Coloured Asphalt Bus Rapid Transit Lanes in The Regional Municipality of York: Integrating Laboratory Performance Testing into Sustainable Pavement Asset Management

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ABSTRACT:

Located north of Toronto, Ontario, The Regional Municipality of York, the sixth largest municipality in Canada, is a thriving community and home to a well-established service sector. York Region's population is expected to grow from 1.1 million in 2013 to 1.8 million in 2041. With more people coming to the Region every year, rapid transit projects provide significant benefits. Bus Rapid Transit (BRT) lanes are built or being built along the three most heavily travelled roads in York Region: Yonge Street, Highway 7 and Davis Drive. To improve the level of safety through enhanced visibility and help residents and motorists easily understand this new transit system and follow the right-of-way, York Region uses coloured asphalt pavement design for its dedicated BRT lanes.

York Region and Metrolinx retained the Centre for Pavement and Transportation Technology (CPATT), located at the University of Waterloo, to identify innovative and sustainable future preservation and maintenance solutions to ensure durability and high performance throughout the material's life cycle.

This paper highlights background information on how coloured asphalt can be used to achieve various technical and social benefits in a number of transportation applications. This paper also highlights the pavement performance results obtained from conducting material testing at the state-of-the-art pavement laboratory at CPATT. These results were used to develop performance prediction models describing the expected path of deterioration over time. Materials under evaluation included those collected during paving operations.

1. INTRODUCTION

Located north of Toronto, the Regional Municipality of York is the sixth largest municipality in Canada with rapid population growth of 1.1 million in 2013 to 1.8 million in 2041. With more people moving to this community, York Region and Metrolinx are proactively promoting efficient transportation. To meet its rapidly increasing need for public transit, York Region has used a coloured asphalt mixture as a surface course for its dedicated Bus Rapid Transit (BRT) lanes as shown in Figure 1 along the three most heavily travelled roads in the Region: Yonge Street, Highway 7 and Davis Drive. The coloured pavement was implemented to improve the level of safety through enhanced visibility and help residents and motorists easily understand this new transit system and follow the right-of-way. The BRT lanes are located along the three most heavily travelled roads in the Region: Yonge Street, Highway 7 and Davis Drive.

Figure 1. A Section of Highway 7 located in York Region, Ontario (Photo Taken on September 2015)

1.1.Background

Denoting dedicated bus lanes in the right-of-way (ROW) has been implemented globally and allows buses to move out of congestion, enabling travellers to get around the busiest corridors faster by using transit. This solution is known as Bus Rapid Transit (BRT) and endeavours to create a more vibrant, livable and sustainable urban development by providing a pedestrian and transit oriented real estate development. Many metropolitan areas around the world have included coloured pavements in their infrastructure to denote dedicated lanes for buses and bicycles. These cities, such as New York, London, Ottawa, Sydney and Auckland, all have colouring applied to all or portions of their dedicated bus lanes [1]. Transit benefits of these installations are well documented in terms of vehicle violation of the lanes, however structural and functional performance has not been investigated systematically and data are scarcer.

Developing a BRT system easily understood by ROW users is necessary in order to maintain a high level of safety. This is traditionally accomplished through signage and lane markings, however the most effective solution is through using a different surface colour for designated lanes. Lane colouring can be accomplished through one of three methods: painting, applying a coloured thermoplastic or laying a thin wearing course of Coloured Hot Mix Asphalt (CHMA).

Painting and applying a coloured thermoplastic on the surface has been popular due to the lower cost of implementation. However, there are still challenges associated with using these surfacing options such as reported by [2]: (1) wearing after winter maintenance activities such as plowing and salting, (2) excessive wearing due to friction caused by buses stopping and starting, (3) wearing due to prolonged heat exposure from bus engines, as shown in Figure 2.

Figure 2. Effect of stopping/starting of buses and engine heat exposure [2]

One challenge is finding scientific literature on the usage of colouring pigment in HMA as an alternative aforementioned colouring methods, as all major chemical suppliers have their own proprietary products. The products tend to be either synthetic binders or pigment solutions. In addition, the usage of these materials in Canada has been very limited and there is no understanding on long-term behaviour and performance.

1.1 Research Scope and Objectives

This research is carried out in partnership between York Region and Metrolinx, and collaboration with the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo to gather performance testing results to develop performance prediction models for BRT lanes. These models are expected to provide better understanding of the in-situ materials' performance and its long-term behaviour that can be used as inputs into the overall asset management plan for BRT lanes as conceptually illustrated in Figure 3.

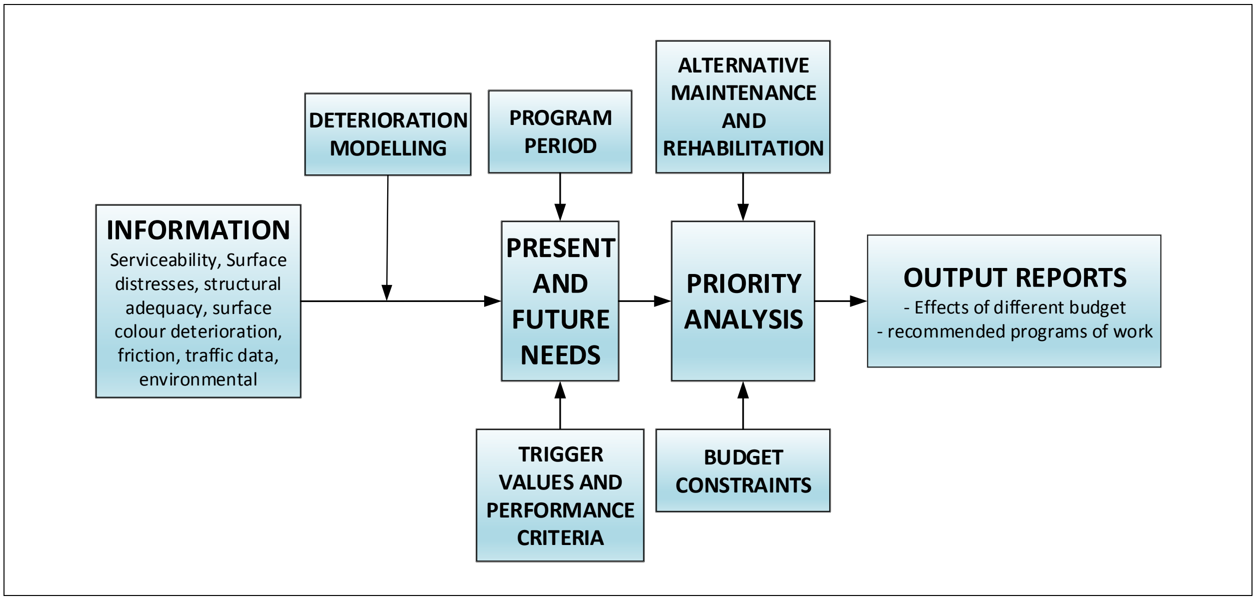


Figure 3. Conceptual Framework of Pavement Management [3]

2. Deterioration Modelling Development

A variety of models and approaches exist that can be applied at different levels of management including: strategic level, network level, and project level [3]. There are number of deterioration modelling options available to road agencies ranging from purely empirical to fairly sophistic Mechanistic-Empirical (M-E), such as the AASHTO's Mechanistic-Empirical Pavement Design Guide (MEPDG). All these deterioration modelling options, however, present a complex process of identifying and characterizing the independent variables and factors that can affect deterioration such as those graphically illustrated in Figure 4. Also shown, by dotted lines, is the interaction of these factors that can further introduce more challenges in deterioration modelling.

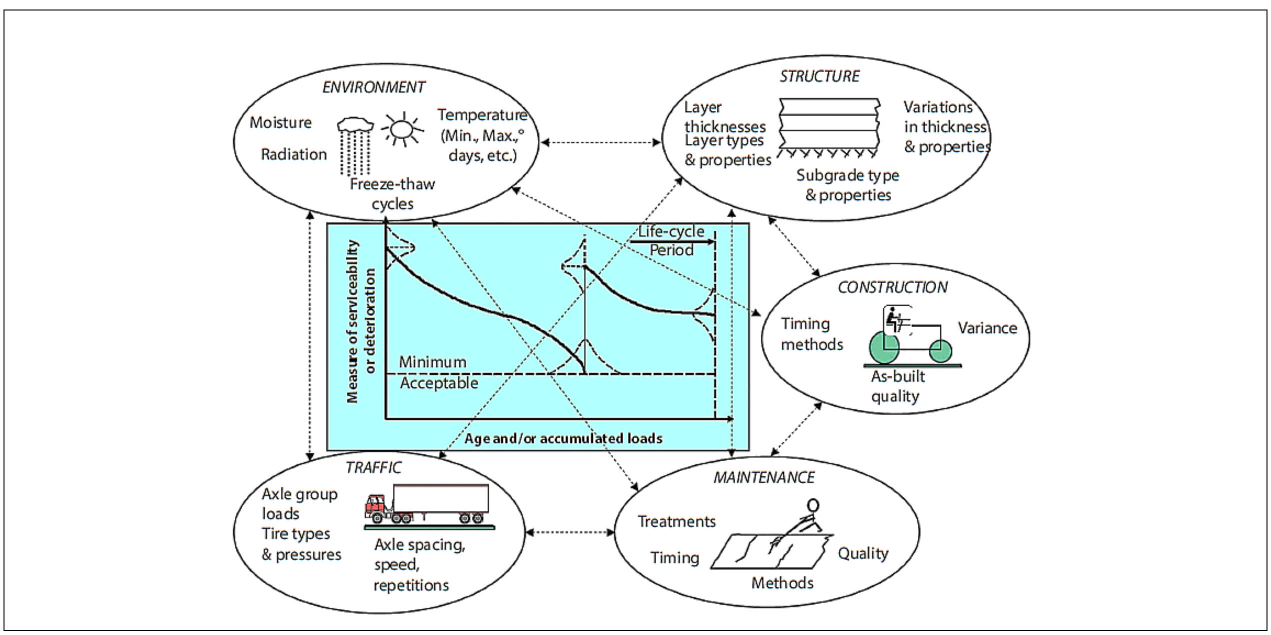


Figure 4. Factors Influencing Pavement Performance [3]

The most comprehensive deterioration model can be developed by using the Mechanistic-Empirical Pavement Design Guide (MEPDG) procedure illustrated in Figure 5 [4]. Developed in 2002 under the National Cooperative Highway Research Program (NCHRP) Project 1-37A [5] was introduced to address the limitations of the AASHTO 1993 Empirical method. The MEPDG uses state-of-the-practice mechanistic models to determine the pavement responses at critical locations within the pavement structure. The responses are then used with empirical transfer functions to predict deterioration over the service life at a specified reliability. Predicted distresses include: (1) International Roughness Index (IRI) to describe "smoothness", (2) permanent deformation in both asphalt bound and granular layers, (3) fatigue cracking in forms of bottom-up and top-down cracks, and (5) thermal cracking.

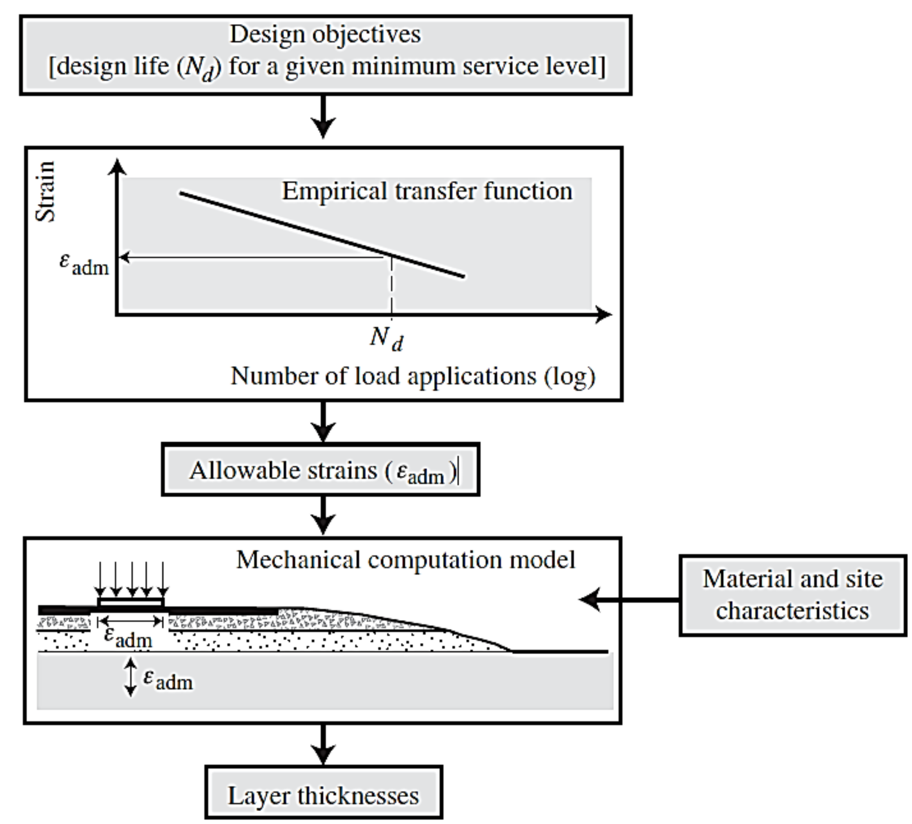


Figure 5. Principle of Mechanistic-Empirical (M-E) Methods [4]

Depending on the availability of aforementioned inputs and importance of the project, MEPDG is capable of performing the deterioration modeling in three levels such as:

- **Level 1:** the most accurate and reliable of all levels. It is commonly used for the most heavily trafficked projects where user safety and economic consequences of early pavement failures are severe.
- **Level 2:** the inputs are based on limited testing and/or are selected from the values provided by the agency. Such values are usually estimated empirically.
- **Level 3:** the least accurate of all levels. Inputs are user selected default values.

3. CASE STUDY

In order to develop deterioration models, an as-built pavement structure located on Highway 7 was selected to develop prediction models for a design life of 50 years. The pavement structure comprised of a total asphalt thickness of 210 mm, underlain by 200 mm of Granular Base and 600 mm of Granular Subbase. The asphalt layer was separated into three layers with a 40 mm surface course, 100 mm binder course, and a 70 mm Rich Bottom Mix (RBM). All asphalt mixtures were designed to meet the requirements of Superpave mixture design method. As-built material properties for asphalt layers used in the analysis are given in Table 1. It should be noted that along Highway 7, two different pigmented mixtures were placed as surface course, referred to as A and B in this paper. In this study, a trial mixture produced in the plant was also included (referred to as C). Mixture C was included to evaluate if there could be any long-term performance improvements by adding fiber additives.

Table 1. Asphalt Layers Inputs

Property		Surface Course Alternatives			Binder Course
	Sieve Size (mm)	A	B	C	BC
Gradation (% Passing)	19.0	100	100	100	95.9
	12.5	83.4	79.6	79.6	70.8
	2.36	56.2	55.0	55.0	53.2
	0.075	5.8	3.0	3.0	4.2
Asphalt cement type		PG 70-28P	PG 64-34	PG 64-34	PG 64-28P
Unit weight (kgf/m^3)		2520.0	2520.0	2520.0	2460.0
Effective binder content (% by Volume)		10.17	10.3	10.3	10.1
Air voids (%)		3.9	3.9	4.0	4.0

The granular base and subbase materials were comprised of crushed stones with as-built material properties given in Table 2.

Table 2. Granular Base and Subbase Inputs

Property	Sieve Size (mm)	Granular A	Granular B-I
Gradation (% Passing)	25.0	100	75.0
	19.0	92.5	-
	9.5	61.5	-
	4.75	45.0	60.0
	1.18	27.5	-
	0.300	13.5	33.5
	0.075	5.0	4.0
Maximum dry unit weight (kgf/m^3)		2038.2	2012.4
Liquid Limit (LL)		6.0	11.0
Plasticity Index (PI)		0.0	0.0
Modulus (MPa)		250.0	150.0

The subgrade soils used in the analysis was assumed to consist of clayey gravels and sands with the resilient modulus for this subgrade type was selected as 30 MPa.

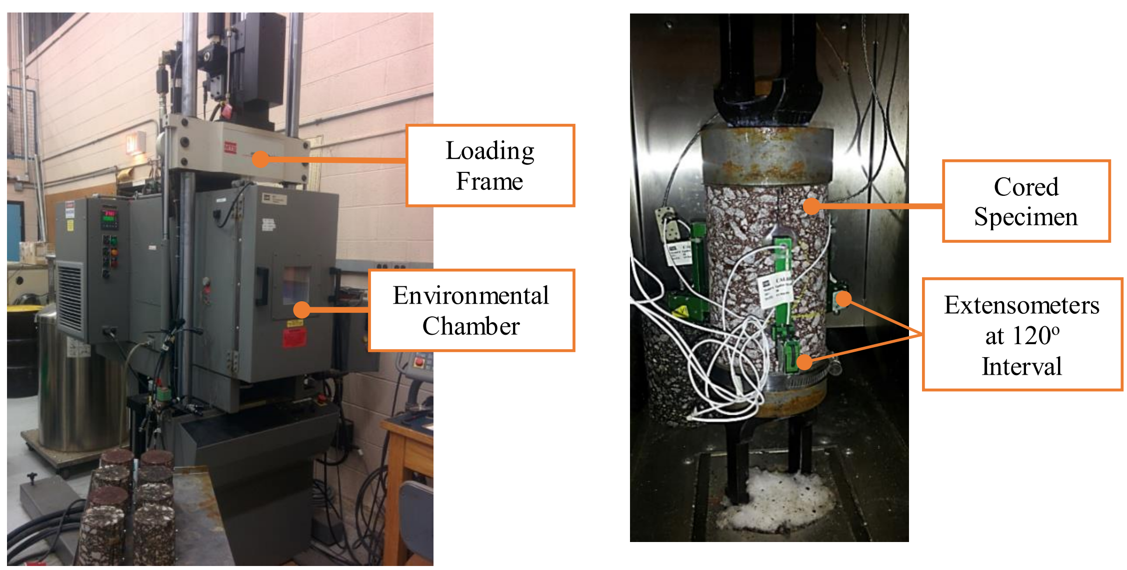
3.1.1. Laboratory Testing of asphalt Mixtures

To increase the reliability of the analysis and perform "Level 1" deterioration modelling, dynamic modulus and binder rheological testing were performed. A brief description of each test is provided in the following sections. Materials tested were those collected during paving sections of Highway 7 BRT lanes.

Asphalt Mixture Dynamic Modulus

Dynamic modulus is abbreviated as E* (pronounced as E-star), where E for elastic modulus and star for dynamic. E* is a complex number that is used to relate stress to strain for linear visco-elastic materials, like asphalt mixtures. E* is one of the material properties that is used in Pavement M-E software to help understanding the effect of using different materials on long-term performance.

For this analysis, dynamic modulus testing was performed by employing a test setup at CPATT as shown in Figure 6 on specimens each measuring 100 mm in diameter and 150 mm in height. Specimens were cored and cut from the middle of a Superpave Gyratory Compacted specimen measuring150 mm in diameter by 180 mm in height, as illustrated in Figure 7. The cored specimens were tested at six loading frequencies (0.1, 0.5, 1, 5, 10 and 25 Hz) and five different temperatures (-10, 4, 21, 37 and 54 degree Celsius) to obtain E* in accordance with AASHTO TP 62-07 "Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures" [6]. Measurements obtain from this test were used as a material property for surface layer and binder course.



(a) 810 MTS loading frame and 651 MTS environmental chamber

(b) Inside view of the environmental chamber

Figure 6. CPATT Dynamic modulus Test Setup

(a) Coring a SGC specimen

(b) Cored and saw-cut dynamic modulus Specimen

Figure 7. Preparing a Dynamic Modulus Testing Specimen

__Asphalt Binder Rheological Testing__

Rheological properties of asphalt binders were evaluated in terms of binder's stiffness (G-star) and phase angle (alpha). These material inputs were measured by using a Dynamic Shear Rheometer (DSR) in accordance with AASHTO T 315-12, "Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)" [7]. For this test, testing was performed at four temperatures (52, 58, 64, 70 degree Celsius).

3.2.Traffic Characteristics

The selected BRT section is a two-lane road. An initial two-way Annual Average Daily Truck Traffic (AADTT) of 120 was used, with 100 percent of buses in the design lane. Operational vehicle speed in the analysis was selected as 60 kilometres per hour. A linear traffic growth of 1.0 percent was used for analysis, with the bus distribution given in Table 3. It should be noted that other vehicle classes (e.g. light passenger vehicles) were ignored in the analysis. The traffic inputs resulted in 3.20 million Equivalent Single Axle Loads (ESALs).

Table 3. Traffic Inputs

Viva Bus Type		Equivalent MEPDG Vehicle class		Distribution
	Van Hool 40-ft A-330	4	Two or three axle buses	40%
	Van Hool 60-ft Articulated AG-300	8	Four or less axle single trailer trucks	60%

The bus distributions were used in conjunction with axle load weights provided by the manufacturer (Table 4) when buses are operating laden (all passengers seated).

Table 4. Viva Buses Axle Load Inputs With All Passenger Seated

Bus Type	Axle load (kg)			
	Front Axle (Single Tire Single Axle)	Rear Axle (Dual Tire Single Axle)	Tag Axle (Dual Tire Single Axle)	Total
A-330	4846	11501	-	16,347
AG-300	6850	9625	6485	22,960

3.3.Climate Inputs

In the Pavement M-E software, climate inputs are incorporated into the performance prediction analysis through the Enhanced Integrated Climatic Model (EICM) which is a product of a computer program that calculates the effect of changes in moisture within the pavement materials over time and depth combined with the effect of freezing and thawing on the pavement response. Inputs such as latitude, longitude, elevation, and depth of water table for a selected weather "station" are required in order to generate climatic file. For the analysis, data from the Lester B. Pearson Airport in Toronto were selected to generate the climate conditions presented in Table 5.

Table 5. Annual Climate Inputs

Parameter	Annual Statistics
Mean annual air temperature (deg.C)	8.1
Mean annual precipitation (mm)	825.2
Freezing index (deg.C – days)	1028.5
Average Number of freeze-thaw cycles	77.6

3.4.Terminal Service Levels

In the MEPDG, structural adequacy is evaluated by the ability of a design to meet sets of targeted threshold (also known as Terminal Service Levels). For this study following thresholds at 90% reliability were retrieved from the Ministry of Transportation Ontario recommended inputs [8].

Table 6. Distress Prediction Target Values

Performance Criteria	Targeted at 90% reliability
Permanent Deformation - Total Pavement (mm)	19.00
AC Bottom-up Fatigue Cracking (%)	25.00
AC Thermal Fracture (m/km)	189.4
AC Top-down Fatigue Cracking (m/km)	378.8
Permanent Deformation – AC only (mm)	6.00

4. DISCUSSION OF RESULTS

The detailed outputs of MPEDG for all are presented in Table 7, while Figure 8 to 9 are the graphical damage accumulation over the service life.

Table 7. MEPDG Output Table

Performance Criteria	Surface Coloured Mixture Type		
	A	**B**	**C**
Terminal IRI (m/km)	4.13	4.11	4.12
Permanent Deformation (total Pavement, mm)	9.36	8.48	8.94
AC Bottom-up Fatigue Cracking (%)	1.45	1.45	1.45
AC Thermal Fracture (m/km)	5.15	5.15	5.15
AC Top-down Fatigue Cracking (m/km)	48.63	48.62	48.62
Permanent Deformation (asphalt layers AC only, mm)	0.13	0.11	0.12

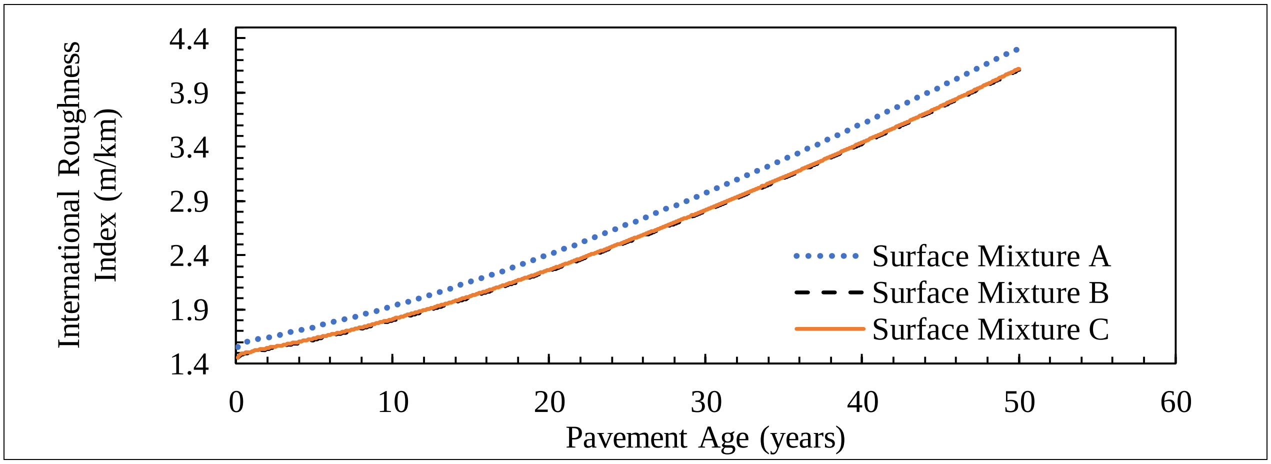


Figure 8. International Roughness Index (IRI) Deterioration Over the Pavement Life

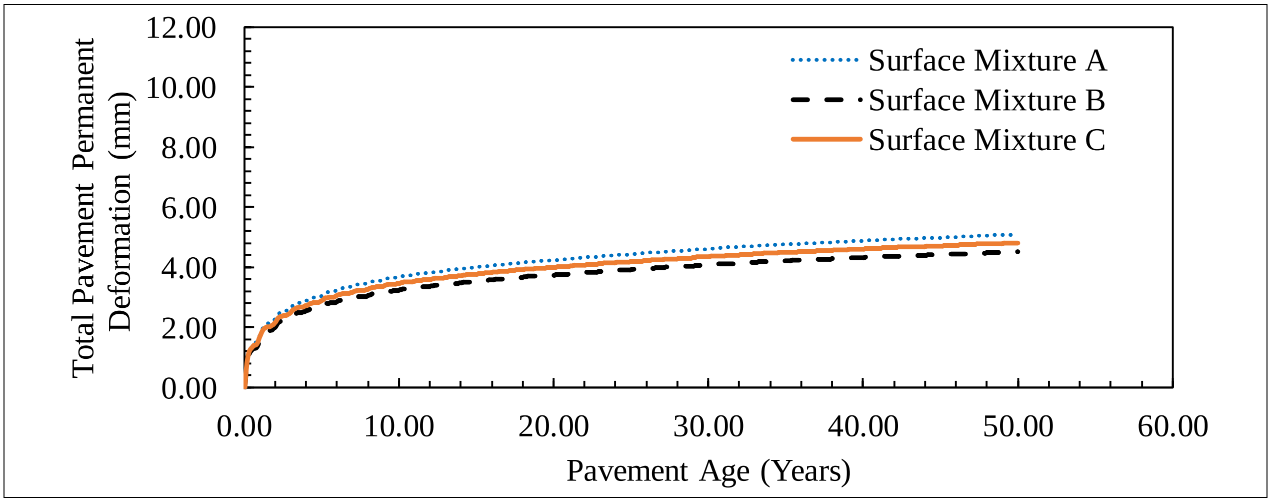


Figure 9. Total Pavement Rutting Over the Pavement Life

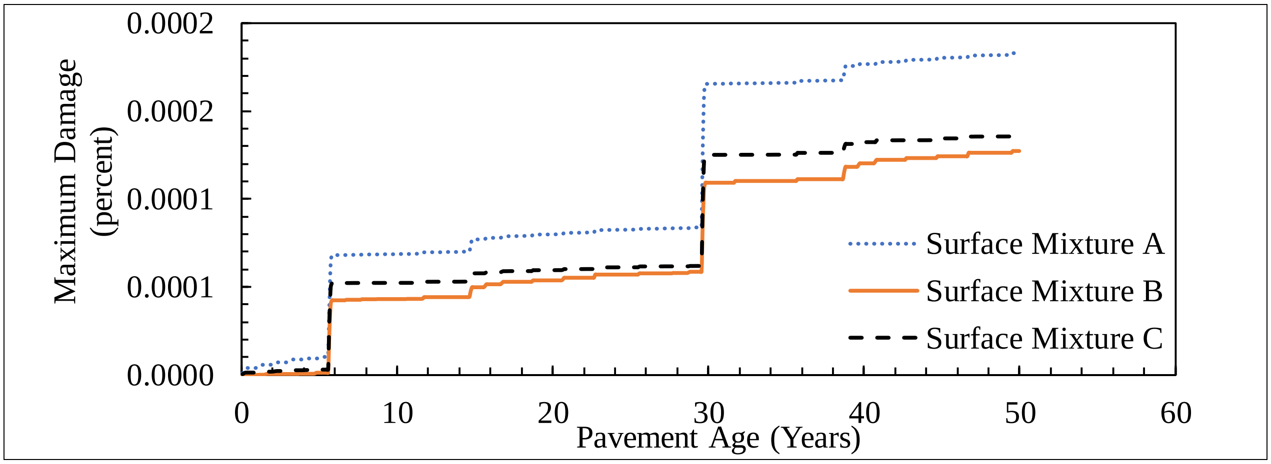


Figure 10. Damage Accumulation Over the Pavement Life

In general, the performance prediction obtained from the MEPDG did not match the expected distress propagation based on practical experience gained by pavement engineers in York Region. The inaccurate prediction stems out of the need to perform local calibration of the individual distress models for Southern Ontario. The default MEPDG models were used in this project due to unavailability of local calibration coefficients in the mean time. Although this method does not offer accurate prediction of pavement performance, the utilization of default MEPDG models is useful in comparing the performance of several pavement designs, mix designs and traffic spectrums [9, 10]. The MEPDG was able to effectively differentiate the effect of using different materials as surface courses. These predicted trends were also observed in laboratory performance testing performed at CPATT [11].

To integrate the MEPDG output in the pavement management, distresses were further combined into an overall composite index, such as Overall Condition Index (OCI) given in Equation 1.

$$OCI = a(RCI) + b(SDI) \qquad \textbf{Eq. 1}$$

where:

$OCI =$ Overall Condition Index

$RCI =$ Riding comfort index

$SDI =$ Surface distress index

$a, b =$ Weight constants

Surface Distress Index (SDI) included distresses predicted by MEPDG were grouped by using Equation 2. Since the units were not the same for all predicted distresses, Equation 3 was used to scale each distress from 0 to 100-point. In Equation 1, Riding Comfort Index was equated to International Roughness Index (IRI), which was scaled from 0 to 100-point similar to distresses used for SDI development.

$$SDI = c(PD_T) + d(FC_{TD}) + e(TC) + f(MC) \quad \textbf{Eq. 2}$$

where:

$SDI =$ Surface distress index

$PD_T =$ Total Permanent deformation of all layers (including granular layers)

$FC_{TD} =$ Fatigue cracking at the surface

$TC =$ Thermal cracking, and

$MC =$ Maximum damage resulted from Bottom-up cracks and top-down cracking at 12.7 mm downward from the surface

$c, d, e, f =$ Weight constants

$$D_i = [1 - \left(\frac{D_i}{D_m}\right)] \times 100 \quad \textbf{Eq. 3}$$

where:

$D_i =$ Distress at age i

$D_m =$ Terminal service threshold value at specified reliability (Table 6)

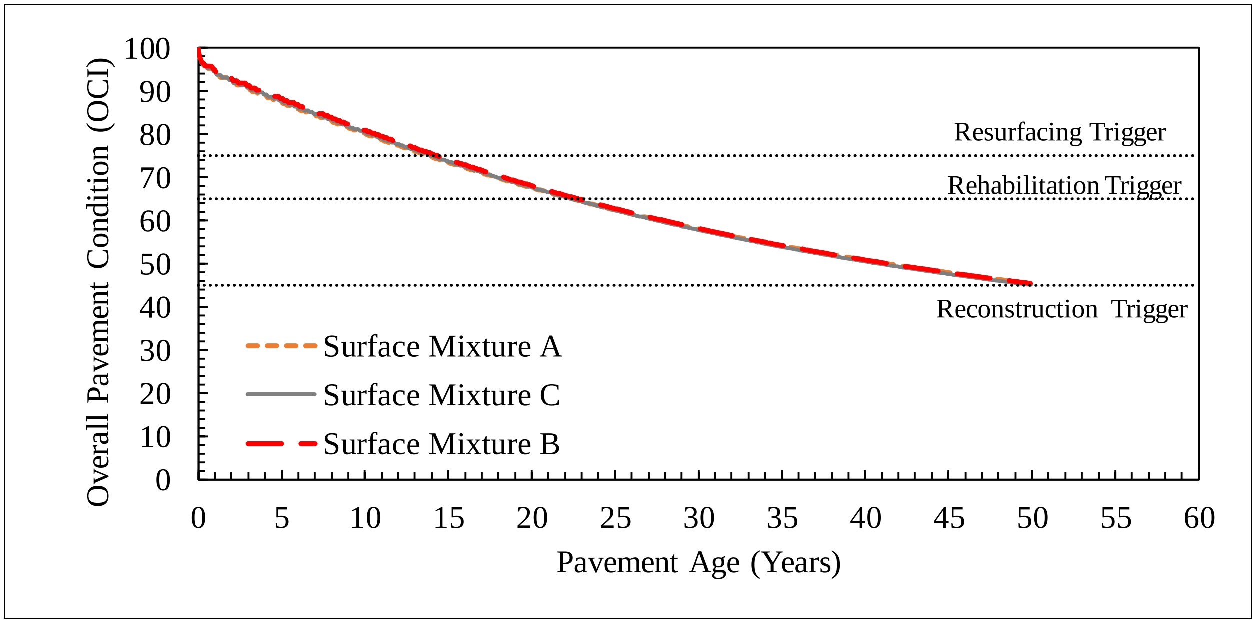


Figure 11. Overall Pavement Condition

5. CONCLUSIONS AND FUTURE STEPS

Results of this paper suggest that MEPDG can be effectively used to discriminate impact of different materials on the service life of a pavement. However, a proper calibration of the empirical transfer models are required to enable MEPDG better predict the performance. As for the next steps, York Region and Metrolinx will work closely with CPATT in locally calibrate the MEPDG by using periodic Automated Distress Survey and Manual Survey.

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