MIX SPECIFIC RUTTING MODEL CALIBRATION IN COLORADO

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Abstract

The Colorado Department of Transportation (CDOT) recently concluded a study to implement and adopt the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide (MEPDG) and its accompanying software into its routine pavement design practice. Implementation of the MEPDG in Colorado required local calibration of the MEPDG distress and smoothness prediction models. This paper discusses the calibration of the "global" rutting model to account for Colorado's unique climate, traffic, and soils conditions as well as the various asphalt concrete (AC) mix types used in the State. A key challenge during the local calibration effort was to produce different rutting coefficients for each AC mix type, e.g., Marshall, Superpave, and polymer modified asphalt (PMA).

Local calibration of the MEPDG global models using CDOT input data was done using nonlinear model optimization tool available in the SAS statistical software. AC rutting, unbound aggregate base rutting, and subgrade rutting global model coefficients were adjusted through local calibration. Four of the ten model coefficients were adjusted. The local calibration coefficient $\beta r1$ turned out to be different for each of the three primary CDOT AC. As expected, the PMA had the lowest value of the $\beta r1$ coefficient among three asphalt mixes, resulting in the lowest AC rutting. The goodness of fit and bias test results indicate an adequate goodness of fit with minimal bias. This local calibration effort improves the overall prediction accuracy of the rutting model and its standard error.

1.0 Introduction

For many years, the Colorado Department of Transportation (CDOT) has used the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* and the 1998 supplement to design new and rehabilitated flexible and rigid pavements (AASHTO 1993, AASHTO 1998). The 1993 AASHTO Pavement Design Guide originated from empirical pavement design equations developed in the late 1950s using pavement performance data collected under a national research program known as the AASHO Road Test (HRB 1962). Over the years, the original empirical pavement design equations were improved to address, as much as possible, identified weaknesses in the design procedure such as (1) the absence of sophisticated materials and traffic loading characterizations algorithms and (2) the lack of algorithms that relate applied truck axle load with pavement mechanical responses that lead to the development and progression of damage, distresses, and smoothness loss.

Although these design guides have served as the primary tool for pavement design in the U.S. and beyond for many decades, and they have been used successfully to design many types of pavements, the inherent weaknesses of the design procedure have resulted in designs of many pavement structures that have under-performed or have failed prematurely. In 1996, the AASHTO Joint Technical Committee on Pavements (JTCP) proposed a shift from empirical-based to mechanistic-based pavement design. This was to be done through the development of a new pavement design guide based on mechanistic principles for the design of new and rehabilitated pavement structures.

In the late 1990s, the highway community, under a national initiative sponsored by the AASHTO Joint Task Force on Pavements (now the Joint Technical Committee on Pavements), embarked on the development of a new design methodology that was able to characterize in-service pavements realistically and provide uniform guidelines for designing flexible, rigid, and composite pavements. After several years of research and development, under the U.S. National Cooperative Highway Research Program (NCHRP) Projects 1-37A and 1-40D (001 & 002), a new state-of-the-art pavement design and analysis procedure emerged—the Mechanistic-Empirical Pavement Design Guide (or simply the MEPDG). This procedure covers 17 pavement design situations and is based on sound principles of engineering mechanics that predict the major types of pavement distresses that occur in the field and the associated smoothness loss through "field-calibrated" performance prediction models or transfer functions. The predictions become the basis for analyzing and designing pavements for various combinations of site factors (climate, traffic, and subgrade). Soon after completion of the research leading up to the deliverables, the MEPDG Manual of Practice was prepared under NCHRP Project 1-40B. This Manual of Practice became the American Association of State Highway and Transportation Officials (AASHTO) balloted and approved interim M-E design standard. A second manual prepared under NCHRP Project 1-40B became AASHTO's Manual of Practice for Local Calibration of the MEPDG. AASHTOWare Pavement ME Design™ or simply ME Design—the production grade, AASHTOWare® pavement design software version 1.0 that supports the MEPDG—was then developed and released in the spring of 2011.

The ME Design software version 1.0 uses same AC rutting transfer function for all AC layers, irrespective of mix type. Several studies concluded that the resistance to rutting depends on AC binder and mix properties, and therefore, the same transfer function may not adequately characterize the rutting performance for all AC layers. This limitation was addressed under NCHRP project 9-30A and the recommendations from NCHRP project 9-30A were implemented in version 2.0 of the ME Design software by providing an option to use layer specific AC rutting transfer functions or model coefficients for each AC layer to reflect binder and mix properties.

After the development of the MEPDG and ME Design, the next step is implementation—adoption and use of that design procedure. Highway agencies in the United States and Canada are in various phases of the implementation effort. Several agencies in the US are using the MEPDG for some form of routine pavement designs (Indiana, Missouri, Utah, and California), and other States are conducting research to implement the procedure (e.g., Arizona, Colorado, Georgia, Mississippi, New York, and Wisconsin). Since the release of ME Design, many US States and Canadian Provinces have accelerated their efforts to implement the MEPDG.

1.1 MEPDG Implementation in Colorado

CDOT has been preparing for the implementation of the MEPDG since 2001, when CDOT and the Colorado Asphalt Pavement Association (CAPA) initiated a project to develop a road map for implementing the MEPDG flexible pavement design and analysis procedure in Colorado. The road map was developed from a series of facilitated meetings between CDOT, CAPA, and industry representatives. An analogous rigid pavement design road map was also developed in 2001. These road maps were updated and refined in 2007 and served as a guide for implementing the MEPDG.

1.2 Objective of the Study

The objective of this study was to provide all information and documents necessary for CDOT and industry to use the latest MEPDG software, including mix specific AC rutting model coefficients, on a day-to-day basis for the design and analysis of new and rehabilitated pavement structures in Colorado.

2.0 Framework of Local Calibration

The framework for local calibration of the MEPDG is adapted after the AASHTO *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide* (AASHTO 2010). In all, model validation and local calibration consists of the 11 steps presented below:

- Step 1: Selection of Hierarchical Input Level for Each Input Parameter
- Step 2: Develop Local Experimental Plan and Sampling Template
- Step 3: Estimate Sample Size for Specific Distress/IRI Prediction Models
- Step 4: Select Pavement Projects
- Step 5: Extract and Evaluate Distress and Project Data
- Step 6: Conduct Field and Forensic Investigations
- Step 7: Assess Local Bias—Validation of Global Calibration Values to Local Conditions, Policies, and Materials
- Step 8: Eliminate Local Bias of Distress and IRI Prediction Models
- Step 9: Assess the Standard Error of the Estimate
- Step 10: Reduce Standard Error of the Estimate
- Step 11: Interpretation of Results, Deciding Adequacy of Calibration Parameters

3.0 Project Selection and Development of Traffic, Climate, and Materials Database

The MEPDG implementation process involved developing a sampling template for project identification and calibration/validation database population. The two sources of data were the CDOT pavement management system and the LTPP database. This includes work done to identify and select candidate projects for inclusion into the project calibration/validation database, as well as the development of the database.

3.1 Identification and Selection of Pavement Projects

The LTPP database contained 72 research-type new AC, AC-overlaid existing AC and JPCP, new JPCP, and unbonded JPCP overlay of JPCP projects in Colorado. Note that some projects were double or triple counted, as they belonged to different pavement type categories at different time periods due to rehabilitation done over the course of their service life.

The CDOT state highway system consists of 11,192 lane miles of pavement. Approximately 9,954 miles are AC pavements, and 1,225 miles are PCC pavements. The entire state highway system was divided into 112,009 individual pavement management sections with an average length of 0.1 miles (approximately 500 ft).

Based on the selection criteria presented, a total of 132 new and rehabilitated pavement projects were selected from the LTPP and CDOT pavement management system databases. It must be noted that not all of the CDOT pavement management system projects had all the required data. However, such projects were selected for inclusion in the project database on the assumption that the required information can be assembled through field and laboratory testing. Figures 1 shows map of Colorado, along with the locations of the selected pavement projects.

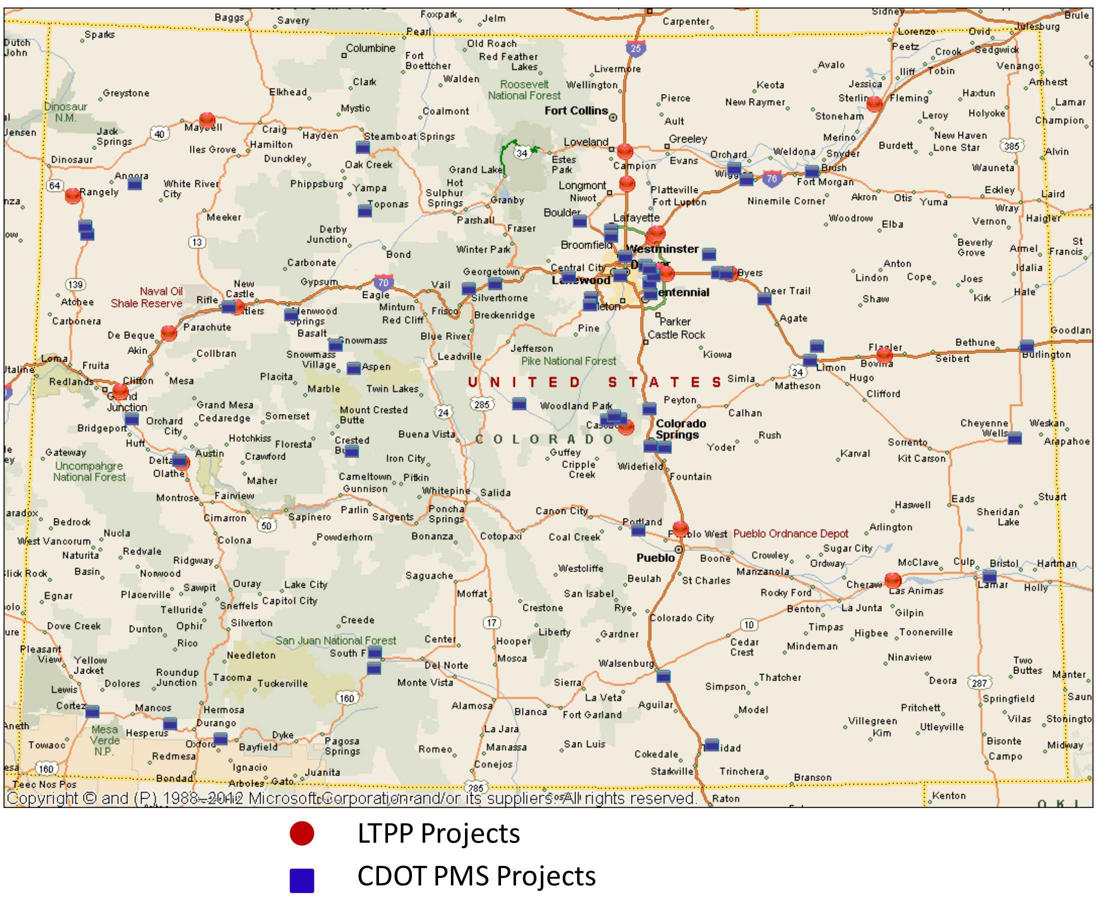

Figure 1. Map of selected pavement projects along the Colorado highway system.

4.0 Verification and Calibration of Rutting Model

This section describes the work done to verify and calibrate (if needed) the MEPDG global flexible pavement distress and smoothness models for Colorado. For this project, “flexible pavement” refers to new AC pavements and AC-overlaid existing AC pavements.

The criteria for performing local calibration were based on (1) whether the given global model exhibited a reasonable goodness of fit (between measured and predicted outputs) and (2) whether distresses/IRI were predicted without significant bias.

Reasonable goodness of fit was determined using the diagnostic statistics R^2 and SEE, while the presence or absence of bias was determined based on the hypothesis test. The criteria used to determine the adequacy of the global models for Colorado conditions are presented in Table 1.

Table 1. Criteria for determining global rutting model adequacy for Colorado conditions.

Criterion of Interest	Test Statistic	Range of R^2 & Model SEE	Rating
Goodness of fit	R^2, percent (all models)	81 to 100	Very good (strong relationship)
		64 to 81	Good
		49 to 64	Fair
		< 49	Poor (weak or no relationship)
	Global AC total rutting model SEE	< 0.1 in	Good
		0.1 to 0.2 in	Fair
		> 0.2 in	Poor
Bias	Hypothesis testing of slope of the linear measured vs. predicted rutting model (b1 = slope of the measured vs. predicted linear model) H0: b1 = 1	p-value	Reject if p-value is < 0.05 (i.e., 5 percent significant level)
	Paired t-test between measured and predicted rutting	p-value	Reject if p-value is < 0.05 (i.e., 5 percent significant level)

4.1 Total Rutting Model

4.1.1 Global MEDPG Total Rutting Model Verification

The MEPDG predicts AC pavement total rutting using separate submodels for the surface AC, unbound aggregate base, and subgrade soil. The same three submodels are utilized for AC-overlaid AC pavement, with modifications as needed to reflect the existing pavement material properties and permanent strain (existing rutting) present in all three layers.
Verification of the MEPDG global total rutting model consisted of the following steps:

1. Run the three MEPDG rutting submodels using global coefficients for all new AC pavement and AC-overlaid AC pavement projects to obtain estimates of total rutting.
2. Perform statistical analysis to determine goodness of fit with field-measured total rutting and bias in estimated total rutting.
3. Evaluate goodness of fit and bias statistics and determine any need for local calibration to Colorado conditions.

Figure 2 shows a plot of the MEPDG global model predicted rutting versus field-measured rutting for all Colorado new AC pavement and AC-overlaid AC pavement projects. Goodness of fit and bias statistics computed from the data are presented in Table 2.

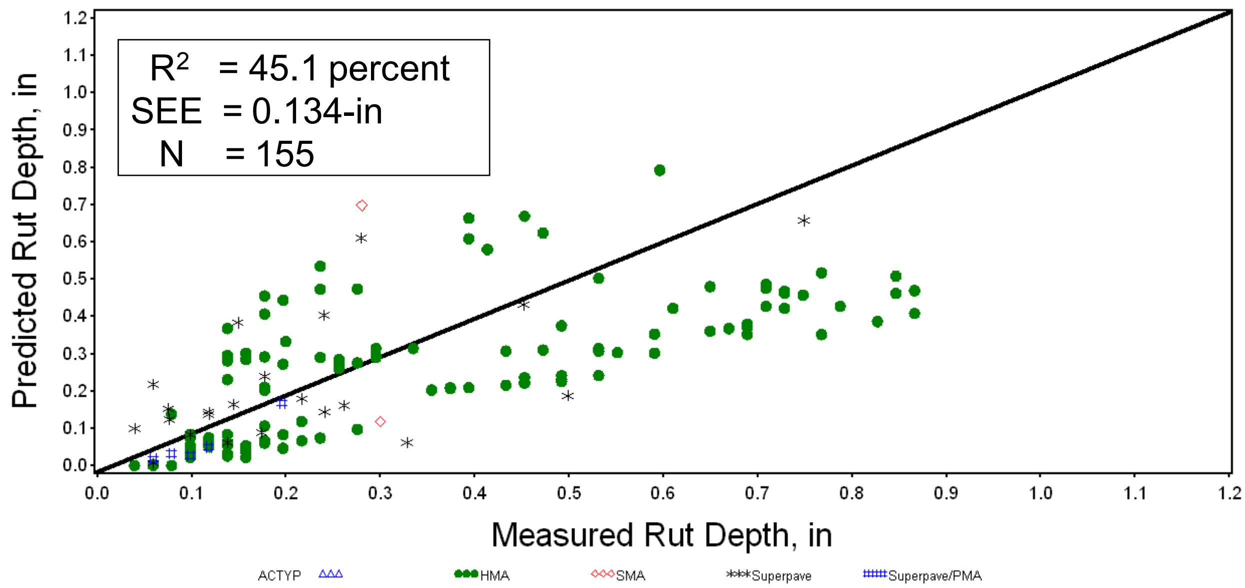

Figure 2. Plot showing MEPDG global model predicted rutting versus measured rutting (AC, unbound aggregate base, and subgrade).

Table 2. Results of statistical evaluation of MEPDG total rutting global submodels for Colorado conditions.

Statistical Analysis Type					
Goodness of Fit			**Bias**		
R^2, %	**SEE**	**N**	**p-value (paired t-test)**	**p-value (Slope)**	**N**
45.1	0.134 in	155	< 0.0001	< 0.0001	155

The information presented in Table 2 shows a poor to fair goodness of fit when compared to the global model statistics. In addition, the global model, failed in hypothesis testing for paired t-test and slope, shows significant bias in predicted total rutting estimates. The MEPDG rutting global model coefficients were, therefore, deemed inadequate for Colorado conditions, and local calibration of this very important model was required.

Description of Local Calibration Procedure

Local calibration of the three rutting submodels consisted of the following steps:

1. Determine the cause of poor to fair goodness of fit and bias produced by the global models.
2. Adjust submodel calibration coefficients as needed based on information derived from step 1 to improve goodness of fit and reduce or eliminate bias. Specifically, the following model coefficients can be adjusted:
    a. AC rutting:
        i. Global calibration coefficients (k1r, k2r, k3r).
        ii. Local calibration coefficients (β1r, β2r, β3r).
    b. Granular base rutting model.

i. Local/global calibration coefficients (ks1).
c. Subgrade rutting model.
i. Local/global calibration coefficients (ks1).

In adjusting three rutting submodels, the researchers considered information obtained through laboratory testing (repeated load permanent deformation and Hamburg Wheel Tracking tests) on the nature and rate of primary and secondary rutting development and from field trenching of new AC pavements to determine the distribution of rutting within the pavement structure. This was done by (1) applying laboratory-derived AC rutting submodel coefficients k1r, k2r, and k3r as seed values and constraining the new local models to be as close as possible to the seed values without compromising goodness of fit and bias and (2) ensuring that the contribution of each submodel to total rutting was close to the field trenching estimates without compromising goodness of fit and bias. A summary of laboratory-measured AC rutting model coefficients k1r, k2r, and k3r and total rutting distribution is presented as follows:

- AC rutting model coefficients obtained from laboratory-measured repeated load permanent deformation tests:
  - k_{1r} = -2.36.
  - k_{2r} = 1.72.
  - k_{3r} = 0.16.
- Average total rutting distribution for all mixes obtained from field trenching:
  - AC surface = 63 percent.
  - Aggregate base/subbase = 11 percent.
  - Subgrade (top 12 in) = 26 percent.

Local calibration was done simultaneously for new AC pavements and AC-overlaid AC pavements. Summary descriptions of the three rutting submodels are presented in Table 3.

Table 3. Description of total rutting prediction submodels.

Model Type	Model Description
AC	$\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{1r} k_z \varepsilon_{r(HMA)} 10^{k_{1r}} T^{k_{2r}\beta_{2r}} N^{k_{3r}\beta_{3r}}$
Unbound aggregate base	$\Delta_{p(soil)} = \beta_{s1} k_{s1} \varepsilon_v h_{soil} \left(\frac{\varepsilon_o}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{n} \right)^{\beta}}$
Subgrade soils	$\Delta_{p(soil)} = \beta_{s1} k_{s1} \varepsilon_v h_{soil} \left(\frac{\varepsilon_o}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{n} \right)^{\beta}}$

Summary of Total Rutting Model Local Calibration Results

The researchers investigated the possible causes of poor goodness of fit and bias, and they found no obvious reasons (such as erroneous inputs). Thus, local calibration proceeded as previously described. The MEPDG global models were calibrated with CDOT input data using nonlinear model optimization tools available in the SAS statistical software. Adjusted AC rutting, unbound aggregate base rutting, and subgrade rutting global model coefficients obtained from step 2 are presented in Table 4 and show that four of the ten global coefficients were adjusted. The local calibration coefficient βr1 was found to be different for three primary AC mixes (Marshall, Superpave, and Polymer modified). As expected, the coefficient βr1 for polymer modified asphalt turned out to be the lowest among three asphalt mixes. The goodness of fit and bias statistics are presented in Table 5. Plots of field-measured versus CDOT-calibrated total rutting are presented in Figure 3 and Figure 4. The goodness of fit and bias test results indicate an adequate goodness of fit with minimal bias not significant at the 5 percent significance level for the locally calibrated total rutting submodels.

The results presented in Table 5 show appreciable change in the goodness of fit between the global models and the Colorado calibrated models (R^2 changed from 45.1 to 61.1, and SEE changed from 0.134 to 0.07 inches). Locally calibrated model goodness of fit was characterized as good. The results presented in Table 5 also show that the significant bias produced by the global models in Colorado had been eliminated through local calibration. This improvement increases overall rutting prediction accuracy and reliability of pavement designs. Thus, new AC pavement and AC-overlaid AC pavement designs in Colorado will be much more accurate and optimum (lower cost) at the selected level of design reliability with the application of the locally calibrated total rutting model.

Figures 5 through 8 present plots of measured and predicted rutting for several projects in Colorado. The plots show reasonable predictions of rutting using the locally calibrated models.

Table 4. Local calibration coefficients for AC, unbound base, and subgrade soil rutting submodels.

Model	**Model Coefficients**	**Global Model Values**	**CDOT Local Model Values**
AC rutting submodel	Kr1	-3.35412	-3.35412
	Kr2	1.5606	1.5606
	Kr3	0.4791	0.3791
	βr1 (Marshall)	1	7.6742
	βr1 (Superpave)	1	6.7
	βr1 (PMA)	1	4.3
	βr2	1	1
	βr3	1	1
Granular base rutting submodel	ks1	2.03	2.03
	βs1	1	0.22
Subbase rutting submodel	ks1	1.35	1.35
	βs1	1	0.37

Table 5. Results of statistical evaluation of MEPDG rutting local models for Colorado conditions.

Statistical Analysis Type					
Goodness of Fit			**Bias**		
R^2, %	**SEE**	**N**	**p-value (paired t-test)**	**p-value (Slope)**	**N**
61.1	0.07 in	202	0.1588	0.0776	202

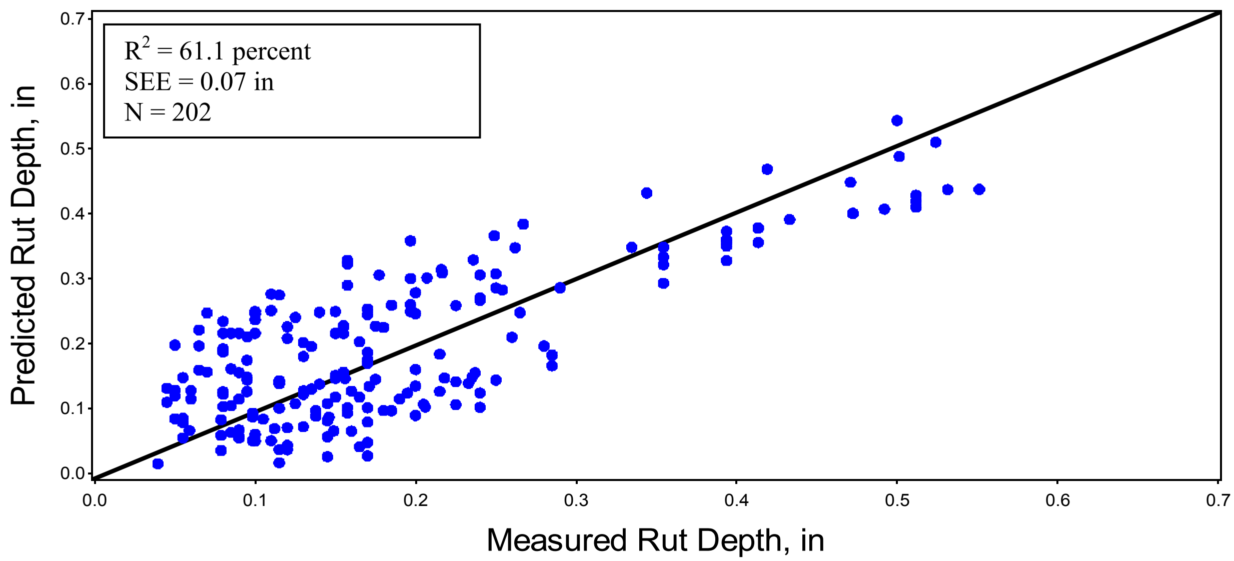

Figure 3. Plot showing predicted using MEPDG submodels with CDOT local coefficients (for all pavements) versus field-measured total rutting.

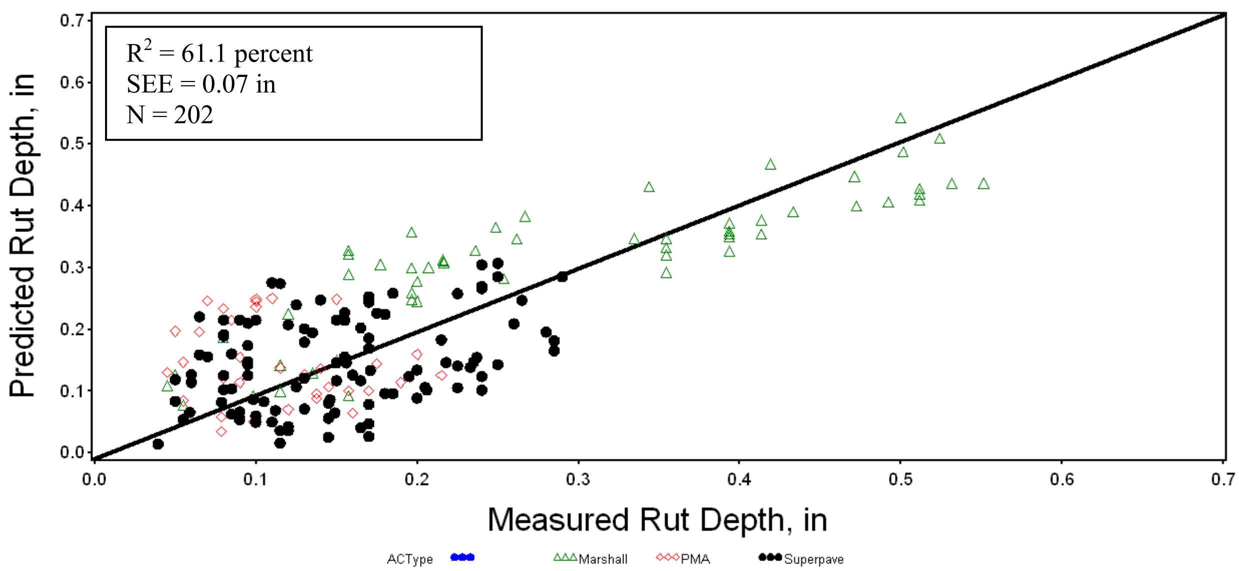

Figure 4. Plot showing predicted using MEPDG submodels with CDOT local coefficients (for each asphalt mix) versus field-measured total rutting.

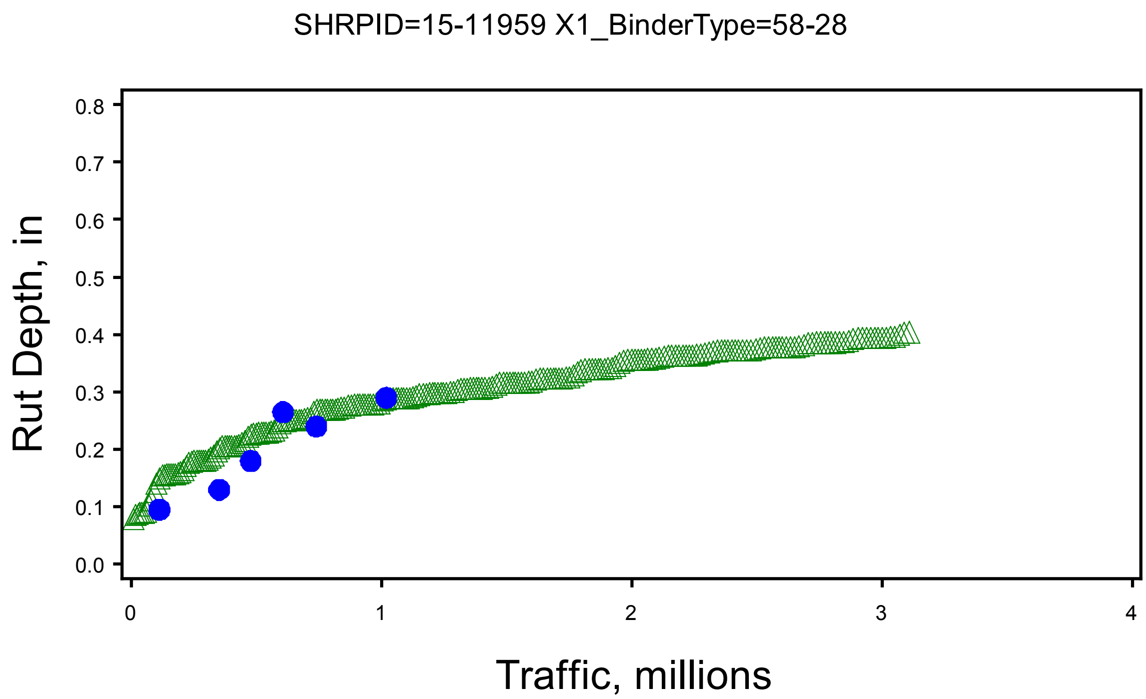

Figure 5. Plot showing predicted rutting versus truck traffic for CDOT pavement management system project 11959 (New AC pavement).

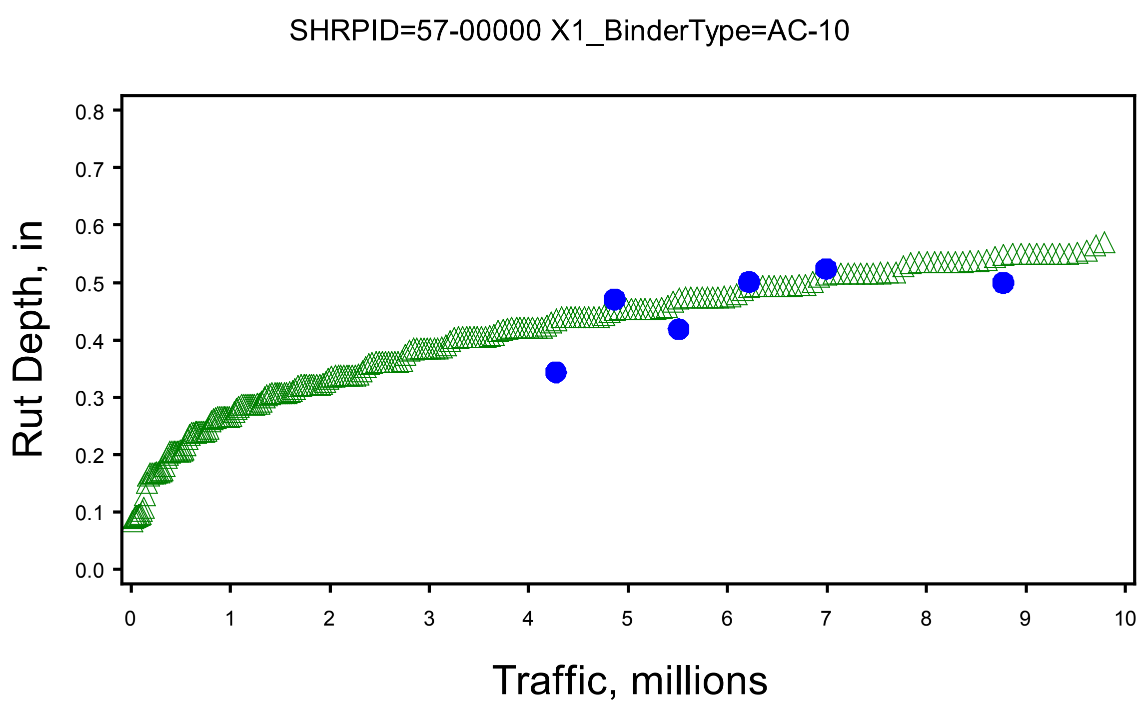

Figure 6. Plot showing predicted rutting versus truck traffic for CDOT pavement management system project 57-00000 (New AC pavement).

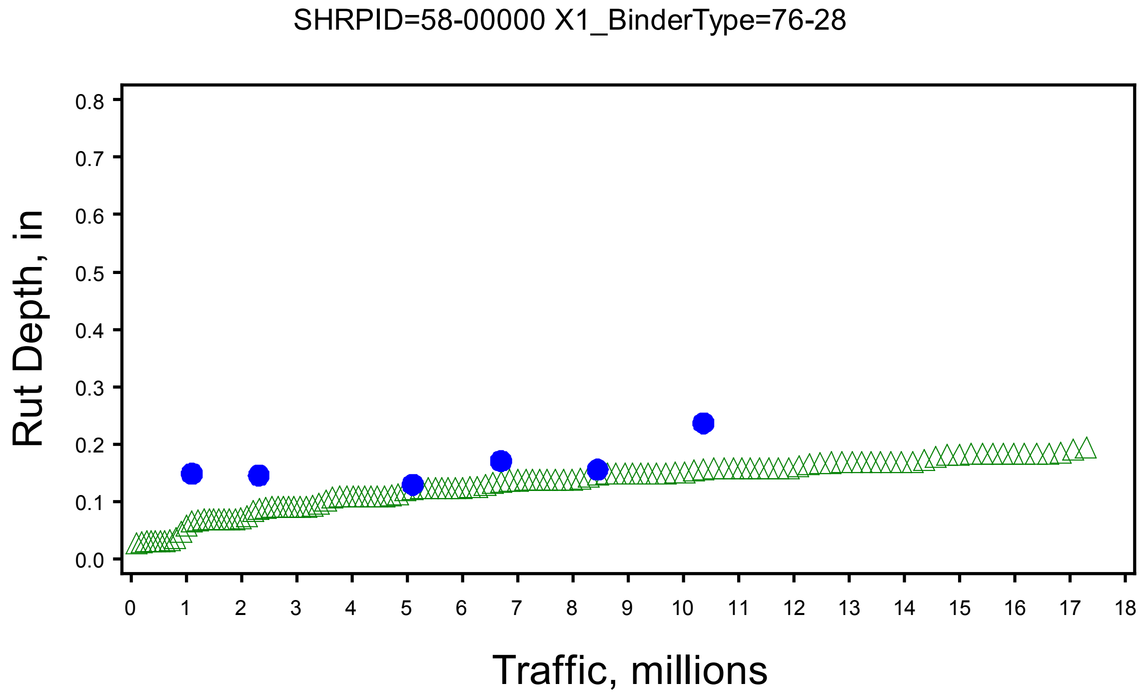

Figure 7. Plot showing predicted rutting versus truck traffic for CDOT pavement management system project 58-00000 (AC overlaid AC pavement).

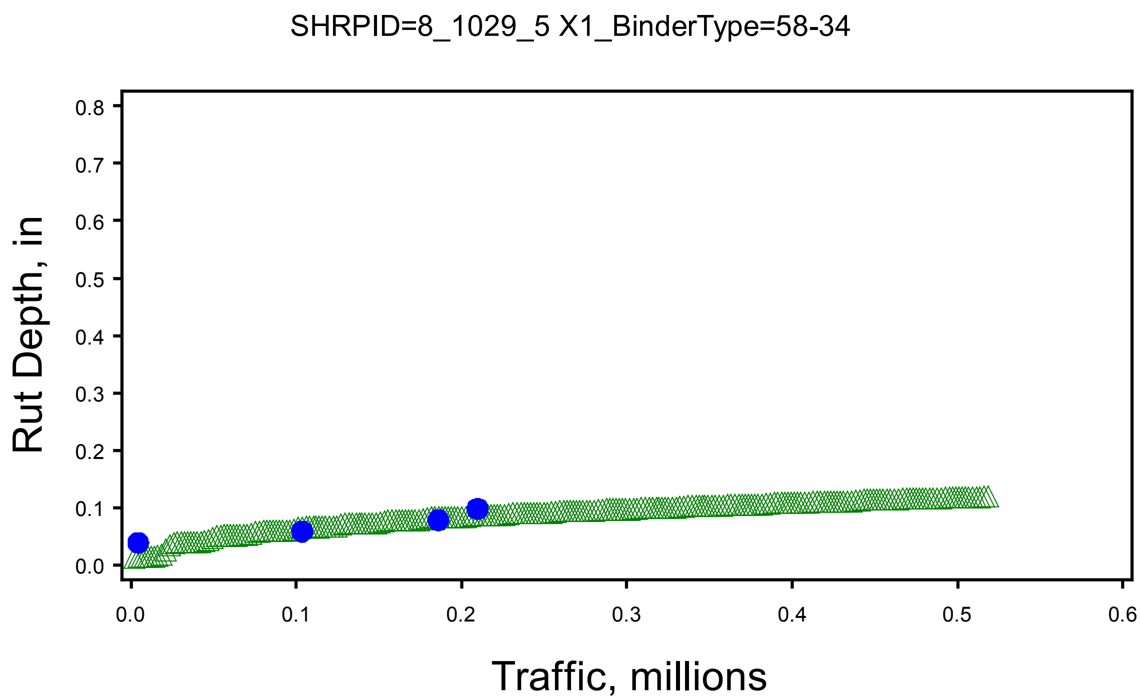

Figure 8. Plot showing predicted rutting versus truck traffic for LTPP project 1029 (AC overlaid AC pavement).

4.2 Estimating Design Reliability for New AC and AC Overlay Pavement Rutting Submodels

The MEPDG estimates pavement design reliability using estimates of rutting standard deviation for any given level of predicted rutting. Thus, for each of the three AC pavement rutting submodels, there was a need to develop a relationship between predicted rutting and the predictions standard error. Predicted rutting standard error prediction equations were developed as follows:

- Divided predicted distress into three or more intervals.
- For each interval, determine mean predicted distress and standard error (i.e., standard variation of predicted – measured distress for all the predicted distress that falls within the given interval).
- Develop a nonlinear model to fit mean predicted distress and standard error for each interval.

The resulting standard error of the estimated distress models developed using the locally calibrated CDOT AC rutting submodels are presented below:

$$SEE(ACRUT) = 0.1414 * ACRUT^{0.25} + 0.001 \quad (1)$$

$$SEE(BASERUT) = 0.0104 * BASERUT^{0.67} + 0.001 \quad (2)$$

$$SEE(SUBRUT) = 0.0663 * SUBRUT^{0.5} + 0.001 \quad (3)$$

where

SEE(ACRUT)	=	AC layer rutting standard deviation, in
SEE(BASERUT)	=	base layer rutting standard deviation, in
SEE(SUBRUT)	=	subgrade layer rutting standard deviation, in
ACRUT	=	predicted AC layer rutting, in
BASERUT	=	predicted base layer rutting, in
SUBRUT	=	predicted subgrade layer rutting, in

5.0 Validation of Rutting Model

5.1 Sensitivity Analysis

The researchers performed a comprehensive sensitivity study as the first step in validating the local CDOT MEPDG calibrated models. This was accomplished as follows:

- Selection of an analysis period of 20 years.
- Development of baseline new pavement designs (AC) with inputs that represent typical CDOT site conditions (climate, traffic, and subgrade), design and construction practices, and pavement materials:

- For AC pavement, inputs included AADTT, AC thickness, asphalt binder type, AC air voids content, AC volumetric binder content, climate, base type, base thickness, and subgrade type.

- Key inputs were varied one at a time across the range of typical values.
- Predicted outcome (rutting) was then plotted input by input to illustrate their impact on rutting.
- The impact on key performance outputs was assessed.

The baseline designs are detailed in Tables 6. The range of the key inputs used for sensitivity analysis is also presented in the table.

Figure 9 present sensitivity plots for AC pavement rutting. The plot shows for each key pavement input of interest the levels of rutting exhibited after 20 years in service. Cumulative traffic applied over the 20-year period was 9.3 million for new AC pavements.

Table 6. Mean (baseline) and range of key inputs used for sensitivity analysis of new AC pavements.

Input Parameter	Values		
	Lower End	**Mean (Baseline)**	**Upper End**
Conventional AC thickness, in	6 in	8 in	12 in
Full depth AC thickness, in	8 in		12 in
Base type	No base	Granular	ATB
Granular base thickness, in	0 in	6 in	12 in
Subgrade type	Fine grained	Coarse grained	
Air voids, percent	3%	7%	9%
Volumetric binder content, percent	7%	11%	13%
Binder type (Superpave)	PG 58-28	PG 64-22	PG 76-28
Initial AADTT	500	2000	5000
Climate (weather stations)	Lamar (Moderate) Approximate 7-day highest temperature = 94.2 ^{o}F, elevation = 3,070 ft	Denver (Moderate) Approximate 7-day highest temperature = 90.6 ^{o}F, elevation = 5,607 ft	La Veta Pass (Very cool) Approximate 7-day highest temperature = 68 ^{o}F, elevation = 10,217 ft

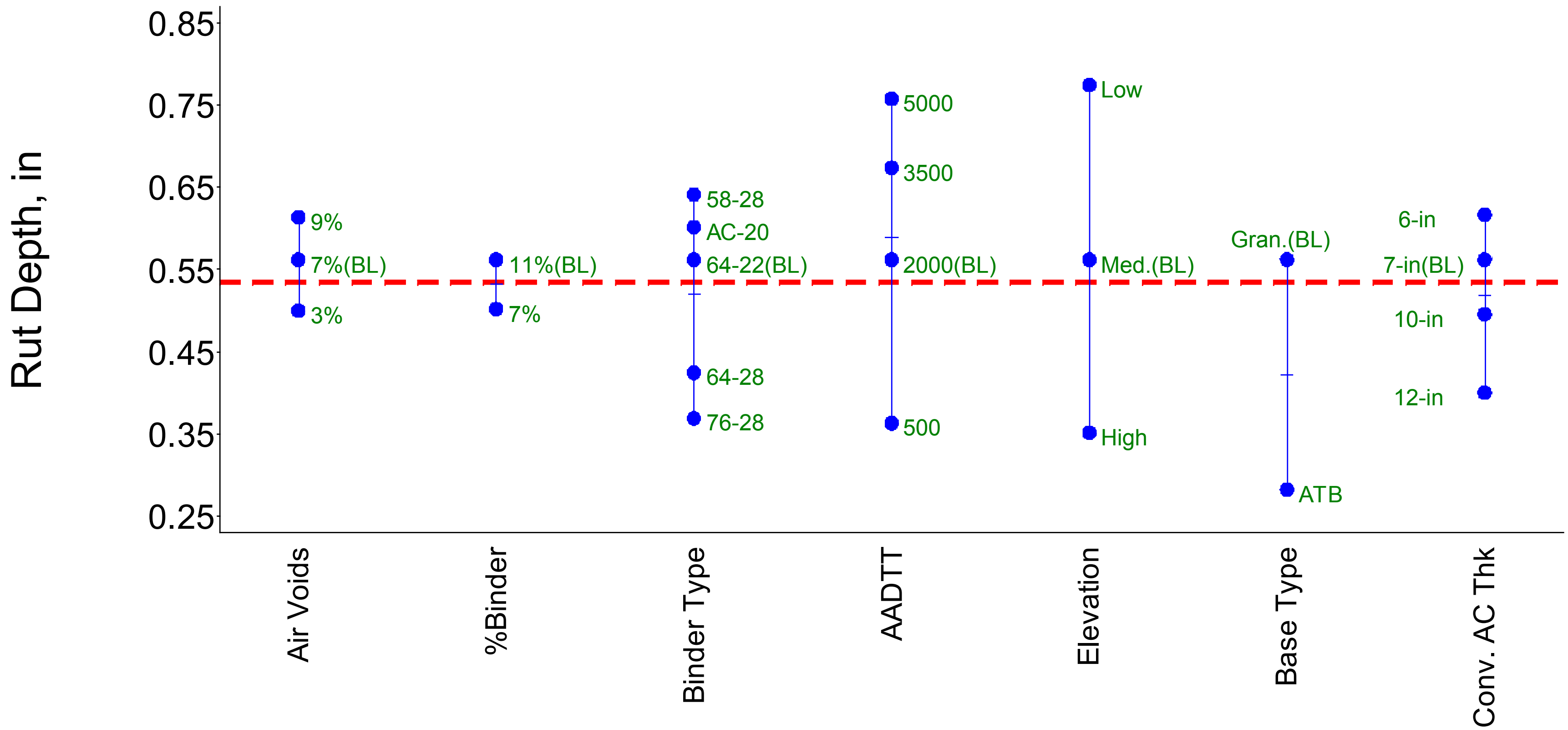

Figure 9. Sensitivity summary for AC pavement total (AC, granular base, and subgrade) rutting. Note the red line represents predicted rut depth for the baseline project in Table 6.

The sensitivity results for total rutting (AC, granular base, and subgrade) shows AADTT, AC thickness, climate, asphalt binder type, and base type are the most sensitive of the input variables analyzed. This implies that pavements with significant cumulative truck traffic applications over their design life (i.e., highly trafficked interstates) will experience significant levels of rutting if remedies such as thicker AC layers and appropriate asphalt binder type are not considered in the design.

The rutting sensitivity analysis results also show that AC pavements located in hotter climate zones exhibit significantly higher levels of rutting than comparable designs in cooler climates. These results can be explained through temperature considerations and their impact on the AC dynamic modulus E*. Low temperatures in cooler climate zones increase E*, which reduces fatigue damage and permanent deformation.

The AC mix properties (percent air voids and binder content) also had a considerable impact on rutting, although they are not the most significant. Thus, choosing and applying the right AC mix for a given climate would help mitigate the development and progression of total rutting.

5.2 Design Comparisons

The local CDOT MEPDG new pavement models (AC) were validated through direct comparison with new pavement designs obtained using the locally calibrated CDOT MEPDG and the 1993 AASHTO Pavement Design Guide.

Pavements were designed using seven test projects located throughout Colorado. Major efforts were made to apply comparable inputs for each project, regardless of the design methodology utilized. Table 7 lists the key inputs.

Table 7. Description of key inputs used for design comparisons.

Key Design Input	AASHTO 1993	CDOT Locally Calibrated MEPDG
Traffic	Comparable cumulative ESALs computed using the MEPDG traffic inputs	Cumulative number of trucks, vehicle class distribution, number of axles per truck, & axle load distribution
Subgrade soil	Resilient modulus (Mr) that is typically wet of optimum (in situ moisture)	Resilient modulus (Mr) at optimum moisture content
Climate	Appropriate drainage coefficient (Cd)	Hourly records of ambient temperature, precipitation, cloud cover, wind speed, and snowfall from the closest weather station with data available in MEPDG for CDOT's provided weather stations
Paving materials	Although the identical material types (e.g., AC, granular base, etc.) were proposed for comparable designs, required inputs differed per design methodology. As much as possible, equivalent inputs were assumed (e.g., AC dynamic modulus vs. appropriate structural coefficient)	
Reliability	Same level of design reliability were used for each direct comparison	
Performance criteria	Pavement Serviceability Index (PSI)	IRI and several distress types. Efforts were made to select IRI values that were approximately equivalent to the CDOT PSI threshold

5.2.1 New AC Pavement Design Comparisons

Table 8 shows a summary of the results from the new AC designs at seven project sites. Figure 10 shows a direct comparison of AC thicknesses achieved for all project comparisons using the two design methodologies. Table 9 shows the results of tests performed to identify possible bias in design AC thickness results. The results show very good 1-to-1 comparison between the AASHTO 1993 AC design procedure and the CDOT MEPDG design procedure for both reconstruction and overlays.

Table 8. Summary of the results from the new AC design projects.

Project Site	Traffic (No. of Trucks)	AC Design Thickness (in)	
		AASHTO 1993	CDOT MEPDG
US 285 Hampden Ave.	7.07 million	7.75	8.75
I-70 E of Mack	6.53 million	5.5	6.0
I-25 Managed Lane Denver (Reconstruction 20 years)	2.17 million	6.5	7.5
I-25 Traffic Lane Denver (Reconstruction 20 years)	30.19 million	13.5	13.5
I-25 Denver (AC Overlay 10 years)	1.01 million	4.0	4.0
US 50 East (AC Overlay 10 years)	2.78 million	4.0	4.0
US 85 Ault/Nunn	6.62 million	6.25	6.0

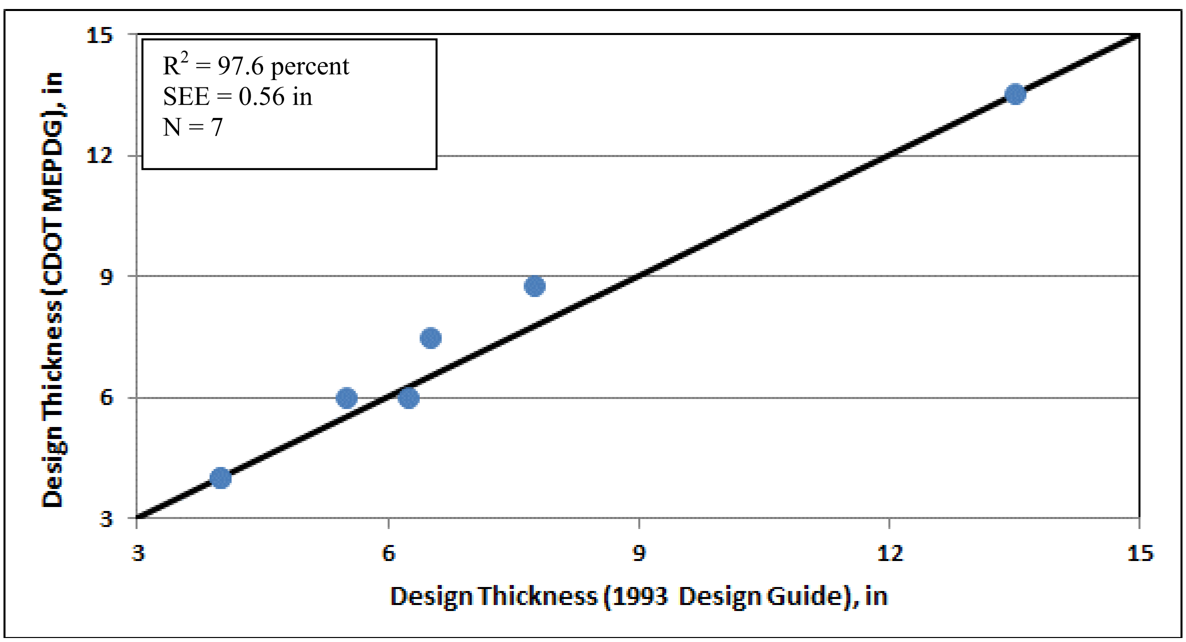

Figure 10. AASHTO 1993 AC design thickness vs. CDOT MEPDG AC design thickness.

Table 9. New AC pavement goodness of fit and bias test for final local CDOT MEPDG and 1993 AASHTO Pavement Design Guide design thicknesses.

Analysis Type	Diagnostic Statistics	Results
Goodness of Fit	R^2	97.6 percent
	SEE	0.56 in
	N	7
Bias	H_0: Intercept = 0	p-value = 0.5885
	H_0: Slope = 1.0	p-value = 0.1897
	H_0: Predicted - measured thickness = 0 (paired t-test)	p-value = 0.1495

6.0 Summary and Conclusions

The MEPDG rutting prediction models have been verified, validated, and recalibrated using Colorado LTPP and pavement management system sections. CDOT pavement sections were included in a valuable database that represents the performance of Colorado pavements over many years. The model verification and calibration effort was successful and provides CDOT with validated mix specific rutting model coefficients that can be used in version 2.0 of ME Design software.

This database was used in the verification, validation, and recalibration process to modify the prediction models to make them more accurate and unbiased (neither over- nor under-prediction). They were also used to establish Colorado design inputs and the appropriate standard deviation or error of each model for use in reliability design. This will make it possible to design a pavement in Colorado with the desired reliability at the optimum cost.

Local calibration of the MEPDG rutting models produced different calibration coefficients for $\beta r1$ for each of the three primary CDOT asphalt mixes. The PMA had the lowest value of the $\beta r1$ coefficient among three asphalt mixes, resulting in the lowest AC rutting. This is typical and as expected when compared to field performance data from in-service flexible pavements located across Colorado.

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