An Evaluation of Suitability of the Pavement ME Design Software for Flexible Pavement Overlay Design

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Abstract

Flexible pavements, surfaced with hot mix asphalt (HMA), are the prevalent pavement structures in Canada and elsewhere. HMA, also called asphalt concrete (AC), overlays are the common treatments to extend their lifecycle. Commonly used AC overlay design methods, e.g., AASHTO 1993, have been providing reasonable trends of design outcomes. However, there are still some concerns related to the outcomes from the AASHTOWare Pavement ME Design (PMED) software. This study evaluates the suitability of the latest version (v3.0) of the PMED software for AC overlay design.

Several overlay design trials for three existing pavements with varying strength, surface condition, layer materials, subgrade type, existing AC mill depth, overlay thickness and traffic loads were completed for nine climatic areas. Analysis showed that AC overlays on milled surfaces result in no reduction in roughness and an increase in total rutting as compared to straight overlays. An increased overlay thickness results in inconsistent variation of the predicted total rutting. Increased traffic loads result in increased roughness, total rutting and AC layer rutting with some inconsistencies and unexpected variations among climatic areas. The total rutting values in overlaid pavements are governed by rutting in subgrade and granular material layers despite that there was no rutting in those materials of the existing pavements. No design input affects the predicted bottom-up fatigue cracking (BUFC) and top-down fatigue cracking (TDFC), except traffic load. Higher fatigue cracking in existing pavements correspond to higher reflective cracking with inconsistencies among climatic areas. Increased mill depths provide no or unexpected effect on the predicted reflective cracking. There is no or negligible variation of transverse cracking among input variables. Transverse reflective cracking is unaffected by milling or overlay thickness with some exceptions and inconsistencies.

Introduction

The design and maintenance of pavements, particularly flexible pavements, are critical aspects of infrastructure management. As pavements age and deteriorate due to traffic loading, environmental factors and material degradation, pavement rehabilitation and overlay design become indispensable for extending the service life and ensuring the continued functioning of these critical transportation assets.

An AC overlay, a form of pavement rehabilitation, involves the placement of new layer(s) of material over an existing pavement to enhance its structural capacity, improve ride quality and mitigate surface distresses. The effectiveness of an overlay design relies heavily on accurate assessments of pavement condition, traffic loads, material properties and environmental factors. Traditionally, empirical methods and other simplistic design guidelines have been utilized for overlay design. The design outcomes from these procedures could be suboptimal in some cases, however, they produced practical trends of the design outcomes for each variation of design inputs. Advancements in pavement engineering and computational technologies have paved the way for the development of more sophisticated design methodologies with particular focus on the Mechanistic-Empirical (ME) design and analysis procedures. Various factors such as model accuracy, applicability to site-specific conditions, user-friendliness and compatibility with the existing design practices influence the practical utility and effectiveness of these software tools in real-world engineering applications.

The PMED software has gained prominence for its ability to integrate mechanistic principles with empirical data, allowing designers to make informed decisions based on pavement structural analysis, material behaviour, and performance predictions. However, despite the promising capabilities of PMED software, there are still some outstanding concerns including accuracy of PMED software models and version to version variations in the predicted distresses. Therefore, there is a pressing need to critically assess the predicted distresses/performance and suitability of the PMED software for flexible pavement overlay design through empirical studies, comparative analyses and validation against field performance data.

This study aims to evaluate the suitability and effectiveness of PMED software, specifically tailored for flexible pavement AC overlay design. This research seeks to provide practical insights into the application of PMED software and identify areas for potential enhancement in overlay design for flexible pavement.

Background

The Transportation Association of Canada (TAC) ME Pavement Design Subcommittee has been evaluating the AASHTOWare PMED software since 2007. Design trials completed in the past include, but are not limited to: effect of traffic loading (flexible/rigid pavements); effect of asphalt mix properties, binder and layer thickness; effect of portland cement concrete (PCC) slab and joint designs, etc. The analysis and results of all these design trials can be found in different technical papers presented in different conferences. The identified issues from these design trials were brought forward to AASHTO Pavement ME Task Force and the software developer, Applied Research Associates (ARA). In August-September 2023, TAC ME Pavement Design Subcommittee completed few trials for flexible pavement AC overlay design using the PMED software v3.0. The variable design inputs were climatic and existing pavement conditions, AC mill depth and overlay thickness and traffic load. This paper presents the results of these design trials and discusses the issues and suitability of the PMED software for AC overlay design.

Findings from Literature Review

Boone[1] compared the overlay design using PMED software with other design methods and found a poor correlation between the AC overlay thickness obtained using PMED and AASHTO 1993. The required overlay thickness was sometimes higher[1] and sometimes lower[2,3] with the PMED software. However, in Manitoba (Canada), Benkelman Beam Rebound (BBR) deflection-based method and PMED software provided a comparable AC overlay thickness[4].

AC overlay thickness using the PMED software was found to be proportional to traffic loads[3,5]. Traffic loads and thickness of existing AC layer are the significant factors for the overlay design thickness using the PMED software [5,6,7]. In the PMED software, existing pavement condition does not always have an impact on the AC overlay design. For example, a thin existing AC layer with high traffic loads will require a thick overlay, regardless of existing pavement condition. A thin existing AC layer in good condition (higher elastic modulus) will require a thicker overlay as compared to an existing thick AC layer in poor condition[5]. Overlay design and performance are not significantly affected by base, subbase and subgrade conditions[5,6]. A study in Manitoba (Canada) also noted that PMED software have some limitations to properly account for the effect of base thickness and has a low sensitivity to subgrade strength[4]. Jasim et al.[5] observed that interface bonding and modulus of existing AC do not always have an impact on the overlay design. However, Wang and Nie[6] found that modulus of the existing AC layer and the condition of the interface bond have a greater impact on the potential for fatigue cracking than they do on the potential for rutting.

PMED software generally under-predicts rutting for AC overlay design[3,4]. The predicted rutting is lower for an AC overlay as compared to a new AC[1]. The probable reason is that PMED software predicts low permanent deformation in the unbound material layers and subgrade for an AC overlay of an existing pavement as compared to that in a new AC pavement. Ahammed et. al.[4] also found that the required AC thickness for a new construction is higher than that required for a rehabilitation (with the same design inputs). Boone [1] found that the predicted rutting in AC overlay is influenced mainly by traffic loads and existing pavement condition. If an existing AC layer is in poor condition, the AC overlay exhibit higher permanent deformation. However, the existing pavement condition has more influence on the total permanent deformation than AC layer permanent deformation. Wang and Nie[6] observed an inconsistency in the predicted rutting for an existing AC layer with low rutting. It was found that a thicker overlay is required or a higher overall AC rutting occurs when existing layer has less rutting.

The PMED software under-predicts rutting for straight overlays. However, it over-predicts rutting for AC overlay projects with milling prior to overlays[4]. Moon[3] also found that milling the existing asphalt layer by 25 mm increases rutting and IRI as compared to a straight overlay. Hung et. al.[8] found that milling before overlay on an existing pavement in good condition (IRI < 1.90 m/km) causes higher IRI and milling before overlay on an existing pavement in poor condition (IRI > 1.90 m/km) does not provide any benefit.

Most state highway agencies have found that the PMED software under-predicts bottom-up fatigue cracking (BUFC)[1,3]. The predicted BUFC was very low, regardless of the thickness of the AC layer. Wang and Nie[6] noted an inconsistency for BUFC for increase in AC overlay thickness when modulus of existing AC layer is high[5]. The predicted top-down fatigue cracking (TDFC) was found to be higher and more variable for coarser and stiffer subgrade soils than finer and weaker subgrade soils[1].

Boone[1] and Schwartz et. al.[9] found that the predicted thermal cracking is very low and does not vary significantly. Their study results suggest that the PMED software under-predicts transverse cracking. However, Moon[3] found that transverse cracking and reflective cracking were over-predicted by the PMED software global model for rehabilitation overlays.

The PMED software predicted terminal IRI is strongly correlated with overlay layer rutting, total pavement rutting, BUFC and thermal cracking[1]. However, Boone[1] found no correlation between the predicted terminal IRI and traffic loads. The predicted IRI was found to be more influenced by functional classification and existing pavement condition. The absence of relationship between IRI and traffic loads and pavement age were unexpected, given that there was a strong relationship between IRI and these two parameters for new flexible pavement. Also, the strong correlation between IRI and the BUFC and thermal cracking is odd, given that a little variability was observed for these distresses.

Objective, Scope and Significance

A limited number of studies evaluated the suitability of the PMED software for flexible pavement AC overlay design, while few other past studies conducted limited global sensitivity analysis of the PMED software predicted distresses to changes in flexible pavement AC overlay design input parameters. There is still a need for further investigation into the suitability of PMED software for designing flexible pavement AC overlay, specially for the latest version of the software. Although previous studies compared PMED software with other design methods and questioned about the adequacy of the PMED software for flexible pavement AC overlay design, the number of publicly available papers/reports that evaluated the impact of various input parameters for AC overlay design in Canadian contexts are scarce. The objectives of the TAC ME Pavement Design Subcommittee design trials are to assess further the sensitivity and effect of various input parameters on flexible pavement AC overlay design in Canada using the latest (web) version (v3.0) of the PMED software. The objective of this paper is to present the details of the completed trial results and analysis.

The design trials conducted in this study have looked into the trends of the predicted distresses for i) varied climate data from nine weather stations across Canada; ii) three existing pavement sections with varied strength and condition in terms of pavement age, surface conditions with varied quantity and severity of distresses, thickness, subgrade stiffness and asphalt binder type, iii) varied AC mill depth, iv) varied AC overlay thickness, and v) varied traffic loads on AC overlays.

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 AC overlay design and analysis.

Software Version and Trial Inputs

All participants used the PMED software version 3.0 with the global calibration coefficients for the selected design trials. The variable design input parameters were climatic conditions, existing pavement strength and conditions, milling depth, AC overlay thickness and traffic load. All other input parameters remained unchanged in the trials, including vehicle class distribution and axle load spectra (from Manitoba), design life (20 years) and design reliability (90%). Tables below present the existing AC layer data (Table 1), pavement surface condition (Table 2), granular base layer data (Table 3), subgrade data (Table 4) and AC overlay layer data (Table 5) used for the design trials.

Table 1. Existing pavement AC surface layer data

Hwy No.	Construction Year	Thickness, mm	Mix Type[1]	Binder Grade
PR 227	1990	100	Bit. B	PG 58-28
PTH 12	1961	225	Bit. B	PG 70-22
PTH 83	1962	260	Bit. B	PG 64-16

Note 1: Aggregate gradation, air voids, effective binder and AC contents, and density were the same for all projects

Table 2. Existing pavement surface condition data

Hwy No.	IRI	Fatigue Cracking			Transverse Cracking			AC Rut Depth[1], mm
		%	Severity	LTE	m/km	Severity	LTE	
PR 227	1.99	1.06	Low	0.8	465	Low	0.8	3.62
PTH 12	2.52	9.11	High	0.1	774	High	0.1	5.34
PTH 83	2.26	2.22	Medium	0.4	1259	Very High	0.1	4.98

Note 1: Granular base and subgrade rut depths were 0.00 for all projects

Table 3. Existing pavement granular base layer data (Manitoba Granular A)

Hwy No.	Thickness, mm	Mr, MPa	Passing, %[1]		LL, %	PI, %	Density, kg/m^3	MC, %	Crushed Agg., %
			4.75 mm	0.075					
PR 227	435	140	49.0	13.6	0	0	2170	10.8	100
PTH 12	190	120	61.0	12.4	17	1	2240	8.5	40
PTH 83	215								

Note 1: The maximum aggregate size was 19 mm for all projects

Table 4. Existing pavement subgrade data

Hwy No.	Type	Mr, MPa	Passing, % (sieve size in mm)					LL, %	PI, %	Density, kg/m³	MC, %
			4.75	2.00	0.425	0.075	0.020				
PR 227	High Plastic Clay (A-7-6)	31.2	98.3	97.1	94.9	81.2	56.8	46	26	1442	26.6
PTH 12		25.5	96.8	95.6	93.7	76.1	58.9	44	27	1617	21.0
PTH 83	Low Plastic Clay (A-6)	21.6	97.3	91.5	75.0	48.4	37.3	36	17	1608	21.4

Note 1: The maximum aggregate size was 19 mm for all projects

Table 5. Overlay AC layer materials data (for all projects)

Mix Type	Passing, %				AV, %	Eff. Binder Content, %	AC Content, %	Density, kg/m³	Binder Grade
	19mm	9.5mm	4.75mm	0.075mm					
SP12.5	100	80.6	52.6	2.8	6.9	10.3	4.8	2276	PG 58-34

Selected Climate Stations and Summary of Climate Data

MERRA climate data from nine climate stations across Canada with varied weather patterns were selected for the design trials. Figure 1 shows the geographic location of the climate stations. The red dots indicate relatively warmer while the blue dots indicate relatively colder climates in Canadian context. Table 6 presents the list of climate stations and the summary of the key climatic parameters.

Figure 1. Geographical location of selected climate stations

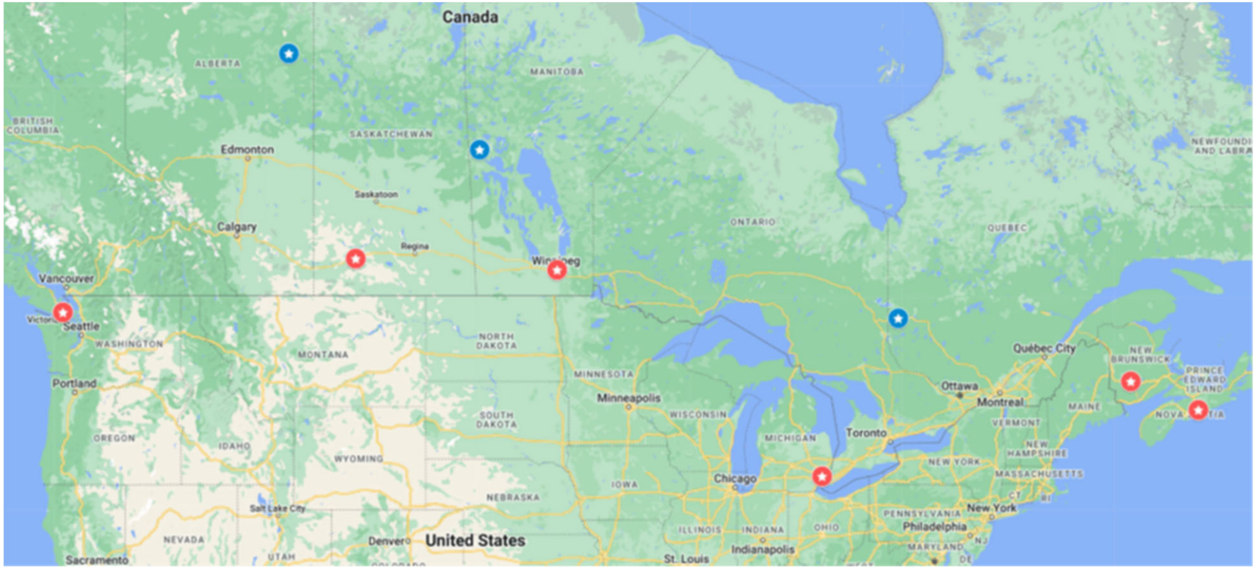


Table 6. MERRA climate stations and data summary

Province	Climate Station (ID)	Mean Annual				Number of Wet Days
		Air Temp., ºC (Min./Max.)	Precipitation, mm	Freezing Index, ºC-days (Frost Depth, m)	No. of Freeze-Thaw Cycles	
BC	Victoria (153883)	10.9 (-15.4/29.4)	1505	10.8 (0.46)	7.2	333
AB	Fort McMurray (163119)	1.3 (-47.1/36.9)	646	1939 (4.40)	72.1	339
SK	Swift Current (155636)	5.2 (-42.1/37.9)	444	1045 (2.03)	100.5	277
MB	Winnipeg (155653)	3.3 (-45.9/38.3)	601	1775 (3.19)	67.6	302
MB	The Pas (160255)	0.2 (-48.1/37,9)	635	2410 (7.53)	58.9	329
ON	Wheatley (146461)	9.6 (-21.7/31.6)	1094	304 (2.04)	52.2	301
QC	Rouyn (153379)	2.1 (-45.7/31.1)	1236	1767 (2.74)	67.4	350
NB	Fredericton (151094)	7.3 (-36.2/32.1)	1584	315 (1.55)	68.8	340
NS	Halifax (149371)	5.0 (-20.1/27.1)	1426	996 (1.12)	81.0	344

Design and Analysis Trial Matrix

Three typical existing pavement sections in Manitoba were used in this round of design trials (two old and one newer pavements). The strength, surface condition, layer materials and subgrade type varied for these projects. Design trials were run for nine different climatic condition across Canada. The matrix of design trials included four design runs with differing inputs for each highway section resulting in a total of 12 trial runs for each climatic area. Table 7 shows the variable input parameters of design trials for each climate station. All other input values were held constant to evaluate the effect of change in the parameters listed in Table 7.

The initial IRI value was 1.1 m/km for straight AC overlay (on un-milled surfaces). It was changed to 1.0 m/km for mill and overlay options because some surface irregularities are eliminated through AC milling operation, which will results in smoother overlay surfaces. The design trial matrix presented in Table 7 were set to compare the predicted distresses for the following scenarios:

1. Trial #1A: Effect of a thin (25 mm) straight overlay on an existing fair-quality AC surface.
2. Trial #1B: Effect of milling (25 mm) and a typical 50 mm overlay as compared to the straight overlay (Trial #1A) with same total AC thickness.
3. Trial #1C: Effect of increased (75 mm) overlay thickness as compared to Trial #1B (50 mm overlay) with the same milling depth.
4. Trial #1D: Effect of increased (doubled) traffic loads as compared to the Trial #1C with the same overlay thickness.
5. Trial #2A: Effect of a typical 50 mm straight overlay on an existing poor-quality AC surface.

6. Trial #2B: Effect of milling (25 mm) and overlay (75 mm) as compared to the straight overlay (Trial #2A) with same total AC thickness.
7. Trial #2C: Effect of increased (100 mm) overlay thickness as compared to Trial #2B (75 mm overlay) with the same milling depth.
8. Trial #2D: Effect of increased (five times) traffic loads as compared to the Trial #2C with the same mill depth and overlay thickness.
9. Trial #3A: Effect of a thin (25 mm) straight overlay on an existing surface with very high amount of transverse cracking.
10. Trial #3B: Effect of a thin (25 mm) partial milling of the existing AC layer and AC overlay (generally called inlay) of the same (25 mm) thickness, which reduced the total AC layer thickness, as compared to the straight overlay (Trial #3A).
11. Trial #3C: Effect of a deeper (50 mm) partial milling and thicker AC overlay (50 mm) as compared to the thin (25 mm) milling and thin AC overlay (Trial #3B).
12. Trial #3D: Effect of increased (five times) traffic loads as compared to the Trial #3C with the same mill depth and overlay thickness.

Table 7. Design trial matrix with varied input parameters

Hwy No.	Design No.	AADTT	Milling Depth, mm	Existing AC After Milling, mm	Overlay Thickness, mm	Total AC, mm	Initial IRI, m/km	Trial ID for Graphs
PR 227	1A	180	0	100	25	125	1.1	PR227_180T_OL25
	1B	180	25	75	50	125	1.0	PR227_180T_Mill25-OL50
	1C	180	25	75	75	150	1.0	PR227_180T_Mill25-OL75
	1D	360	25	75	75	150	1.0	PR227_360T_Mill25-OL75
PTH 12	2A	170	0	225	50	275	1.1	PTH12_170T_OL50
	2B	170	25	200	75	275	1.0	PTH12_170T_Mill25-OL75
	2C	170	25	200	100	300	1.0	PTH12_170T_Mill25-OL100
	2D	850	25	200	100	300	1.0	PTH12_850T_Mill25-OL100
PTH 83	3A	130	0	260	25	285	1.1	PTH83_130T_OL25
	3B	130	25	235	25	260	1.0	PTH83_130T_Mill25-OL25
	3C	130	50	210	50	260	1.0	PTH83_130T_Mill50-OL50
	3D	650	50	210	50	260	1.0	PTH83_650T_Mill50-OL50

Note: T = Number of trucks, OL = overlay thickness, Mill = milling depth

Results, Analysis and Discussion

Tables 8a, 8b and 8c present the summary of predicted distresses at the end of design life (20 years). The predicted BUFC values were zero (0%) for all projects and climate stations. Therefore, BUFC is excluded from the tables. A detailed analysis and discussion are presented in the following sections using graphical trend of the predicted distresses. Only the trends of predicted distresses for selected number of climate stations are presented in each graphics for an ease of understanding and tracking the changes in trends and the impacts of varied input parameters. These representative climate stations were selected to demonstrate the widespread variation of predicted distresses in differing climatic conditions.

Table 8a. Summary of predicted distresses (BC, AB and SK)

Project Location	**Design No.**	**IRI (m/km)**		**Rutting (mm)**		**Fatigue Cracking** BUFC + Reflective **(% lane area)**	**Transverse Cracking** Thermal + Reflective **(m/km)**	**Thermal Cracking (m/km)**	**TDFC (%)**
		Initial	**Terminal**	**Total**	**AC**				
Victoria, BC	1A	1.10	2.68	7.03	0.13	2.63	373.30	0.19	4.69
	1B	1.00	2.56	8.62	2.00	2.63	373.30	0.19	4.69
	1C	1.00	2.54	8.05	1.93	1.73	373.30	0.19	4.69
	1D	1.00	2.57	9.08	2.33	2.44	373.30	0.19	4.69
	2A	1.10	2.92	6.56	0.95	10.32	604.94	0.19	4.69
	2B	1.00	2.74	7.33	1.45	5.24	604.94	0.19	4.69
	2C	1.00	2.70	6.89	1.36	2.04	604.11	0.19	4.69
	2D	1.00	2.84	9.06	2.11	12.02	604.94	0.19	4.69
	3A	1.10	3.10	6.15	0.28	3.81	968.51	0.19	4.69
	3B	1.00	3.00	6.99	0.73	3.83	968.51	0.19	4.69
	3C	1.00	3.02	7.87	1.57	3.83	968.51	0.19	4.69
	3D	1.00	3.09	10.31	2.45	4.74	968.51	0.19	4.69
Fort McMurray, AB	1A	1.10	2.77	8.44	0.66	2.68	373.30	0.19	4.69
	1B	1.00	2.74	12.32	4.76	2.71	362.04	0.19	4.69
	1C	1.00	2.72	11.39	4.61	2.72	373.30	0.19	4.69
	1D	1.00	2.79	13.09	5.59	2.86	373.30	0.19	11.49
	2A	1.10	2.58	9.62	2.47	11.32	15.71	0.19	4.69
	2B	1.00	2.53	10.24	3.17	11.32	105.41	0.19	4.69
	2C	1.00	2.71	9.56	2.88	11.35	332.10	0.19	4.69
	2D	1.00	3.06	12.91	4.49	16.69	604.94	0.19	13.76
	3A	1.10	2.59	7.92	0.67	4.03	196.85	0.19	4.69
	3B	1.00	2.52	9.24	1.76	4.05	222.11	0.19	4.69
	3C	1.00	2.41	11.05	3.48	4.14	16.90	0.19	4.69
	3D	1.00	3.31	14.93	5.44	6.67	968.51	0.19	13.56
Swift Current, SK	1A	1.10	2.70	7.24	0.15	2.62	373.30	0.19	4.69
	1B	1.00	2.61	8.41	1.50	2.64	380.21	0.55	4.69
	1C	1.00	2.59	7.82	1.52	2.64	373.30	0.19	4.69
	1D	1.00	2.64	8.79	1.83	2.70	373.30	0.19	10.56
	2A	1.10	2.94	6.78	0.85	10.55	605.46	0.21	4.69
	2B	1.00	2.83	7.05	1.08	10.56	604.94	0.19	4.69
	2C	1.00	2.81	6.63	1.02	10.49	604.94	0.19	4.69
	2D	1.00	2.88	8.66	1.57	12.02	604.94	0.19	13.7
	3A	1.10	3.14	6.10	0.24	3.79	968.51	0.19	4.69
	3B	1.00	3.06	7.48	1.12	3.83	970.70	0.28	4.69
	3C	1.00	3.06	7.48	1.12	3.83	970.70	0.28	4.69
	3D	1.00	3.15	9.72	1.73	4.51	970.70	0.28	13.39

Table 8b. Summary of predicted distresses (MB and ON)

Project Location	**Design No.**	**IRI (m/km)**		**Rutting (mm)**		**Fatigue Cracking** BUFC + Reflective **(% lane area)**	**Transverse Cracking** Thermal + Reflective **(m/km)**	**Thermal cracking (m/km)**	**TDFC (%)**
		Initial	**Terminal**	**Total**	**AC**				
Winnipeg, MB	1A	1.10	2.47	8.42	0.17	2.63	32.90	0.65	4.69
	1B	1.00	2.68	9.91	1.69	2.65	403.99	4.28	4.69
	1C	1.00	2.61	9.05	1.72	2.65	333.43	1.44	4.69
	1D	1.00	2.71	10.17	2.08	2.72	385.13	1.44	10.44
	2A	1.10	2.51	7.49	0.90	10.65	50.87	3.24	4.69
	2B	1.00	2.39	7.81	1.19	10.66	37.60	1.10	4.69
	2C	1.00	2.38	7.36	1.15	10.66	33.50	0.66	4.69
	2D	1.00	2.94	9.58	1.77	12.59	613.18	0.66	13.66
	3A	1.10	2.41	6.80	0.26	3.82	29.37	0.41	4.69
	3B	1.00	2.31	7.67	0.61	3.83	30.55	0.48	4.69
	3C	1.00	2.33	8.43	1.19	3.87	50.87	3.24	4.69
	3D	1.00	3.21	10.69	1.85	4.75	988.84	3.24	13.35
The Pas, MB	1A	1.10	2.51	9.61	0.17	2.64	14.35	0.19	4.69
	1B	1.00	2.43	11.22	1.86	2.66	22.86	0.19	4.69
	1C	1.00	2.40	10.25	1.87	2.65	25.52	0.19	4.69
	1D	1.00	2.76	11.47	2.26	2.73	373.30	0.19	11.47
	2A	1.10	2.51	8.33	0.99	10.70	19.38	0.19	4.69
	2B	1.00	2.42	8.65	1.32	10.69	15.41	0.19	4.69
	2C	1.00	2.40	8.09	1.26	10.69	13.89	0.19	4.69
	2D	1.00	2.97	10.49	1.95	12.77	604.94	0.19	13.85
	3A	1.10	2.44	7.64	0.28	3.84	14.20	0.19	4.69
	3B	1.00	2.34	8.55	0.66	3.84	17.86	0.19	4.69
	3C	1.00	2.36	9.46	1.31	3.88	20.68	0.19	4.69
	3D	1.00	3.24	12.16	2.04	4.80	961.00	0.19	13.64
Wheatley, ON	1A	1.10	2.71	7.12	0.15	2.63	373.30	0.19	4.69
	1B	1.00	2.62	8.46	1.77	2.62	373.30	0.19	4.69
	1C	1.00	2.60	7.94	1.79	1.72	373.30	0.19	4.69
	1D	1.00	2.63	8.94	2.17	2.43	373.30	0.19	4.69
	2A	1.10	2.95	6.82	0.96	10.40	604.94	0.19	4.69
	2B	1.00	2.80	7.20	1.28	5.27	604.94	0.19	4.69
	2C	1.00	2.76	6.79	1.21	2.05	604.32	0.19	4.69
	2D	1.00	2.90	8.89	1.88	11.95	604.94	0.19	10.65
	3A	1.10	3.15	6.10	0.24	3.80	968.51	0.19	4.69
	3B	1.00	3.05	6.89	0.64	3.82	968.51	0.19	4.69
	3C	1.00	3.07	7.61	1.27	3.82	968.51	0.19	4.69
	3D	1.00	3.14	9.90	1.58	4.69	968.51	0.19	6.65

Table 8c. Summary of predicted distresses (QC, NB and NS)

Project Location	**Design No.**	**IRI (m/km)**		**Rutting (mm)**		**Fatigue Cracking** BUFC + Reflective **(% lane area)**	**Transverse Cracking** Thermal + Reflective **(m/km)**	**Thermal cracking (m/km)**	**TDFC (%)**
		Initial	**Terminal**	**Total**	**AC**				
Rouyn, QC	1A	1.10	2.81	8.71	0.75	2.71	373.30	0.19	4.69
	1B	1.00	2.79	12.82	5.33	2.73	370.55	0.19	4.69
	1C	1.00	2.77	11.98	5.11	2.75	373.30	0.19	4.69
	1D	1.00	2.84	13.81	6.20	2.93	373.30	0.19	11.06
	2A	1.10	2.62	10.11	2.79	11.63	17.10	0.19	4.69
	2B	1.00	2.87	10.77	3.53	11.61	451.93	0.19	4.69
	2C	1.00	2.98	10.06	3.22	11.61	604.93	0.19	4.69
	2D	1.00	3.13	13.68	5.04	18.47	604.94	0.19	13.69
	3A	1.10	2.51	8.21	0.76	4.14	47.81	0.19	4.69
	3B	1.00	2.41	9.66	1.97	4.17	37.28	0.19	4.69
	3C	1.00	2.46	11.70	3.95	4.27	18.30	0.19	4.69
	3D	1.00	3.37	15.89	6.15	7.74	968.50	0.19	13.48
Fredericton, NB	1A	1.10	2.79	8.22	0.75	2.70	373.30	0.19	4.69
	1B	1.00	2.78	12.50	5.49	2.74	373.30	0.19	4.69
	1C	1.00	2.75	11.84	5.41	1.68	373.30	0.19	4.69
	1D	1.00	2.82	13.77	6.70	2.40	373.30	0.19	8.53
	2A	1.10	3.08	9.70	2.92	11.51	604.94	0.19	4.69
	2B	1.00	2.94	10.49	3.74	6.14	604.94	0.19	4.69
	2C	1.00	2.87	9.78	3.38	1.98	583.34	0.19	4.69
	2D	1.00	3.10	13.50	5.45	17.06	604.94	0.19	13.42
	3A	1.10	3.25	7.74	0.76	4.10	968.51	0.19	4.69
	3B	1.00	3.17	9.30	2.10	4.15	968.51	0.19	4.69
	3C	1.00	3.22	11.30	4.15	4.25	968.51	0.19	4.69
	3D	1.00	3.35	15.46	6.49	7.55	968.51	0.19	12.7
Halifax, NS	1A	1.10	2.74	7.06	0.10	2.62	373.30	0.19	4.69
	1B	1.00	2.64	8.05	1.28	2.62	373.30	0.19	4.69
	1C	1.00	2.62	7.44	1.24	1.74	373.30	0.19	4.69
	1D	1.00	2.65	8.34	1.49	2.44	373.30	0.19	4.69
	2A	1.10	2.97	6.52	0.77	10.37	604.94	0.19	4.69
	2B	1.00	2.82	6.78	0.96	5.43	604.94	0.19	4.69
	2C	1.00	2.78	6.36	0.88	2.10	604.69	0.19	4.69
	2D	1.00	2.90	8.25	1.36	11.63	604.94	0.19	11.87
	3A	1.10	3.18	5.99	0.10	3.80	968.51	0.19	4.69
	3B	1.00	3.07	6.62	0.47	3.80	968.51	0.19	4.69
	3C	1.00	3.09	7.23	1.00	3.80	968.51	0.19	4.69
	3D	1.00	3.15	9.35	1.53	4.52	968.51	0.19	9.64

Predicted Roughness

Figure 2 shows the variations of the increased surface roughness (terminal IRI minus initial IRI) for various overlay and traffic load scenarios for all three projects and three climatic areas. The trends of the increased surface roughness for changes associated with overlay options and climatic conditions are discussed below.

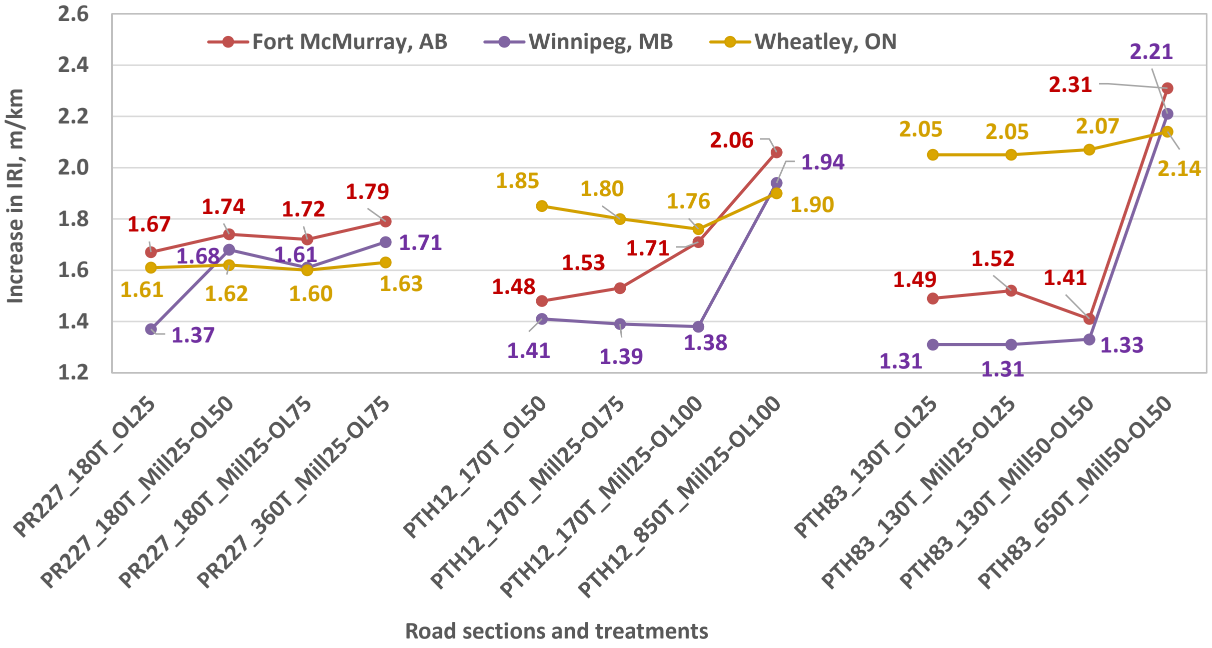


Figure 2. Variations of increased surface roughness (IRI)

PR 227: Low Roughness (IRI = 1.99 m/km) in Existing Pavement

- The predicted increase in IRI is 1.67 m/km for a 25 mm straight overlay and it increased to 1.74 m/km for 25 mm mill and 50 mm AC overlay (i.e., with the same total AC layer thickness) in Fort McMurray. Similar trends are noticed in Wheatley and Winnipeg. These trends indicate that there is an increase in surface roughness for mill and overlay option as compared to the straight overlay option. Such trend indicates that there is no benefit of milling an existing distressed AC layer, prior to an overlay, in terms of predicted surface roughness.
- An increase in AC overlay thickness from 50 mm to 75 mm resulted in a minor reduction in the IRI, which is not as high as practically expected.
- There is a small increase in IRI (e.g., from 1.72 m/km to 1.79 m/km in Fort McMurray) when doubling the traffic loads.

PTH 12: High Roughness (IRI = 2.52 m/km) in Existing Pavement

- The predicted increase in IRI is 1.48 m/km for a 50 mm straight overlay (thicker than that on PR 227) and it increased to 1.53 m/km after milling 25 mm and overlaying with 75 mm AC (i.e., with the same total AC layer thickness in Fort McMurray. Opposite trends are noticed in Winnipeg and Wheatley with reduction in IRI values for mill and overlay option as compared to the straight overlay option. The trends for PR 227 and PTH 12 show that there are inconsistencies in predicted surface roughness between projects and climatic areas.
- An increase in overlay thickness from 75 mm to 100 mm resulted in a minor reduction in the IRI values in Wheatley and Winnipeg, but an increase in Fort McMurray, which are also inconsistent trends and not as practically expected.
- There is a noticeable increase in the IRI values when increasing the traffic loads by five times.

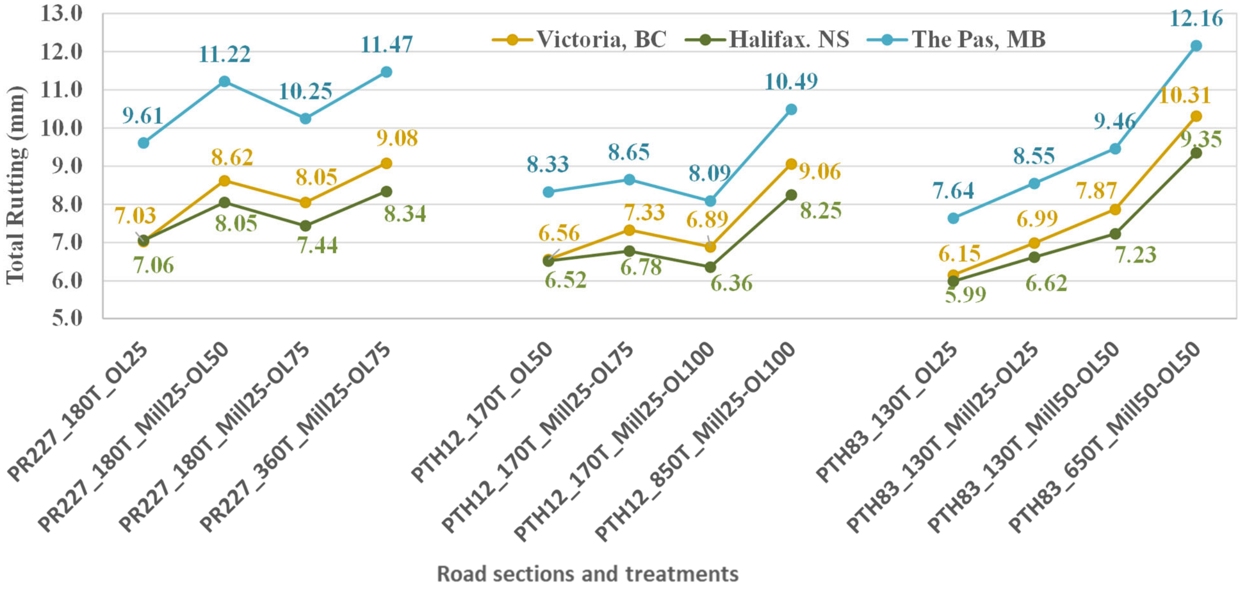
PTH 83: Moderate Roughness (IRI = 2.26 m/km) in Existing Pavement

- There is an increase in IRI (from 1.49 to 1.52 m/km) in Fort McMurray, but no change in Winnipeg and Wheatley, for 25 mm mill and 25 mm overlay option (with no increase in total AC layer thickness) as compared to 25 mm straight overlay (with 25 mm increase in the total AC layer thickness). The trends also show that there are inconsistencies in predicted surface roughness between projects and climatic areas.
- An increase in mill depth and overlay thickness from 25 mm to 50 mm resulted in the reduction of the IRI value in Fort McMurray, but increase of IRI values in Wheatley and Winnipeg. Such trends again indicate inconsistency in the predicted IRI among climatic areas.
- There is a noticeable increase in the IRI when increasing traffic loads by five times. The trends of increased IRI values also indicate that the impact of increased traffic loads is more significant in colder climatic conditions (such as Fort McMurray and Winnipeg) than in warmer climatic conditions (such as in Wheatley). Further assessment is required to understand the effect of climatic parameters (e.g., precipitation and freezing index) on asphalt mix properties as well cracking and rutting performance to understand the reason(s) for such variation of the IRI values among climatic areas.

Predicted Total Rutting

Figure 3 shows the variations of the predicted total rutting (permanent deformation) for various overlay and traffic load scenarios for all three projects and selected climatic areas. The trends of the predicted total rutting for changes associated with overlay options and climatic conditions are discussed below.

Figure 3. Variations of the predicted total rutting



PR 227: Low Amount (3.62 mm) of Rutting in Existing Pavement

- The predicted total rutting increases for 25 mm milling and 50 mm overlay option as compared to the straight 25 mm overlay option in all climatic areas. This indicates that a new AC layer experiences higher rutting as compared to an existing aged/hardened AC layer.

- A comparison between 50 mm and 75 mm overlay options (with 25 mm milling in both cases) shows that there is a slight decrease in the total rutting with a thicker overlay. However, the predicted total rutting for 25 mm milling and 75 mm overlay option is still higher than the straight 25 mm overlay option. Such trends further indicate that a new AC layer experiences higher rutting as compared to an existing hardened AC layer.
- The predicted total rutting increases with an increase in traffic loads.
- Climatic condition has significant effect on the predicted total rutting. The colder climate (such as in The Pas) exhibit higher rutting than warmer climates (such as Victoria or Halifax), which is not as expected or experienced in the field.

PTH 12: Low Amount (5.34 mm) of Rutting in Existing Pavement

- The trends of predicted total rutting for various rehabilitation options, traffic load scenarios and climatic exposures are similar to PR 227.

PTH 83: Low Amount (4.98 mm) of Rutting in Existing Pavement

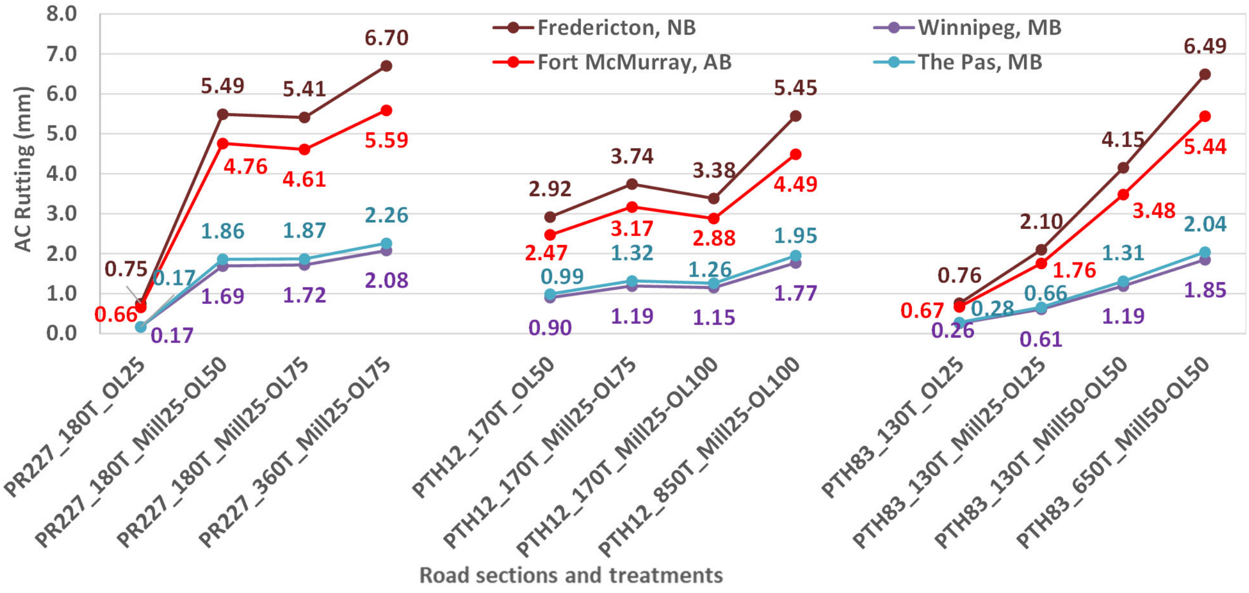
- The predicted total rutting increases for 25 mm milling and 25 mm overlay option (with no increase total AC thickness) as compared to the straight 25 mm overlay option (with 25 mm increase in total AC thickness) in all climatic areas.
- A comparison between 25 mm and 50 mm overlay options (with no increase total AC thickness in both cases) shows that there is an increase in total rutting with a thicker new AC. This further indicates that a new AC layer experiences higher rutting as compared to an existing aged/hardened AC layer.
- The predicted total rutting increases with an increase in traffic loads.
- Climatic condition has significant effect on the predicted total rutting. However, a colder climate (such as in The Pas) exhibits higher rutting compared to warmer climates (such as in Victoria or Halifax).

Some other studies[3,4,8] had also found that milling provided no benefit or would even increase distresses. It was justified by the reduction of the total AC layers when milling the existing surface[3]. The design trials presented in this paper is showing that even when replacing the milled thickness with new AC (keeping the same total AC thickness), milling provided neglectable benefit in terms of IRI and increased the rutting.

Predicted AC Layer Rutting

The variations of the predicted AC layer rutting for various overlay and traffic load scenarios for all three projects and selected climatic areas are shown in Figure 4. The trends of the predicted AC layer rutting follow similar trends as the total rutting. Colder climatic areas (e.g., Fort McMurray) experience higher AC layer rutting than warmer climatic area (e.g., Winnipeg). The average AC layer rutting (2.04 mm) accounted for 22 % (ranged from 1.7 to 42.2 %) of the average total rutting (9.15 mm) and the granular base and subgrade accounted for 78% (on average) of the total rutting. While the rutting depths in the granular base layer and subgrade of existing pavement were zero for all projects, the contribution of granular base layer and subgrade to the total rutting in overlaid pavement does not appear to be technically sound. This makes the suitability of the PMED software questionable.

Figure 4. Variations of the predicted AC layer rutting



Predicted AC Bottom-Up Fatigue Cracking

The predicted BUFC values are zero regardless of rehabilitation options, existing pavement layer thickness, existing pavement surface condition, milling depth, overlay thickness, traffic load and climatic exposure. This may indicate that there will be no BUFC in the AC overlays because they fall above the mid-depth (neutral axis) of the AC layer. Additional design trials were run for PR 227 project, which has the weakest pavement structure, by increasing mill depth to leave 25 mm and 50 mm of the existing AC in-place and increasing AC overlay thickness to 50 mm and 100 mm, respectively, but the predicted BUFC values were still zero. The same result was obtained for PTH 12, leaving 50 mm of the existing AC layer in-place after milling and overlaying with 100 mm of new AC. Accordingly, all the predicted BUFC values seem to be questionable. These results agree with other studies [1,3] that observed that PMED software under-predicts the AC BUFC.

Predicted AC BUF Plus Reflective Cracking

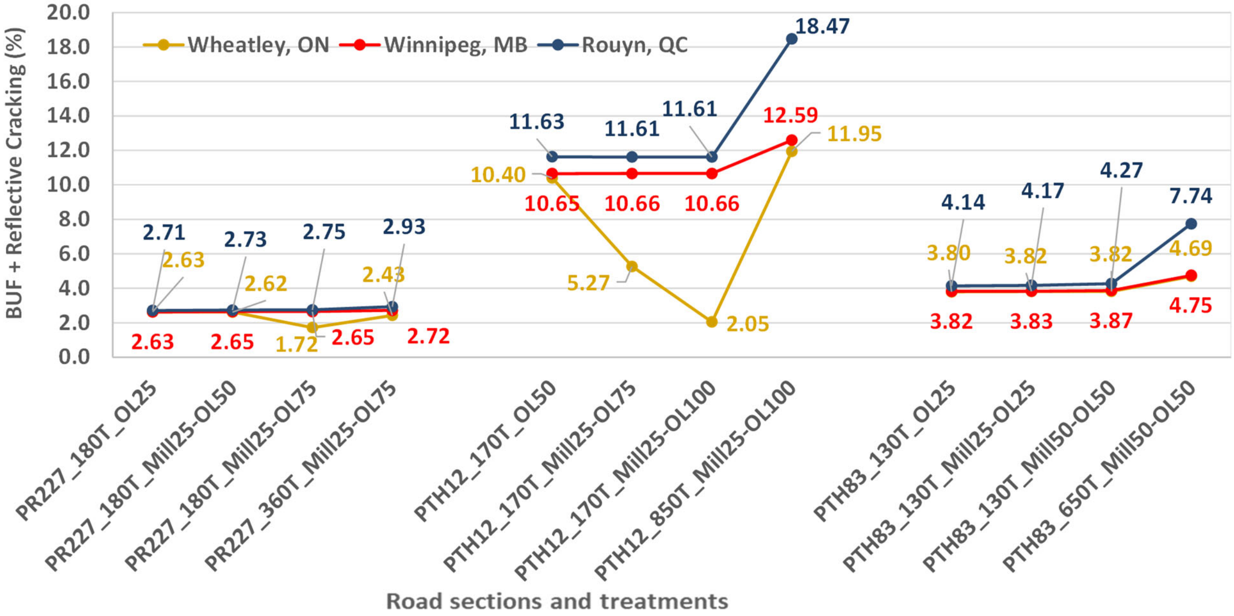
Figure 5 shows the variations of the predicted bottom-up fatigue (BUF) plus reflective cracking for various overlay and traffic load scenarios for all three projects and selected climatic areas. The trends of the predicted cracking for associated changes are discussed below.

PR 227: Low Amount (1.06%) and Low Severity (LTE = 0.8) BUFC in Existing Pavement

- There is a slight increase in the predicted BUF plus reflective cracking for mill and overlay option as compared to the straight overlay option for an existing pavement with low severity and low amount of BUFC.
- A thicker overlay (25 mm milling and 75 mm overlay) provided the same or a slight increase in BUF plus reflective cracking (as compared to 25 mm milling and 50 mm overlay) in Winnipeg and Rouyn, but a reduction in the BUF plus reflective cracking in Wheatley. Such trends seem to be inconsistent and questionable.

- The BUF plus reflective cracking slightly increases with traffic loads.

Figure 5. Variations of the predicted AC layer bottom-up fatigue and reflective cracking



PTH 12: High Amount (9.11%) and High Severity (LTE = 0.1) BUFC in Existing Pavement

- There is a slight increase in the predicted BUF plus reflective cracking in Winnipeg for mill and overlay options, but there is a significant reduction in Wheatley, and a slight reduction in Rouyn as compared to the straight overlay option. Such trends seem to be inconsistent and questionable.
- A thicker overlay (25 mm milling and 100 mm overlay) option produced the same amount of BUF plus reflective cracking in Winnipeg and Rouyn, but a significant reduction in Wheatley (as compared to 25 mm milling and 75 mm overlay option). Such trends also seem to be inconsistent.
- The BUF plus reflective cracking increases with an increase in traffic loads.
- A higher amount of BUFC in existing pavement on PTH 12 produced a higher BUF plus reflective cracking as compared to PR 227, which has a lower amount of BUFC in the existing pavement.

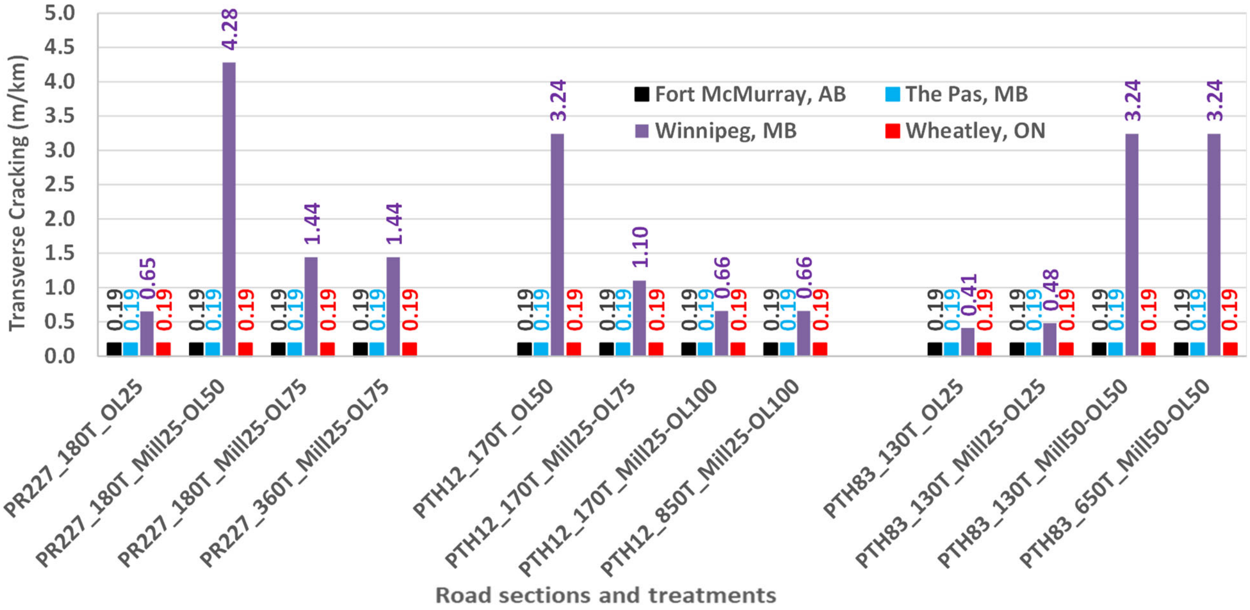
PTH 83: - Low Amount (2.22%) and Medium Severity (LTE = 0.4) BUFC in Existing Pavement

- There is a slight increase in the predicted BUF plus reflective cracking with partial milling of the existing AC prior to 25 mm AC overlay (with no increase in the total AC thickness) as compared to 25 mm straight overlay (with 25 mm increase in the total AC thickness).
- An increased mill and overlay thickness with 50 mm milling and 50 mm new AC option provided the same or an increase in BUF plus reflective cracking as compared to 25 mm milling and 50 mm overlay option.
- The predicted BUF plus reflective cracking increases with increase in traffic loads.

Predicted Transverse Cracking

The variations of the predicted Transverse Cracking (TC) for various overlay and traffic load scenarios for all three projects and selected climatic areas are shown in Figure 6. The predicted TC remains unchanged at 0.19 m/km in all climatic areas (except in Winnipeg and Swift Current), regardless of rehabilitation options, mill depth and overlay thickness. Such trends do not seem to reflect practical experiences. These results agree with the findings in other studies[1,9] that found that PMED software under-predicts thermal cracking. The variation of the predicted TC in Winnipeg indicates that milled and overlay options will have higher TC on PR 227 and PTH 83, but a lower TC on PTH 12 as compared to the straight overlay option, which are inconsistent results. A thicker overlay has shown to reduce TC on PR 227 and PTH 12, but increase in TC on PTH 83, which are also inconsistent.

Figure 6. Variations of the predicted transverse cracking



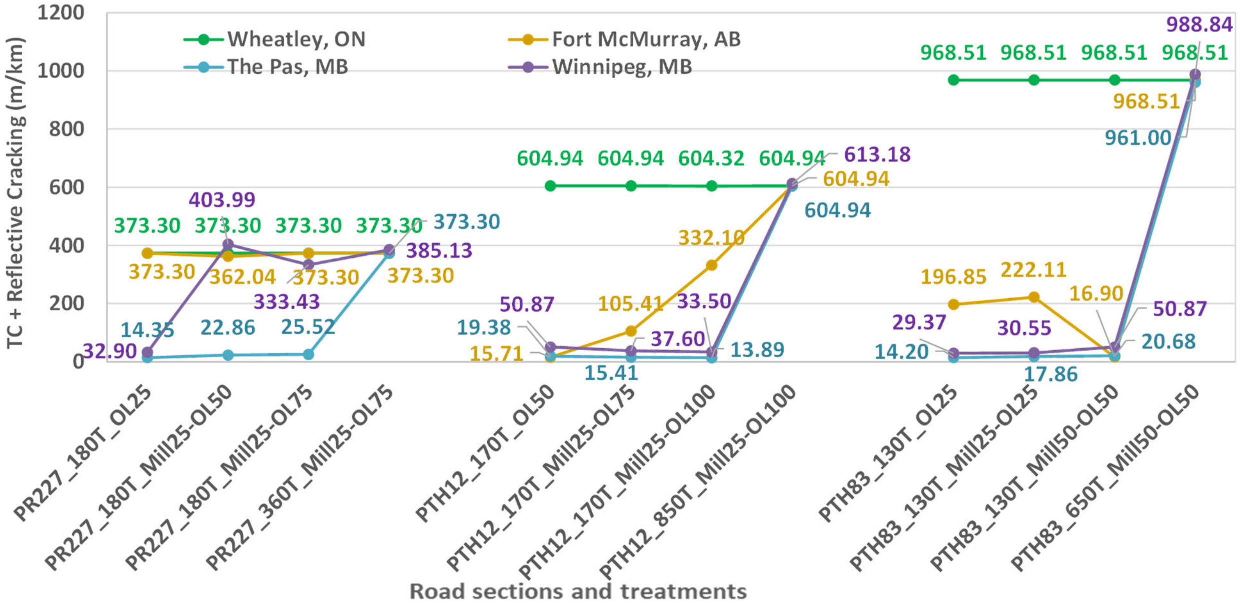
Predicted Transverse Plus Reflective Cracking

The variations of the predicted transverse plus reflective cracking for various overlay and traffic load scenarios for all three projects and selected climatic areas are shown in Figure 7. The predicted TC plus reflective cracking varies among climatic areas. However, the effects of milling, overlay thickness and traffic loads on the predicted TC plus reflective cracking are inconsistent. There is no change in some cases, a logical change in some cases or a counterintuitive trends in other cases among different climatic areas and projects. A high amount of TC in existing pavement does not result in higher amount of reflective cracking in some instances. For example:

- Cracking remains unchanged in Wheatley on all three highway sections and rehabilitation options, but there are changes in other climate areas.
- There is a reduction in cracking for mill and overlay option on PR 227 in Fort McMurray, but an increase in cracking for all other climatic areas and projects.

- A thicker overlay reduces cracking on PR 227 and PTH 12 in Winnipeg and on PTH 83 in Fort McMurray. However, the predicted cracking increases on PR 227 in The Pas and Fort McMurray, on PTH 12 in Fort McMurray and on PTH 83 in Winnipeg and The Pas.
- A higher traffic load increases the predicted TC plus reflective cracking, with some exception, e.g., Wheatley.
- PTH 83 has higher existing TC (1,259 m/km) as compared to PR 227 (TC = 465 m/km). Wheatley exhibits higher predicted TC plus reflective cracking on PTH 83, which is expected, but Fort McMurray exhibits higher cracking on other projects, which is counterintuitive.

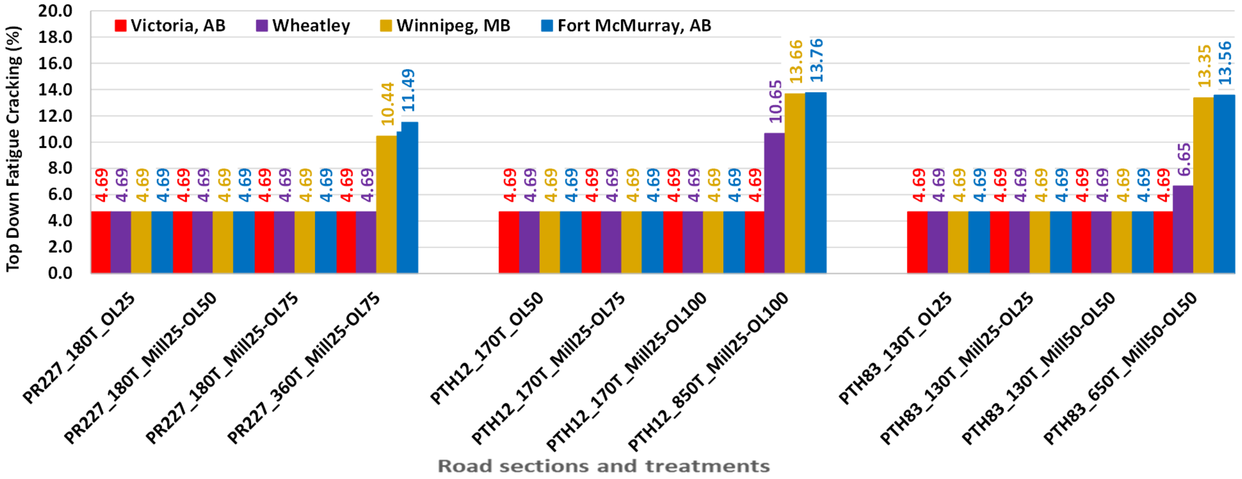
Figure 7. Variations of the predicted transverse plus reflective cracking



Predicted Top-Down Fatigue Cracking

Figure 8 shows that the predicted TDFC remains unchanged to 4.69 % regardless of milling depth, overlay thickness and climatic areas, except for the variation of traffic loads. Higher traffic loads have no effect on the predicted TDFC in some climatic areas (e.g., in Victoria), while it has significant effect in other climatic areas (e.g., in Wheatley, depending on the amount of increase in traffic loads, in Winnipeg and Fort McMurray). Such trends do not seem to be consistent or as practically expected. In trials with increased traffic loads, PR 227 had the least total AC thickness (150 mm) and PTH 12 had the highest total AC thickness (300 mm) while PTH 83 had a total AC thickness of 260 mm. PTH 12 experienced higher TDFC than PR 227. This indicate that a thicker AC layer experiences higher TDFC, which is questionable.

Figure 8. Variations of the predicted top-down fatigue cracking



Summary and Conclusions

This study attempted to evaluate the suitability of the PMED software for flexible pavement AC overlay design in Canada, specifically in terms of trends and soundness of the predicted distresses, with several input variables. In general, the trends and variations of the predicted distresses by the PMED software for the selected input variables did not meet expectations and consistency requirements. The findings in this study may help identifying areas for potential enhancement of the software for overlay design of flexible pavements. The key findings are summarized below:

1. There is no apparent benefit of partial milling of an existing AC layer prior to AC overlay in terms of predicted IRI and there are inconsistencies in trends among projects and climatic areas. An increase in traffic loads resulted in a higher IRI. However, the variations among climatic areas were not as practically expected.
2. Partial milling prior to AC overlay resulted in higher total and AC layer rutting compared to a straight AC overlay, even when keeping the same total AC thickness, indicating that a new AC layer experiences higher rutting as compared to an existing hardened AC layer.
3. A thicker overlay reduces total and AC layer rutting. Higher traffic loads results in a small increase in total and AC rutting.
4. Subgrade and granular base layer are the main contributors (average 78 %) of the total rutting, despite that there was no rutting in the subgrade and granular base layer of existing pavements. Colder climatic areas experienced a higher AC layer rutting as compared to warmer areas. Such outcomes were not expected.
5. The predicted BUFC remains at 0.0% and is unaffected by design inputs.
6. A higher amount of BUFC in an existing AC layer generally means a higher amount of predicted reflective cracking. An increased mill depth has no or inconsistent effect on the predicted reflective cracking. The trends of the predicted reflective cracking were inconsistent among climatic areas.
7. In general, there is no or negligible variation of the predicted transverse cracking among the projects, input variables and climatic areas, with some exceptions that also have inconsistent variations among projects.

8. The effect of milling or overlay AC thickness and traffic loads on the predicted reflective cracking is inconsistent. The effect of the amount of TC in the existing pavements on the predicted reflective cracking is also inconsistent among projects and climatic areas.
9. The predicted TDFC remains unchanged at 4.69% regardless of projects, rehabilitation treatments and climatic conditions, except for the traffic loads. The effect of higher traffic loads is also inconsistent among climatic areas. A thicker AC layer experiences higher TDFC, which is questionable.

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