in lower AC layer and total rutting compared to Level 3 inputs in all climates. Both Level 1 and Level 3 inputs predict higher AC layer and total rutting in colder climates and lower rutting in warmer climates. Level 1 inputs yield lesser amounts of bottom-up and top-down fatigue cracks, with a greater sensitivity to variation of inputs, than Level 3 inputs. This paper presents the details of the trials, results, analyses and findings.

Introduction

The majority of highway agencies and their engineering service providers across North America and elsewhere around the globe have been using empirical design methods such as the AASHTO 1993[1] pavement design guide for pavement structural design over the last several decades. The AASHTO 1993 design method requires a few key parameters such as design traffic loads, resilient modulus of subgrade, AC, base and subbase materials and pavement service quality to come up with designs for flexible pavements. Although the initial (i.e., post-construction) and the desired terminal (i.e., end of design service life) quality of services are design inputs, this method cannot predict each individual distress in pavement such as surface smoothness in terms international roughness index (IRI), thermal cracking (TC), bottom-up fatigue cracking, top-down fatigue cracking (TDFC) and rutting in pavements. AASHTOWare PMED software[2], 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 various design inputs of pavement layer materials, subgrade, truck traffic and climate including asphalt mix properties.

PMED software has three levels for key design inputs, such as traffic data, properties of subgrade and the properties of the proposed pavement layer materials, based on the quality of those input parameters. For designing and analyzing flexible pavement structures using the PMED software, there are three quality levels (Levels 1 to 3) of asphalt mix inputs[3].

Level 1: Level 1 inputs, which can only be obtained through comprehensive laboratory tests, are recommended for the most reliable design and analysis outcomes. The PMED program permits the users to insert the mechanical properties of asphalt binder and AC mixes. Level 1 input data for asphalt binder includes viscosity, complex modulus and phase angles at multiple temperatures. Level 1 input data for AC mixes include dynamic modulus at multiple temperature and frequencies, indirect tensile strength, and creep compliance at multiple temperature and loading time. However, costly and sophisticated equipment, highly skilled personnel and significant time are required to obtain Level 1 input data, which are challenging for the PMED software users including pavement design professionals with different highway agencies and their engineering service providers.

Level 2: Level 2 inputs provide moderately reliable results. These inputs can be derived from a limited number of laboratory tests for mechanistic properties.

Level 3: Level 3 inputs consist of typical physical and volumetric properties of AC mixes e.g., aggregate gradation, asphalt mix unit weight or density, air voids content, asphalt binder content, and effective binder content or voids in mineral aggregates (VMA), and the penetration-viscosity or performance grades (PG) of asphalt binder. The PMED software also has some default properties of AC mixes. Consequently, PMED software license holders generally use Level 3 inputs for day-to-day design and/or analysis of pavement structures and for impact assessment of traffic loads, construction quality, layer materials and subgrade. This may result in low confidence in design inputs and outcomes of design/analysis or impact assessment, with potential dispute between different parties.

Level 3 inputs for typical AC mixes can be established from the construction database of each highway agency, which do not require extensive effort, and the desired asphalt binder grades for each project site. If Level 3 inputs are used, the adopted models in the PMED software calculate the mechanistic properties based on the correlation with the physical and volumetric properties. As a result, the design and analysis outcomes using the Level 3 inputs are considered to provide the least reliable results.

To compare the design/analysis outcomes and better understand the impacts of Level 1 and Level 3 inputs, the Transportation Association of Canada (TAC) ME Pavement Design Subcommittee conducted several design trials using inputs from five asphalt mixes containing 0 to 40% RAP and 11 weather stations across Canada. The outcomes from these design trials have also allowed for assessing the consistency of the predicted distresses and the suitability of the PMED software for day-to-day pavement design and analysis purposes. This paper presents the details of trial results and findings.

Background

The TAC ME Pavement Design Subcommittee has been evaluating the AASHTOWare PMED software since 2007. Design trials completed in the past to assess the software predicted distresses in flexible and rigid pavements include, but are not limited to, the following topics: Effect of Traffic Loads (Flexible/Rigid Pavements), Asphalt Mix Properties, Asphalt Binder Grades, Pavement Layer Thickness, Portland Cement Concrete (PCC) Slab and Joint Designs, Granular Base and Subbase Types and Stiffness, Subgrade Types and Stiffness, etc. The results of all these design trials are available in different technical papers presented in different conferences (refer to papers 4, 5, 6 and 7, for examples).

Although the PMED software has been under development and refinement for over two decades, despite its robustness in pavement design and analysis, and despite its ability to predict long-term performance of pavement structures, Canadian highway agencies are still facing challenges to implement this software. Some key concerns noted from the design trials stated above and agency uses include:

- Low sensitivity of predicted distresses in pavements due to some key inputs such as subgrade and unbound base/subbase properties and thickness;
- Inconsistencies in predicted distresses due to variation of some design inputs;
- Significant variation of predicted distresses between successive software versions;
- Significant amount of rutting in subgrade and base/subbase of overlayed pavements despite there being no such rutting in existing pavement;
- Unexpected variation of some predicted distresses between differing climatic conditions;
- No or negligible difference in predicted thermal cracking among differing climatic conditions in Canada with a PG 58-34 asphalt binder despite climatic inputs have colder than -34 °C temperatures;
- Large variation of climatic input parameters between ground-based, NARR and MERRA climate databases;
- The inability to come up with a unique set of calibration factors in each jurisdiction; and
- The uses of this software are limited to pavements with asphalt and concrete surfaces only.

As the PMED software is going through continuous changes or enhancement, the TAC ME Design Subcommittee (Subcommittee) elected to continue the assessment of software in terms of sensitivity, consistency and practicality of predicted distresses for changes in key design input parameters. In May to June 2024, the Subcommittee completed design trials using Level 1 and Level 3 input data of five AC mixes from Manitoba provincial highways. The latest online version (v3.0) of the PMED software was used in these design trials.

The selected asphalt mixes contained 0 to 40% RAP. Design trials were run using the climate data from eleven separate weather stations across Canada (as presented in ensuing sections of this paper). This paper presents the results of these design trials to compare the predicted distresses between Level 1 and Level 3 inputs of the above specified mixes, discusses the variability of the results and assess the suitability of the PMED software in terms of consistency and practicality of the predicted distresses.

Findings from Literature Review

The State of Florida has performed some sensitivity analyses with different materials inputs and noted that AC mix dynamic modulus is one of the most sensitive input parameter to predicted distresses[8]. PMED software[2] estimates the dynamic modulus (E*) values using Witczak model when Level 3 input data of asphalt mixes and asphalt binders are used. The estimated dynamic modulus values with the Witczak model were shown to fairly match with the measured values at intermediate temperatures. However, the estimated dynamic modulus values at high temperatures were shown to be lower than the measured values[9,10]. Studies elsewhere have shown that the dynamic modulus values predicted by Witczak model are relatively accurate[11,12]. However, a study in Manitoba[13] involving six rehabilitation projects noted that Level 1 inputs provide more accurate estimates of pavement distresses compared to Level 3 inputs.

Esfandiarpour et al.[14,] presented a Manitoba case study for three different mixes comparing the PMED software predicted distresses using laboratory measured Level 1 vs. local Level 3 asphalt mix properties. These AC mixes were taken from Manitoba provincial highway projects. The study noted some differences and inconsistencies in predicted distresses between these two levels of input parameters among the three mixes, as summarized below:

i. Mix A had PG 52-34 asphalt binder and 13.5% voids in mineral aggregates (VMA), Mix B had PG 52-28 asphalt binder and 12.4% VMA and Mix C had PG 52-34 asphalt binder and 13.9% VMA. All mixes had almost identical air voids contents (3.9 to 4.0%) and same gradation specifications.
ii. Level 3 inputs provided a notably higher amount of TDFC for Mix A, same amount of TDFC for Mix B and a notably higher amount of TDFC for Mix C than the Level 1 inputs.
iii. Level 3 inputs provided a slightly higher amount of BUFC for Mix A, same amount of BUFC for Mix B and a slightly higher amount of BUFC for Mix C than Level 1 inputs.
iv. Level 3 inputs provided a significantly lower amount of TC for Mix A, a significantly higher amount of TC for Mix B and a notably higher amount of TC for Mix C than Level 1 inputs.
v. Level 3 inputs provided a higher amount of AC layer rutting for Mix A, same amount of AC layer rutting for Mix B and higher amount of AC layer rutting for Mix C than Level 1 inputs.

Hasan et. Al[15] conducted a field validation of PMED software predictions for six pavement sites in New Mexico, covering AC mixes with RAP contents ranging from 15% to 35%. Level 1 inputs produced IRI and rutting predictions that closely matched field performance. Level 2 and Level 3 AC mix inputs under predicted dynamic modulus values compared to laboratory measured (Level 1) values.

Difenderfer[16] conducted a study involving two pavement sections and multiple design trials of these sections using Level 1, 2 and 3 asphalt mix inputs into the PMED software. Fatigue cracking predictions using Level 3 asphalt mix inputs showed slight differences attributable to binder type, following a trend of reduced fatigue cracking with the use of stiffer binders. The rutting model generally over predicted from the expected rutting. Rutting predictions using Level 3 inputs also showed slight differences due to binder type, following the expected trend of reduced rutting with stiffer binders. However, these differences were not statistically significant and, more importantly, were not as pronounced as would be expected based on field experience with binder performance.

Scope, Objectives and Significance

The use of Level 1 inputs for every AC mix type that an agency uses is not always possible due to resource constraints. This leads to the use of the typical Level 3 local or default input values for the design and analysis of pavements using the PMED software. As indicated earlier in this paper, past design trials conducted by the Subcommittee noted some issues with the PMED software.

Several past studies conducted elsewhere (see literature review above for examples) indicated that Level 1 inputs provide accurate results than Level 3 inputs and some others noted significant differences in predicted distresses between these two levels of AC mix inputs. Some studies have noted that the predicted dynamic modulus values from Level 3 inputs fairly match with the measured values, while other studies noted that accuracy of the predicted dynamic modulus values vary depending on dynamic modulus test temperatures. In this study, several design trials using Level 1 and Level 3 inputs of asphalt mixes were completed. These design trials included five asphalt mixes from Manitoba provincial highways containing 0 to 40% RAP. For each AC mix, design trials were run for 11 different weather stations across Canada. These resulted in a total of 110 design trials in this study.

The objectives of this study were:

i) comparing the amount of predicted distresses between Level 1 and Level 3 design inputs of asphalt mix properties and asphalt binders;

ii) investigating the differences in the trends of predicted distresses between these two levels of inputs;

iii) comparing the trends of predicted distresses among varied climatic areas between this two inputs levels; and

iv) assessing the suitability of the PMED software in terms of its ability to predict the distresses in flexible pavements in a consistent and practical manner.

The objective of this paper is to present the results of the above-mentioned trials, along with detailed analyses and findings. The information presented in this paper may assist agencies and interested individuals in assessing the suitability of the PMED software and the impact of input quality on flexible pavement design and performance.

Software Versions and General Design Inputs

All participants used the PMED software version 3.0 with the global calibration coefficients in all design trial runs. The summary of general design input parameters is presented in Table 1. The varied inputs for design trial runs include Level 1 and Level 3 mix properties from five different asphalt concrete (AC) mixes with varied amount of RAP content. These asphalt mixes were placed on Manitoba highways. Design trials for each asphalt mix and each input level also included varied climatic data from eleven weather stations across Canada. Details of varied climatic data and asphalt mix inputs are presented in the next sections in this paper.

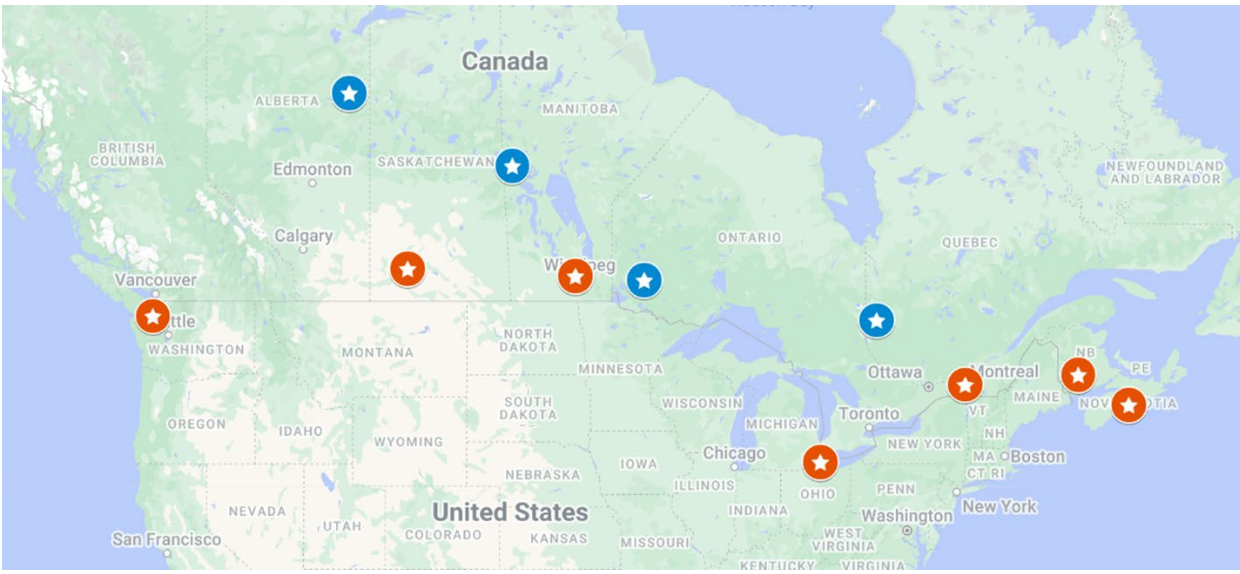
Table 1. General design inputs for design trials

Item		Value Used
Climate Data		MERRA-2 from 11 weather stations across Canada
Truck Traffic		Two-way 2,500 trucks/day (1,000 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% for all distresses
HMA Properties		Five asphalt mixes with varied physical, volumetric and mechanical properties, and asphalt binder grades. All other input parameters such as poisons ratio, reference temperature, thermal conductivity and heat capacity remained unchanged to software calculated default values in all design trials
Pavement Structures	AC Surface	150 mm thick Bit. B (Manitoba) mixes
	Base	200 mm thick granular base (MB GBC-I) with an annual representative resilient modulus (Mr) value of 225 MPa
	Subbase	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 resilient modulus (Mr) value of 35.0 MPa

Selected Weather Stations and Summary of Climate Data

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

Figure 1. Geographic locations of weather stations across Canada



The red dots indicate relatively warmer 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 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.

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

As noted in the introductory and background sections of this paper, the PMED software input parameters have three different levels (Level 1 to Level 3) based on the quality of the data. For the design trials included in this paper, five different AC mixes from Manitoba provincial highway projects were selected. The RAP contents in these mixes varied from 0 (zero) to 40 percent. The laboratory testing for Level 1 inputs such as dynamic modulus, creep compliance and indirect tensile strength of these AC mixes were conducted at the University of Manitoba. Level 1 inputs for asphalt binders, such as complex modulus, viscosity and phase angles, were determined by Central Laboratory staff of Manitoba Transportation and Infrastructure (MTI). The physical and volumetric properties of asphalt mixes reflect the values established in the asphalt mix design.

Design trials were conducted for each of the selected weather stations using both Level 1 and Level 3 inputs. The summary of Level 3 properties for these five AC mixes is presented in Table 3. Table 4 presents the summary of Level 1 inputs for these five mixes. Table 5 presents the summary of asphalt binder Level 1 input properties.

Table 3. Level 3 properties of selected AC mixes

Asphalt Mixes		**Mix #1**	**Mix #2**	**Mix #3**	**Mix #4**	**Mix #5**
Mix Type		MB Bit. B	MB Bit. B	MB Bit. B	MB Bit. B	MB Bit. B
Aggregate Type		Gravel	Gravel	Gravel	Limestone	Limestone
RAP (%)		0	10	40	0	40
Volumetric Properties						
Unit Weight (kg/m^3)		2409	2415	2405	2380	2398
Effective Binder Content by Volume (%)		9.5	9.9	8.6	10.2	8.8
Air Voids (%)		4.0	3.6	4.5	3.8	3.9
Void in Mineral Aggregates (%)		13.5	13.5	13.1	14.0	12.7
Asphalt Binder Content by Weight of Mix (%)		5.2	5.2	5.0	5.6	4.8
Physical Properties						
Aggregate Gradation (% Passing)	19 mm	100	100	100	100	100
	9.5 mm	80	82	78	80	81
	4.75 mm	62	63	61	61	60
	75 µm (0.075 mm)	5.0	5.8	4.5	4.5	5.8
Virgin Asphalt Binder Grade		Pen. 150-200	Pen. 150-200	Pen. 200-300	Pen. 150-200	Pen. 150-200
Blended (Virgin/RAP) Asphalt Binder Grade		PG 52-28	PG 52-28	PG 58-22	PG 52-28	PG 64-16

Table 4. Level 1 properties of selected AC mixes

AC Mixes	Dynamic Modulus (E*) (MPa)							Creep Compliance (1/GPa)				IDT Strength at -10 °C (MPa)
	Frequency/ Temperature	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz	Test Temperature/ Loading Time	Low Temp. (-20 °C)	Mid Temp. (-10 °C)	High Temp. (0 °C)	
Mix #1	-10 (°C)	17034	21279	23017	26881	28416	30026	1 sec.	0.024846	0.044804	0.083214	2.3468
	5 (°C)	5222	8095	9411	13299	15095	17627	2 sec.	0.025738	0.047988	0.096281	
	25 (°C)	805	1389	1738	3066	3901	5338	5 sec.	0.027193	0.054612	0.126927	
	40 (°C)	366	542	624	1001	1278	1812	10 sec.	0.028606	0.062115	0.162306	
	54 (°C)	323	390	403	581	703	933	20 sec.	0.030012	0.072406	0.216153	
								50 sec.	0.033596	0.092780	0.321389	
								100 sec.	0.037921	0.116273	0.444512	
Mix #2	-10 (°C)	19500	22933	24458	27026	28530	29702	1 sec.	0.024904	0.043416	0.088101	2.6685
	5 (°C)	9325	10601	13045	16761	18345	19972	2 sec.	0.025630	0.046055	0.100221	
	25 (°C)	1537	2464	3047	4952	6023	7447	5 sec.	0.027503	0.051523	0.127015	
	40 (°C)	504	728	885	1499	1910	2584	10 sec.	0.028770	0.057509	0.159744	
	54 (°C)	345	414	459	628	752	1001	20 sec.	0.030647	0.065844	0.208516	
								50 sec.	0.033895	0.081780	0.306134	
								100 sec.	0.037480	0.100189	0.418754	
Mix #3	-10 (°C)	22565	26380	29126	31223	32859	34172	1 sec.	0.023039	0.032337	0.065345	3.12366
	5 (°C)	9470	12759	14283	17944	19601	20926	2 sec.	0.023554	0.033776	0.071674	
	25 (°C)	1654	2738	3409	5565	6750	9064	5 sec.	0.024454	0.036606	0.086481	
	40 (°C)	471	700	855	1487	1938	2642	10 sec.	0.025293	0.039636	0.103574	
	54 (°C)	340	402	458	635	767	1033	20 sec.	0.026322	0.043820	0.127630	
								50 sec.	0.028270	0.052147	0.177085	
								100 sec.	0.030567	0.061232	0.235843	
Mix #4	-10 (°C)	19715	23597	25026	28703	30046	31320	1 sec.	0.036765	0.054276	0.121677	2.39468
	5 (°C)	7225	11254	11597	16207	17866	19994	2 sec.	0.038043	0.057095	0.137026	
	25 (°C)	1326	2257	2775	4749	5847	7670	5 sec.	0.040454	0.062859	0.171908	
	40 (°C)	633	696	929	1498	1927	2678	10 sec.	0.042718	0.070373	0.212475	
	54 (°C)	314	435	410	607	765	1087	20 sec.	0.045683	0.080211	0.271167	
								50 sec.	0.051189	0.098551	0.386590	
								100 sec.	0.055942	0.120932	0.521588	
Mix #5	-10 (°C)	23448	27586	29225	33060	34734	36647	1 sec.	0.033568	0.047343	0.089167	2.56404
	5 (°C)	9967	13122	14530	17936	19345	20957	2 sec.	0.034396	0.049714	0.097824	
	25 (°C)	2178	3515	4328	6734	7944	9664	5 sec.	0.035991	0.054573	0.116355	
	40 (°C)	704	1097	1357	2271	2898	3730	10 sec.	0.037575	0.059506	0.137688	
	54 (°C)	438	564	654	977	1204	1578	20 sec.	0.039610	0.066370	0.167416	
								50 sec.	0.042778	0.077916	0.224138	
								100 sec.	0.046091	0.090886	0.290346	

Table 5. Level 1 properties of selected blended asphalt binders

AC Mixes	Temperature	Complex Modulus (G*) (Pa)	Phase Angle (deg.)	Brookfield Viscosity (mPa-sec) (at 135°C)
Mix #1	15 °C	6.04×10^6	49.5	850
	35 °C	2.87×10^5	63.9	
	70 °C	2180	81.8	
	76 °C	1080	84.1	
Mix #2	15 °C	1.14×10^7	41.8	1088
	35 °C	5.10×10^5	61.0	
	70 °C	4250	78.5	
	76 °C	2030	81.3	
Mix #3	15 °C	8.92×10^6	44.9	621
	35 °C	3.88×10^5	64.3	
	64 °C	4280	81.0	
	70 °C	1910	83.8	
Mix #4	15 °C	7.52×10^6	48.5	888
	35 °C	3.24×10^5	64.0	
	70 °C	2470	81.7	
	76 °C	1190	83.9	
Mix #5	15 °C	1.08×10^7	42.7	1329
	35 °C	5.64×10^5	60.0	
	76 °C	2350	80.5	
	82 °C	1190	83.1	

The results from these design trials were then used to compare the impact of varied AC mixes Level 1 and Level 3 design inputs on the predicted distresses in different climatic conditions. The suitability of the PMED software in predicting pavement performance in terms of predicted surface distresses as expected or as experienced in the field was also assessed.

Results, Analysis and Discussion

The summary of predicted distresses at the end of the 20-year design service life for selected mixes corresponding to Level 1 and Level 3 inputs are presented in Tables 6a, 6b and 6c. Detailed analyses and discussion are presented in the following sections using graphical trends of the predicted distresses. Only the trends of predicted distresses for a selected number of weather stations are presented in each graphical figure for ease of understanding and tracking the changes in trends and the impacts of varied input parameters. These representative weather stations were selected to demonstrate the widespread variation of predicted distresses in differing climatic conditions.

Table 6a. Predicted distresses: Victoria, Fort McMurray, Swift Current, Winnipeg and The Pas

Weather Station	Design No.	Trial	Predicted Distresses: Terminal IRI (m/km)	Total Rutting (mm)	AC BUFC (%)	AC TC (m/km)	AC TDFC (%)	AC Rutting (mm)
Victoria, BC	1	AC Mix 1 L1	2.18	8.18	1.45	40.97	12.23	2.45
	2	AC Mix 2 L1	2.17	7.74	1.45	40.97	12.82	2.03
	3	AC Mix 3 L1	2.15	7.36	1.46	40.97	12.04	1.74
	4	AC Mix 4 L1	2.16	7.50	1.45	40.97	12.34	1.83
	5	AC Mix 5 L1	2.15	6.99	1.45	40.97	13.48	1.40
	1	AC Mix 1 L3	2.20	9.18	1.46	40.97	11.50	3.37
	2	AC Mix 2 L3	2.20	9.11	1.45	40.97	11.56	3.30
	3	AC Mix 3 L3	2.18	8.18	1.48	40.97	12.87	2.42
	4	AC Mix 4 L3	2.20	9.37	1.46	40.97	11.44	3.53
	5	AC Mix 5 L3	2.17	7.57	1.45	40.97	13.56	1.86
Fort McMurray, AB	1	AC Mix 1 L1	2.71	11.69	1.49	512.54	14.17	5.81
	2	AC Mix 2 L1	2.69	10.84	1.46	512.54	14.20	4.98
	3	AC Mix 3 L1	2.67	10.05	1.53	512.54	14.17	4.27
	4	AC Mix 4 L1	2.63	10.05	1.46	463.01	14.19	4.24
	5	AC Mix 5 L1	2.64	8.94	1.47	512.54	14.23	3.19
	1	AC Mix 1 L3	2.51	14.71	1.53	140.81	14.16	8.74
	2	AC Mix 2 L3	2.50	14.53	1.48	140.27	14.16	8.56
	3	AC Mix 3 L3	2.69	12.05	1.64	553.29	14.20	6.16
	4	AC Mix 4 L3	2.52	15.15	1.49	139.99	14.16	9.16
	5	AC Mix 5 L3	2.67	10.06	1.48	588.92	14.23	4.34
Swift Current, SK	1	AC Mix 1 L1	2.57	7.78	1.45	512.54	14.16	2.07
	2	AC Mix 2 L1	2.56	7.28	1.45	512.54	14.19	1.60
	3	AC Mix 3 L1	2.55	6.93	1.45	512.54	14.14	1.34
	4	AC Mix 4 L1	2.55	7.15	1.45	512.54	14.16	1.51
	5	AC Mix 5 L1	2.54	6.70	1.45	512.54	14.22	1.14
	1	AC Mix 1 L3	2.28	8.55	1.46	88.19	14.13	2.75
	2	AC Mix 2 L3	2.28	8.56	1.45	93.95	14.13	2.77
	3	AC Mix 3 L3	2.57	7.78	1.47	588.92	14.19	2.05
	4	AC Mix 4 L3	2.29	8.79	1.45	90.66	14.11	2.97
	5	AC Mix 5 L3	2.55	7.10	1.45	588.92	14.22	1.41
Winnipeg (Rosser), MB	1	AC Mix 1 L1	2.60	7.74	1.45	512.54	14.16	1.99
	2	AC Mix 2 L1	2.60	7.55	1.45	512.54	14.19	1.82
	3	AC Mix 3 L1	2.58	7.07	1.46	512.54	14.16	1.43
	4	AC Mix 4 L1	2.59	7.19	1.45	512.54	14.17	1.52
	5	AC Mix 5 L1	2.58	6.88	1.45	512.54	14.22	1.28
	1	AC Mix 1 L3	2.42	8.91	1.46	248.80	14.13	3.08
	2	AC Mix 2 L3	2.41	8.82	1.45	231.53	14.14	3.00
	3	AC Mix 3 L3	2.61	7.86	1.47	588.92	14.19	2.09
	4	AC Mix 4 L3	2.41	9.08	1.46	225.78	14.13	3.23
	5	AC Mix 5 L3	2.59	7.29	1.45	588.92	14.23	1.57
The Pas (Wanless), MB	1	AC Mix 1 L1	2.62	8.12	1.46	512.14	14.19	2.34
	2	AC Mix 2 L1	2.61	7.64	1.45	512.54	14.20	1.90
	3	AC Mix 3 L1	2.60	7.39	1.46	512.54	14.17	1.72
	4	AC Mix 4 L1	2.60	7.50	1.45	505.47	14.19	1.79
	5	AC Mix 5 L1	2.59	6.91	1.45	512.54	14.23	1.30
	1	AC Mix 1 L3	2.46	9.22	1.46	290.18	14.16	3.37
	2	AC Mix 2 L3	2.40	9.14	1.45	190.97	14.16	3.30
	3	AC Mix 3 L3	2.62	8.04	1.48	588.92	14.20	2.25
	4	AC Mix 4 L3	2.38	9.41	1.46	152.05	14.16	3.54
	5	AC Mix 5 L3	2.60	7.57	1.45	588.92	14.23	1.84

Table 6b. Predicted distresses: Wheatley, Waldhof, Rouyn, Montreal and Fredericton

Weather Station	Design No.	Trial	Predicted Distresses					
			Terminal IRI (m/km)	Total Rutting (mm)	AC BUFC (%)	AC TC (m/km)	AC TDFC (%)	AC Rutting (mm)
Wheatley, ON	1	AC Mix 1 L1	2.24	7.98	1.45	41.34	13.86	2.25
	2	AC Mix 2 L1	2.23	7.45	1.45	42.75	13.97	1.75
	3	AC Mix 3 L1	2.36	7.18	1.46	234.91	13.82	1.56
	4	AC Mix 4 L1	2.23	7.32	1.45	40.98	13.88	1.66
	5	AC Mix 5 L1	2.25	6.77	1.45	94.79	14.09	1.19
	1	AC Mix 1 L3	2.27	8.96	1.46	40.97	13.75	3.15
	2	AC Mix 2 L3	2.27	8.89	1.45	40.97	13.76	3.08
	3	AC Mix 3 L3	2.24	7.94	1.48	40.97	13.97	2.18
	4	AC Mix 4 L3	2.27	9.11	1.46	40.97	13.73	3.28
	5	AC Mix 5 L3	2.23	7.37	1.45	40.97	14.11	1.66
Waldhof, ON	1	AC Mix 1 L1	2.65	8.85	1.46	512.54	14.17	3.04
	2	AC Mix 2 L1	2.65	8.52	1.45	512.54	14.20	2.76
	3	AC Mix 3 L1	2.63	7.96	1.47	512.54	14.17	2.25
	4	AC Mix 4 L1	2.63	8.06	1.45	512.54	14.17	2.32
	5	AC Mix 5 L1	2.62	7.48	1.45	512.54	14.23	1.83
	1	AC Mix 1 L3	2.43	10.44	1.47	155.06	14.14	4.58
	2	AC Mix 2 L3	2.42	10.35	1.46	153.42	14.14	4.48
	3	AC Mix 3 L3	2.65	8.82	1.50	588.92	14.20	3.01
	4	AC Mix 4 L3	2.43	10.70	1.46	152.60	14.14	4.82
	5	AC Mix 5 L3	2.64	8.14	1.46	588.92	14.23	2.37
Rouyn, QC	1	AC Mix 1 L1	2.76	12.64	1.50	512.54	14.17	6.76
	2	AC Mix 2 L1	2.74	11.46	1.47	512.54	14.20	5.60
	3	AC Mix 3 L1	2.72	10.82	1.55	512.54	14.16	5.04
	4	AC Mix 4 L1	2.66	10.77	1.46	434.70	14.17	4.97
	5	AC Mix 5 L1	2.68	9.28	1.47	512.54	14.23	3.53
	1	AC Mix 1 L3	2.51	15.91	1.54	42.91	14.14	9.94
	2	AC Mix 2 L3	2.51	15.71	1.48	42.64	14.14	9.75
	3	AC Mix 3 L3	2.75	12.99	1.70	547.81	14.20	7.11
	4	AC Mix 4 L3	2.53	16.43	1.49	42.52	14.14	10.44
	5	AC Mix 5 L3	2.72	10.90	1.49	588.92	14.23	5.09
Montreal, QC	1	AC Mix 1 L1	2.63	7.88	1.45	512.54	14.10	2.12
	2	AC Mix 2 L1	2.62	7.35	1.45	512.54	14.14	1.62
	3	AC Mix 3 L1	2.61	7.02	1.46	512.54	14.09	1.39
	4	AC Mix 4 L1	2.62	7.23	1.45	512.54	14.10	1.54
	5	AC Mix 5 L1	2.60	6.77	1.45	512.54	14.20	1.17
	1	AC Mix 1 L3	2.47	8.72	1.46	295.66	14.06	2.87
	2	AC Mix 2 L3	2.47	8.65	1.45	285.25	14.06	2.82
	3	AC Mix 3 L3	2.63	7.87	1.47	588.92	14.14	2.09
	4	AC Mix 4 L3	2.47	8.89	1.46	275.38	14.06	3.02
	5	AC Mix 5 L3	2.62	7.17	1.45	588.92	14.20	1.45
Fredericton, NB	1	AC Mix 1 L1	2.55	12.81	1.51	214.86	14.31	6.90
	2	AC Mix 2 L1	2.57	11.64	1.47	286.09	14.16	5.78
	3	AC Mix 3 L1	2.67	11.00	1.58	451.21	14.11	5.20
	4	AC Mix 4 L1	2.38	10.98	1.46	49.03	14.14	5.15
	5	AC Mix 5 L1	2.61	9.35	1.47	420.55	14.20	3.59
	1	AC Mix 1 L3	2.51	16.35	1.57	40.97	14.10	10.35
	2	AC Mix 2 L3	2.51	16.17	1.50	40.97	14.10	10.17
	3	AC Mix 3 L3	2.43	13.03	1.79	43.26	14.17	7.11
	4	AC Mix 4 L3	2.53	16.86	1.51	40.97	14.10	10.87
	5	AC Mix 5 L3	2.40	11.10	1.50	65.63	14.22	5.25

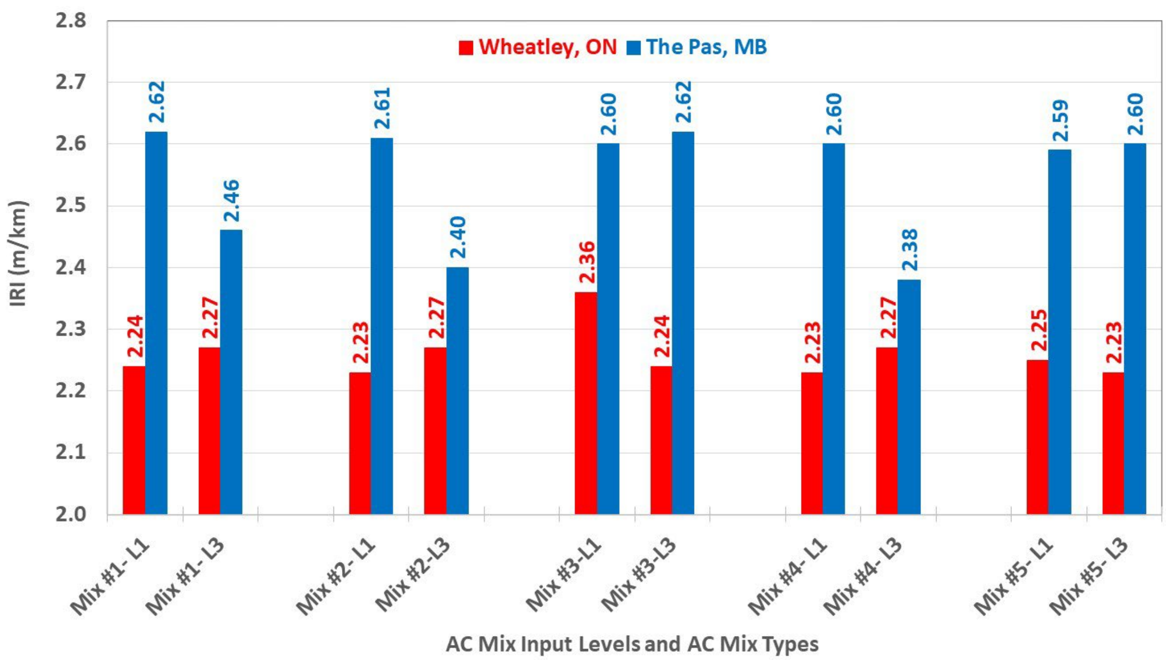
Table 6c. Predicted distresses: Halifax

Weather Station	Design No.	Trial	Predicted Distresses					
			Terminal IRI (m/km)	Total Rutting (mm)	AC BUFC (%)	AC TC (m/km)	AC TDFC (%)	AC Rutting (mm)
Halifax, NS	1	AC Mix 1 L1	2.26	7.32	1.45	41.00	13.97	1.61
	2	AC Mix 2 L1	2.25	6.92	1.45	41.51	14.04	1.24
	3	AC Mix 3 L1	2.32	6.63	1.45	157.78	13.95	1.05
	4	AC Mix 4 L1	2.24	6.84	1.45	40.97	13.98	1.21
	5	AC Mix 5 L1	2.24	6.47	1.45	56.56	14.14	0.93
	1	AC Mix 1 L3	2.27	7.97	1.46	40.97	13.89	2.17
	2	AC Mix 2 L3	2.27	7.93	1.45	40.97	13.89	2.13
	3	AC Mix 3 L3	2.26	7.34	1.46	40.97	14.06	1.60
	4	AC Mix 4 L3	2.28	8.11	1.45	40.97	13.89	2.28
	5	AC Mix 5 L3	2.24	6.82	1.45	40.97	14.16	1.14

Effect of Level 1 vs Level 3 AC Mix Inputs on Predicted Roughness

Figure 2 shows the variations of the predicted surface roughness for Level 1 and Level 3 inputs from the five AC mixes used in this study.

Figure 2. Variations of the predicted IRI

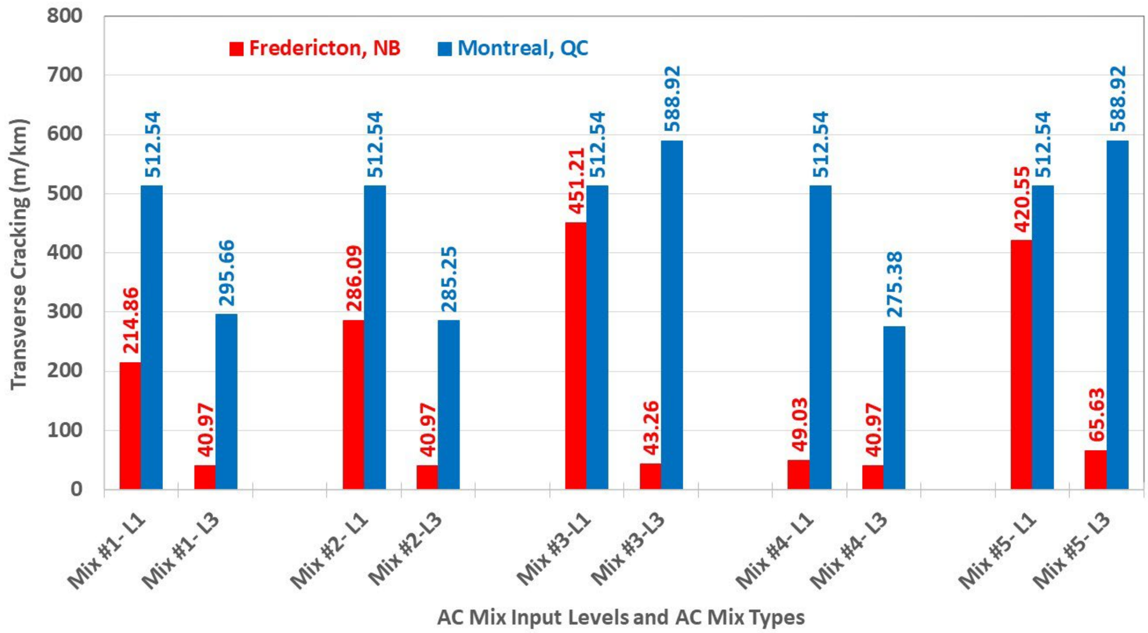


As shown in Figure 2 (above), the predicted surface roughness (IRI) varies significantly between AC mix input levels, AC mix types and climatic conditions. Colder climatic areas (e.g., The Pas, MB) exhibited significantly higher IRI values than warmer climates (e.g., Wheatley, ON), which are mostly related to other types of distresses predicted by the PMED software. Level 1 inputs resulted in lower IRI in warmer climates (e.g., Wheatley) for AC mixes #1 (with 0% RAP), #2 (with 10% RAP) and #4 (with 0% RAP), but higher IRI for AC mixes #3 (with 40% RAP) and #5 (with 40% RAP) than Level 3 inputs. However, trends are reversed for colder climates with Level 1 inputs resulting in higher IRI for AC mixes #1, #2 and #4 (with ≤10% RAP), and lower IRI for AC mixes #3 and #5 (with 40% RAP) Level 3 inputs. A statistical analysis indicated that the predicted IRI values mostly depend on the predicted total fatigue cracking (BUFC plus TDFC), traverse cracking (TC) and rutting. The effect of precipitation and freezing index were minimal. Subgrade parameters were excluded from this analysis as they remained unchanged in all design trials.

Effect of Level 1 vs Level 3 AC Mix Inputs on Predicted Transverse Cracking

Figure 3 shows the variations of the predicted TC for Level 1 and Level 3 inputs from the five AC mixes included in this study. Figure 3 shows that the predicted TC varied significantly between colder and warmer climates. Colder climates (e.g., Montreal, QC) produced significantly higher amounts of transverse cracking than warmer climates (e.g., Fredericton). Level 1 inputs had no impact on predicted TC in colder climates due to changes in AC mix type (despite variation of RAP contents and binder grades), but noticeable variation was observed for warmer climates among the AC mix types with a higher amount of TC with increased RAP (stiffer binder) contents. Conversely, Level 3 inputs resulted in some variations in colder climates with a higher amount of TC with 40% RAP (stiffer binder in Mix #3 and #5) content than 0% and 10% RAP (softer binder) contents but had no or minimal impact in warmer climates among AC mixes despite variation of RAP contents and binder grades. These trends seem to be inconsistent and unexpected.

Figure 3. Variations of the predicted transverse cracking

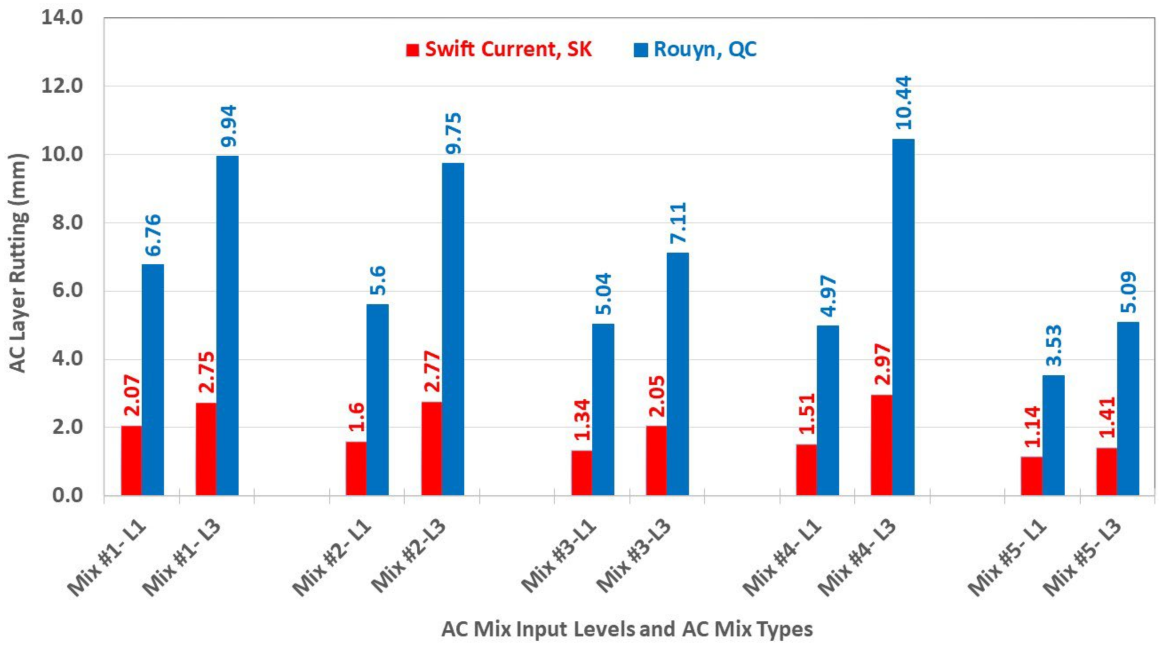


In colder climates (e.g., in Montreal), Level 1 inputs produced higher amounts of TC for Mix #1, #2 and #4 (with 0 to 10% RAP i.e., with softer asphalt binders), but lower amounts of TC for Mix #3 and #5 (both with 40% RAP and stiffer asphalt binders), than Level 3 inputs. In warmer climates, Level 1 inputs produced higher amounts of TC than Level 3 inputs for all AC mixes. These trends are also questionable.

Effect of Level 1 vs Level 3 AC Mix Inputs on Predicted AC Layer Rutting

Figure 4 shows the variations of the predicted AC layer rutting for Level 1 and Level 3 inputs from the five AC mixes used the trials. As shown in Figure 4, Level 1 AC mix inputs resulted in lower amounts of rutting in AC layers compared to Level 3 inputs for all AC mixes and climates (regardless of RAP contents and asphalt binder grades). Mixes with stiffer blended asphalt binders (40% RAP contents) exhibited lower amounts of rutting in AC layers, suggesting that binder stiffness plays a crucial role in reducing rutting. Figure 4 also shows that Rouyn (QC) with colder climate (maximum temperature of 31.1 °C) experienced significantly higher amount of rutting in the AC layer than Swift Current (SK) with warmer climate (maximum temperature of 37.9 °C), regardless of the levels of AC mix inputs. Such trends are unexpected.

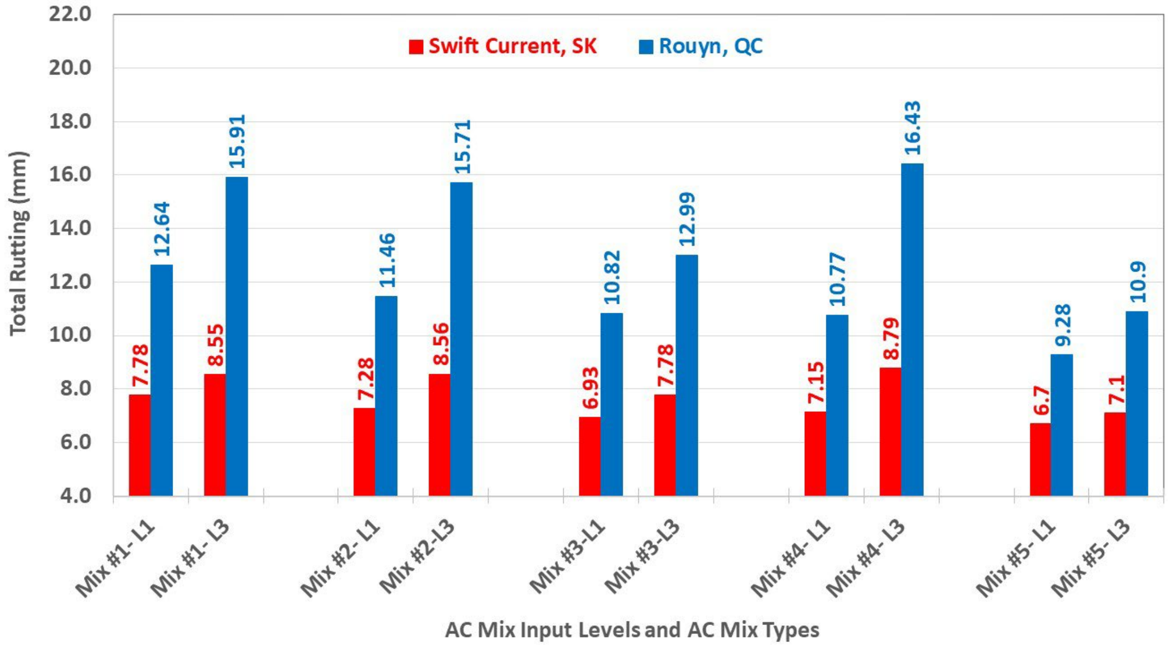
Figure 4. Variations of the predicted AC layer rutting



Effect of Level 1 vs Level 3 AC Mix Inputs on Predicted Total Rutting

Figure 5 shows the variations of the predicted total rutting for Level 1 and Level 3 inputs for the five AC mixes included in this study. As shown in the figure, the trends of predicted total rutting are similar to the trends of rutting in AC layer. The total pavement rutting values were 5.5 to 6.0 mm higher than the AC layer rutting indicating that rutting in subgrade, subbase and base layers contributed an additional 5.5 to 6.0 mm. Since the input parameters for subgrade, granular subbase and base layers remained unchanged in all design trials, such prediction may be reasonable.

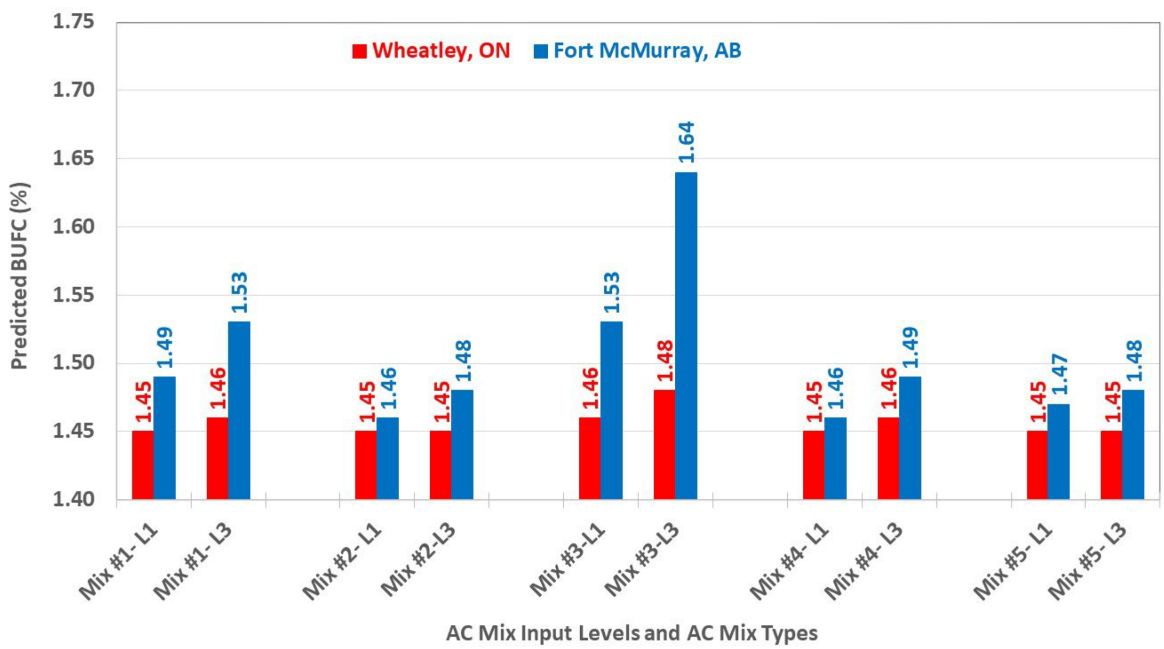
Figure 5. Variations of the predicted total rutting



Effect of Level 1 vs Level 3 AC Inputs on Predicted Bottom-Up Fatigue Cracking (BUFC)

Figure 6 shows the variations of the PMED software predicted BUFC for Level 1 and Level 3 inputs from five AC mixes included in this study.

Figure 6. Variations of the predicted BUFC

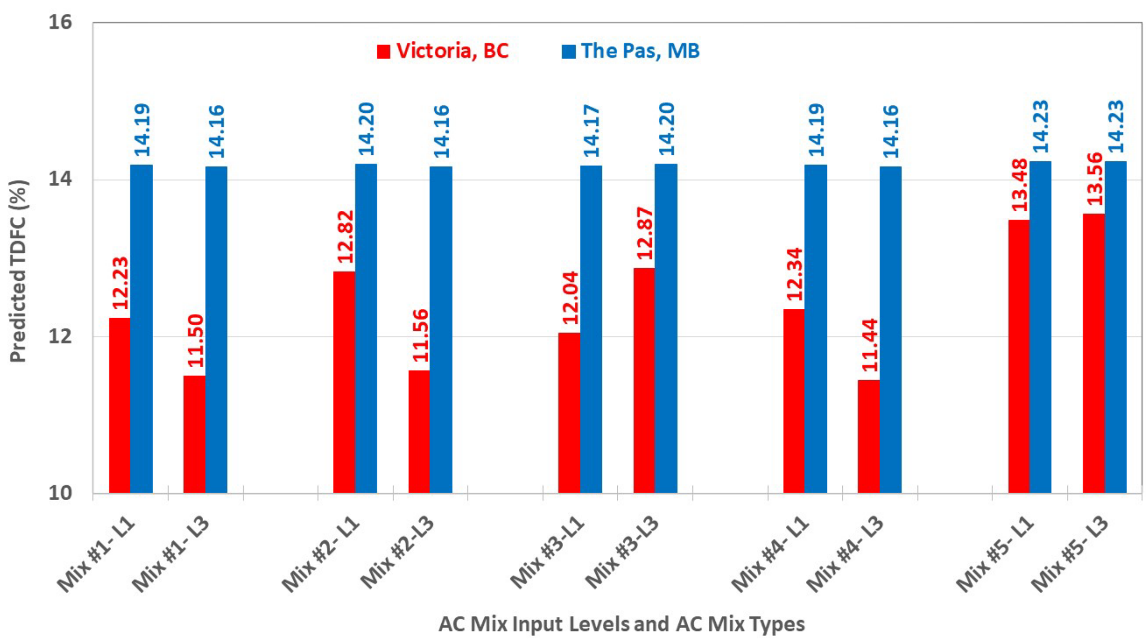


As shown in Figure 6 (above), in general, the amounts of predicted BUFC are lower with Level 1 AC mix inputs than Level 3 inputs. The differences in the predicted BUFC values between these two input levels are, in general, higher in colder climates (e.g., in Fort McMurray, AB) than in warmer climates (e.g., in Wheatley, ON). AC Mix #3 (40% RAP, PG 58-22 binder and 4.5% AV contents) experienced higher amounts of BUFC than Mix #2 (10% RAP, PG 52-28 binder and 3.6% AV). Alternatively, Mix #5 (40% RAP, PG 64-16 binder and 3.9% AV contents) experienced lower amounts of BUFC than Mix #4 (0% RAP, PG 52-28 binder and 3.8% AV contents) for both climates and both levels of inputs. These indicate that higher AV contents result in increased amounts of BUFC, which is reasonable, and stiffer binder reduces the amounts of BUFC, which is questionable.

Effect of Level 1 vs Level 3 AC Inputs on Predicted Top-Down Fatigue Cracking (TDFC)

Figure 7 shows the variations of the predicted TDFC for Level 1 and Level 3 inputs from five AC mixes. The trends in Figure 7 shows that Level 1 AC mix inputs provided higher amounts of TDFC for Mixes #1, #2 and #4 (with 0% to 10% RAP), but lower (or similar) amounts of TDFC for Mixes #3 and #5 (with 40% RAP) than Level 3 inputs. The differences in the predicted TDFC between Level 1 and Level 3 AC mix inputs are more pronounced in warmer climates (e.g., Victoria, B.C.) than colder climates (e.g., in The Pas, MB), which experienced minimal or no differences between these two inputs levels. Such trends of the predicted TDFC seem to be the opposite of the trends observed for the BUFC.

Figure 7. Variations of the predicted TDFC



Summary and Conclusions

PMED software is a modern and sophisticated pavement design and analysis tool. However, there have been some long-standing concerns associated with the sensitivity, consistency and practically of the predicted distresses for changes in some key design input parameters. Accordingly, the TAC ME Pavement Design Subcommittee has continued the assessment of this software since 2007 as it is going through continuous evolution. The focus of this study was to evaluate the impacts of Level 1 and Level 3 inputs on predicted distresses using the PMED software for five asphalt mixes containing 0 to 40% RAP in varied climatic conditions across Canada. The findings in this study may help identify areas for potential enhancement to the software. The key findings are summarized below:

1. Level 1 AC mix inputs had no impact on TC in colder climates, but had noticeable impact in warmer climates, with opposite trends for Level 3 inputs. Level 1 inputs provided higher TC than Level 3 inputs for mixes with softer asphalt binders in colder climates, but the trends reversed for stiffer asphalt binders. In warmer climates, Level 1 inputs produced higher TC for all AC mixes. These trends are unexpected.
2. Level 1 AC mix inputs provided lower AC layer rutting than Level 3 inputs for all mixes and climates. Colder climates experienced significantly higher AC layer rutting than warmer climates, regardless of input levels, which are unexpected.
3. The trends of total pavement rutting were similar to the trends of AC layer rutting.
4. Level 1 AC mix inputs provided lower BUFC than Level 3 inputs with significant differences in colder climates than in warmer climates. A higher AV contents increased BUFC, as expected. A stiffer binder reduced BUFC, which is questionable.
5. The predicted TDFC and BUFC showed opposing trends, and its reason is unclear.
6. The variation predicted IRI was found to be mostly dependent on the variation of predicted cracking and rutting.

Overall, PMED software does not appear to provide consistent and practical results or trends of some predicted distresses due to variation of AC mix inputs. The estimation of AC mixes mechanical properties (i.e., Level 1 inputs) from physical/volumetric properties and asphalt binder grades (i.e., Level 3 inputs) using the model used in the PMED software does not seem to be consistent.

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