Comparative Analysis of Pavement Rehabilitation Designs Using AASHTOWare Pavement ME, AASHTO 1993 and Surface Deflection Methods

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Abstract

Currently, the majority of the highway projects in Manitoba involve the rehabilitation of the existing pavements. Asphalt concrete (AC) overlays with levelling, milling, cold in-place recycling (CIR) with expanded asphalt and pulverization of the existing AC or rubblization of existing portland cement concrete (PCC) are the common rehabilitation practices. Manitoba uses the surface deflection based and/or the AASHTO 1993 methods for these rehabilitation designs and is currently evaluating the new AASHTOWare Pavement ME design method. This paper presents a comparative analysis of the required AC overlay using these three design procedures for the above mentioned options. The suitability of the globally calibrated rutting and roughness models and the potential for successful calibration are also discussed.

Results show that the deflection based and Pavement ME Design methods provided comparable overlay structures for the selected projects. However, establishing a reasonable target value for each distress in the Pavement ME is necessary for comparable overlay thicknesses. The Pavement ME Design program under predicted the rutting for two projects with straight overlays. However, it over predicted the rutting for these projects for the milling and overlay option. These results are unexpected and raise the question as to whether a local calibration effort will be effective. The CIR should be considered as an AC layer for a reasonable overlay thickness using the Pavement ME Design program. Using the Pavement ME Design program, the required AC thickness for the new construction is higher than that required for the rehabilitation which is also questionable.

Introduction

Background

Over the last several years, the majority of the highway projects in Manitoba have been the rehabilitation of existing pavements. The expenditure for pavement rehabilitation is expected to continue to increase since most of the pavement structures in the Province have exceeded their design life. Straight AC overlay with levelling (no milling), AC overlays with milling, CIR (with expanded asphalt) and pulverization treatment of the existing AC or rubblization of existing PCC surfaces are the common methods of pavement rehabilitation in Manitoba.

Manitoba Infrastructure and Transportation (MIT) has been using the surface deflection (Benkelman Beam Rebound) based method, developed by the Roads and Transportation Association of Canada (currently known as the TAC), and/or the "AASHTO 1993 Guide for Design of Pavement Structures" for the rehabilitation design of flexible, rigid and composite (AC over PCC) pavements. These empirical design procedures provided pavement structures which perform well in the Manitoba environment. In 2007, MIT started to evaluate the AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG) and to compare the MEPDG design with traditional designs.

The new AASHTOWare Pavement ME design and analysis method is based upon the MEPDG which was developed by the National Cooperative Highway Research Program (NCHRP). The MEPDG method uses the fundamental properties of pavement and subgrade materials. The calculated responses (stress, strain, etc.) of a selected pavement structure have been correlated with the observed performance in terms of international roughness index (IRI) and surface distresses (rutting, cracking and faulting) under various traffic loading and climatic conditions. This new program has been under development and refinement for over a 15-year period. However, many users, including Manitoba, are facing difficulties with the adoption of the MEDPG or the Pavement ME Design program as a day to day pavement design or analysis tool. Several issues were identified and discussed by Ahammed et al. (1).

In 2013, MIT conducted an in-house analysis on the applicability of the globally calibrated rutting and roughness models for several AC and PCC pavement designs. The results indicated that the Pavement ME Design program model for the IRI produced a large variation between the predicted and observed values whereas the Pavement ME Design program over predicted the rutting in all cases. An Alberta study found that Pavement ME (DARWin ME) design over predicts rutting for new AC designs but under predicts the rutting for AC overlay designs (2). Based on the results of a limited number of projects in Manitoba, local calibration was deemed required before the implementation of the Pavement ME Design program in Manitoba.

This paper presents a comparative analysis of the required AC overlay thicknesses using the above mentioned three design procedures for varied traffic, subgrade soils and layer thicknesses of the existing pavements. The overlay design examples include different treatments of the existing AC and PCC surfaces. A comparison of the predicted and measured distresses is also presented for two AC overlay design projects. This analysis will provide a better understanding of differences in overlay thicknesses using different methods of pavement rehabilitation design. This will also assist the Department to confirm or adopt a design procedure that better reflects Manitoba conditions. The potential of successful calibration is also discussed based upon the presented results.

Objectives and scope

The objectives of this paper are:

i) To present a comparative analysis of the required thickness of AC overlay using three design procedures: a) AASHTO 1993 Method, b) Surface Deflection Based Method, and c) AASHTOWare Pavement ME Design program.

ii) To investigate the impacts of varying subgrade soils and the strength of existing pavements on the required AC overlay for different traffic volumes.

iii) To evaluate the suitability of the globally calibrated rutting and roughness models to the Manitoba condition.

Examples of six pavement rehabilitation projects (five AC pavements and one composite pavement) have been presented to compare the required AC overlays for the straight overlay (no milling), AC milling, AC pulverization, AC cold-in-place recycling (CIR) and PCC rubblization treatments. The global calibration coefficients of the AASHTOWare Pavement-ME Design program are used in the overlay design trials. The design lane truck volume varies from 80 trucks per day to 850 trucks per day. The subgrade soils for these projects are high plastic clay with varying group index (GI) (based upon the AASHTO soil classification), silty sand and fine sand. The existing pavement AC layer thickness varies from 75 mm to 285 mm and the base layer thickness varies from 100 mm to 375 mm for the existing AC surfaced pavements. The composite pavement has 100 mm AC over a 200 mm jointed reinforced concrete pavement (JRCP) and 125 mm base.

Project Description

Six pavement rehabilitation projects are selected for the design analysis presented in this paper. Five projects are located on expressways (PTH 1 and PTH 16) and one project is located on a collector (PTH 23). Four of these six projects are included in the 2013-2015 capital programs for pavement rehabilitation. Rehabilitation of the other two projects was completed in 1989. These two projects are used to compare the overlay designs as well as to compare the predicted performance and rutting. The roughness and rut data collected in 2007 are used to compare the measured international roughness index (IRI) and rut depth with the Pavement ME Design program predicted IRI and rut depth. Figure 1 is a map showing the locations of these projects. Table 1 presents the description of locations of the projects, existing pavements layer thicknesses, construction histories, strengths (as available) and proposed rehabilitation treatments. The strengths of the existing AC surfaced pavements were measured in terms of the Benkelman Beam Rebound (BBR) values. BBR represents the mean plus two standard deviations of the Benkelman Beam rebound values collected over several years i.e., a Manitoba BBR value is a multi-year statistic, as opposed to the single year statistic used by many agencies. This provides a better indication of the existing pavement strength (average condition over a number of years). No BBR data were collected for concrete and composite pavements.

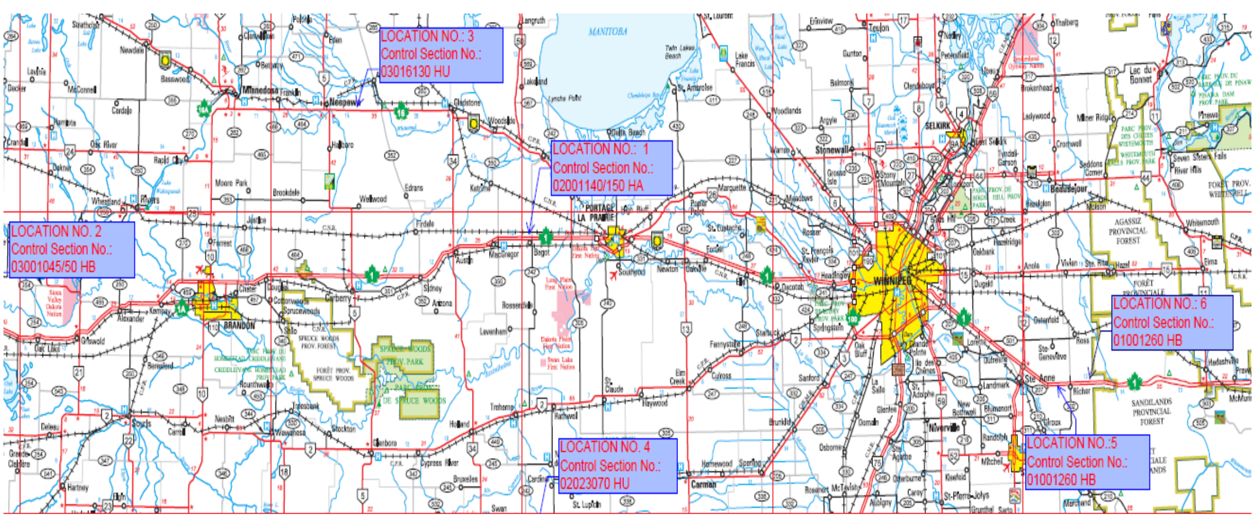

Figure 1: Project location map

Table 1: Description of projects

ID no. (Hwy no.)	Project location	Layer thickness and construction year	BBR (mm)	Rehabilitation option(s)
Project 1 (PTH 1)	C.S. 02 001 140HA/150HA): 1.4 km west of PTH 16 to 5.8 km east of PTH 16 (7.2 km)	100 mm AC (1993) 200 mm JRCP (1970) 125 mm Granular (1970) HP clay (A-7-6) subgrade (GI = 20)	N/A	Remove existing AC, rubblize JPCP and overlay with new AC
Project 2 (PTH 1)	C.S. 03 001 045HB/050HB): PR 678 (Virden) to 3.6 km east of west jct of PR 254 (21.9 km)	100 mm AC (1994) 250 mm Granular (1993) Fine sand (A-2-4) subgrade (GI = 0)	0.60	Mill 35 mm and overlay with new AC
Project 3 (PTH 16)	C.S. 03 016 130HU): East jct of PTH 5 to west jct of PR 352 (15.2 km)	285 mm AC (1960-1988) 100 mm Granular (1960) HP clay (A-7-6) subgrade (GI = 16)	0.54	a) Mill 25 mm and overlay with new AC b) CIR 100 mm and overlay with new AC c) Pulverize 285 mm AC and overlay with new AC
Project 4 (PTH 23)	C.S. 02 023 070HU): PA 666 (St. Leon Access) to PR 244 (3.3 km)	75 mm AC (1989) 375 mm Granular (1989/1964) HP clay (A-7-6) subgrade (GI = 20)	1.89	Mill 25 mm and overlay with AC
Project 5 (PTH 1)	C.S. 01 001 260HB): 0.2 km west of PR 302 to 4.3 km east of PR 302 (4.5 km)	100 mm AC (1971) 330 mm Granular (1971) Silty Sand (A-2-4) subgrade (GI = 2)	0.53	75 mm AC overlay (1989)
Project 6 (PTH 1)	C.S. 01 001 260HB): 4.3 km east of PR 302 to 9.8 km east of PR 302 (5.5 km)	100 mm AC (1971) 150 mm Granular (1971) Fine Sand (A-2-4) subgrade (GI = 0)	0.39	75 mm AC overlay (1989)

**PTH = Provincial Trunk Highway, PR = Provincial Road, PA = Provincial Access, HP = High Plastic, GI = Group index, N/A = Not Applicable, AC = Asphalt Concrete, JRCP = Jointed Reinforced Concrete Pavement, CIR = Cold In-place Recycling (with expanded asphalt).*

Traffic Data

Manitoba Level 1 truck traffic volume, axle load spectra (ALS), monthly truck traffic distribution and truck traffic classification are used in the design/analysis for all projects presented in this paper. However, the 1989 truck volumes for Projects 5 and 6 are back estimated from the current volumes using the typical growth rate. A compounded growth rate of 2% is assumed for calculating the 20 years total load repetitions. Table 2 presents the summary of the traffic data for all these projects.

Table 2: Summary of truck traffic loadings

Project no.	AADTT (2-way)	Design AADTT	Truck factor	20 years accumulative loading	Truck distribution (major trucks)	Count location
1	2,140	856	3.3	24,700,000 ESALs 7,601,370 Trucks	Class 9 = 50.6%, Class 10 = 19.6% and Class 13 = 14.0%	Station #65
2	1,800	720	3.3	21,200,000 ESALs 6,386,180 Trucks	Class 9 = 59.0%, Class 10 = 18.2% and Class 13 = 12.1%	Station #62
3	730	365	3.3	10,700,000 ESALs 3,241,700 Trucks	Class 9 = 49.8%, Class 10 = 20.3% and Class 13 = 16.9%	Station #80
4	160	80	3.0	2,100,000 ESALs 710,040 Trucks	Class 6 = 18.7%, Class 9 = 31.7%, Class 10 = 16.0% and Class 13 = 11.9%	TWRG 2
5	870	350	3.3	10,200,000 ESALs 3,089,410 Trucks	Class 9 = 49.9%, Class 10 = 19.8% and Class 13 = 17.5%	Station #61
6	870	350	3.3	10,200,000 ESALs 3,089,410 Trucks	Class 9 = 49.9%, Class 10 = 19.8% and Class 13 = 17.5%	Station #61

AADTT = Annual average daily truck traffic, ESAL = Equivalent single axle load

Materials Data

The materials inputs for the new asphalt concrete (Manitoba Bituminous B) overlays, existing AC, rubblized concrete, CIR asphalt, pulverized asphalt, granular base and subgrade are Level 3 (average from typical projects in Manitoba). Table 3 presents a summary of the Manitoba Level 3 materials properties. Same gradations are used for the new and the existing AC layers (% passing 19 mm = 100, % passing 9.5 mm = 79, % passing 4.75 mm = 62 and % passing #200 = 4.1). The input Poisson ratios are 0.35 for AC, 0.4 for CIR and 0.4 for all unbound materials (pulverized asphalt base, granular base and subgrade). The asphalt binders for new AC and CIR are penetration grade 120-150 for all projects except PTH 23 (Project 4) for which PG 58-28 (Pen. 150-200) is used. Additionally, the PG 58-34 binder is used for the new AC layer (overlay) in alternative design trials for all projects to compare with the design (overlay) using the penetration graded binder. The penetration values for the existing asphalt (reclaimed) binders vary widely among the projects depending on age and grade (which is unknown) of the original binders. The penetration values ranged from 20 to 40 among the reclaimed asphalts tested by the MIT central laboratory. For the existing AC layer, 40-50 penetration grade is selected for all designs which is the hardest default binder in the Pavement ME Design program. Other material properties inputs are from the Pavement ME Design program default values.

Table 3: Summary of materials properties

Properties	Asphalt mix	CIR	Base	Subgrade
Materials type	New AC (bituminous mix Type B): Air voids = 5%, effective binder content = 10% (by volume), unit weight = 2,350 kg/m^3 Existing AC: Air voids = 3%, effective binder content = 10% (by volume), unit weight = 2,350 kg/m^3	Treated with foamed asphalt: Air voids = 11.1%, effective binder content = 12.3% (by volume), unit weight = 2,150 kg/m^3; % passing 19 mm = 100, % passing 9.5 mm = 87, % passing 4.75 mm = 67, % passing #200 = 7.4	Crushed gravel: 25 mm nominal max. size, 13.7% passing #200; non-plastic; moisture = 8.0 %; unit weight = 2,220 km/m^3	Varied based upon soil survey data and density testing (average from typical projects)
Modulus, strength and other properties	Calculated from the mix and binder properties (by the Pavement ME Design program).	Calculated from the mix and binder properties (by the Pavement ME Design program).	*Crushed gravel: Mr = 170 MPa; **Rubblized concrete = E= 700 MPa; ***Pulverized asphalt: Mr = 207 MPa	A-7-6 (20) = 30 MPa A-7-6 (16) = 40 MPa A6 (10) = 55 MPa A-2-4 (2) = 125 MPa A-2-4 (0) = 150 MPa
AASHTO 1993 layer coefficients and strength properties	0.42	0.30	Crushed gravel = 0.12; Rubblized concrete = 0.30; Pulverized asphalt = 0.14	

Annual representative value, **middle value from the range recommended in the MEPDG Manual of Practice, * Same as Manitoba Granular A base.*

Climate Data

The climate data from the nearest weather stations (Winnipeg for Projects 1, 4, 5, and 6, and Brandon for Projects 2 and 3) are used.

Overlay Design and Analysis

As mentioned earlier, three design methods are used to estimate the required AC overlay thicknesses for different treatments of the existing pavements. This section presents the comparative analysis of the overlay designs and performance. The design criteria for AC overlay using the AASHTOWare Pavement ME Design program is summarized in Table 4. The target reliability is 90% for all distresses for Projects 1-3 and 5-6. The target reliability is 85% for Project 4 for all distresses. The top-down fatigue cracking is ignored for all designs.

Table 4: Overlay design criteria using the AASHTOWare Pavement ME Design program

Project no.	Initial IRI (m/km)	Terminal IRI (m/km)	Total permanent deformation (mm)	Total cracking (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	Permanent deformation - AC only (mm)
1	0.9	2.5	19	50	189.4	15	12
2	0.9	2.5	19	50	189.4	15	12
3	1.0	2.5	19	50	189.4	15	12
4	0.9	2.7	19	50	189.4	25	12
5	1.0	2.5	19	50	189.4	15	12
6	1.0	2.5	19	50	189.4	15	12

Project 1: Rehabilitation of the existing composite pavement

This project is categorized as very high traffic (20 years load repetitions ≥ 20 million ESALs) with a weak subgrade (AASHTO A-7-6). The rehabilitation of this project consists of milling (removal) of the existing AC and rubblization of the existing JRCP. Since no BBR data were collected for this road section, the design comparison is limited to AASHTOWare Pavement ME (Pavement ME) and AASHTO 1993 design methods. The first design trial using the Pavement ME Design, with the estimated thickness from the AASHTO 1993 and 120-150 penetration grade binder, showed that the design does not meet the IRI and thermal cracking criteria (Table 1). Since the IRI is related to thermal cracking and other distresses, use of an appropriate binder is critical for proper assessment of the predicted IRI. The next trial used a PG 58-34 binder which is selected in consideration of local environment, binder cost and performance risk (a softer binder may cause increased rutting). Table 5 presents a comparison of the overlay designs for Project 1.

Table 5: Summary of overlay designs for Project 1

Design method	AC overlay (mm)	Predicted distresses						
		Terminal IRI (m/km)	Total permanent deformation (mm)	Total (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	AC top-down fatigue cracking (m/km)	AC Permanent deformation (mm)
AASHTO 1993	*225							
Pavement ME (Pen. 120-150)	225	2.78	16.14	-	608.57	1.58	49.15	7.70
Pavement ME (PG 58-34)	215	2.50	18.28	-	35.16	1.62	50.00	9.53

** Thickness includes 12.5 mm for levelling with no structural value*
***Red indicates predicted value exceeded the target.*

As shown in Table 5, the predicted total and AC rutting increased by approximately 2 mm with the changing of the asphalt binder from Pen 120-150 to PG 58-34 but with 10 mm reduction in AC overlay thickness. However, all distresses are within the target limits when PG 58-34 (i.e., an appropriate binder) is used for the project climate. The required AC overlay is 215 mm with the use of PG 58-34 binder. With an additional 12.5 mm for levelling, the total AC layer thickness is 225 mm which is the same as that provided by the AASHTO 1993 design method. However, the required AC thickness using the Pavement ME Design program may be quite different if a different elastic modulus input for the rubblized concrete is used. For the fractured PCC, the default modulus in Pavement ME Design program is 13,790 MPa. With this modulus value, Pavement ME Design program shows that 175 mm AC overlay is sufficient i.e., 40 mm less than the AC thickness required for an elastic modulus value of 700 MPa. In Manitoba, the falling weight deflecttometer (FWD) deflection basin produced a backcalculated modulus value of 7,300 MPa for a rubblized concrete overlaid with AC. Therefore, a careful selection of the elastic modulus is important for this material. Pavement ME does not provide any guideline for the use of the backcalculated modulus for a rubblized concrete layer.

Project 2: Rehabilitation of the existing asphalt pavement (very high traffic)

This project is also categorized as very high traffic (20 years load repetitions ≥20 million ESALs). However, the subgrade is considered strong (AASHTO A-2-4). The rehabilitation of this project consists of milling (removal) of the 35 mm from existing AC (65 mm will remain in place) and new AC overlay. The design comparison is done for deflection based, AASHTOWare Pavement ME Design and AASHTO 1993 pavement design methods. The subgrade soil for this project is classified as frost susceptible according to the criteria used by MIT. The structural number (95 mm for this project) from the AASHTO 1993 is increased by 25% for a frost susceptible subgrade. The adjusted structural number is 119 mm. For the design trials using the Pavement ME Design program, both 120-150 penetration grade binder and PG 58-34 binder are used. Table 6 presents a comparison of the overlay designs for Project 2.

As shown in Table 6, the predicted total and AC rutting increase by approximately 1 mm for changing the asphalt binder from Pen. 120-150 to PG 58-34 for the same AC layer thickness. However, all distresses are within the target limits when PG 58-34 is used, except the top-down fatigue cracking which exceeds the program default target. The further reduction of AC overlay in the Pavement ME Design results in a significant increase in the AC top-down fatigue cracking which may not be desirable. The required AC overlay is 160 mm to meet the default AC top-down fatigue cracking target.

Table 6: Summary of overlay designs for Project 2

Design method	AC overlay (mm)	Predicted distresses						
		Terminal IRI (m/km)	Total permanent deformation (mm)	Total (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	AC top-down fatigue cracking (m/km)	AC permanent deformation (mm)
BBR based	140							
AASHTO 1993	*165							
Pavement ME (Pen. 120-150)	140	2.52	13.30	34.84	608.57	1.45	449.70	6.37
Pavement ME (PG 58-34)	140	2.28	14.67	34.85	138.40	1.45	499.36	7.63
Pavement ME (PG 58-34)	160	2.24	13.82	34.84	124.94	1.45	***373.97	7.33

** Using a layer coefficient of 0.30 and 0.12 for the existing AC and granular base, respectively.*
***Red indicates predicted value exceeded the target.*
**** Pavement ME Design Program default target is 378.80 m/km*

Table 6 shows that when using the deflection based method, the required AC overlay is 140 mm. When using the AASHTO 1993 design method with an adjustment for the frost susceptibility, the required AC overlay is 165 mm (110 mm AC with no adjustment for the frost susceptibility). Ignoring the AC top-down fatigue cracking but not highly exceeding this distress over the program default target, the required AC overlay is 140 mm. For this project, the AC overlay thickness is similar for the BBR based and Pavement ME Design methods. This raises the question as to whether the factor used in Manitoba for adjusting the structural number (SN) to account for the subgrade soil frost susceptibility is appropriate and whether an adjustment factor should also be used for the rehabilitation design using the deflection based method. A frost susceptible subgrade soil causes higher cracking of the AC layer and increased roughness of the pavement. These apply to both newly constructed and rehabilitated pavements and are independent of the design method or the design traffic loading. Manitoba requires a review of the approach to deal with the subgrade soil frost susceptibility issue.

Project 3: Rehabilitation of the existing asphalt pavement (high traffic)

This project is also categorized as high traffic (20 years load repetitions ≥10 million ESALs and < 20 million ESALs) with weak subgrade (AASHTO A-7-6). Three rehabilitation options for this project are: 1) milling (removal) of the 25 mm from existing AC (260 mm AC will remain in place) and AC overlay, 2) CIR (with foamed asphalt) 100 mm from the existing AC (185 mm will remain in place) and AC overlay, and 3) pulverize existing 285 AC to produce 285 mm of pulverized asphalt base layer and AC overlay. For CIR option, Pavement ME design trials are done considering CIR as an AC layer (CIR-AC) and CIR as a sandwich granular (CIR-Gran.). The design comparison is done for the deflection based, AASHTOWare Pavement ME and

AASHTO 1993 design methods as for Project 2. For the design trials using the Pavement ME, both 120-150 penetration grade binder and PG 58-34 binder are used as mentioned for Projects 1 and 2. Table 7 presents a comparison of the AC overlay designs for Project 3.

Table 7: Summary of overlay designs for Project 3

Design method	**AC overlay (mm)**	**Predicted distresses**						
		Terminal IRI (m/km)	**Total permanent deformation (mm)**	**Total (reflective + alligator) (%)**	**AC thermal cracking (m/km)**	**AC bottom-up fatigue cracking (%)**	**AC top-down fatigue cracking (m/km)**	**AC permanent deformation (mm)**
BBR based (Mill)	50							
BBR Based (CIR)	55							
BBR Based (Pulv.)	*225							
AASHTO 1993 (Mill)	105							
AASHTO 1993 (CIR)	85							
AASHTO 1993 (Pulv.)	*210							
Pavement ME (Pen. 120-150) (Mill)	50	2.74	10.61	36.79	608.57	1.45	49.10	3.66
Pavement ME (PG 58-34) (Mill)	55	2.45	10.59	36.79	98.31	1.45	48.97	3.73
Pavement ME (PG 58-34) (CIR-AC)	55	2.42	10.13	36.79	65.54	1.45	49.04	3.52
Pavement ME (PG 58-34) (CIR-Gran.)	200	2.49	12.03	0.02 (?)	122.34	1.47	50.36	6.81
Pavement ME (PG 58-34) (Pulv.)	240	2.52	13.41	-	96.11	1.54	63.00	5.44

** Thickness includes 12.5 mm for levelling with no structural value.*
***Red indicates predicted value exceeded the target.*
Pulv. = Pulverize

Table 7 shows again that Pavement ME design with 120-150 penetration grade binder does not meet the IRI and thermal cracking criteria. The required AC overlays for the mill and overlay option are 50 mm, 105 mm and 55 mm using the deflection based, AASHTO 1993 and Pavement ME (with PG 58-34 binder) design methods, respectively. The required AC overlays for the CIR (CIR-AC) and overlay option are 55 mm, 85 mm and 55 mm using the deflection based, AASHTO 1993 and the Pavement ME design methods, respectively. For the pulverize and overlay option, the required AC overlays are 225 mm, 210 mm and 240 mm (250 mm for the Pavement ME including levelling) using the deflection based, AASHTO 1993 and Pavement ME design methods, respectively. For the mill and CIR options, the required AC overlays are similar for surface deflection based and Pavement ME design methods. The thicker AC overlay using the AASHTO 1993 for these two options may be related to the use of inappropriate layer coefficients for the existing AC and base layers and inaccurate subgrade properties/strength. For the pulverization option, AASHTO 1993 provided the thinnest design and Pavement ME provided the thickest design. The pulverization and overlay option is, in fact, a new construction (reconstruction) design in the Pavement ME. Since the base layer and subgrade have no or low influences on the required AC thickness, the thicker AC overlay from Pavement ME Design program than other methods is not surprising. The predicted total cracking (reflective + fatigue) appears to be inaccurate as the bottom up fatigue cracking alone is 1.47 %.

Table 7 also shows that when using the CIR as a sandwich layer (CIR-Gran.), the required AC overlay using the Pavement ME is 200 mm (210 mm including levelling). This is significantly higher than the CIR-AC option indicating that the CIR (with expanded asphalt) should be considered an AC layer.

Project 4: Rehabilitation of the existing asphalt pavement (low traffic)

This project is categorized as low traffic (20 years load repetitions ≥0.3 million ESALs and <3 million) with a weak subgrade (AASHTO A-7-6). The subgrade soil contains some organics (discontinuous layer with varying content, depth and thickness). The rehabilitation of this project consists of milling (removal) of the 25 mm from existing AC (50 mm will remain in place) and new AC overlay. The design comparison is done for deflection based, AASHTOWare Pavement ME and AASHTO 1993 design methods. The SN (113 mm for this project) from the AASHTO 1993 design method is increased by 20% for this type of subgrade. The adjusted SN is 134 mm. A subgrade resilient modulus of 18 MPa provides a SN of 134 MPa when using the AASHTO 1993. Table 8 presents a comparison of the overlay designs for Project 4.

Table 8 shows that using the deflection based and AASHTO 1993 methods, the required AC overlays are the same (175 mm) for the project subgrade condition. As the Pavement ME design program is unable to adequately account for the effect of the subgrade properties including the organics and strength, the comparison of the Pavement ME design with the AASHTO 1993 is limited to a design with no organics in the subgrade. Using the AASHTO 1993 design method, with no adjustment for the organics, the required AC overlay is 125 mm. The required AC overlay is 50 mm using the Pavement ME Design program. The Pavement ME provides a significantly lower AC overlay thickness than the AASHTO 1993 method. A new construction design using the Pavement ME with the same inputs as the overlay design for all layers showed that a total of 100 mm AC (50 new plus 50 existing) is sufficient for this project if the top-down fatigue cracking (416 m/km) is ignored. To keep the top-down fatigue cracking within the program default target (378.8 m/km), the required AC thickness is 115 mm (65 mm new plus 50 mm existing). This 15 mm additional AC requirement for the new construction as compared to the rehabilitation for this project may not be justified.

Table 8: Summary of overlay designs for Project 4

Design method	AC overlay (mm)	Predicted distresses						
		Terminal IRI (m/km)	Total permanent deformation (mm)	Total (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	AC top-down fatigue cracking (m/km)	AC permanent deformation (mm)
BBR based	175							
AASHTO 1993 (no organics)	**125							
AASHTO 1993 (organics)	175							
Pavement ME (*PG 58-28)	**175	2.45	9.41	33.00	517.89	1.17	40.71	2.43
Pavement ME (PG 58-34)	**50	2.49	14.59	33.22	142.99	1.17	338.80	3.01

** Equivalent to Pen. 150-200 (No Pen. 150-200 binder grade in the Pavement ME for Level 3 analysis)*
*** Using a Mr = 30 MPa (no consideration of organics)*
****Red indicates predicted value exceeded the target.*

Projects 5 and 6: Predicted versus observed distresses for asphalt overlay

These two projects are located side by side and are categorized as high traffic (20 years load repetitions ≥ 10 million ESALs and <20 million ESALs) with a strong subgrade (AASHTO A-2-4). Both sections were originally constructed in 1971 with a 100 mm AC surface layer but with different base layer thicknesses. The granular base thicknesses are 330 mm and 150 mm for Projects 5 and 6, respectively. Both projects were overlaid with 75 mm AC in 1989 and were included in the long term pavement performance (LTPP) program study (GPS-6B). The existing BBR values are 0.53 mm for Project 5 and 0.39 mm for Project 6. The BBR values indicate that the Project 6 has stronger foundation (subgrade) than Project 5 (a westerly transition from a silty sand subgrade to fine/coarse sand subgrade). However, the pre-overlay (1989) BBR values are unavailable at this time. Therefore, the analysis for these two projects is limited to comparing the Pavement ME Design program predicted roughness and rut with the observed data and comparing the overlay design with the AASHTO 1993 method. MIT collected the automated roughness and rut data from these sites in 2007. Therefore, the overlay performance analysis/comparison of these projects used a design life of 18 years. The overlay design comparison used a 20-year design life. Table 9 and Table 10 present comparisons of the overlay designs for Project 5 and 6, respectively.

Table 9: Comparison of the predicted and observed distresses for Project 5

Design method	AC overlay (mm)	Predicted and observed distresses						
		Terminal IRI (m/km)	Total permanent deformation (mm)	Total (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	AC top-down fatigue cracking (m/km)	AC permanent deformation (mm)
Observed distresses	**75	*2.19	*9.30					
Pavement ME (Pen. 120-150)	75	*2.34	*4.33	34.85	608.57	1.45	560.99	4.33
Pavement ME (Pen. 120-150) (Mill)	75	*2.55	*11.15	35.70	608.57	1.45	521.69	5.03
AASHTO 1993	**65							
Pavement ME (PG 58-34)	90	2.16	5.69	34.85	60.49	1.45	497.51	3.01

** After 18 years of service*
*** AC thickness includes 12.5 mm for levelling*
****Red indicates predicted value exceeded the target.*

Table 9 shows that the Pavement ME predicted IRI is 2.34 m/km and the total rutting is 4.33 mm after 18 years. The 2007 distress survey showed that the observed roughness is 2.19 m/km and the total rutting is 9.3 mm. These show an over prediction of IRI and an under prediction of rutting for this project. The difference in the IRI is not high and cannot be explained easily because of its dependence on many factors. The large under prediction of the rutting is critical. The Pavement ME design for the mill and overlay with the same inputs as the straight overlay but entering zero rutting and 25 mm milling thickness instead of 12.5 mm rutting and no milling showed that predicted IRI is 9% higher and the predicted total rutting is 160% higher than the straight AC overlay option. These raise questions whether models and transfer functions are fundamentally accurate and the local calibration effort is justified.

As shown in Table 9, the required AC overlay (20-year design) for Project 5 is 65 mm using the AASHTO 1993 method. Limiting the top-down fatigue cracking to 500 m/km (80% reliability) and using a PG 58-34 binder, the required AC overlay using the Pavement ME design program is 90 mm (100 mm including levelling). However, to limit the top-down fatigue cracking to 378.8 m/km (program default target) and using a PG 58-34 binder, the required AC overlay using the Pavement ME design program is 115 mm (125 mm including levelling).

Table 10: Comparison of the predicted and observed distresses for Project 6

Design method	AC overlay (mm)	Predicted and observed distresses						
		Terminal IRI (m/km)	Total permanent deformation (mm)	Total (reflective + alligator) (%)	AC thermal cracking (m/km)	AC bottom-up fatigue cracking (%)	AC top-down fatigue cracking (m/km)	AC permanent deformation (mm)
Observed distresses	**75	*1.41	*6.52					
Pavement ME (Pen. 120-150)	75	*2.34	*4.33	34.85	608.57	1.45	560.99	4.33
Pavement ME (Pen. 120-150) (Mill)	75	*2.50	*10.55	35.70	608.57	1.45	562.49	5.10
AASHTO 1993	**100							
Pavement ME (PG 58-34)	95	2.12	5.84	34.84	61.16	1.45	510.30	5.84

** After 18 years of service*
*** AC thickness includes 12.5 mm for levelling*
****Red indicates predicted value exceeded the target.*

Table 10 shows that the Pavement ME predicted IRI is 2.34 m/km and the total rutting is 4.33 mm after 18 years for Project 6. These values are the same as for Project 5 despite different subgrade strength and base thickness for these two projects. This indicates that base thickness has little value when using the Pavement ME for overlay design as in the case of new construction design. The 2007 distress survey showed that the observed roughness is 1.41 m/km and the total rutting is 6.5 mm. These show an over prediction of IRI and an under prediction of rutting as for Project 5. However, the difference between observed and the predicted IRI is high for this project which a concern for using the Pavement ME Design program. The Pavement ME design for the mill and overlay option with the same inputs as the straight overlay option predicted significantly higher IRI and rutting as in the case of Project 5.

As shown in Table 10, the required AC overlay (20-year design) for Project 6 is 100 mm using the AASHTO 1993 method. Limiting the top-down fatigue cracking to 500 m/km (80% reliability) and using a PG 58-34 binder, the required AC overlay using the Pavement ME Design program is 95 mm (110 mm including levelling) which is close to the AASHTO 1993 method in this case. However, to limit the top-down fatigue cracking to 378.8 m/km (program default target) and using a PG 58-34 binder, the required AC overlay using the Pavement ME is 120 mm (130 mm including levelling). Surprisingly the total rutting and AC layer rutting values are the same indicating no rutting of the base or subgrade.

Design Summary

Table 11 presents the summary of AC overlay thicknesses for Projects 1 to 6. As shown in the table, the differences in the AC overlay thickness vary among the design methods. This may be a result of lack of accuracy of the inputs for the existing structure to the AASHTO 1993 as well as the Pavement ME design programs and inadequate or unreasonable effects of different inputs to the Pavement ME Design program.

Table 11: Summary of overlay designs

ID no. (Hwy no.)	Existing layer treatments	Remaining existing AC (mm)	AC overlay (mm)		
			BBR	AASHTO 1993	Pavement ME
Project 1(PTH 1)	Rubblize 200 mm PCC	Nil	N/A	225	215 (*225)
Project 2 (PTH 1)	Mill 35 mm AC	65	140	165	140
Project 3 (PTH 16)	Mill 25 mm AC	260	50	105	55
	CIR 100 mm AC	185	55	85	55
	Pulverize 285 mm AC	Nil	225	210	240 (*250)
Project 4 (PTH 23)	Mill 25 mm AC (no organics)	50	N/A	125	50
	Mill 25 mm AC (with organics)	50	175	175	N/A
Project 5 (PTH 1)	Levelling (no milling)	100	N/A	65	90 (100)
Project 6 (PTH 1)	Levelling (no milling)	100	N/A	100	95 (110)

**Includes 12.5 mm for levelling.*

Conclusions

This paper presents a comparative analysis of pavement designs using the traditional surface deflection (BBR), AASHTO 1993 and the AASHTOWare Pavement ME Design programs. The impacts of varying subgrade soils and the strength of existing pavement on the required AC overlay are compared. The suitability of the globally calibrated rutting and roughness models for the Manitoba condition is discussed. The main conclusions are summarized below:

1. The differences in the AC overlay thickness vary among the design methods which may be a result of the accuracy of the inputs for the existing structure.

2. The BBR based method and Pavement ME Design method provided comparable design for the projects included in this paper. The variation of AC overlay thicknesses for some projects using the AASHTO 1993 method are considered to be related to incomplete information of layer thicknesses, improper layer coefficients and incomplete information regarding the type of subgrade.

3. Previously MIT decided to ignore the Pavement ME Design program predicted top-down fatigue cracking. It appears that establishing reasonable target values for all distresses including the top-down fatigue cracking and the use of an appropriate asphalt binder are important for recommending reasonable pavement structures using the Pavement ME Design method.

4. Pavement ME over predicted the roughness and under predicted the rutting for both projects presented in this paper for the straight overlay with no milling designs. However, the Pavement ME Design program over predicted the rutting for the mill and overlay option with the same construction, traffic, layer thicknesses and materials inputs.

5. Pavement ME is a good analytical tool but appears to have some significant limitations such as the inability to properly account for the effect of base thickness, a low sensitivity to subgrade strength and the unexpected prediction for different treatment alternatives. These items pose the question whether a local calibration effort for the existing models will be effective.

6. The CIR with expanded asphalt should be considered as an AC layer for a reasonable AC overlay thickness. The required AC overlay using the Pavement ME is unreasonably high if it is considered a sandwich layer.

7. For the same construction, traffic, layer and materials inputs in the Pavement ME Design program, the required AC thickness for new construction is higher than that for rehabilitation. This is questionable and requires further investigation.

References

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