Implementing the AASHTOWare Pavement ME Design Guide: Manitoba Issues and Proposed Approaches

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Abstract

Manitoba Infrastructure and Transportation (MIT) has been using the new Mechanistic Empirical Pavement Design Guide (MEPDG) since 2007 in conjunction with traditional design practices. The objective of this paper is to discuss issues and prospects in using this new design tool by using design examples of typical flexible, rigid and composite (asphalt over concrete) pavements. The influence of traffic volume, asphalt, concrete thickness, base thickness, asphalt binder type, subgrade support and base layer strength on the predicted roughness and surface distresses are analyzed to demonstrate the issues and prospects. The approaches that Manitoba is considering in to order to adopt this new tool in conjunction with Manitoba's local experience are also discussed.

Analysis indicates that the default asphalt layer rutting limit of 6 mm is too conservative and the longitudinal cracking model is unreliable. The required asphalt layer thickness could be significantly reduced if the asphalt rutting limit is increased to 12 mm, asphalt longitudinal cracking is ignored and an appropriate asphalt binder is used. In the Pavement ME Design, the base layer exceeding 250 mm and subbase layer are shown to produce no practical influence on the required asphalt thickness. It is recommended that a catalogue of base and subbase thicknesses be developed for frost protection requirement based on local experience. The Pavement ME Design program can be then used to determine the required asphalt thickness. The resilient modulii (stiffness) of base and subgrade are shown to significantly influence the predicted distresses and roughness. The required concrete thickness is shown to be significantly lower than that which Manitoba usually constructs.

Introduction

Background

MIT has been using the AASHTO 1993 guide or its earlier version(s) for the design of new flexible, rigid and composite pavements and for the design of rehabilitated rigid and composite pavements. For the rehabilitation of flexible pavements, the surface deflection (Benkelman Beam Rebound) based method is being used. These empirical design procedures provided pavement structures, both for new construction and rehabilitation, which perform well in the Manitoba environment. AASHTO terminated the licensing and technical support for the AASHTO 1993 pavement design guide software DARWin in June, 2012.

The new AASHTO Pavement ME design and analysis method is based on the MEPDG 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, stain, etc.) of a selected pavement structure have been correlated with the observed performance (in terms of international roughness index i.e., IRI) and surface distresses (rutting, cracking and faulting) under various traffic loading and climatic conditions. Although this new program has been under development and refinement for over a 15-year period, many users including Manitoba, are still uncomfortable to adopt the MEDPG or the Pavement ME Design program as a day to day pavement design or analysis tool. Issues include but are not limited to:

i) effectiveness of subgrade support,
ii) impact of frost susceptible soils,
iii) impact of the presence of organics in subgrade soils,
iv) effectiveness of granular base and subbase layer thicknesses,
v) frost and swelling protection,
vi) influence of asphalt binder,
vii) variation of required asphalt layer thickness with the variation of design traffic volumes,
viii) axle load spectra (ALS) does not include the steering axle, and
ix) requirement of a very thin concrete layer.

These issues are of particular importance because of the discontinuation of the AASHTO 1993 pavement design guide software which was a popular program, especially for the design of new flexible pavements.

This paper discusses some of the above mentioned issues that Manitoba is experiencing when using the Pavement ME Design program. The sensitivity of asphalt, concrete and base thicknesses and subgrade type to the predicted performance (roughness) and surface distresses (rutting, cracking, faulting, etc.) are evaluated. The layer equivalency between asphalt and granular base/subbase thicknesses is also compared. Design examples for typical flexible, rigid and composite pavements are presented to demonstrate these issues. Approaches that Manitoba is considering to overcome these issues and to produce pavement structures that are comparable to traditional designs are presented. The design examples, observations and proposed approaches will assist the AASHTOWare Pavement ME Design software users to better understand the design issues, to consider the suggested approaches and to increase knowledge from the discussion among the users, readers of the paper and the conference participants.

Experiences of Different Agencies

The MEPDG or Pavement ME Design program is a complex pavement design tool. Implementation of this program requires high technical skills and significant financial resources. Several North American highway agencies have taken initiatives to adopt this new design guide/tool. Some agencies are evaluating the experiences of other users. Baus and Stires (1) summarized the status of the MEPDG implementation in the United States. In Canada, several provincial and municipal agencies are evaluating this guide and working to develop the required inputs.

Florida performed sensitivity analyses with different materials inputs. The predicted distresses were found to be most sensitive to the asphalt concrete (AC) dynamic modulus, layer thickness, base modulus, subgrade modulus, portland cement concrete (PCC) coefficient of thermal expansion, joint spacing, dowel bar diameter and PCC compressive strength (2). Maryland found that an increase in base thickness resulted in a slight decrease in fatigue cracking and a negligible change in rutting while an increase in asphalt thickness resulted in a decrease in both fatigue cracking and rutting (3). For the flexible pavements, North Carolina found the IRI to be insensitive to traffic and material inputs (4).

Iowa observed that the predicted AC longitudinal cracking, alligator cracking, AC rutting and subgrade rutting are sensitive to changes in the design truck volume. However, the predicted subbase rutting and IRI are insensitive to the design truck volume (5). A Canadian study found that the predicted rutting is sensitive to changes in AC layer thickness and modulus while changes in the base layer thickness and stiffness showed little or no effect on predicted permanent deformation (6). An Alberta study found that DARWin ME overpredicts rutting for new AC designs but under predicts the rutting for AC overlay designs (7).

A sensitivity analysis performed by Idaho showed that for flexible pavements, longitudinal cracking is extremely sensitive to AC layer thickness and properties, base layer thickness, subgrade strength, traffic and climate whereas the bottom up fatigue cracking is extremely sensitive to AC layer thickness, AC mix properties, base layer thickness, truck volume and axle load spectra. Total rutting is extremely sensitive to AC layer thickness and truck volume and very sensitive to subgrade strength. IRI is sensitive to only truck volume (8). Minnesota and Montana observed that the AC longitudinal cracking and rutting predictions are questionable (9, 10). In a global sensitivity analysis for rigid pavements, slab width, mix properties, slab thickness, coefficient of thermal expansion and joint spacing were found to be most sensitive (11). Global sensitivity analysis for flexible pavements indicated that AC properties, AC layer thickness, surface shortwave absorptivity and Poisson's ratio are most sensitive parameters. Base and subgrade properties were found to range from insensitive to sensitive (12).

The examples of the research results presented above show mixed experiences with the MEPDG including the predicted distresses and roughness. Such inconsistent research results hinder the implementation of the MEPDG as a day to day pavement design tool. Agencies are struggling to find an appropriate process to deal with these issues. This paper discusses some of these issues and suggests possible solutions.

Objectives

The main objectives of this paper are:

i) to present examples of flexible and rigid pavement designs using local traffic, climate and materials data to demonstrate some practical issues and prospects,
ii) to provide recommendations for using the AASHTOWare Pavement ME Design considering the issues that are presented, and
iii) to discuss the requirements of local calibration/verification of the performance and distress models.

Traffic, Materials and Climate Data

For the analysis presented in this paper, typical asphalt and base thicknesses, typical subgrade types, Level 3 asphalt (Manitoba Bituminous B), base and subgrade materials properties and typical truck traffic volumes are used. For the axle load distribution, Manitoba Level 1 axle load spectra (ALS), temporal (monthly and hourly) truck traffic distribution and truck traffic classification from the Weigh in Motion (WIM) Station on the Provincial Truck Highway 1 (PTH 1) at Richer, Manitoba are used. The truck traffic stream at this count station consists of 49.9% Class 9 (5-axle semitrailer), 19.8% Class 10 (semitrailer) and 17.5% Class 13 (8-axle Btrain). Climate data from Winnipeg is used in all analysis. Table 1 provides a summary of the materials properties used in the analysis. The design lane truck volumes varied from 250, 500 and 1,000 trucks per day.

Table 1: Summary of Materials Properties Used in the Analysis

Properties	**Asphalt Mix and Binder**	**PCC Mix**	**Granular A (Base)**	**Granular C (Subbase)**
Materials type	Bituminous mix Type B: Maximum size = 19 mm, fines = 4%, air voids = 5%, effective binder content = 10% (by volume), unit weight = 2,350 kg/m^3	Normal concrete with 19 mm maximum size limestone	Non-plastic crushed lime stone (19 mm maximum size)	Non-plastic gravel (37.5 mm maximum size)
Modulus, strength and other properties	Calculated from the mix and binder properties (by the Pavement ME Design program). Asphalt binder = PG 58-34 (in general)	28-day compressive strength = 32 MPa, 340 kg cement (Type GU), w/c ratio = 0.40	*Mr = 140 MPa OMC = 9.0 % Unit weight = 2,170 km/m^3	**Mr = 120 MPa OMC = 6.4 % Unit weight = 2,200 km/m^3
AASHTO 1993 layer coefficients and strength properties	0.42	Modulus of elasticity, E = 29,000 MPa, Modulus of rupture = 4.6 MPa	0.14	0.12
PCC Joint Design		Lane width = 4.3 m, joint spacing = 4.6 m, dowel dia. = 35 mm, dowel spacing = 300 mm		

*Result from the laboratory testing at the University of Manitoba.
** Estimated from typical layer coefficients of base and subbase.

Table 2 provides a summary of typical flexible pavement structures in Manitoba for different subgrade types and truck volumes or equivalent single axle loads (ESALs). For the ESAL calculation, a truck factor of 3.25 is used. For a Provincial Truck Highway (PTH), usually 150 mm asphalt concrete and 200 mm base (Granular A) layers are constructed. Subbase (Granular C) depth varies to match the total structural number (SN) required for different traffic volumes (design ESALs) and subgrade condition. Table 2 also shows alternative pavement structures for the high plastic clay subgrade for the design volumes of 500 and 1,000 trucks per day. The subbase thickness was reduced to 450 mm (same as that for the design traffic of 250 trucks per day) for these alternative designs. Table 2 shows that if the design truck volume increases from 250 to 500, Manitoba uses an additional 100 mm subbase or 30 mm AC. Similarly, if the design volume increases from 500 to 1,000 trucks per day, Manitoba uses an additional 125 mm subbase or 35 mm AC. For a frost susceptible clayey silt or sandy silt subgrade, Manitoba increases the required SN by 25% which provides a similar design as for the high plastic clay subgrade. For the fine sand subgrade, 150 mm AC, 150 mm base and 200 mm C base are constructed for a design lane traffic volume of 1,000 trucks per day. For continuous rock, 150 mm AC, 100 mm base and 100-200 mm subbase are constructed for a design lane traffic volume of 1,000 trucks per day. The service lives usually exceed the design life in terms of roughness (IRI) and rutting.

Table 2: Summary of Typical Flexible Pavement Structures for Different Subgrade Types and Traffic Volumes (at 90% Reliability)

Subgrade Type and Resilient Modulus	**Design Traffic Volume (trucks/day)**	**Design (20-year) ESALs x 10^6 (Truck Factor = 3.25)**	**Bituminous Layer Thickness (mm)**	**Granular A Base thickness (mm)**	**Granular C Base Thickness (mm)**
High Plastic Clay (A-7-6), Mr = 30 MPa	250	7.2	150	200	450
	500	14.4	150	200	550
	500	14.4	180	200	450
	1,000	28.8	150	200	675
	1,000	28.8	215	200	450
Clayey Silt (A-4), Mr = 65 MPa	1,000	28.8	150	200	650
Fine Sand (A-2-4), Mr = 150 MPa	1,000	28.8	150	150	200
Cont. Rock, Mr > 150 MPa	1,000	28.8	150	100	100-200

Tables 3 and 4 provide a summary of typical PCC and composite pavements in Manitoba for varying truck volumes. Typically 225 mm to 275 mm PCC over a 100 mm base and 200 mm subbase are constructed for the design truck volumes of 250, 500 and 1,000 per day. Although the design life is 20 years, the concrete pavements usually perform well for over 30 years. For composite pavements, as shown in Table 4, 50 mm concrete is replaced with a 100 mm asphalt layer.

Table 3: Summary of Typical Rigid Pavement Structures for Varying Traffic Volumes (at 80% Reliability)

Subgrade Type and Subgrade Support	**Design Traffic Volume (trucks/day)**	**Design (20-year) ESALs x 10^6 (1.5*Flexible ESALs)**	**PCC Thickness (mm)**	**Granular A Base thickness (mm)**	**Granular C Base Thickness (mm)**
High Plastic Clay (A-7-6), K = 40.72 KPa/mm	250	10.8	225	100	200
	500	21.6	250	100	200
	1,000	43.2	275	100	200

Table 4: Summary of Typical Composite Pavement Structures for Varying Traffic Volumes (at 80% Reliability)

Subgrade Type and Subgrade Support	**Design Traffic Volume (trucks/day)**	**Design (20-year) ESALs x 10^6 (1.5*Flexible ESALs)**	**Bituminous Layer Thickness (mm)**	**PCC Thickness (mm)**	**Granular A Base thickness (mm)**	**Granular C Base Thickness (mm)**
High Plastic Clay (A-7-6), K = 40.72 KPa/mm	250	10.8	100	200	100	200
	500	21.6	100	200	100	200
	1,000	43.2	100	225	100	200

Pavement ME Design Analysis for Flexible Pavements

Effect of Traffic Volumes

Table 5 presents the summary of AASHTOWare Pavement ME Design program predicted roughness and surface distresses for varying truck volumes and for a high plastic clay subgrade. The typical base and subbase thicknesses, as shown in Table 2, are used in this analysis. Table 5 also presents the Pavement ME Design program calculated ESALs and corresponding pavement structures that Manitoba typically constructs for these lower ESALs. Table 5 shows that 155 mm AC is required for a design volume of 250 trucks per day to control the roughness and all the surface distress criteria. For this truck volume, a 150 mm thick AC layer is sufficient to pass all criteria, except the AC longitudinal (i.e. top down fatigue) cracking. However, if ESALs estimated by the Pavement ME Design program are used, Manitoba will construct only 100 mm AC for this traffic level with a base and subbase thickness of 200 mm and 450 mm, respectively. It should be noted here that none of the AASHTO 1993 and the Pavement ME Design methods incorporate the steering axle or axle with single tires in ESAL calculation or in the ALS. Manitoba uses the Modified Shell equations to calculate the load equivalency for different axles including the steering axle. However, the steering axle alone may not explain the large difference between Manitoba and the Pavement ME Design for the calculated ESALs. Manitoba should also confirm the axle load data from the WIM stations and the truck factors that are in use.

Table 5: Summary of Flexible Pavement ME Design Outputs for Varying Truck Volumes (Initial IRI = 1.0 m/km, PG 58-34 binder and High Plastic Clay Subgrade)

Design AADTT		**250**	**500**	**500**	**1,000**	**1,000**	**1,000**
Layer Thicknesses (mm): AC/A Base/C Base (Used in Pavement ME Design)		**155/200 /450**	**150/200 /550**	**175/200 /450**	**150/200 /675**	**215/200 /450**	**240/200 /450**
Pavement ME Design Calculated ESALs (million)		**1.92**	**3.84**	**3.84**	**7.68**	**7.68**	**7.68**
Typical Structures for Pavement ME Design Calculated ESALs (mm): AC/Base/Subbase		**100/200 /450**	**125/200 /450**	**125/200 /450**	**150/200 /450**	**150/200 /450**	**150/200 /450**
Terminal IRI	Target (m/km)	2.7	2.7	2.7	2.7	2.7	2.7
	Predicted (m/km)	2.61	2.72	2.66	2.84	2.69	2.65
Total Pavement Rutting	Target (mm)	19	19	19	19	19	19
	Predicted (mm)	16.94	20.44	18.77	24.50	20.15	18.82
AC Bottom Up Cracking	Target (%)	25	25	25	25	25	25
	Predicted (%)	1.91	2.90	2.00	14.55	1.86	1.69
AC Transverse Cracking	Target (m/km)	189.4	189.4	189.4	189.4	189.4	189.4
	Predicted (m/km)	51.31	52.58	45.47	52.55	37.66	33.20
AC Top Down Cracking	Target (m/km)	378.8	378.8	378.8	378.8	378.8	378.80
	Predicted (m/km)	372.88	534.70	344.09	741.89	155.24	73.68
AC Layer Rutting	Target (mm)	12	12	12	12	12	12
	Predicted (mm)	5.64	7.73	7.41	10.64	9.38	8.79

For the design lane traffic of 500 and 1,000 trucks per day, the typical Manitoba pavement structures with a 150 mm AC layer and thick base/subbase layers are insufficient to pass the roughness, total rutting and longitudinal cracking criteria. Figure 1 shows the design charts for the design traffic volume of 500 trucks per day. As shown in the figure, the expected service life is 15 years for this design case based on the total rutting criterion. As shown in Table 5, Pavement ME design requires 175 mm AC and 240 mm AC layers, respectively, for these two design traffic levels (500 and 1,000 trucks per day). This shows that for an increase of design lane traffic volume from 250 to 500 trucks per day, an additional 20 mm AC is required. For an increase of design lane traffic volume from 500 to 1,000 trucks per day, an additional 65 mm AC is required. The additional AC thickness requirements for the increased design lane volume from 250 to 500 and from 500 to 1,000 trucks per day using the AASHTO 1993 method is 30- 35 mm. The requirement of a thicker bituminous (asphalt) layer and their variation with a variation of design traffic volume are not unexpected but they do not correspond to Manitoba's practice. A local calibration/verification of the Pavement ME Design models may be required to confirm whether this thicker AC layer or additional AC thickness are warranted for Manitoba conditions.

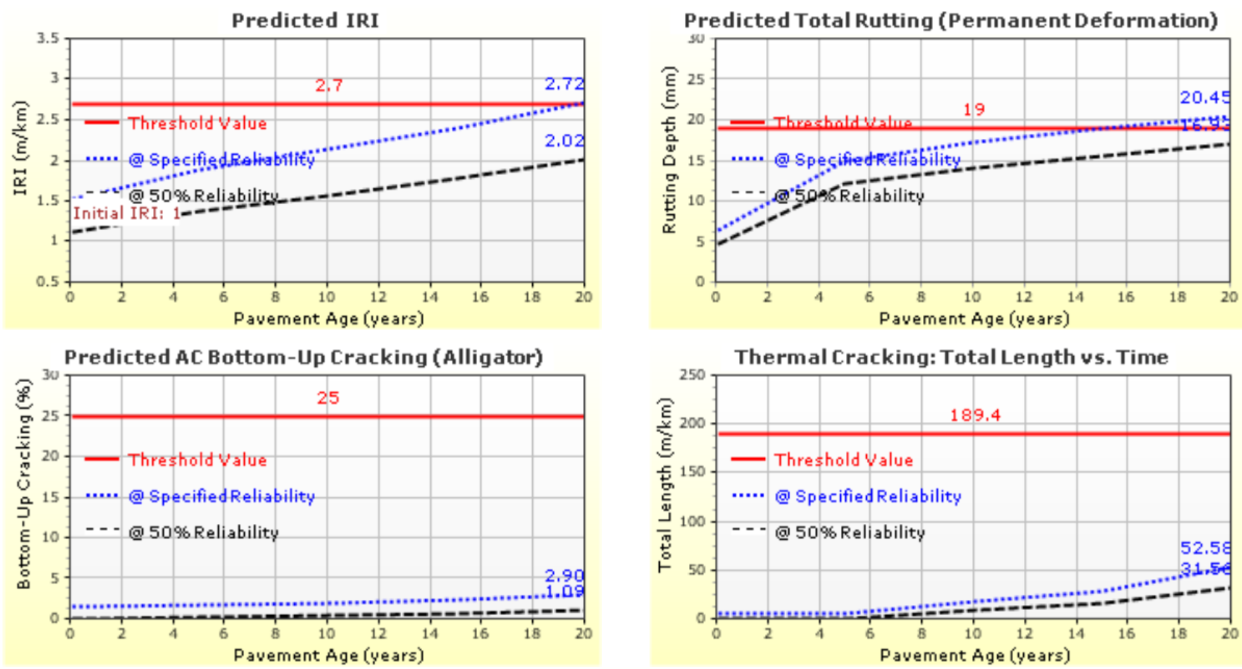

Figure 1: Flexible Pavement ME Design Charts for 500 trucks per day (Initial IRI = 1.0 m/km, AC = 150 mm, base = 200 mm, subbase = 550 mm and High Plastic Clay Subgrade)

Table 5 also shows that the predicted AC layer rutting is greater than 6 mm in all design cases, except for the design lane volume of 250 trucks per day. A 270 mm and 325 mm AC mat are required to limit AC layer rutting to 6 mm for the design lane volume of 500 and 1,000 trucks per day. In Manitoba, total rutting is used as one of the criteria to trigger maintenance or rehabilitation without accounting for the individual contribution of AC, base/subbase and subgrade layers to total rutting. An AC layer rutting over 12-13 mm would indicate an excessive flow (and compression) of the asphalt mix. Therefore, it is recommended that AC layer rutting limiting criteria be increased to 12 mm to be more practical in terms of AC thickness requirements.

Effect of AC Binder Grade

The Pavement ME Design is used to evaluate the variation of the predicted roughness and surface distresses for a variation of AC binder grade. The design lane traffic of 1,000 trucks per day and a high plastic clay subgrade are used in this analysis. The analysis result is summarized and presented in Table 6. As shown in the table, if the AC binder high temperature grade is increased by one level (from 58 to 64 °C) i.e., if a harder/stiffer binder is used, there will be a corresponding reduction in roughness, total rutting, fatigue cracking, longitudinal cracking and AC rutting. The transverse cracking will increase. As expected, the reverse trend is observed when the AC binder high temperature grade is decreased from 58 to 52 °C or from 64 to 52 °C. Alternatively, a decrease of the AC binder low temperature grade from -34 to -40 °C (i.e., use of a softer binder) will result in a decrease of transverse cracking and an increase of all other surface distresses and roughness. No unusual trend of predicted distress for the change of AC binder grade is observed. Analysis (as presented in Table 5 and Table 6) also shows that for the design traffic of 1,000 trucks per day and a high plastic clay subgrade, the AC thickness could be reduced from 240 to 220 mm (20 mm reduction) with a change in binder from PG 58-34 to PG 64-34. A comparison of increased binder cost and reduced AC layer cost is required for the selection of the appropriate option.

Table 6: Effect of Asphalt Binder Grade (Initial IRI = 1.0 m/km, Design Traffic= 1,000 Trucks per day and High Plastic Clay Subgrade)

Asphalt Binder		**PG 58-34**	**PG 64-34**	**PG 52-34**	**PG 52-40**	**PG 64-34**
Layer Thicknesses (mm) AC/A Base/C Base		**215/200/450**	**215/200/450**	**215/200/450**	**215/200/450**	**220/200/450**
Terminal IRI	Target (m/km)	2.7	2.7	2.7	2.7	2.7
	Predicted (m/km)	2.69	2.67	2.71	2.73	2.66
Total Pavement Rutting	Target (mm)	19	19	19	19	19
	Predicted (mm)	20.15	19.17	21.34	22.50	18.90
AC Bottom Up Cracking	Target (%)	25	25	25	25	25
	Predicted (%)	1.86	1.81	1.93	2.01	1.77
AC Transverse Cracking	Target (m/km)	189.4	189.4	189.4	189.4	189.4
	Predicted (m/km)	37.66	60.88	18.98	5.15	59.27
AC Top Down Cracking	Target (m/km)	378.8	378.8	378.8	378.8	378.80
	Predicted (m/km)	155.24	119.69	195.78	232.53	100.66
AC Layer Rutting	Target (mm)	12	12	12	12	12
	Predicted (mm)	9.38	8.57	10.38	11.36	8.47

Effectiveness of Base and Subbase Layers

Table 7 presents the summary designs used to evaluate the effectiveness of base and subbase layer thicknesses on the Pavement ME Design program predicted surface distresses and roughness. The design lane traffic of 1,000 trucks per day and a high plastic clay subgrade are used in this analysis. An optimization analysis using the Pavement ME program shows that a 220 mm AC, 25.4 mm base and 25.4 mm subbase are required to pass all the design criteria. Table 7 also shows that a 215 mm AC, 225 mm base and 25.4 mm subbase are sufficient for this design truck volume and subgrade. This indicates that 5 mm AC can be replaced with 200 mm base. The total rutting decreases with an increase in base thickness, however the base thickness over 225 mm has no practical influence in terms of reducing the AC thickness. In Manitoba, the layer equivalency is 1 mm AC equals to 3 mm base.

Further analysis by replacing 225 mm base with 225 mm subbase, as presented in Table 7, shows that subbase is ineffective in reducing the predicted total rutting (the predicted total rutting increases from 18.94 mm to 19.56 mm). The predicted total rutting increases with an increase in subbase layer thickness which is unexpected. The bottom up fatigue cracking decreases while the predicted longitudinal (AC top down) cracking, transverse cracking and AC layer rutting increase with an increase in both base and subbase thickness as expected.

Table 7: Effect of Base and Subbase on Flexible Pavement Design (Initial IRI = 1.0 m/km, Design Traffic= 1,000 Trucks per day, PG 58-34 binder and High Plastic Clay Subgrade)

Layer Thicknesses (mm) AC/A Base/C Base		**220/25.4/25.4 (Optimized)**	**215/225 /25.4**	**215/450 /25.4**	**215/675 /25.4**	**215/25.4/ 225**	**215/25.4 /450**	**215/250 /0**
Terminal IRI (m/km)	Target	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	Predicted	2.65	2.65	2.65	2.65	2.67	2.69	2.65
Total Pavement Rutting (mm)	Target	19	19	19	19	19	19	19
	Predicted	18.78	18.94	18.80	18.78	19.56	20.21	18.84
AC Bottom Up Cracking (%)	Target	25	25	25	25	25	25	25
	Predicted	2.73	2.00	1.79	1.72	2.33	2.14	1.97
AC Transverse Cracking (m/km)	Target	189.4	189.4	189.4	189.4	189.4	189.4	189.4
	Predicted	34.81	39.21	42.75	45.26	36.59	38.47	38.74
AC Top Down Cracking (m/km)	Target	378.80	378.8	378.8	378.8	378.8	378.8	378.8
	Predicted	214.10	97.41	105.74	162.98	192.44	231.68	94.77
AC Layer Rutting (mm)	Target	12	12	12	12	12	12	12
	Predicted	8.35	9.04	9.52	9.78	8.78	9.01	9.09

Figure 2 and Figure 3 show the design outputs for the design lane traffic volumes of 250 trucks per day and 500 trucks per day, respectively. In these trials, the base and subbase thicknesses are 225 mm and 25.4 mm respectively, as in the case of 1,000 trucks day. The required AC thicknesses are 150 mm and 165 mm AC for 250 and 500 trucks, respectively. These outputs indicate that base or subbase have no added benefit for the Pavement ME Design.

Design Structure

Layer type	Material Type	Thickness(mm):
Flexible	Default asphalt concrete	150.0
NonStabilized	Crushed stone	225.0
NonStabilized	A-1-a	25.4
Subgrade	A-7-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.0
Air voids (%)	5.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2013 (initial)	500
2023 (10 years)	1,000,180
2033 (20 years)	2,219,400

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (m/km)	2.70	2.59	90.00	93.22	Pass
Permanent deformation - total pavement (mm)	19.00	15.91	90.00	99.58	Pass
AC bottom-up fatigue cracking (percent)	25.00	2.12	90.00	100.00	Pass
AC thermal cracking (m/km)	189.40	57.19	90.00	100.00	Pass
AC top-down fatigue cracking (m/km)	378.80	377.79	90.00	90.06	Pass
Permanent deformation - AC only (mm)	6.00	5.47	90.00	95.28	Pass

Figure 2: Pavement ME Design Output for the Design Traffic of 250 Trucks/day.

Design Structure

Layer type	Material Type	Thickness(mm):
Flexible	Default asphalt concrete	165.0
NonStabilized	Crushed stone	225.0
NonStabilized	A-1-b	25.4
Subgrade	A-7-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.0
Air voids (%)	5.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2013 (initial)	1,000
2023 (10 years)	2,000,370
2033 (20 years)	4,438,810

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (m/km)	2.70	2.65	90.00	91.65	Pass
Permanent deformation - total pavement (mm)	19.00	18.11	90.00	94.86	Pass
AC bottom-up fatigue cracking (percent)	25.00	2.47	90.00	100.00	Pass
AC thermal cracking (m/km)	189.40	52.09	90.00	100.00	Pass
AC top-down fatigue cracking (m/km)	378.80	370.90	90.00	90.49	Pass
Permanent deformation - AC only (mm)	12.00	7.29	90.00	100.00	Pass

Distress Charts

Figure 3: Pavement ME Design Output for the Design Traffic of 500 Trucks/day.

Currently, the Pavement ME Design program has no module to analyze the frost protection requirement. In practice, additional base/subbase may be required for frost protection. It is recommended that Manitoba develop a catalogue of base/subbase thicknesses based on local experience and use the Pavement ME Design program to determine the required AC thickness.

As shown in Table 7, the design trial with 215 mm AC and 250 mm base layers produces similar results to the design with 215 mm AC, 225 mm base and 25.4 mm subbase (Table 7). Therefore, the subsequent trials and analysis use varying AC and 250 base layers (no subbase).

Effect of Subgrade and Base Strengths

Table 8 presents the summary of predictions by the Pavement ME Design program for varying subgrade and base strengths. The base (250 mm) thickness, subgrade type (high plastic clay) and the design lane traffic (1,000 trucks per day) are kept unchanged in this analysis. The base resilient modulus (Mr) inputs are: 1) 140 MPa at the optimum moisture content (OMC) and maximum dry density (subject to seasonal variation), 2) 140 MPa as annual representative (no seasonal variation) and 3) 280 MPa at the OMC and maximum dry density (subject to seasonal variation). The subgrade Mr is 30 MPa (as the annual representative) for these three trials. Then the subgrade Mr is varied as: 1) 30 MPa as the annual representative value, 2) 30 MPa at the OMC (subject to seasonal variation) and 3) 60 MPa at the OMC (subject to seasonal variation). The base and subgrade Mr at the OMC were obtained from laboratory testing.

The results presented in Table 8 show that the predicted surface distresses and roughness using the Mr at the OMC for both base and subgrade are different from that using the annual representative Mr values. Since it is difficult to accurately determine the annual representative Mr for the service life, the value at the OMC should be used for both base and subgrade.

Table 8: Effect of Subgrade and Base Strengths (Initial IRI = 1.0 m/km, PG 58-34 binder)

Layer Thicknesses (mm) AC/A Base		**215/250**	**215/250**	**215/250**	**205/250**	**215/250**	**215/250**	**210/250**
Subgrade Type		A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6
Subgrade Mr (MPa)		30*	30*	30*	30*	30**	60**	60**
Base Mr (MPa)		140*	140**	280**	280**	140**	140**	140**
Terminal IRI (m/km)	Target	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	Predicted	2.66	2.65	2.63	2.65	2.80	2.65	2.66
Total Pavement Rutting (mm)	Target	19	19	19	19	19	19	19
	Predicted	19.19	18.82	18.31	18.95	24.01	18.79	19.06
AC Bottom Up Cracking (%)	Target	25	25	25	25	25	25	25
	Predicted	2.18	1.69	1.68	1.73	2.25	1.95	2.01
AC Transverse Cracking (m/km)	Target	189.4	189.4	189.4	189.4	189.4	189.4	189.4
	Predicted	32.22	33.20	38.74	40.86	38.74	38.74	40.06
AC Top Down Cracking (m/km)	Target	378.80	378.80	378.8	378.8	378.8	378.8	378.8
	Predicted	110.40	73.68	53.18	55.46	55.33	119.98	140.96
AC Layer Rutting (mm)	Target	12	12	12	12	12	12	12
	Predicted	7.97	8.79	9.49	9.72	8.57	9.10	9.21

*Annual Representative ** Values at the OMC

The Pavement ME Design analysis also shows that predicted roughness, total rutting and fatigue cracking decreased with an increase in base layer Mr although there is an increase in AC layer rutting. The AC thickness can be reduced by 10 mm (from 215 mm to 205 mm) with an increase in base Mr from 140 MPa to 280 MPa for this design. The predicted roughness, total rutting and bottom up fatigue cracking also decreased with an increase in subgrade Mr. The possible reduction of AC thickness for the increase in subgrade Mr from 30 MPa to 60 MPa is less than 5 mm i.e., no practical change of design although there is a substantial reduction in total rutting.

The increase in base Mr from 140 MPa to 280 MPa resulted in a reduction of predicted longitudinal cracking whereas the increase in subgrade strength from 30 MPa to 60 MPa resulted in an increase of predicted longitudinal cracking. This indicates that the longitudinal cracking model is not reliable. It is recommended that Manitoba ignores the predicted longitudinal cracking at this time.

Influence of Subgrade Classification

Table 9 presents the results of Pavement ME Design trials for different types of subgrades. For the frost susceptible clayey silt (A-4) and fine sand subgrades, typical Mr (annual representatives), gradation and plasticity are used. To determine the impact of soil classification (compare between A-7-6 and A-4 subgrades), the Mr for the high plastic clay (A-7-6) subgrade is increased to 65 MPa. The traffic volume and PG grade are kept the same. For the continuous rock foundation, 100 mm base/200 mm subbase, 100 mm base/200 mm gravel overburden and 100 base/200 mm high plastic clay overburden are used because the program requires two unbound layers over the rock.

Table 9: Effect of Subgrade Types on Flexible Pavement Design (Initial IRI = 1.0 m/km, Binder = PG 58-34 and Design Traffic = 1,000 trucks per day)

Layer Thicknesses (mm) AC/A Base/C base		**215/250 /0**	**215/250 /0**	**175/250 /0**	**215/250 /0**	**125/250 /0**	**100/100 / 200**	**100/100/0**	**130/100/0**
Subgrade Type		A-7-6	A-4	A-4	A-2-4	A-2-4	Rock	200 mm Gravel /Rock	200 mm HP Clay /Rock
Subgrade Mr (MPa)		65	65	65	150	150	Default	120/ Default	30/ Default
A Base/ C base Mr (MPa)		140/ NA	140/ NA	140/ NA	140/ NA	140/ NA	140/ 120	140/NA	140/NA
Terminal IRI (m/km)	Target	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	Predicted	2.59	2.55	2.65	2.41	2.62	2.55	2.55	2.69
Total Pavement Rutting (mm)	Target	19	19	19	19	19	19	19	19
	Predicted	16.93	16.93	18.75	15.21	18.89	16.24	15.50	13.41
AC Bottom Up Cracking (%)	Target	25	25	25	25	25	25	25	25
	Predicted	1.78	1.78	2.58	1.68	21.92	24.86	24.86	23.83
AC Transverse Cracking (m/km)	Target	189.4	189.4	189.4	189.4	189.4	189.4	189.4	189.4
	Predicted	38.74	38.95	47.38	38.96	63.73	69.41	69.41	63.12
AC Top Down Cracking (m/km)	Target	378.80	378.80	378.8	378.8	378.8	378.8	378.8	378.8
	Predicted	352.52	352.08	664.13	543.50	1,469.5	1,653.97	1,653.97	2,464.27
AC Layer Rutting (mm)	Target	12	12	12	12	12	12	12	12
	Predicted	9.59	9.58	10.31	9.94	11.31	10.76	10.78	9.76

Table 9 shows that the predicted roughness and surface distresses are identical for the high plastic clay and clayey silt subgrades for the same Mr values. This indicates that the Pavement ME Design program is not able to analyse the impact of frost susceptible soils. The predicted roughness, total rutting and AC fatigue cracking decrease as the subgrade Mr increases. The AC longitudinal cracking increases abruptly with an increase in subgrade strength. A thicker AC mat is required to pass the longitudinal cracking criteria for the stronger subgrade and the rock layer. Since the longitudinal cracking model prediction is shown to be unreliable, the design analysis attempted to determine the minimum AC thicknesses that are required for the clayey silt, fine sand and the rock subgrade/foundation ignoring the longitudinal cracking failure.

Table 9 shows that 175 mm AC and 250 mm base are the minimum requirement for the clayey silt subgrade. As in the case of high plastic clay subgrade, additional base thickness exceeding 250 mm results in minimal reduction of AC thickness. Manitoba typically constructs 150 mm AC, 200 base and 650 mm subbase (or 175 mm AC, 200 mm base and 550 mm subbase) for this design traffic and subgrade. It is recommended that a design catalogue for minimum base thickness should be developed until AASHTO addresses the subgrade frost susceptibility issue.

As mentioned earlier, Manitoba increases the calculated structural number by 25% for the frost susceptible soils. A Mr value of 30 MPa provides ~25% higher SN than the SN for a Mr value of 65 MPa (for the same subgrade type) when using the AASHTO 1993 for this design traffic of 1,000 trucks per day. This additional SN corresponds to an additional 80 mm asphalt or 250 mm base using the AASHTO 1993 procedure. Figure 4 presents the Pavement ME design with a reduced Mr of 30 MPa for the clayey silt subgrade. As shown in Figure 4, an additional 50 mm AC is required (requires 265 mm instead of 215 mm) to pass all the design criteria for this traffic

(1,000 design trucks day) with an effective Mr of 30 MPa. The required additional AC is 90 mm (requires 265 mm instead of 175 mm) if the longitudinal cracking prediction is ignored. This approach appears to be interesting from Manitoba's perspective. Further investigation is required to confirm this trend.

Design Structure

Layer type	Material Type	Thickness(mm):
Flexible	Default asphalt concrete	265.0
NonStabilized	Crushed stone	250.0
Subgrade	A-4	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.0
Air voids (%)	5.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2013 (initial)	2,000
2023 (10 years)	4,000,740
2033 (20 years)	8,877,620

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (m/km)	2.70	2.60	90.00	92.99	Pass
Permanent deformation - total pavement (mm)	19.00	18.88	90.00	90.78	Pass
AC bottom-up fatigue cracking (percent)	25.00	1.62	90.00	100.00	Pass
AC thermal cracking (m/km)	189.40	30.20	90.00	100.00	Pass
AC top-down fatigue cracking (m/km)	378.80	51.72	90.00	100.00	Pass
Permanent deformation - AC only (mm)	12.00	8.03	90.00	99.97	Pass

Figure 4: Flexible Pavement ME Design with a Reduced Mr Value for the Frost Susceptible Clayey Silt Subgrade (Initial IRI = 1.0 m/km and Design Traffic = 1,000 trucks per day)

For the fine sand (A-2-4) subgrade (Table 9), the use of 125 mm AC and 250 mm base meets all criteria except the longitudinal cracking. Manitoba typically constructs 150 mm AC, 150 base and 200 mm subbase for this design traffic and subgrade. However, the selected Mr value for fine sand subgrade appears to be high if compared with the MEPDG default value. For the rock foundation, 100 mm AC, 100 mm base and 200 mm subbase are sufficient to pass all criteria, except the longitudinal cracking. For the high plastic clay overburden, 130 mm AC is required to pass all criteria, except the longitudinal cracking. Typically 150 mm AC, 100 base and 100-200 mm subbase are used for this design traffic and foundation. It should be noted again that these typical structures constructed in Manitoba are based on the ESALs calculated using the local truck factor. The Pavement ME predicted ESALs, if used in Manitoba, will result in significantly thinner structures.

Influence of Organics in Subgrade

Organics are present in many areas of Manitoba. Manitoba increases up the calculated structural number by 10 to 40% depending on the depth, thickness, severity and extent of the organic layer/content if the organic layer is to remain in place. For example, for a 100 mm or thicker continuous layer with 7 to 10% organics located within 0 to 600 mm depth below the design subgrade, the calculated SN will be bumped up by 40%. A high plastic organic clay (A-7-5) subgrade with the same gradation as an A-7-6, liquid limit of 88, plasticity index of 56, dry unit weight of 1,200 kg/m^2 (reduced by ~20% from the inorganic clay) and OMC of 40% is used to demonstrate the impact of organics. A Mr value 10 MPa is used in the Pavement ME which provides ~40% higher SN compared to the SN for a Mr value of 30 MPa in the AASHTO 1993 method. For a design traffic of 1,000 trucks per day, Manitoba uses 500 mm extra base/subbase or 150 mm extra AC for this example of organic clay subgrade and design traffic.

Table 10 provides a summary of different design scenarios using the Pavement ME Design program. As shown in the table, an extra 500 mm base has little effect in reducing the roughness and total rutting. However, an extra 95 mm AC is sufficient to pass all the design criteria for this traffic (1,000 design trucks day) and organic clay subgrade with an effective Mr of 10 MPa. The additional AC thickness requirement is substantially lower than the Manitoba's practice. Further investigation is required to confirm this requirement.

Table 10: Effect of Organic Subgrade on Flexible Pavement Design (Initial IRI = 1.0 m/km, Binder = PG 58-34, Design Traffic = 1,000 trucks per day)

Layer Thicknesses (mm) AC/A Base		**215/250**	**215/750**	**310/250**
Subgrade Type		A-7-5 (Organic)	A-7-5 (Organic)	A-7-5 (Organic)
Subgrade Mr (MPa)		10	10	10
Terminal IRI	Target (m/km)	2.7	2.7	2.7
	Predicted (m/km)	2.83	2.76	2.65
Total Pavement Rutting	Target (mm)	19	19	19
	Predicted (mm)	24.67	22.33	18.70
AC Bottom Up Cracking	Target (%)	25	25	25
	Predicted (%)	2.67	1.77	1.65
AC Transverse Cracking	Target (m/km)	189.4	189.4	189.4
	Predicted (m/km)	37.98	44.89	25.94
AC Top Down Cracking	Target (m/km)	378.80	378.80	378.80
	Predicted (m/km)	49.20	55.25	48.69
AC Layer Rutting	Target (mm)	12	12	12
	Predicted (mm)	8.14	9.58	5.97

Pavement ME Design Analysis for Rigid Pavements

Manitoba typically constructs concrete pavements on a high plastic clay subgrade. Concrete layer thickness varies from 225 mm to 275 mm which is usually placed over a 100 mm base and 200 mm subbase. Table 11 presents a summary of concrete pavement designs for the design life of 20 years using Pavement ME Design program. As shown in the table, 155 mm concrete layer is adequate for the design traffic of 250 and 500 trucks per day. For the design traffic of 1,000 trucks per day, 165 mm concrete is required. Further design trials indicated that 155 mm concrete is good enough for 30 years for the design traffic of 500 trucks per day. A 170 mm thick concrete pavement is required for a design life of 30 years with the design traffic of 1,000 trucks per day. An extra 10-15 mm concrete is required for doubled design traffic i.e., for the increased design traffic from 500 to 1,000 trucks per day. The design thickness and variation for varied traffic and design life are significantly lower than Manitoba's practices. Field validation is required to confirm such low thickness requirements and that the practical minimum (e.g., 200 mm) thickness will work for all Manitoba traffic conditions. Manitoba does not have concrete pavements with such a minimal thickness.

Table 11: Summary of Rigid Pavement ME Design Outputs for Different Truck Volumes (Initial IRI = 1.0 m/km, Base = 100 mm, Subbase = 200 mm and Subgrade = High Plastic Clay)

Design AADTT		250	500	1000
Layer thicknesses (mm) PCC		**155**	**155**	**165**
Pavement ME ESALs x 10^6		**2.96**	**5.91**	**11.82**
Typical Concrete Thickness for Pavement ME Calculated ESALs (mm) at 80% Reliability		**180**	**200**	**225**
Terminal IRI	Target (m/km)	2.7	2.7	2.7
	Predicted (m/km)	1.54	1.59	1.59
	Acceptance	Pass	Pass	Pass
PCC Transverse Cracking	Target (% Slabs)	15	15	15
	Predicted (% Slabs)	6.78	10.47	11.18
	Acceptance	Pass	Pass	Pass
Mean Joint Faulting	Target (mm)	3	3	3
	Predicted (mm)	0.51	0.53	0.53
	Acceptance	Pass	Pass	Pass

Pavement ME Design Analysis for Composite Pavements

Manitoba typically constructs 100 mm AC over a concrete layer which varies depending on the traffic. Figure 5 presents the Pavement ME Design output for a composite pavement for a design life of 20 years and for the design traffic of 1,000 trucks per day. As shown in the figure, a 100 mm AC layer over a 150 mm concrete layer is sufficient to pass all the design criteria. The required AC thickness matches the expectation or Manitoba's practice. However, as stated earlier, the concrete layer thickness requires validation with the field performance data.

Design Structure

Layer type	Material Type	Thickness(mm):
Flexible	Default asphalt concrete	100.0
PCC	JPCP Default	150.0
NonStabilized	Crushed stone	100.0
NonStabilized	A-1-b	200.0
Subgrade	A-7-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.0
Air voids (%)	5.0

Traffic

Age (year)	Heavy Truck (cumulative
2013 (initial)	2,000
2023 (10 years)	4,000,740
2033 (20 years)	8,877,620

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (m/km)	2.70	1.98	90.00	99.87	Pass
Permanent deformation - total pavement (mm)	19.00	7.22	90.00	100.00	Pass
Total Cracking (Reflective + Alligator) (percent)	15	6.63	-	-	Pass
AC thermal cracking (m/km)	189.40	99.22	90.00	100.00	Pass
JPCP transverse cracking (percent slabs)	15.00	3.83	90.00	100.00	Pass
AC bottom-up fatigue cracking (percent)	25.00	1.45	90.00	100.00	Pass
AC top-down fatigue cracking (m/km)	378.80	48.64	90.00	100.00	Pass
Permanent deformation - AC only (mm)	12.00	7.22	90.00	100.00	Pass

Figure 5: Composite Pavement ME Design Output (Initial IRI = 1.0 m/km)

Conclusions and Recommendations

This paper presents an analysis of pavement design using the AASHTOWare Pavement ME Design program to demonstrate the practical sensitivity of different input parameters. Varying design traffic volumes, asphalt, base and subbase layer thicknesses, base and subgrade strengths and asphalt binder types are used in this analysis. Manitoba's traditional pavement designs are also presented to compare with Pavement ME designs and demonstrate practical issues and prospects. Examples of concrete and composite pavement designs are also presented to examine the practicality of the results. Possible or recommended approaches to handle these issues and the needs for local calibration are also discussed. The main conclusions are summarized below:

1. The required AC thickness using the Pavement ME design is significantly higher than Manitoba's current practice. The required AC layer thickness increases substantially for design traffic volumes exceeding 250 trucks per day if the AC layer rutting is limited to 6 mm. Since the total rutting is used as one of the criteria to trigger maintenance or rehabilitation in Manitoba, it is recommended that AC rutting limit be increased to 12 mm to be more practical in terms of AC thickness requirement.

2. For an increase of design traffic from 250 to 500 and from 500 to 1,000 trucks per day, an additional 20 mm and 65 mm, respectively, of asphalt are required given that AC layer rutting is limited to 12 mm instead of 6 mm. These required additional asphalt thicknesses cannot be replaced with any amount of base or subbase. These variations and limitations do not agree with Manitoba's practice.

   A local calibration of the Pavement ME Design models may be required to confirm whether the thicker AC layers or additional AC thickness are warranted for Manitoba conditions.

3. No unusual trend of predicted distresses for a change of AC binder grade is observed. For the design traffic of 1,000 trucks per day and a high plastic clay subgrade, the AC layer thickness can be reduced by 20 mm by using the PG 64-34 AC binder instead of the PG 58-34 binder. A cost comparison of these two alternatives is required to select the appropriate option.

4. The total rutting is shown to decrease with an increase in base thickness as expected. However, the predicted total rutting is shown to increase with an increase in subbase layer thickness which is unexpected. The bottom up fatigue cracking decreases while the predicted longitudinal (AC top down) cracking, transverse cracking and AC layer rutting increase with an increase in base or subbase thickness as expected.

5. The Pavement ME design examples presented in this paper showed that 5 mm AC can be replaced with 200 mm base up to a maximum base thickness of 250 mm. The base layer exceeding 250 mm is shown to produce no practical influence on the required asphalt thickness. The subbase layer is shown to have no practical influence in reducing the required asphalt thickness. However, extra base/subbase may be required for frost protection. It is recommended that Manitoba develop a catalogue of base/subbase

thicknesses based on the local experience and use the Pavement ME Design program to determine the required AC layer thickness for different subgrade and traffic conditions.

6. The longitudinal cracking model is found to be unreliable. It is recommended that Manitoba ignore the predicted longitudinal cracking model at this time.

7. The resilient modulii of base and subgrade are shown to produce significant influences on the predicted distresses and roughness. Since it is difficult to accurately determine annual representative Mr, values at the OMC should be used for the base, subbase and subgrade.

8. A design example presented in this paper showed that the AC thickness can be reduced by 10 mm with an increase in base Mr from 140 MPa to 280 MPa.

9. The Pavement ME Design program is not able to address the frost susceptibility. Ignoring the AC longitudinal cracking and frost susceptibility, Pavement ME designs are shown to be reasonable provided that the AC layer rutting is limited to 12 mm. It is recommended that a design catalogue for minimum base/subbase thicknesses be developed until AASHTO address the subgrade frost susceptibility issue.

10. For continuous bedrock, 100 mm base and 100-200 mm subbase layer will provide a reasonable AC thickness design by ignoring the AC longitudinal cracking and limiting the AC layer rutting to 12 mm.

11. For a subgrade containing organics, the extra AC layer thickness requirement is found to be significantly lower than Manitoba's Practice. However, extra base thickness showed no influence in the AC thickness requirement.

12. For concrete and composite pavements, the required concrete thicknesses are shown to be significantly lower than Manitoba's current practice. Such thickness requirements should be verified using local performance data and experience.

References

1. Baus, R. L. and Stires, N. R., Mechanistic-Empirical Pavement Design Guide Implementation, Department of Civil and Environmental Engineering, University of South Carolina, Report No. GT06-10, July 2010.
2. Fernando, F. G., Oh, J., and Ryu, D., Phase I of MEPDG Program Implementation in Florida, Report D04491/PR15281-1, Texas Transportation Institute, College Station, TX, 2007.
3. Schwartz, C., Implementation of the NCHRP 1-37A Design Guide, Report No. SP0077B41, Maryland State Highway Administration, Lutherville, MD, 2007.
4. Kim, R. and Muthadi, N., Implementation Plan for the New Mechanistic- Empirical Pavement Design Guide, NCDOT Project 2005-28, North Carolina State University, Raleigh, NC, 2007.
5. Ceylan1, H., Coree, B., and Gopalakrishnan, K., Evaluation of the Mechanistic - Empirical Pavement Design Guide for Implementation in Iowa, The Baltic Journal of Road and Bridge Engineering, Vol. 4(1):12, 2009.

6. Ali, O, Evaluation of the Mechanistic Empirical Pavement Design Guide (NCHRP 1-37A), Report No. RR- 216, National Research Council (NRC), Ottawa, ON, Sept. 2005.
7. He, W., Juhasz, M., Crockett, J. and Lakkavali, V., Evaluation of Darwin-ME Pavement Rutting Prediction Models Using Data from Alberta's Pavement Management Systems, The 2011 Conference of the Transportation Association of Canada, Edmonton, Alberta, 2011.
8. Bayomy, F., El Badawy, S. and Awed, A., Implementation of the MEPDG for Flexible Pavements in Idaho, Report # KLK 557, NIATT, University of Idaho, 2012.
9. Velasquez, R., Hoegh, K., Yut, I., Funk, N., Cochran, G., Marasteanu, M., and Khazanovich, L., Implementation of the MEPDG for New and Rehabilitated Pavement Structures for Design of Concrete and Asphalt Pavements in Minnesota, Report MN/RC 2009-06, Minnesota Department of Transportation, St. Paul, MN, 2009.
10. Montana Department of Transportation, Performance Prediction Models, http://mdt.mt.gov/research/docs/research_proj/pave_model/final_presentation.pdf, 2007.
11. Ceylan, H., Sensitivity Evaluation of the MEPDG for Rigid Pavements, Transportation Research Board, Webinar, February 07, 2013.
12. Schwartz, C. W., Li, R., Kim, S. H., Ceylan, H., Gopalakrishnan, K., Sensitivity Evaluation of MEPDG Performance Prediction, Final Report NCHRP Project 1-47, Transportation Research Board, December 2011.