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EVALUATION OF PRE-OVERLAY RUT DEPTH FOR LOCAL CALIBRATION OF THE MEPDG RUTTING MODEL IN ONTARIO

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Abstract: Pre-overlay rut refers to the terminal rut depth at the end of previous life cycle of a rehabilitated flexible pavement section. Sensitivity analyses have shown that it is a very important input parameter for the rut depth prediction of rehabilitated sections in the mechanistic-empirical pavement design guide (MEPDG). However, due to limitations of historical pavement performance database, the pre-overlay rut is not always available. An uncertain pre-overlay rut would result in an inefficient local calibration, particularly when the pavement management system data are used for local calibration. This paper presents results from an investigation to estimate the pre-overlay rut depth and its effects on local calibration results based on data from Ontario's long-term pavement management system. The study showed that 7mm, the average value of terminal rut depth, can be used for the pre-overlay rut when it is unavailable for local calibration. This result overturned the 4mm assumption that the ministry staff suggested before.

1 Introduction

The need for a mechanistic approach was first recognized in 1986 when AASHTO Guide for Design of Pavement Structures was developed. In March 1996, the AASHTO Joint Task Force, NCHRP and FHWA decided to work on development of a mechanistic-empirical pavement design methodology. A decade later in 2004, the Mechanistic-Empirical Pavement Design Guide (MEPDG) was developed by NCHRP under project 1-37A [1]. In July 2008, the AASHTO released the interim edition of the Manual of Practice (MOP) of the MEPDG [2]. More recently a Guide for local calibration of the MEPDG based on the research under project 1-40D was published in 2011 [3].

Transfer functions or distress models in the MEPDG that link the structural responses and pavement distresses and performance were globally calibrated using the Long Term Pavement Performance (LTPP) data. These distress models may not represent locally utilized material, traffic, climate, subgrade soil, and construction and maintenance practices. Due to these various differences in local conditions, globally calibrated coefficients would not be the optimum choice. Although the LTPP data included pavement sections from Ontario, still globally calibrated calibration coefficients were found to be over predicting distresses, particularly the rut depth [4]. Therefore there is a strong need to conduct local calibration for pavement design in the province of Ontario.

In response to this need, a research project was initiated by the Ministry of Transportation of Ontario (MTO) to develop a local calibration database by using the long-term pavement performance data that have been collected through the second-generation Pavement Management System (PMS-2) operated by the Ministry since 1980s. In Ontario, a vast majority of roads have flexible pavements, and a main portion of them are rehabilitated sections. In the later stage of the project, additional efforts were made to calibrate the MEPDG rutting models for rehabilitated flexible pavements.

The pre-overlay rut refers to the terminal rut depth at the end of previous life cycle of a rehabilitated flexible pavement section. Sensitivity analyses indicated that in addition to many inputs commonly required to new pavements, pre-overlay rut was a very important parameter that has been overlooked by many previous local calibration studies. It is particularly sensitive for the rut depth prediction. Unfortunately, the actual rutting values were not measured in Ontario until 2002, while majority of PMS-2 flexible pavement sections starts their life cycles (either new or rehabilitated) before 2002. On the other hand, conflicting evidences were found during literature review in the hope of finding some 'Level-3' values for this particular input parameter. Clearly, an uncertain pre-overlay rut would result in an inefficient local calibration. Therefore, an investigation was carried out to develop some guidelines and criteria for determining the pre-overlay rut value for rehabilitated flexible pavements for local calibration in Ontario. The ultimate goal of the investigation was to minimize the impact of an uncertain pre-overlay rut value on the accuracy of level-1 local calibration. This paper presents the result from this investigation based on the MTO's PMS-2 data.

2 Literature Review

The AASHTO MOP of the MEPDG [2] recommends a detailed step-by-step plan for assessment of existing pavement condition, or pre-rehabilitation condition assessment. It also provides hierarchical input levels for pavement evaluation for rehabilitation design. The pavement is evaluated on the basis of multiple categories e.g. structural and material durability, functional adequacy sub surface drainage conditions, sectional variations and other miscellaneous constraints.

For the Washington State, Li et al. (2009) performed local calibration for pavement section under WSDOT [5]. The calibration procedure involved (a) bench testing (b) model analysis (c) calibration (d) validation, and (e) iteration. In bench testing sensitivity of various input parameters on distresses were observed. They divided the region in two parts Western and Eastern Washington. Different design parameters and distress data for calibration sections were used for these two regions. The pavement distress conditions on the design lane right before the first overlay were also different, pre-overlay rut value of 0.18in. (4.572mm) and 0.32in. (8.128mm) was used for Western and Eastern regions of Washington.

Hoegh et al. (2010) performed local calibration of the MEPDG rutting models for 12 pavement sections under the Minnesota Department of Transportation research facility (MnROAD) [6]. They observed an abrupt increment in the predicted rutting for first month, so instead of adjusting the calibration coefficients they followed an unconventional approach by modifying global rutting models to remove the first-month rutting from the base and subgrade layer. It was observed that modified rut model was giving a better prediction of rutting for MnDOT.

Hall et al. (2011) performed an initial local calibration for flexible pavements for the state of Arkansas using LTPP and PMS database. On average a total rut of 0.18 in (4.83 mm) was observed in the pavement sections under consideration. Pre-overlay rutting in 80% of the considered pavement sections was from 0.1 in (2.54 mm) to 0.3 in (7.62 mm). Author suggested that *"rutting measurements (typically by straightedge) were recorded as a maximum of 0.3in regardless of actual measurements."[7].*This statement shows the possibility of uncertainty in measurement of rutting values due to limitations of the straightedge instrument.

A study to evaluate globally calibrated rutting models based on Alberta's PMS data was done by He et al. [8]. They used input level 3 for pre-rehabilitation condition. Pre-rehabilitation rut of 5.8 mm with rehabilitation condition 2 (Good) was used for pavement sections with milling before overlay, while 5.6 mm with rehabilitation condition of 3 (Fair) was used for overlays with no milling sections. They concluded that globally calibrated models had close predictions for overlays with no milling and under predicted rutting for sections with milling before overlays.

Recently Jannat [4] developed a pavement section database for Ontario`s local calibration of MEPDG distress models. She developed a database of 101 section cycles with high quality section specific material, pavement performance and traffic data. Here the term *section cycle* refers to the life of a section from its construction year (or the time of reconstruction or rehabilitation) to the year before the next major rehabilitation. She further did calibration and validation for IRI and rutting of around 79 section cycles with globally calibrated models using DARWin-ME^{TM} software. Pre-overlay rut of 4 mm was used for section cycles when pre-rehabilitation rut was unknown, as suggested by the Ministry staff. Her study concluded that DARWin-ME^{TM} generally over predicts rutting for Ontario pavement sections using globally calibrated models.

A comprehensive sensitivity analysis for the globally calibrated rutting model was done in NCHRP project 1-37A [1]. Rutting in flexible pavements was found to be generally sensitive to AC mix stiffness, traffic, subgrade modulus, AC mix air voids, AC thickness, environmental conditions, asphalt content, base thickness, subgrade modulus, truck traffic, traffic analysis level, bed rock depth, depth to ground water table etc. However, this sensitivity study was mainly confined to the new flexible pavement sections.

3 Effects of Pre-Overlay Rut

According to MTO's *Manual for Condition Rating for Flexible Pavements: Distress Manifestations* (SP-024) [9], permanent deformations can be defined as a combination of transverse undulations, longitudinal depressions or pavement surface distortions like dishing, bumps, dips, tenting or stepping at cracks etc. In the MEPDG rutting is estimated for each sub-season at the mid-depth of each sub-layer within the pavement structure to account for the different incremental permanent deformation under different traffic loading and material aging effects of various environmental factors (e.g., moisture and temperature) [2]. A strain-hardening rule is applied to calculate the cumulative permanent deformation. Figure 1 illustrates schematically the strain-hardening rule for rehabilitated section. The broken line shows the conceived rut growth for existing layers. The actual rut depth of the pavement after rehabilitation should include the permanent deformation developed in the new overlays and any new deformation in the existing layers. However, due to the cumulative nature of the permanent deformation of pavement materials, to determine the added plastic deformation needs the knowledge of the historical information, which is often unavailable at the time of overlay design.

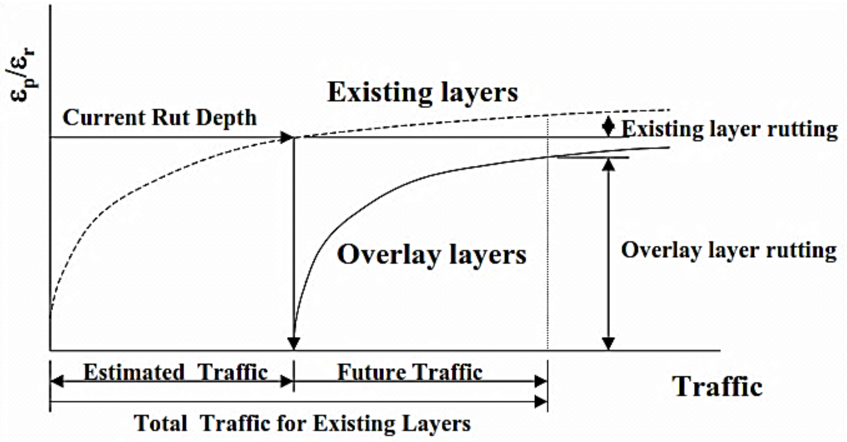

Figure 1: Effect of pre-overlay traffic on accumulation of rutting (after NCHRP 1-37A [1])

The approach that the MEPDG takes to estimating the missed rutting history in Figure 1 is to evaluate the pre-overlay rut depth from condition assessment of existing pavements. Ideally, a trench investigation should be done to determine the terminal rutting at different pavement structure layers. This information is then used to estimate the traffic, based on which the position at the broken line can be determined. Finally, the new rutting on the existing layers can be estimated by deducting the pre-overlay rut depth.

Of course, rarely is a trench investigation done. Realizing this hard-to-be-justified requirement, the MEPDG further provides an alternative but much easier solution: to obtain only the terminal total rut depth before rehabilitation. Using this total rut value, the DARWin-ME^{TM} applies some default proportional values to estimate the rut at each layer. The subsequent steps are then the same as described in the preceding paragraph. Those default proportional values are tabulated and made available in [1]. The MEPDG also recommends that all agencies develop a similar kind of table. Note that this table is different from percentages specified by AASHO Road Test. Results of the AASHO Road Test showed that generally 9 % of total flexible pavement rutting is occurred in subgrade [10]. As another side remark, the pre-overlay rut from a trench investigation corresponds to a Level 1 input, whereas the total surface rut plus default proportioning table is considered as a Level 3 input.

As the pre-overlay rutting values increase, the base and subgrade becomes stiff due to strain hardening. This results in lower rut values in base and subgrade during life of the subsequent overlay life cycle. Figure 1 shows that, due to the hardening effect of traffic prior to the overlay, the greater is the pre-overlay rutting, the slower the rutting in existing layers accumulates during the overlay period [1].

Sensitivity analysis was done in order to evaluate the effect of this input parameter for a typical rehabilitated flexible pavement. Results of this sensitivity study are shown in Figure 2. Clearly, for this particular section of 11 years life, the terminal rut depth at the year of 2009 varies from about 5 mm to more than 8mm when the pre-overlay rut depth at the end of 1997 is taken in the range from 4 to 12 mm. This figure also shows that by increasing the pre-overlay rut, the rate of increase in the terminal rut is decreasing. The major input parameters of this typical pavement sections used in sensitivity study are given in Table 1. For complete details of these input parameters, refer to [4].

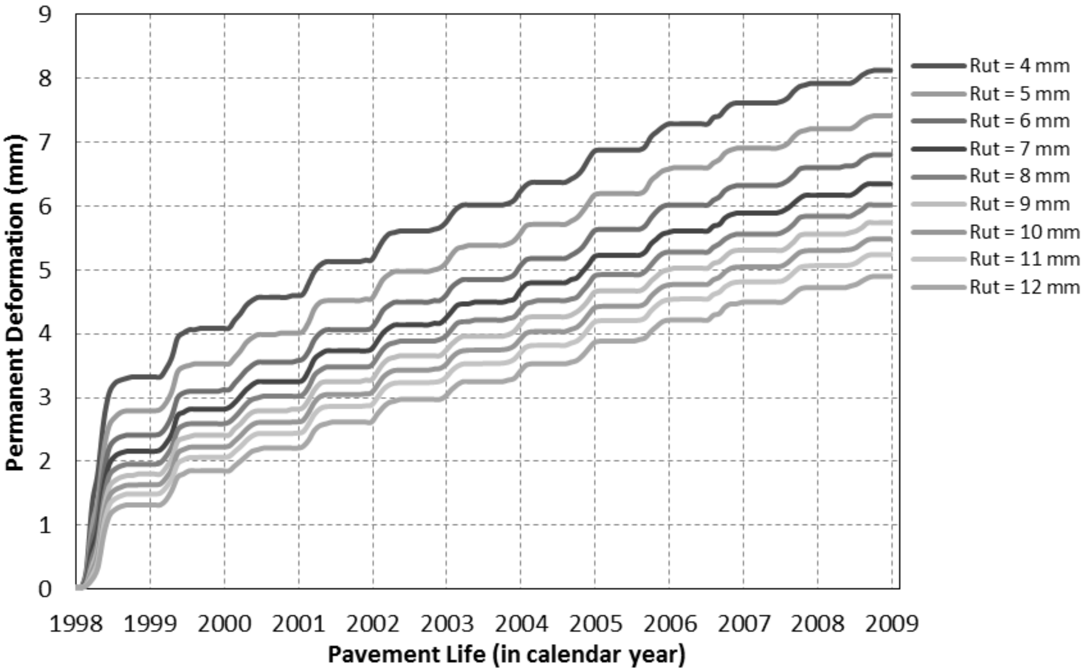

Figure 2: Sensitivity of permanent deformation to pre-overlay rut value (ranging from 4 mm to 12 mm) for a typical rehabilitated flexible pavement

Table 1 Major input parameters of section used for sensitivity study

Total AADTT	Total Layers	AC layer thickness	Granular layer thickness	Subgrade Modulus	Latitude	Longitude	Elevation
10,892,600	6	270 mm	762 mm	41 MPa	43.84686	-79.54848	279.91m

Further analysis have shown that other distresses such as IRI, transverse cracking and fatigue cracking are also sensitive to pre-overlay rut. However, transverse cracking and fatigue cracking models are not further analyzed due to limitation of database; for details of the reason, refer to [4]. The IRI is also not studied because it is the combination of other distresses. Therefore, the subsequent study will focus on the permanent deformation or rutting prediction.

4 RESEARCH METHODOLOGY

All MEPDG analysis was run in DARWin-ME^{TM} (the official AASHTOWare for MEPDG) Version 1.0 Build 1.0.18. Historical climate records of 34 climatic stations in Ontario (available in software package) were used for climate data. Input parameters such as project sites, pavement structures, types of layer materials, traffic volume, truck percentage and traffic growth factor were site specific and they were taken from the recently developed local calibration database based on the MTO's PMS-2 database and contract documents; for more details refer to [7]. Other Level 2 or Level 3 inputs such as asphalt concrete (AC) and granular material characterizations, and traffic loading data (e.g. axle load distribution, typical axle per truck, tire configuration) were taken from the default values recently developed by the MTO staff [11].

The performance data including rut depth, international roughness index (IRI) and other more MTO-specific performance indices including ride comfort index (RCI), surface distress manifestation index (DMI) and pavement condition index (PCI) were taken from the PMS-2 database. The PMS-2 database has bulk of data available for DMI, RCI and PCI starting from 1985. MTO document SP -024 provides a complete description of all the surface distresses and their evaluation method [6]. In current data collection procedure ride quality is measured by IRI. Since 1997, MTO has used IRI to measure roughness [12], while empirical relations are used to predict RCI from it. PCI is a combination of DMI and RCI. It is a composite index for pavement serviceability ranging from 0 to 100 that measures the density, severity of surface distresses (cracks and rutting) and ride comfort of the road. MTO is currently primarily using PCI to evaluate the performance of flexible pavements.

Rutting measurement in Ontario was started in 2002 and it has been carried out by the Ministry staff using the Automatic Road Analyzer (ARAN). In PMS-2 reliable rut depth readings were only available after 2004 and included. Therefore, any pavement sections selected for local calibration of which the life cycle starts before 2004 have no pre-overlay rutting information. To estimate this important parameter, two approaches are taken in this study: 1) frequency distribution analysis, and 2) regression analysis. The summary statistics and variability of the pre-overlay rut depth is calculated from the frequency distribution analysis. In order to improve the estimation precision, a regression analysis between the rut depth and DMI and RCI was carried out. The PCI was not selected as an explanatory variable because, as explained above, the PCI is a function of DMI and RCI.

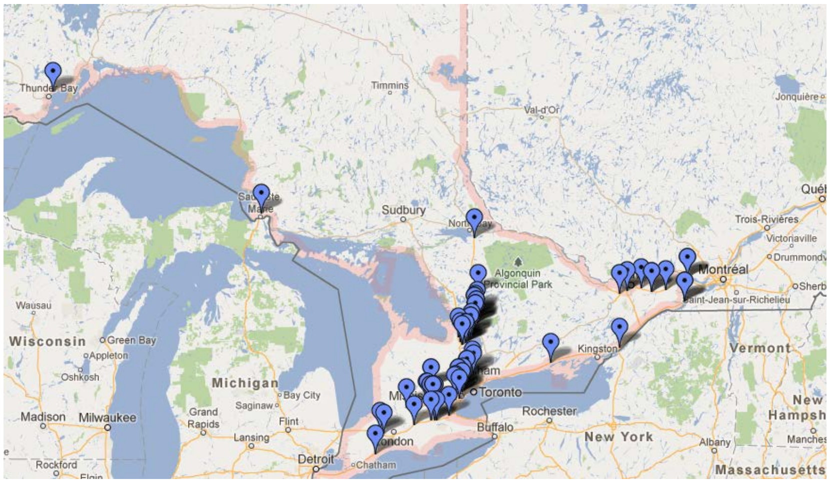

Figure 3: Locations of the 51 flexible pavement sections on Google Maps

Finally, local calibration of the rutting model is performed by using different pre-overlay rut values. For this purpose, 51 rehabilitated pavement sections from both Southern and Northern Ontario were selected to investigate whether a general trend between observed and predicted rutting values can be observed. The geographical locations of the selected sections are shown in Figure 3. These sections were taken from Highway 6, 7, 8, 11, 85, 400, 401, 403, 404, 410,417and 427. For the purpose of local calibration, 50% reliability was used for the whole analysis.

5 CRITERIA FOR IDENTIFICATION OF TERMINAL RUT

Pre-overlay rut or terminal rut data was collected from PMS data of Ontario. Identification of terminal rut was not clearly evident in data due to inconsistencies in the field observed rutting, therefore identification of terminal rut was done by two approaches.

In first approach, maximum rutting values from each section cycle of all pavements was selected and treated as the terminal rut. Then it was make sure that not to include incomplete section cycles as the rut values corresponding to these section cycles would not be the end of cycle or terminal rut value. Drawback of this approach due to discrepancies in the data, occasionally a maximum rut value does not means the end of pavement life. End of pavement life cycle dictated by DMI and RCI.

Therefore, in the second approach the identification was done on the basis of DMI and RCI. Rationally, DMI value of pavement should decrease supposing no major maintenances have been done during pavement life. Therefore, abrupt increase of DMI is an indication of an overlay and rutting value corresponding to the previous year was identified as the pre-overly rut of this section. All pre-overlay rut of sections was identified on the basis of same concept. In this identification process it was also confirmed not to include incomplete section cycle because rut values corresponding to these section cycles would not be the end of cycle or terminal rut value.

6 STATISTICAL Estimation of Pre-Overlay Rut Depth

6.1 Frequency Distribution

Frequency distribution is one of the most basic types of statistical analysis for any type of data. The rut data from the flexible pavement sections in the PMS-2 were analyzed. A total of 1175 flexible pavement sections identified from the first approach of identification of pre-overlay rut (based on maximum rut values). For each section, maximum rut depth of the life-cycle treated as the terminal rut depth because maximum rut is generally the pre-overlay rut when no intermediate rehabilitation has been performed. Finally, these pre-overlay rut values were used to construct a histogram, shown in Figure 4. Table 2 presents some other statistical parameters of the frequency distribution. On the basis of frequency distribution, a mean value of 7 mm can be used as a Level 3 input for the pre-overlay rut value for pavement sections in Ontario that does not have any reliable surface rut information available. Similar results were obtained from the frequency distribution of second identification approach (based on DMI and RCI), therefore results are not included here.

6.2 Regression Analysis

The pre-overlay rut values may be better predicted if some empirical relationship can be established with other more readily available data such as DMI and RCI. Note that PCI is not used because PCI is essentially a mathematical function of DMI and RCI. The IRI is not used either, because the RCI in recent years was also a function of IRI. Based on a set of data from 864 pavement sections from the PMS-2 database, the regression analysis of the rut depth expressed by the DMI and RCI were conducted. Unfortunately, regression did not result in a very good fit with a R^2 value of only 0.22. Regression statistics are shown in Table 3. Comparing the standard deviation (1.835 mm) in Table 2 and the standard error (1.600 mm) in Table 3, reduction of variation of the rut depth is very limited. This poor fitness of this data can be explained by many factors as the both DMI and RCI (before 1997) are subjective values. These analyses were done by using constant pre-overlay rut for one group. Because of this, the use of the regression result does not seem to be promising. Thus, a further analysis is carried out to investigate the effects of the pre-overlay rut on local calibration.

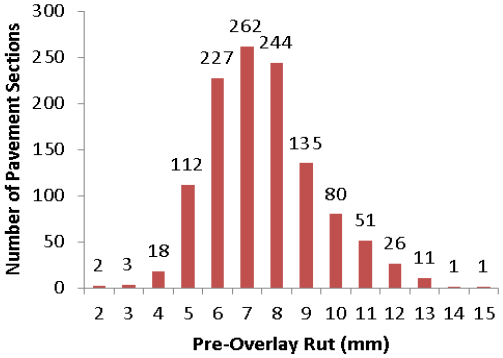

Figure 4: Histogram of the life-cycle maximum rut depth from PMS-2 database

Table 2 Parameters of frequency distribution for pre-overlay rut

Functions	Total Rut (mm)
Minimum	2.360
Maximum	15.333
Mean	7.053
Mode	6.261
Standard Deviation	1.835

Table 3: Regression statistics of Rut depth as a function of RCI and DMI

Multiple R	0.476
R Square	0.227
Adjusted R Square	0.225
Standard Error	1.60
Observations	864

7 Effects of Pre-Overlay Rut on Local Calibration

DARWin-ME^{TM} default globally calibrated models were used in this study to predict rutting using local parameters for rehabilitated flexible pavement sections. Preliminary 51 rehabilitated flexible pavement sections were analyzed with a preliminary total rut value of 4 mm. This pre-overlay rut value was selected because it was recommended by the MTO staff [4]. The number of AC layers in those pavement sections varies from 2 to 7, showing that some sections have undergone through multiple rehabilitation activities in their service history.

DARWin-ME^{TM} analyses were repeated for different pre-overlay rut depths ranging from 4 to 12 mm at an incremental step of 1 mm. According to MTO pavement condition rating manual, wheel-path rut severity at these range of rutting values are from very slight to slight class [9]. A total of 51 x 9 = 459 pavement simulations were run for this study. The end of life observed rutting was then compared with the DARWin-ME^{TM} predicted rutting. The results are summarized in Figure 5. More statistics are shown in Table 4.

Over prediction of total rutting is evident from the results when in first analysis pre-overlay rut of 4 mm was used, show in Figure 5(a). Similar results were also predicted by [4], where only 9 rehabilitated pavement sections were under predicting rutting values. Although the trend of over prediction of rutting was visible throughout Ontario but it was more clearly observed in Northern Ontario, where 14 out of 16 new and rehabilitated pavement sections were over predicting the rutting values. While only 2 of the 9 under predicted pavement sections were from Northern Ontario showing even a severe over prediction trend particularly for Northern Ontario.

As the frequency distributions showed the mean max rut value is 7 mm, therefore all 51 rehabilitated pavement sections were reanalyzed with a pre-overlay rut value of 7 mm. Comparison of observed with predicted rut values is shown in Figure 5(d). In this case, the bias was reduced to 0.477 mm, in contrast of the 3.206 mm bias for pre-overlay of 4 mm. This significant improvement in bias was the reason that triggers this study to analyze more variations of rut depth.

Comparison of the graphs in Figure 5 shows that the simple regression relationship between the observed rutting and predicted rutting is converged after the pre-overlay rut is greater than 8 mm. This is a very interesting observation, which, to the author's best knowledge, was not reported in earlier literature. Comparison of Table 4 further shows that pre-overlay rut of 8 mm leads to a minimum bias among the 51 pavement sections, whereas a selection of 9 mm leads to the least root mean square error (RMSE). These all suggest that for future local calibration, a pre-overlay rut of 7 to 9 mm can be taken, which will improve accuracy and precision of rut prediction of globally calibrated model.

Table 4: Regression analysis results for multiple pre-overlay rut values.

Parameter	Pre-overlay Rut (mm)								
	4	5	6	7	8	9	10	11	12
R Square	0.151	0.153	0.152	0.150	0.153	0.153	0.153	0.153	0.153
Mean BIAS	3.206	2.095	1.281	0.477	0.067	-0.403	-0.801	-1.235	-0.605
RMSE	4.709	3.772	3.222	3.004	2.672	2.594	2.598	2.638	3.701
SD	3.323	2.914	2.663	2.494	2.355	2.269	2.213	2.198	2.912

8 CONCLUSIONS

This study primarily focused on pre-overlay rut depth. Although this is only one input of MEPDG software it is a highly sensitive parameter for prediction of rutting in rehabilitated sections. Both statistical analysis and DARWin-ME^{TM} simulation confirmed that 4 mm, the value suggested by the MTO staff, should not be used as a default value for local calibration when site-specific value is unavailable. Rather, Ontario's roads possess a widely varying terminal rut depth before rehabilitation. Without introducing any local calibration coefficients in DARWin-ME^{TM}, the study has shown that both the bias and RMSE reduced drastically when the average terminal rut depth of 7 mm was used for the pre-overlay value. Further analysis also suggested that a value more than 8 mm does not seem to change a whole lot of the local calibration results. Of course, this observation has yet to be confirmed when more detailed section-by-section longitudinal calibration is performed, which is the task for future work of the project.

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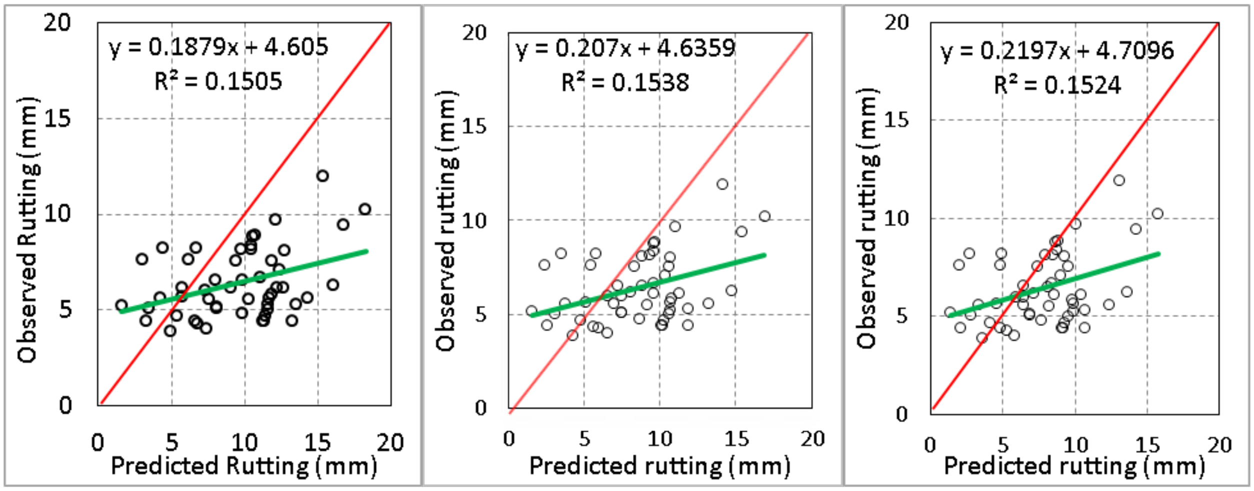
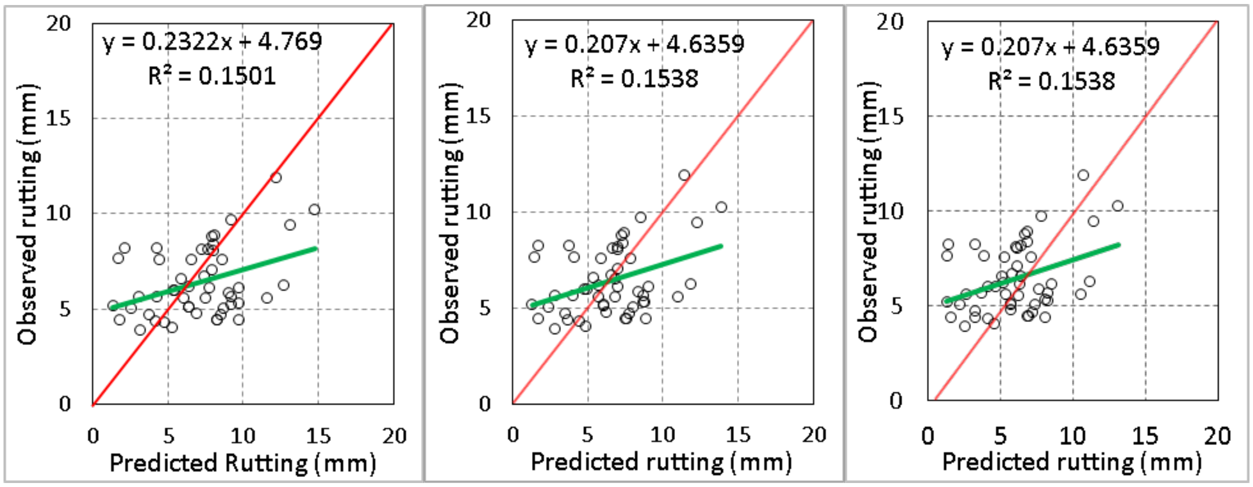
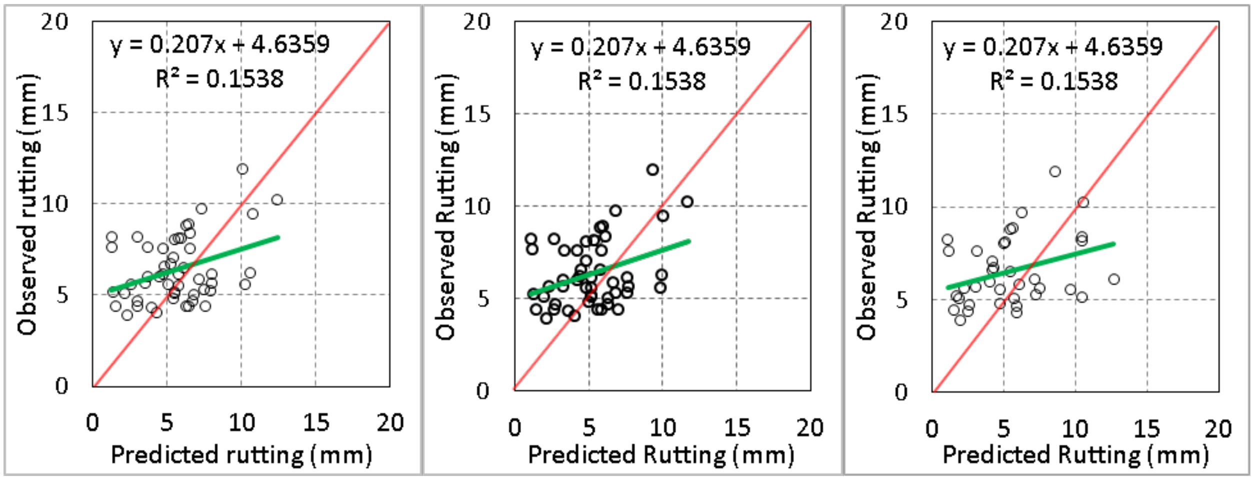


(a) Pre-overlay rut = 4 mm (b) Pre-overlay rut = 5 mm (c) Pre-overlay rut = 6 mm



(d) Pre-overlay rut = 7 mm (e) Pre-overlay rut = 8 mm (f) Pre-overlay rut = 9 mm



(g) Pre-overlay rut = 10 mm (h) Pre-overlay rut = 11 mm (i) Pre-overlay rut = 12 mm

Figure 5: Comparison of predicted with observed rut depth

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