Evaluation of Darwin-ME Pavement Rutting Prediction Models Using Data from Alberta's Pavement Management System

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ABSTRACT

Research under the United States-Canada joint Strategic Highway Research Program and the Long Term Pavement Performance study has led to the development of the Mechanistic-Empirical Pavement Design Guide (M-EPDG) and its software package known as DARWin-ME^{TM}. An integral part of M-EPDG is the utilization of the predicted performance to evaluate the pavement structure being designed in its ability to carry the traffic loading in the design period. One of the key performance indicators being evaluated during structural design is the amount of permanent deformation, or rutting, in the pavement structure as a result of truck traffic.

As with any research the study results of the M-EPDG may not be readily applicable to all jurisdictions. Earlier studies done by Alberta Transportation indicated differences in pavement material models adopted in the M-EPDG compared to those found in Alberta. It is important that the various models in M-EPDG and the associated DARWin-ME™ software package be validated against conditions in Alberta.

Alberta Transportation's Pavement Management System contains decades of pavement inventory and performance data. With the accumulation of automatically collected pavement roughness and rut data since the late 1990s, the PMS database could be mined to explore trends with pavement rutting. This paper provides the summary of the analysis results on these trends, and compares them with the predicted rutting results from the DARWin-ME™. The study found that for flexible pavements with non-stabilized granular base courses, when compared to the measured pavement rutting at the network level, the amount of total pavement deformation was over predicted by the default rutting model for flexible pavements in the new construction category. However, the predictions were much closer to the measured rutting with pavements after rehabilitation. The predicted rutting appeared to be generally lower than the measured values (under predicting) for those pavements treated by milling prior to overlay, while it compared reasonably well to the measured rutting for pavements treated with straight overlays. These study results could provide insights into the local calibration of the various performance prediction models in DARWin-ME™ as the new pavement design package is studied and evaluated for its potential adoption by Alberta Transportation.

INTRODUCTION

Recent developments in the Mechanistic-Empirical Pavement Design Guide (M-EPDG) have provided many advanced tools to designing and analyzing pavement structures with its software package known as DARWin-ME™ (DARWin-ME). As with any research the study results of the M-EPDG may not be readily applicable to all jurisdictions. Alberta Transportation has been actively pursuing M-EPDG implementation. Initial work done by the department indicates differences between default truck inputs (vehicle class distribution and axle load spectra) in DARWin-ME and those from department Weigh-in-Motion scales. As well, differences between the predicted dynamic modulus values for department asphalt mixes when compared to actual dynamic modulus values have also been found *[1]*.

One of the many advanced tools in DARWin-ME is the ability to predict future pavement distress developments for designed structures. The DARWin-ME software evaluates the pavement structure in terms of the expected performance under design traffic loadings and given climatic environments. It uses the predicted performance and design performance targets to determine whether the pavement structure under evaluation meets the design reliability. The designer can then make adjustments to the pavement structure in order to satisfy the design criteria.

Since the default performance prediction models provided in DARWin-ME were globally calibrated primarily based on the Long Term Pavement Performance (LTPP) database as well as some other state and Federal agency research projects in the United States (US) *[2]*, it is important that the various models in the software be verified, calibrated and validated against conditions in Alberta. The first step in studying the models is to verify the predicted outputs against the measured pavement performance in Alberta.

The DARWin-ME software uses multiple performance targets or criteria in its analysis. These include top down and bottom up (fatigue) cracking, transverse cracking, permanent deformation (rutting), and roughness. Most of these are measured at the network level by Alberta Transportation and stored in the department's Pavement Management System (PMS). The pavement roughness and rut data are collected using automated tools, and go through multiple quality checks before they are accepted in the PMS. Currently all types of pavement cracking data are subjectively collected along with other types of pavement distress data such as ravelling and shoulder distresses. While this manually collected pavement distress data is very useful for pavement rehabilitation decisions at the network level, problems do exist in terms of the consistency and whether the sampled data is a fair representation of the pavement section. Recognizing these issues, this study is focused on the rutting distress due to the fact it is measured objectively by the department and has been since the late 1990s. This provides a good basis for model verification and calibration. Pavement roughness is not assessed at this time since it is modeled based on other distresses in M-EPDG *[2]*.

STUDY APPROACH AND OBJECTIVES

The M-EPDG pavement design method and the DARWin-ME software are being assessed by a growing number of transportation agencies in the US and Canada, and researchers in many jurisdictions have published results from earlier studies. Hoegh et al used the measured rut depths from 12 test sections located at Minnesota's cold weather road research facility (MnROAD) to evaluate predicted rut depths for a variety of pavement structures, and found the M-EPDG rutting model over predicted the total rut depth when compared to the measured values for all the test sections *[3]*. Kim et al selected 20 cases from the Iowa state PMS and tried to verify the M-EPDG predicted pavement distresses including rutting, and concluded that the rutting model over predicted for new flexible pavements and for asphalt concrete (AC) overlays on flexible pavements, but under predicted rutting for AC overlays on rigid pavements *[4]*. In another study done by Hall et al, 26 pavement sections were collected from both the LTPP test sites in the State of Arkansas and from the State's PMS to verify the M-EPDG predicted distresses with flexible pavements. The study concluded that the rutting model over predicted for flexible pavements for that state *[5]*. A common method used in all these studies is the use of measured performance from individual pavement sections in their model evaluations.

This study adopts a unique network level approach to investigating the rutting issue on provincial highways. Instead of studying the rutting performance of individual projects, the averaged rut depths of inventory sections from the network are organized in meaningful groups. These rut depths are then plotted against age for all the pavement sections in each separate group. Then, DARWin-ME analyses are performed using group-averaged parameters in terms of pavement structures, performance, traffic and climate characteristics. The pavement inventory and performance data in Alberta Transportation's PMS provided the basis for the study.

The objective of this study is to analyse the predicted rut depth from the DARWin-ME software for each of the groups, and compare the DARWin-ME outputs to the measured rut depths at the network level. The comparison results could then provide guidance for future calibration of the performance models in DARWin-ME toward its final adoption.

DEVELOPMENT OF DARWin-ME INPUTS FROM PMS

The department's PMS database contains approximately 10,000 inventory sections. These pavement sections are defined by the historical construction and rehabilitation limits. Each inventory section is homogeneous in terms of the structural layers and thicknesses, which also determine the pavement types. The provincial highway network has over 27,400 kilometres of paved sections, which consist of mostly flexible pavements with asphalt concrete (AC) surface layers. The length of rigid (concrete or composite) pavements is less than 0.2% of the paved network. The flexible pavements are further divided into subtypes with those having non-stabilized granular base courses (GBC) and those with stabilized base courses. In order to reduce the number of variables, this study is focused only on the flexible pavements with non-stabilized GBC.

Grouping of inventory pavement sections

Even by focussing on flexible pavements with GBC, the database is still populated with thousands of pavement sections. The study team considered that newly constructed pavements might have different performance patterns than pavements after rehabilitation, and that rehabilitated pavement sections that had milling might perform differently than those without milling. The inventory sections are therefore divided in three categories as (a) pavements that have not received rehabilitation after construction; (b) pavements rehabilitated using milling and overlay; and (c) pavements rehabilitated without milling (i.e. straight overlays). Additionally, since the highway network is spread over a wide geographical area, to facilitate the climatic inputs using DARWin-ME, further groupings were developed according to the department's district locations that cover the whole Province.

A total of 14 pavement groups resulted after these steps – five under the new construction category, four in the rehabilitation with milling category and five in the straight overlay category. The number of homogeneous inventory sections included in these groups range from approximately 100 to 1,400. As an example for one of the 14 groups, Figure 1 shows a map of the Lethbridge district. The numbers in the map show locations of the nearby weather stations with historical climate data records assembled for use in DARWin-ME. The pavement sections under study are plotted with highlighted lines on the same map using the department's GIS tools. The sections in this group are those that have not received rehabilitation since initial construction. Similar maps for pavement sections belonging to the "rehabilitation with milling" or to the "straight overlay" categories in the same district, as well as those in other districts, were produced separately.

Once the grouping were established, to carry the analysis using DARWin-ME a number of representative inputs had to be developed for each group, which included structural layer thicknesses, material and subgrade properties, traffic loading information, performance criteria and climate information. These are described in the following paragraphs.

Pavement structural layers

The PMS database contains detailed historical pavement as-built data with layer thicknesses, material and subgrade types, location limits and years of construction. All the inventory sections belonging to the flexible pavement with GBC were extracted from the past ten years' PMS reports. The structural attributes of the collected inventory sections include asphalt material layer thickness and GBC layer thickness. For the groups with pavement rehabilitation activities additional information was assembled. This includes pre-rehabilitation surface condition, AC overlay thickness and milling thickness, if applicable.

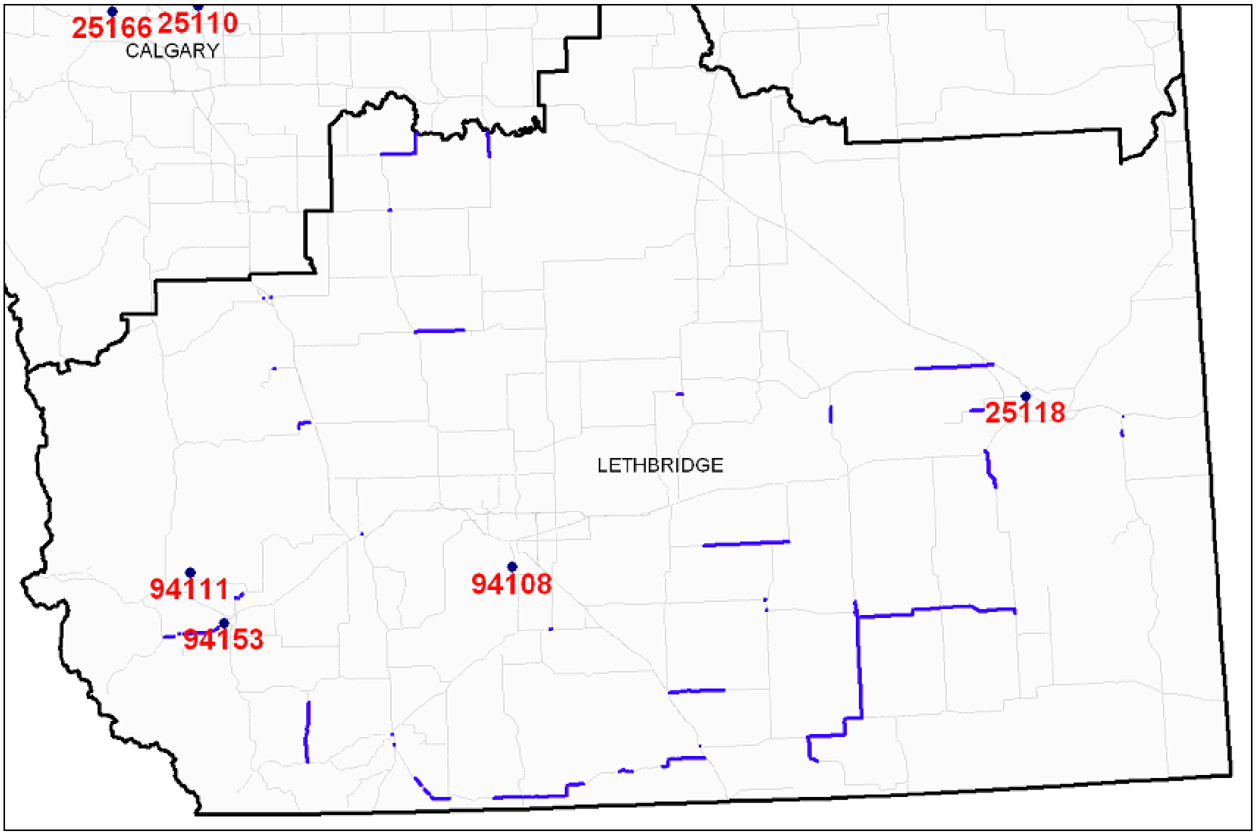

Figure 1 Pavement sections without rehabilitation in the Lethbridge district

Material and subgrade properties

The PMS stores layer material types, the AC binder types and AC mix type, but lacks detailed material properties such as aggregate gradations, dynamic modulus and volumetric data. Because Alberta Transportation has yet to fully develop its materials library with DARWin-ME, detailed materials inputs were developed from a variety of sources. Actual data from similar type projects and AC mixes was used where available (e.g. AC mix gradation, volumetrics, tensile strength values; GBC gradation). Where detailed data was not available, best estimates were made using department specification parameters and engineering judgement (e.g. for GBC resilient modulus and Atterberg limits). For subgrade materials, the PMS provides the soil types (where the soil log data is available) and the average resilient modulus - these values were used along with default soil type gradations and typical or default Atterberg limits for subgrade characterization.

Traffic loading data

The traffic volume data comes from the PMS traffic history table which contains the annual average daily traffic (AADT) and percent truck traffic data for the past 10 years. This data provides the truck volume inputs for the individual groups in the form of annual average daily truck traffic (AADTT). In addition to the traffic volume data from the PMS, the monthly adjustment factors, vehicle class and distribution factors, and axles per truck, as well as the axle load spectra, were generally provided from the closest Weigh-in-Motion station (WIM) (of note is that the department has six WIM across the provincial highway network). Since the PMS only maintains traffic volume data for the past 10 years, the previous years' data was assembled from regression analyses which enabled forecasting back to 1990 levels to cover the full 20 year design analysis period.

Performance data

Pavement rutting depth data are collected at the network level and using vehicles equipped with multiple laser sensors. The rutting data are reported at 50 metre (m) intervals along with the pavement roughness data. For this analysis, the measured rut depth and roughness were averaged over the length of the individual inventory sections. Additional inputs such as the pre-rehabilitation condition in terms of rut depth and overall pavement distress condition also had to be provided.

A summary of the representative pavement structure, traffic and performance data for the 14 analysis groups in the study are provided in Table 1. While most of the table is self-explanatory, the pre-rehabilitation condition values were based on overall pavement distress condition ratings which were then converted to DARWin-ME pavement rating input values for level three rehabilitation designs. The pre-rehabilitation condition value of two represents a pavement in good condition while a value of three represents a pavement in fair condition. Of note is that the pre-rehabilitation roughness values are provided for information only and are not actually input into DARWin-ME.

Table 1 Grouped input data for flexible pavements with granular base course from PMS

	Group #	GBC Thickness Before (mm)	AC Layer Thickness Before (mm)	Average Milling Thickness (mm)	AC layer Thickness After	Subgrade (MPa)	1990 AADT Calculated	1990 Truck %	Pre-rehab IRI (m/km)	Pre-rehab Rut Depth (mm)	Pre-rehab Condition
New Construction	28	167	N/A	N/A	104	39	238	21.1	N/A	N/A	N/A
	30	385	N/A	N/A	218	38	4473	23.3	N/A	N/A	N/A
	37	227	N/A	N/A	140	38	239	23.1	N/A	N/A	N/A
	27	268	N/A	N/A	154	40	1311	26.9	N/A	N/A	N/A
	1	382	N/A	N/A	225	38	10379	20.2	N/A	N/A	N/A
Milling Before Overlay	MILL 1	279	313	50	343	30	2792	24.2	2.65	5.8	2
	MILL 2	227	255	50	285	41	9534	18.0	2.65	5.8	2
	MILL 3	222	145	50	175	44	6149	14.6	2.65	5.8	2
	MILL 4	192	162	50	192	42	3953	20.0	2.65	5.8	2
Straight Overlay	46	220	225	0	311	30	3624	17.4	2.23	5.6	3
	5	249	184	0	280	43	5378	17.9	2.23	5.6	3
	18	217	202	0	295	39	1181	12.9	2.23	5.6	3
	44	251	125	0	199	37	906	24.7	2.23	5.6	3
	40	201	130	0	204	39	3145	13.2	2.23	5.6	3

ANALYSIS USING DARWIN-ME PAVEMENT DESIGN PACKAGE

The DARWin-ME software package requires many detailed inputs to run an analysis. Even though the PMS provided much of the information related to the pavement structure and performance, as discussed previously, detailed inputs for all materials were not readily available. Material inputs were a hybrid of actual available data, typical department values, experience and engineering judgement and were at a level three hierarchical input level. However, given that this was a network level analysis, the lack of a higher input level (i.e. level one or two) and lack of project specific data was deemed acceptable.

Pre-rehabilitation condition, rut and milling data, were also at input level three and were from PMS condition data based on multiple years' PMS reports. In general, a 20 year analysis period was adopted for all the groups, which is consistent with the department's pavement design practices. An initial pavement roughness of 0.7 m/km was selected based on average post-construction IRI records in the PMS. Performance criteria were based on typical department acceptable criteria (e.g. ten percent bottom up fatigue cracking) although these criteria were not relevant to the analysis. The design reliability levels varied from 50% to 95% according to the department's Pavement Design Manual *[6]*. However, for the purposes of this study, only the rut depth corresponding to the 50% reliability level was used.

The DARWin-ME software was shipped with historical climate data with 27 weather stations in the Province of Alberta. DARWin-ME provides a powerful tool known as virtual weather station that allows climate data from multiple weather stations to be triangulated to a specific location for climate data infilling. The detailed climate data along with the detailed axle load distribution inputs enables DARWin-ME to produce month-to-month calculations of permanent pavement deformations for the representative pavement structure in each group. For analysis purposes, virtual weather stations were created by triangulating the nearby available climate stations to the geographic centre of the district under analysis.

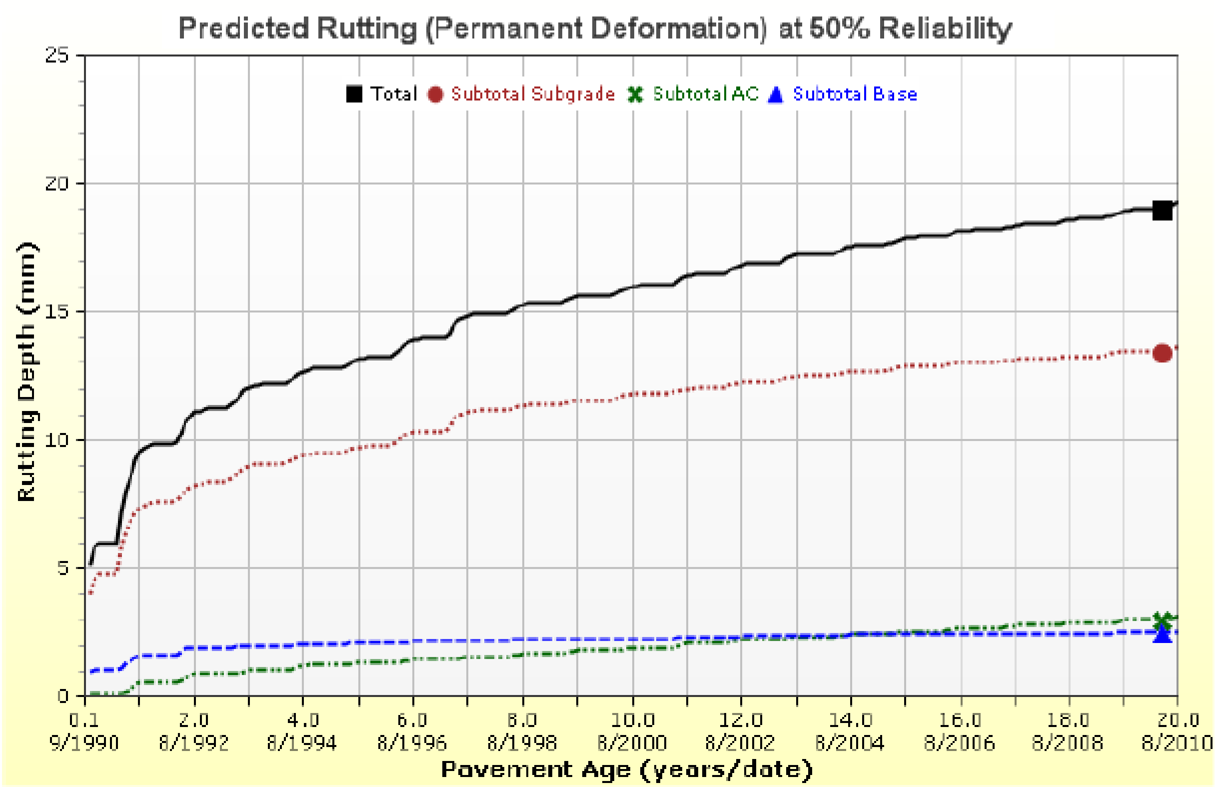

Figure 2 Sample output of predicted pavement rutting from Darwin-ME for new construction

Figure 2 shows an example of the predicted pavement rutting in which the total pavement rutting is the sum of the permanent deformations in the AC surface, granular base and subgrade.

COMPARISONS

For analyzing rutting trends with groups associated with rehabilitation, the total predicted rutting depth corresponding to the 50% reliability level was chosen to compare with the measured average rut depths in the PMS. The measured rut depth is plotted against the pavement age of the inventory sections in individual groups using Microsoft® Excel, which are then compared with the forecasted rut depth from DARWin-ME for the corresponding group plotted on the same chart. Figures 3 to 5 shows examples of the comparison results of the cases in (a) new construction, (b) milling before overlay and (c) straight overlay categories, respectively. In these figures, the scattered points represent measured rut depths from individual inventory pavement sections, and the curve with a solid line is the DARWin-ME predicted rutting progress for the representative pavement structure of the given analysis group.

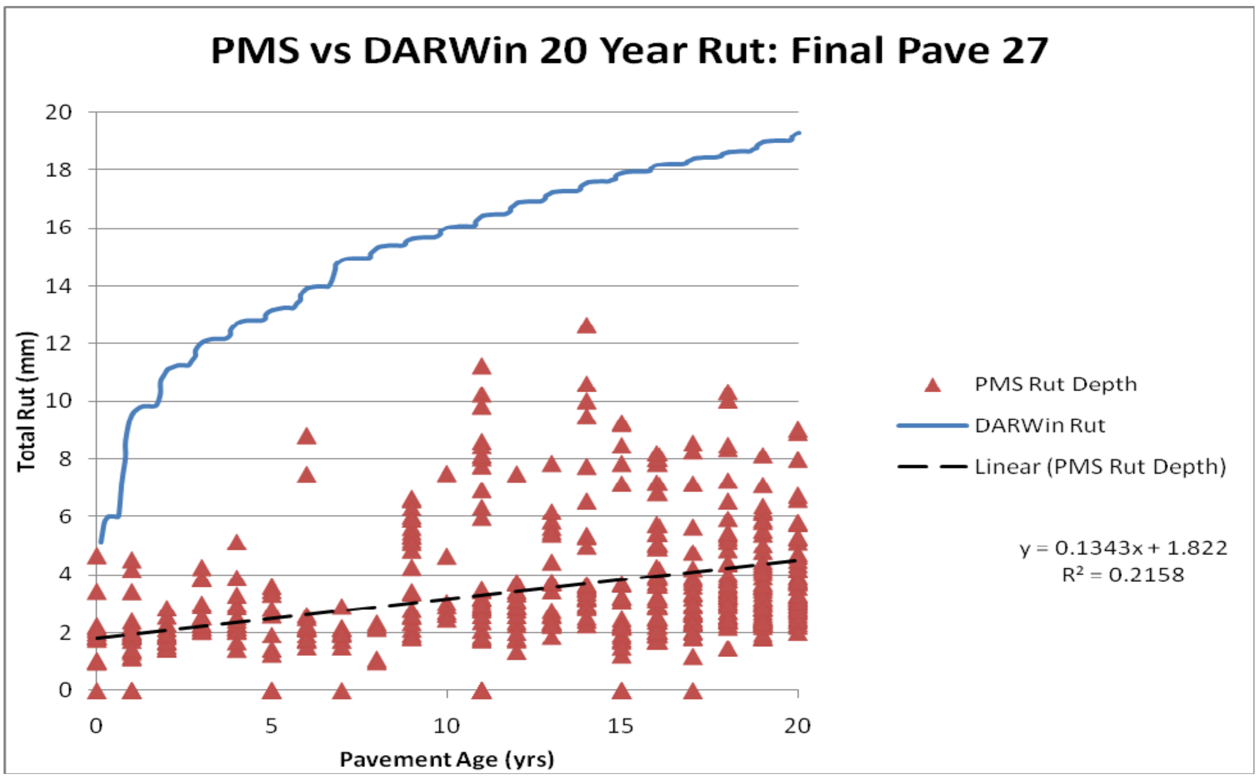

Figure 3 Predicted vs. measured total pavement rutting for new construction

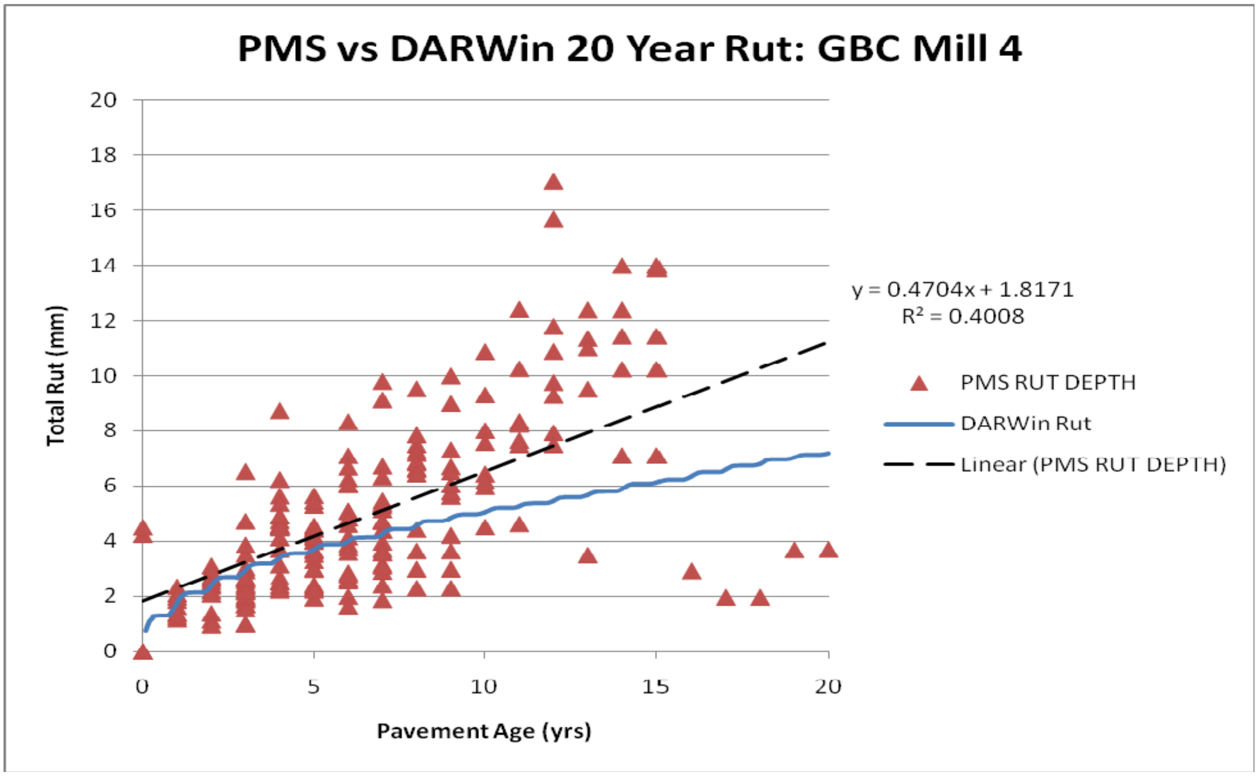

Figure 4 Predicted vs. measured total pavement rutting for milling before overlays

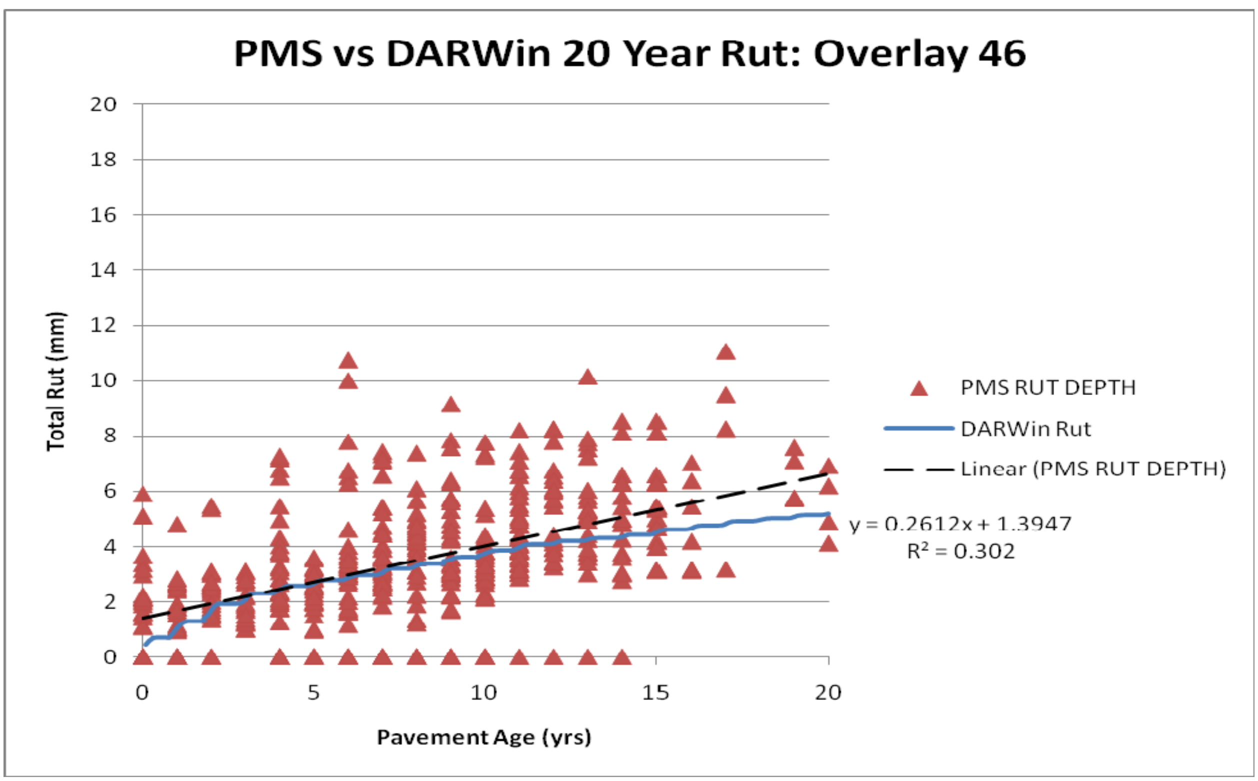

Figure 5 Predicted vs. measured total pavement rutting for straight overlays

To summarise the differences in these comparisons, regression lines (shown in dashed straight lines) are inserted in the graphs for estimating the representative measured rut depths. Both the predicted and measured rutting depths at year 20 are entered in Table 2 below.

Table 2 Grouped comparisons for predicted vs. measured total pavement rutting

	Group #	No. of Sections	Predicted Total Rutting at year 20 (mm)	Measured Total Rutting at year 20 (mm)	Difference (mm)
New Construction	28	745	16	4	12
	30	721	17	5	12
	37	649	14	4	10
	27	749	19	5	14
	1	393	20	5	15
Milling Before Overlay	MILL 1	95	3	5	-2
	MILL 2	226	6	11	-5
	MILL 3	244	8	7	1
	MILL 4	206	7	11	-4
Straight Overlay	46	504	5	7	-2
	5	1406	5	6	-1
	18	1033	3	6	-3
	44	531	6	4	2
	40	631	7	5	2

It is evident that for all the groups in the “new construction” category the DARWin-ME model over predicted the total pavement rutting by a significant amount. The amount of over predicting at year 20 could be in the range of 10 millimetres (mm) or more. Conversely, the predictions were much closer to the measured rutting with pavements after rehabilitation. The predicted rutting appeared to be generally lower than the measured values for sections treated with milling actions, with the differences to the trend line ranging from 1 to 5 mm at year 20, while it compared reasonably well to the measured rut values for pavements with straight overlays, and the differences to the trend line was 1 to 3 mm at year 20.

One can see from Figure 2 that much of the predicted rutting is occurring early in the performance period. Given that these are new construction sections, the over prediction for the new construction sections is likely due to the high early pavement age predicted rutting for base and subgrade as reported by others *[7]*.”

SUMMARY AND CONCLUSIONS

The permanent pavement deformation model in M-EPDG was studied using the pavement inventory data from Alberta Transportation’s Pavement Management System. Instead of studying performance of individual pavement sections, the study used historical structural and performance data based on network level groups to compare measured pavement rutting to the DARWin-ME predicted total pavement rutting depths. The study found that, for Alberta Transportation:

- The globally calibrated permanent deformation model in M-EPDG consistently over predicts total pavement rutting for new flexible pavements with granular base courses on the provincial highway network.
- In contrast, the M-EPDG model tends to under predict total rutting for flexible pavements after rehabilitation that involved milling, with occasional exceptions. The amount of under predicted rutting is moderate.
- The M-EPDG model had close predictions for the 20 year total rutting for flexible pavements rehabilitated with straight overlays.

It is considered that the initial findings of this study will provide insights for future calibration of the performance models in DARWin-ME for Alberta conditions. Future calibration studies should be extended to include more pavement types, fine tuning of the grouping method, additional distress models, and input parameter sensitivity analysis.

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