Project No. NCHRP 20-07/ Task 422

User Review of the AASHTO 'Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide'

FINAL REPORT

Prepared for
Transportation Research Board

of

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DISCLAIMER

User Review of the AASHTO 'Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide'

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SUMMARY/ABSTRACT

This project "User Review of the AASHTO Guide for Local Calibration of the MEPDG" was a project to prepare a critical review of the Local Calibration Guide from the viewpoint of a general pavement practitioner. The results show that local calibration is at the same time very straightforward but also more complex than anticipated. The equations used can be straightforward, and the statistical tests used are relatively standard, but the myriad of factors involved, including the need for input from practitioners to provide expertise in local calibration is evident from this review. The first two sections of this report are provided as background and support for the changes that are advocated in section 3. A detailed description of changes recommended to improve the Local Calibration Guide was developed based on this effort and is included as Section 3. It is anticipated that local calibrations performed based on an improved Local Calibration Guide developed following these recommendations will be easier to perform and also easier to compare to other local calibration efforts. As previous local calibration efforts have led to improvements in the models in the PMED software, it is expected that this will continue and therefore it is also recommended to develop a process to gather and disseminate the latest information on calibration to all users.

1. BACKGROUND AND INTRODUCTION

Pavements are the most ubiquitous and complex engineered system in our environment. Pavements connect every large city, and every small city. Pavements connect to your house, school, work, parks and other recreation areas. Millions of miles of pavement are walked, biked or driven on every day by millions of people. How can something that is everywhere be so complex? Pavements are man-made engineered systems constructed mainly using local materials, following local conditions, local history and affected by local environmental conditions and local practices. A whole area of study is devoted to geological differences and soil engineering (geotechnical engineering), which is the foundation of all pavements. Pavements are composed of different materials (aggregates, binders, fillers, etc.) that are most cost-effective if procured locally. Pavements are exposed to very different climates, ranging from the relatively constant 75 degrees F of South Florida to the below freezing temperatures of Northern Ontario. Pavements are exposed to different levels of loading, from a pavement on a major shipping route to a rural pavement connecting two remote cities. Human nature and personal preference along with the previously mentioned local conditions and history has all had some influence on the different ways pavements are structured, designed and constructed in different locations. Is it no surprise that any mechanistic model to describe the complex, diverse engineered system that we collectively call 'pavements' requires local calibration?

The mechanistic design model most widely used for pavements is AASHTOWare Pavement ME Design (PMED). PMED uses the inputs of the different materials, different layer configurations, different climates and different loadings and converts the stresses into distresses while also considering the incremental effects of environment and fatigue. PMED has been nationally calibrated with Long Term Pavement Performance (LTPP) data to address size effects and other circumstances that won't allow us to go straight from small sample test results to full-size in place field conditions without some adjustment. The PMED software is licensed worldwide. Implementation of the software is an ongoing effort, and local calibration is an important part of implementation. Local calibration is also a necessary part of validation after major software updates. The Pavement ME National Users Group recently identified local calibration and verification as the most common difficult or challenging part of implementation. In that same meeting report, 14 of the 25 responding States noted that they had performed local calibration. Based on the survey performed for this project, the number of States that have identified that they have performed local calibration is 28, with 3 others currently in process of performing local calibration. Several States have also performed local calibration more than once. Local calibration will be an ongoing process used by States as improvements are made to the PMED software, so methods to make it less challenging in practice, and especially in the minds of the users, is key. More users are performing local calibration and now is an opportune time to improve and streamline the process. Based on the volume of users and interest in this area, and the knowledge that has been gained in performing the numerous local calibrations, it is clear that changes are needed to the AASHTO Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide. It is also clear that a more automated method to perform calibrations and recalibrations is a current need of the AASHTO Pavement ME Design software Users community. As of the development of this document, that effort has already started as part of a separate AASHTOWare initiative.

This report consists of the following sections: (1) a history of AASHTO Pavement ME software versions and the changes that would affect local calibration including a summary of the Survey on Local Calibration performed in April 2018, (2) review of the current contents in the Local Calibration Guide, and (3) specific recommendations on revisions to the Local Calibration Guide. The Reference section includes standard references included in the report, but also includes a listing by State of Local Calibration reports identified, thesis reports identified, and National or other reports related to local calibration. The Appendices contain (A) listing of all current and previously documented global calibration factors and equations, (B) details from the 2018 Local Calibration survey and results (summarized in section 1) and (C) examples of what is expected in the next version of the Local Calibration Guide (as described in section 3).

1.1 Local Calibration History

AASHTO Pavement ME Design started as NCHRP Project 1-37, Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures in 1996. That project led to the much larger NCHRP 1-37a, Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures, Phase II. Table 1 provides the past and current NCHRP projects under the pavements area most related to local calibration. Other NCHRP projects have also been completed in the materials area (NCHRP 4-36 and 9-30A) but are not included here.

Table 1- NCHRP Projects Related to AASHTO Pavement ME Design

1-37A	Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures
1-40	Facilitating the Implementation of the Guide for the Design of New and Rehabilitated Pavement Structures
1-40(A)	Independent Review of the Recommended Mechanistic-Empirical Design Guide and Software
1-40(D)	User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software
1-40(D)01	Technical Assistance to NCHRP and NCHRP Project 1-40A: Versions 0.9 and 1.0 of the M-E Pavement Design Software (Flexible)

1-40(D)02	Technical Assistance to NCHRP and NCHRP Project 1-40A: Versions 0.9 and 1.0 of the M-E Pavement Design Software (Rigid)
1-41	Models for Predicting Reflection Cracking of Hot-Mix Asphalt Overlays
1-42	Top-Down Fatigue Cracking of Hot-Mix Asphalt Layers – Phase 1
1-42A	Models for Predicting Top-Down Cracking of Hot-Mix Asphalt Layers
1-47	Sensitivity Evaluation of MEPDG Performance Prediction
1-51	A Model for Incorporating Slab/Underlying Layer Interaction into the MEPDG Concrete Pavement Analysis Procedures (Completed 12/2016)
1-52	A Mechanistic-Empirical Model for Top-Down Cracking of Asphalt Pavement Layers (Active)
1-53	Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance (Active)
1-59	Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade Soils Susceptible to Shrink/Swell and/or Frost Heave on Pavement Performance (Pending)
1-61	Evaluation of Bonded Concrete Overlays on Asphalt Pavements (Active)

As noted above, a number of follow on NCHRP projects followed and continue to this day, as the most complex mechanistic based pavement design software is continuously improved. A number of these NCHRP projects have been incorporated into upgrades of the software, but projects recently completed or still in progress also will lead to changes that will impact local calibration. AASHTOWare has started a more regular schedule for future software updates. The AASHTO Website notes that none of the FY 2017 enhancements "have any impact on the transfer function calibration coefficients". It is also noted that based on a technical audit of the software a global recalibration of the flexible and semi-rigid pavements is planned in FY 2018. As these on-going projects in Table 1 emphasize, local calibration should not be considered a one-time event, but part of the evolution and improvement of the pavement design software. As the calibration factors increase in number and complexity it is increasingly relevant that a relatively standard method be developed and computerized to assist in recalibrating the software.

1.1.1 Chronology of AASHTO Pavement ME Design Software Changes related to Local Calibration

Figure 1- June 2004 MEPDG Review Software CD

In the span of less than two decades AASHTO Pavement ME Design has evolved from the original MEPDG Design Guide software CD (shown in Figure 1) based on the original NCHRP 1-37A project to the current AASHTOWare Pavement ME Design (PMED) software Version 2.4. A timeline of these changes are noted in Table 2. Note that the term MEPDG has generically been and continues to be used to describe the software and the design process collectively, even though the software name changed to DARWin-ME in 2011 and Pavement ME Design (PMED) in 2013. PMED has also been used to collectively refer to DARWin-ME and PMED. In literature published after 2013, DARWin-ME was often noted as AASHTO Pavement ME Design 1.0. But, the literature published before 2013, such as the FHWA TechBrief on the AASHTOWARE Website and research reports completed before 2013, note the 2011 version as DARWin-ME. Other references published before 2013 also use DARWin-ME to describe the software at the time, as that is what it was called before the 2013 rebranding to PMED. Based on the number of references that use PMED Version 1.0 to actually describe DARWin-ME, PMED Version 1.0 is also noted in Table 2. It should also be noted that the 2013 AASHTO Pavement-ME Version 1 software is actually the same as the previous Darwin-ME, the software itself did not change in 2013, just the name changed.

Table 2- MEPDG to DARWin-ME to AASHTO Pavement ME Design Chronology

2004	NCHRP 1-37A completed (original MEPDG) Review software provided to States (June 2004)
2007	NCHRP 1-40D Recalibration of MEPDG (MEPDG Version 1.0)
2007	AASHTO approves MEPDG as Interim AASHTO Guide
2008	NCHRP 1-40B Local Calibration and Manual of Practice project
	AASHTO MEPDG Manual of Practice, July 2008 (Interim Edition)
	Guide for Local Calibration of the MEPDG
2009	MEPDG Version 1.10 (September 2009)
2010	AASHTO Adopts Local Calibration Guide – November 2010 (current version)
2011	AASHTO DARWin-ME released (also later called Pavement ME Design Version 1.0)

	NCHRP 20-07/Task 288 complete (rigid recalibration for CTE)
2012	NCHRP 20-07/Task 317: Update of MEPDG Manual of Practice started
2013	AASHTO Pavement ME Design (PMED)Version 1 (Build 1.3.29 dated 3/26/2013)
	AASHTO PMED Educational Version released (1.5.08)
2014	January – AASHTO PMED Version 2 (Build 2.0.19) (citrix capability and layer by layer asphalt rutting added) Changes affecting calibration: asphalt rutting model
	April/May – FHWA MEPDG Local Calibration Webinars presented -Introduction to Local Calibration -Preparing for Local Calibration -Determining the Local Calibration Coefficients http://me-design.com/MEDesign/Webinars.html
	April 2014– NCHRP 20-07/Task 327 results presented to Joint Technical committee on Pavements (rigid pavement recalibration)
	July 2014- PMED Version 2 (2.1.22) (backcalculation added, subgrade moduli in sensitivity analysis added)
2015	AASHTO MEPDG Manual of Practice, Second Edition (current version) approved by AASHTO Based on PMED Version 1
	PMED Version 2 (Build 2.2) Changes affecting calibration: reflection cracking model added, added semi-rigid options, fully integrated CTE changes from NCHRP 20-07/Task 327
2016	PMED Version 2 (Build 2.3.0) Changes affecting calibration: Added SJPCP Analysis Model based on BCOA-ME
2017	PMED Version 2.4(Build 2.3.1)* - added Backcalculation Tool (BcT) Version 1.0

*The latest User Group report noted that V2.4 was the formal designation for this version, but the AASHTOWare website and the software itself note it as V2.3.1

The chronology presented in Table 2 was developed using a combination of sources: Release Notes from the AASHTOWARE website for the most recent changes (2013-current), and, literature reviews from different State local calibration studies (Iowa, Georgia, Washington State and Wyoming) for the 2004 to 2013 changes. Some of the research reports also reference MEPDG V 0.6, V 0.9, V 1.003 or V 1.1, but no dates for those changes were found in the literature. Now that the Pavement ME Design software is under the umbrella of AASHTOWare any future changes should be more controlled and accurately recorded.

The version of the software that was used to perform a local calibration is necessary to compare calibration values for different States or in a Region, it could be confusing to make comparison of precision and bias for different versions of the software if the global calibration values changed.

It should be noted that changes in the PMED software do not automatically require recalibration, even if a model in the software changes. If the Agency is not using that pavement type that is being modeled (i.e. like semi-rigid bases in PMED Build 2.2), then there is no need to recalibrate if that is the only change in the software.

1.1.2 MEPDG Users Groups

The MEPDG User Groups started with a peer exchange initiated by Wisconsin DOT in 2013 involving the Mid America AASHTO Region (MAASTO). FHWA and AASHTO expanded this in 2014 to all four AASHTO Regions (NASTO, SASHTO, MAASTO and WASHTO) in 2014. An outgrowth of this was the development of National User Group meetings. Two National meetings have been held, (1) December 14-15, 2016 in Indianapolis, Indiana and (2) October 11-12, 2017 in Denver, Colorado. The third annual National Users Group meeting is scheduled for November 7-8, 2018 in Nashville, Tennessee. Detailed Reports and Appendices for both of these meetings are available on the TPF -5 (305) Pooled-Fund website. The TPF-5(305) transportation pooled-fund study is actively supporting the MEPDG User Groups. TPF-5(305), Regional and National Implementation and Coordination of ME Design, is led by FHWA and currently includes 20 State DOTs and 2 Canadian Provinces (Manitoba Transportation, AL, AZ, CA, CO, FHWA, FL, GDOT, IA, IL, KS, KY, MDOT SHA, MI, MO, NC, ND, NV, Ontario MOT, PA, SC, VA, WI). The study site is located at: http://www.pooledfund.org/Details/Study/549.

1.2 Survey Results Summary and Discussion

A survey of the members of the AASHTO Committee on Materials and Pavements was conducted related to local calibration in April 2018. A copy of the survey and a summary of the results are found in Appendix B. An Excel document with the complete results is also available. This section provides the highlights from the short survey. Based on responses from 46 State DOTs and Ontario (47 total responses) 40% of the respondents have already implemented AASHTO PMED in some form, and another 35% are considering implementation, as shown in Figure 2. The specific States that responded to this question are as follows:

Asphalt and Concrete (15): Arizona, Colorado, Georgia, Indiana, Kentucky, Missouri, Nevada, New Jersey, New Mexico, Pennsylvania, South Carolina, Utah, Virginia, Wyoming, and Ontario

Asphalt Only (1): Maine

Concrete Only (3): California, Florida, North Dakota

No, not yet (16): Alabama, Connecticut, Delaware, Iowa, Massachusetts, Mississippi, Nebraska, New York, North Carolina, Ohio, Rhode Island, South Dakota, Tennessee, Texas, Vermont, Washington

No plans (4): Alaska, Illinois, Minnesota, New Hampshire

No, never (1): Montana

Other (6): Arkansas*, Kansas*, Maryland, Oklahoma*, Oregon, Wisconsin *currently calibrating

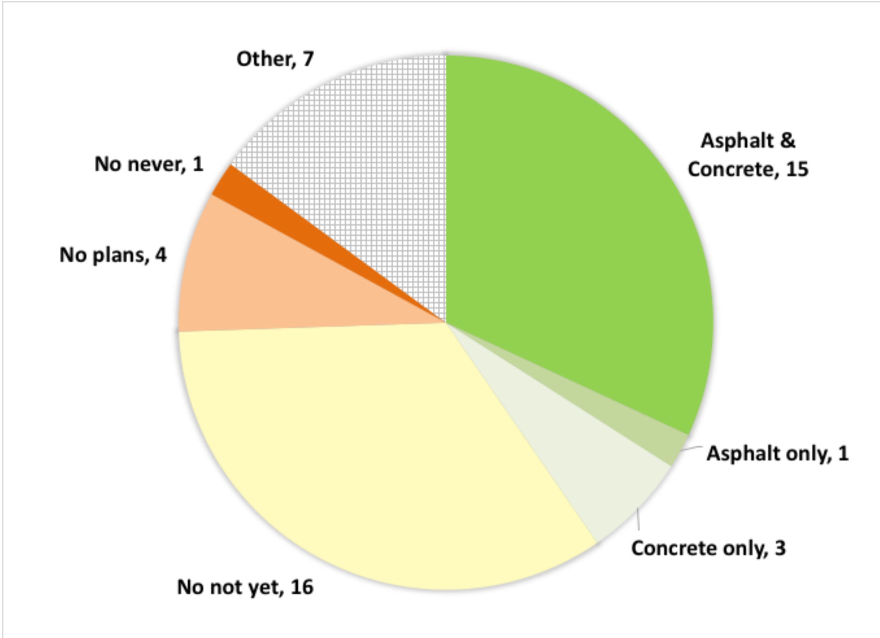

Figure 2- Do you currently use AASHTO Pavement ME either for your State/Provinces pavement designs or for comparison designs (parallel effort)?

Twenty-nine States and Ontario noted that they have performed a local calibration, as shown in Figure 3. Of these, twenty different research reports have been located that reflect local calibration efforts for different States. The individual efforts may not have calibrated all the models or they may have in a few cases only used Level 3 inputs, but it appears they all have been an effort at local calibration. Another 3 States noted as Other (Maine, Nebraska and South Carolina) in the map are in the process of calibration. Fourteen States noted they have not performed a local calibration. As shown in the map, many States in the Northeast noted they had not calibrated, some others (Maine) have been identified as performing calibration in-house. This could be an opportunity for a potential Transportation Pooled-Fund research project for local calibration of neighboring states or the region as a whole, depending upon how similar their pavement practices are.

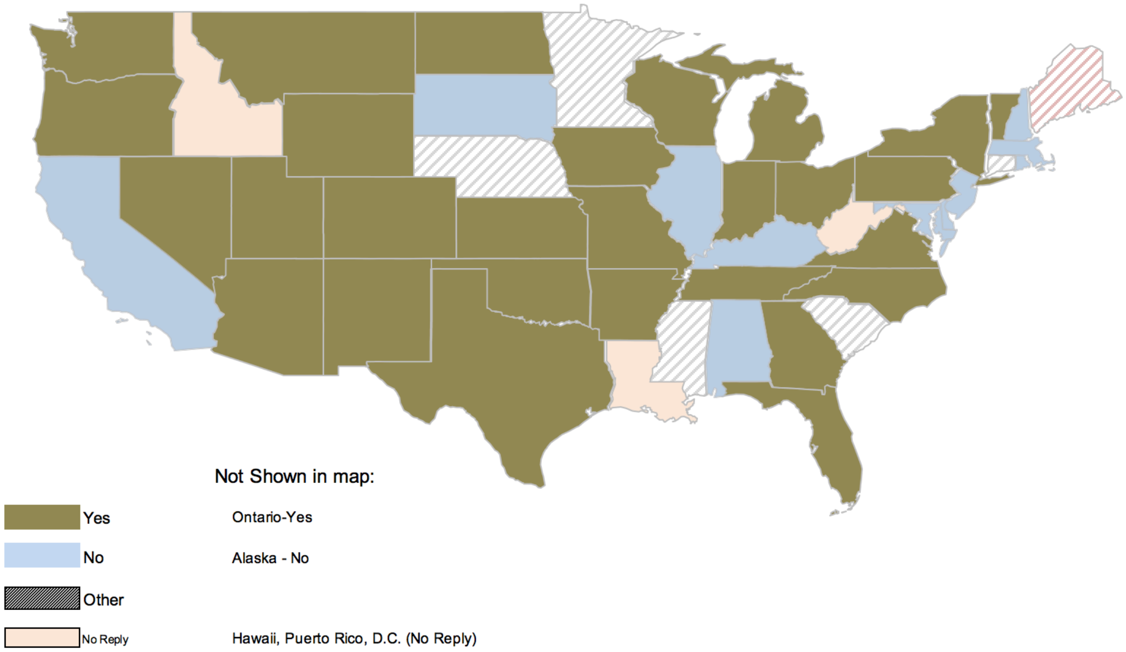

Figure 3- Have you ever performed (or contracted) a local calibration of AASHTO PMED?

Twenty-four States noted that they had performed Local calibration after 2010, when the Local Calibration Guide was first published. Twenty of these states noted that the Local Calibration Guide was used in the research. Review of the available research reports identified that they all recognized the Local Calibration Guide as a reference if they were after 2010, and many specifically referenced using the specific process in the Local Calibration Guide.

A question on specific studies related to PMED elicited the responses noted in Table 3. A number of States reported efforts in materials and traffic studies in the latest National Users Group meeting report [Pierce, 2018], and these also showed up as the most performed specialty studies in this survey.

Table 3 - Responses to "Have you performed (or contracted) specialty studies for PMED?

Specialty Studies Performed?	Number of responses
Traffic Data Analysis	26
Materials Catalog/Categorization	25
Sensitivity	20
Training	18
Climate Specific Study	11
None	6

Sensitivity studies were also identified by a high number of respondents, discussions and use of sensitivity studies was also found in the individual research reports on local calibration. Local calibration is obviously recognized as just one part of implementing PMED.

Another question was related to what conditions or issues were encountered as part of local calibration, the responses are noted in Figure 4. Sample size was identified by most. Both examples used in the current Local Calibration Guide noted sample size issues. Sample size issues also appear in the National User Group report, especially as related to JPC pavements. Other potential responses dealt with pavement management system data (PMS). At least one State noted that they used PMS data with conversions along with PMS data directly. This combination was seen in the local calibration research reports and was also shown in the examples in the Local Calibration Guide.

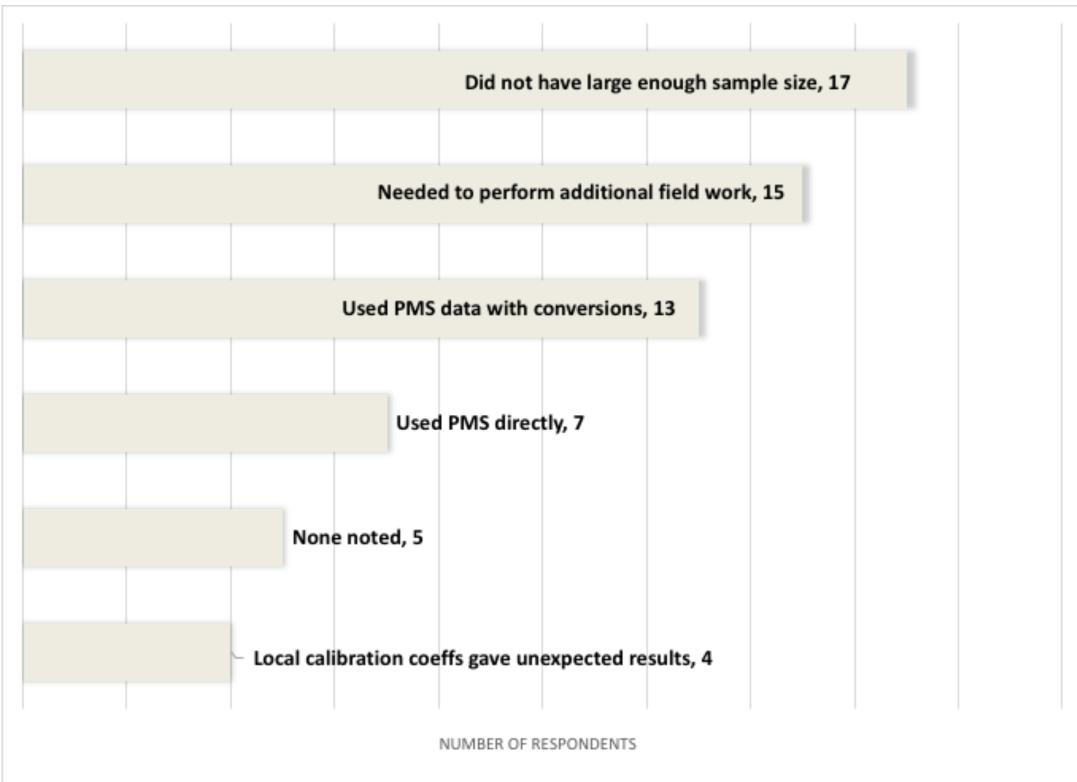

Figure 4 – Indicate any of the conditions you encountered in performing the latest local calibration (Check all that apply)

States checking the "unexpected results" included North Carolina, whose local calibration research effort identified issues with the unbound aggregate base which lead to additional research on characterizing aggregate bases [Chow et.al, 2013].

Other issues noted:

- Lack of Material inputs for older projects
- Needed new testing equipment (CTE- coefficient of thermal expansion)
- Needed to do additional materials testing

- Lack of WIM (Weigh-in-motion) data

The last question in the Survey was open-ended and requested: Did you encounter any other special situations in local calibration you can share? A portion of the responses are noted below:

- "it was found that the model in the Manual of Practice (MOP) is questionable for both the alligator and Longitudinal cracking, the standard error increases as the amount of alligator or longitudinal cracking increases."
- "cementitious stabilized material base layers were never calibrated at the national level."
- "Climatic model (soil PI, passing #200, etc.) is very sensitive to the IRI. The critical pavement performance criteria for pavement design in PavementME is always the IRI, never the fatigue cracks. To local calibrate the soil in the EICM in relation to IRI is close to impossible. "
- ""borrowed" a couple of LTPP sites from our neighboring states "
- "New materials used recently will require different calibration "
- "the major distress for new HMA pavement is top-down alligator cracking which is not modeled in MEPDG. "
- "JPC-longitudinal cracking and rutting are not modeled in MEPDG. "
- "There was either little to no cracking, or a lot of cracking in our calibration sections. "
- "major distress for"… "new (doweled) JPCP is multi-cracking (including longitudinal and transverse cracking) and rutting due to studded tire wear, but longitudinal cracking and rutting are not modeled in MEPDG."
- "Concrete cracking quantities made calibration difficult. There was either little to no cracking, or a lot of cracking in our calibration sections. During the most recent recalibration of the concrete models, a model to estimate the curl/warp input was developed. This was done to induce more cracking in our design to better match our experience with concrete."
- "Did not have any field validation of rutting per layer and our pavement management data does not distinguish between top-down and bottom-up cracking."

The comment about borrowing LTPP sites is another area where pooled-fund research may be beneficial, States could identify pavement sections that use similar materials and do a pooled-fund study to monitor those pavements as a region, like a Regional LTPP program. Comments on the lack of distress or variety of distress has also been identified in the MEPDG User Group meetings. Other comments relate to the conditions that are not modeled in the software, or specific concerns with the results of the local calibration.

1.3 Global and Local Calibration

Calibration of the AASHTO Pavement ME Design software involves correlating the measured distresses to the predicted distress from the software. A perfect correlation would have measured values = predicted values. In the real world there are differences between the measured and predicted values. The standard error of the estimate (SEE or S_e) is a measure of these differences, so it is a measure of the accuracy of the model. A smaller SEE value typically, but not always, indicates a more accurate model.

1.3.1 Global Calibration and the Manual of Practice (MOP) 2008 and 2015 Versions

Global calibration was performed for the original NCHRP 1-37A project which developed the original MEPDG software, and then again for the NCHRP 1-40 projects that also developed the Local Calibration Guide and the original Mechanistic -Empirical Pavement Design Guide, A Manual of Practice (MOP). AASHTO adopted the MOP officially in 2008. The AASHTO version (AASHTO, 2008) notes that the calibration factors included in that document are based on the 1-40D project, but the rigid calibration factors are the same as reported in the original 1-37A project. The current edition of the MOP (AASHTO, 2015) does not specify the basis for the calibration factors noted for the flexible or rigid models, although they have changed from the 2008 MOP, especially for rigid pavements (see Appendix A). It is assumed based on documentation from the NCHRP 20-07 Task 317 project (the project that was the basis for the 2015 MOP) that some of the changes from the 2008 to the 2015 version were based on documented technical errors found with the original 2008 MOP, changes to align with what was in the then current (when the project started in 2011) AASHTO DARWin-ME software, and changes to the rigid calibration factors due to the NCHRP 20-07/Task 288 project. But as shown in Appendix A, the Task 288 values are different than what is in the 2015 MOP. Some time elapsed between the completion of Task 317 and the publishing of the 2015 MOP, and therefore those changes most likely occurred during this time span.

The 2008 and 2015 version of the MOPs both note that they include the following prediction models:

HMA- Surfaced Pavements and HMA Overlays

- Total Rutting: HMA, unbound aggregate base and subgrade rutting
- Non-Load Related Transverse Cracking
- Load Related Alligator Cracking, Bottom-Up
- Load Related Longitudinal Cracking, Top-Down
- Reflective Cracking
- Smoothness

PCC Pavements and PCC Overlays

- JPC: Faulting, Load Transfer efficiency (LTE)
- JPC Transverse Cracking
- JPC joint spalling
- CRCP – LTE
- CRCP Punchouts
- Smoothness for JPC and CRCP

The 2015 MOP also identified that it changed calibration coefficients in the following models:

- HMA Rutting model (Unbound materials), ks1
- HMA Fatigue Cracking, kf2 and kf3

- HMA Thermal cracking, kt (Levels 1, 2 and 3)
- HMA Rutting model, k2r and k3r
- JPC Faulting model, C1, C2, C3, C4 and C7
- CRC punchout model, A_{PO}, alpha PO and beta PO

The effect of these changes for the Flexible and Rigid models is discussed below.

FLEXIBLE:
Based on the values of the calibration coefficients in the Current PMED software (Version 2.4-Build 2.3.0), the flexible (HMA) calibration coefficients in the software are the same as noted in the 2008 and 2015 versions of the MOP except as described below. These three changes seem minor but could have a major impact on local calibration since they affect several different models (cracking, rutting and IRI). Based on this it is questionable to compare local calibrations (i.e. SEE (S_e) values) that were performed using different versions of these values.

The HMA fatigue/load related cracking coefficients (kf2 and kf3) went from negative values to positive values. These coefficients were both non-zero exponents which related the allowable loads to the strain (kf2) and the dynamic modulus of the asphalt (kf3), respectively, as noted in the equation below. A local calibration performed using these values as negative instead of positive would not be comparable since it would totally change the equation that is being calibrated. Two recent local calibration research reports noted these values as negative as shown in Section 1.3, Table 2.

$$N_{f-HMA} = k_{f1}(C)(C_H)\beta_{f1}(\varepsilon_t)^{k_{f2}\beta_{f2}}(E_{HMA})^{k_{f3}\beta_{f3}} \qquad (5\text{-}4a)$$

The HMA rutting coefficients (k2r and k3r) were switched. The 2008 MOP k2r became the 2015 MOP k3r and viceversa. These calibration coefficients were also non-zero exponents, k2r for loading and k3r for pavement temperature as shown in the equation below. Since these were not simply linear changes, comparing different local calibrations that used these factors unswitched would also totally change the equation that is being calibrated. Two recent local calibration research report identified the switched values as shown in Section 1.3, Table 2.

$$\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{1r} k_z \varepsilon_{r(HMA)} 10^{k_{1r}} n^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}} \qquad (5\text{-}1a)$$

The HMA IRI equation includes a Site Factor component. The method to compute the SF changed from the 2008 MOP to the 2015 MOP as shown below. Based on the fact that the comparison of measured and predicted IRI in Figure 5-6 in the 2008 MOP is the exact same Figure 5-6 in the 2015 MOP, this appears to have had absolutely no effect on the calibration. But if different equations were used in local calibration a difference would be expected in calibration. Some of the reports noted in Section 1.3 used the 2008 MOP value, and some used the 2015 MOP value.

Michigan identified this difference and used the 2015 MOP value. Iowa identified a SF equation different than either of the ones noted in the MOP versions.

2008 MOP

$$SF= AGE[0.02003(PI+1) + 0.007947(Precip +1) + 0.000636(FI + 1)]$$

2015 MOP

$$SF = Age^{1.5}\left\{\ln\left[\left(Precip+1\right)\left(FI+1\right)p_{02}\right]\right\}+\left\{\ln\left[\left(Precip+1\right)\left(PI+1\right)p_{200}\right]\right\} \qquad (5\text{-}15b)$$

IOWA

$$SF= AGE[1+ 0.5556FI)(1+ p_{200}) \times 10^{-6}$$

RIGID:

Based on the values of the calibration coefficients in the Current PMED software (Version 2.4-Build 2.3.0) and the 2008 and 2015 MOP as shown in Appendix A, the rigid (JPCP and CRCP) model has been globally calibrated a number of times and therefore the global calibration coefficients have changed numerous times. Throughout the different global recalibrations, the C1 and C2 values for the Transverse cracking model and the IRI calibration coefficients (C1-C4) are the only values that stayed constant.

Realization of an issue with the method of testing the concrete coefficient of thermal expansion (CTE) drove the first separate recalibration that was completed in the 2011/2012 timeframe: NCHRP 20-07, Task 288. Unusual results using the Task 288 recalibration values, including significantly thinner pavements just due to the different calibration factors, drove the second NCHRP 20-07, Task 327, which started in 2012/2013. The concrete recalibration project, Task 327, was completed in April 2014. The recommended values from the Task 327 project are the values now in the current PMED software version 2.3. Neither the Task 288 or the Task 327 values are in the 2015 MOP, but they have both apparently have been used by States performing local calibration. Two different versions of Task 288 values were found and are noted in Appendix A, one from the Task 327 report and the other from a journal paper that described local calibration of the JPC (Mu et. al. 2016). Michigan DOT also recently identified significant slab thickness decreases between PMED Versions 2.0 and 2.2. Michigan DOT has recently recalibrated their rigid pavements again, this time to PMED version 2.3.

The Task 327 reports notes that the use of different software versions and different calibration data sets led to the concerns that prompted the need for the Task 327 project in the first place. Based on the many changes in the software it is not recommended to compare local calibrations to global calibrations (i.e. SEE (Se) values) that were performed using different definitions of global coefficients.

1.3.2 Local Calibration

As part of this project, 20 different State DOT research reports have been identified and collected that involve local calibration of MEPDG/ PMED. To prepare this document, these reports were reviewed, along with other documentation (NCHRP Reports, MEPDG User Group reports, TRB papers, and thesis documents) related to local calibration.

Based on a review of the current literature, and the changes in calibration coefficients and models, many of the local calibrations that have been performed previously have increased our overall understanding of the models used in the PMED but trying to compare these reports can be complicated. Reasons for that include the items discussed in Section 1.3.1 and:

-LCGuide left a lot of the details that were in other documents out (MEPDG 1-37A reports and Appendices, MOP), therefore the different calibration efforts, even though they did follow the LCGuide, did not perform it the same way.

-LCGuide did not explain the meaning and use of calibration coefficients, apparently relying on the MOP definitions and the discussions in the Appendix of the MEPDG, therefore some calibration efforts may have been calibrated incorrectly (i.e. changing mechanistic model coefficients using just statistical methods and no laboratory testing).

-LCGuide did not provide a clear means of consistently documenting the results of a local calibration effort, therefore it is not easy to compare different calibration efforts. Some provided SEE (S_e) values for split samples separately and some did not clearly note what global calibration factors were used.

-Since in some cases the global calibration coefficients have changed a number of times, and in some cases the mechanistic models themselves have changed, it is difficult to compare the different SEE (S_e) values, since they are based on different global calibration factors.

The LCGuide was developed in 2007/2008 and has not been updated in the decade since, but the software has changed numerous times and much knowledge has now been gained from different local calibration efforts

-Issues in the models have been identified and have led to new research for improvements to the models

-Outside factors have also complicated some of the models (i.e CTE testing issue)

Tables 3 -7 shows the results of local calibration efforts from some of the most recent State sponsored research reports. Each of these reports were performed by a different research team. Table 3 identifies the number of pavement sections that were used in the calibration and how the results were validated. As noted, the software used by the reports varied from DarWIN ME 3.1 to the latest version of the PMED (Version 2.3). Although the different SEE (S_e) values are included in the Table, due to the discussion in Section 1.3.1, comparing these values is really not recommended. Many State reports identified at least one distress that was not prevalent in their state, and the SEE (S_e) is reflective of the distress values used, so if the distress is small the SEE (S_e) will be small. This is evident in the case of Kansas in Table 3, they have an extremely low SEE (Se) value for faulting but they also have extremely low faulting. The States using more than the minimum number of sections typically used their PMS data and the ones with the smaller number of sections did field testing to confirm some of the inputs. Some States did not calibrate all the models. Even comparing specific models and using the most recent reports, the global calibration values that were used were not the same and other considerations include:

- If PMS data was used, the State had to convert their methods of collecting cracking into the method used by PMED
- The validation procedures used were not always clearly defined
- Some provided different options for local calibration factors (noted as value1|value2 in the cell)
- Different methods were used for calibration in some cases
- Some research reports identified potential errors in the previous (2008) or current MOP (2015)

Some specific facts from the latest research reports are noted below:

Iowa noted that both the FAULTMAX equation and the IRI equation for JPC in the 2008 MOP did not match the software they were using (PMED 2.1.24). (The equations are also the same in the 2015 MOP.) Iowa also defined and used additional statistical values beyond R^2 and SEE(Se) to evaluate regression models; LOE (line of equality) R^2 and MAPE(mean absolute percentage error). Although they calibrated to V2.1.24 they did report on preliminary studies comparing the results of V2.2 with their local calibration factors developed using V2.1.24. They noted differences in IRI prediction between PMED V2.1.24 and V2.2, which they attributed to changes in the Freezing Index Factor and EICM (Enhanced Integrated Climatic Model) changes. Iowa also noted that their flexible pavement distress was mainly reflective cracking, so they will need to fully recalibrate to PMED Version 2.2., which now includes the new reflection cracking model. Iowa used two approaches to IRI calibration, one using the local calibration values for the distresses and one using the national values for the distresses.

Kansas used PMS data for the distresses used for this calibration effort and Level 3 traffic, climate and materials inputs. They found differences in their HMA sections related to subgrade modulus, so they calibrated asphalt based on two levels of modulus. They did not identify any bottom-up asphalt cracking in their PMS, so they did not calibrate the asphalt bottom-up fatigue cracking model. They identified very small faulting values of mainly less than 0.01 inch in their data (The accuracy of the faulting test itself is +/- 1/32" or 0.03 inches). They did not include calibration of the JPC transverse cracking model in the report, but they noted they did calibrate the JPC IRI model.

Louisiana used a new process for fatigue and rutting, setting one of the fatigue (bf2) and rutting (br2) factors to 1 and only changing the other two, they noted the description of the process was available as a published paper [Wu et. al, 2015]. They also used a Finite Element Analysis to determine a new C1 factor for JPC cracking based on their typical 20-foot joint spacing instead of 15 ft. They checked reasonableness of their local calibration results by running 15 projects with the 1993 design and the calibrated PMED and comparing. They did not include soil-cement projects in their calibration due to concern with the reflective cracking model.

Michigan compared results for PMED V2.0, 2.2 and 2.3 in their latest report (2017). That report identified changes from V 2.0 to 2.3 that would require recalibration of the rigid pavement but not the flexible pavement. They also had a concern (similar to Iowa) that the freezing index was different between PMED V 2.0 and 2.2 and it was one of the factors that affected their results. An earlier (2015) Michigan report shared a method to compute flexible pavement rutting contribution using a transverse profile.

Virginia used PMS data in their local calibration. They did not have enough JPC sections to perform a calibration. They did not calibrate flexible top-down cracking, thermal cracking or chemically stabilized layers fatigue due to pending revisions in the software, or lack of sensitivity to Virginia's conditions. They noted a lack of initial IRI values for their projects and they were concerned that this may have been why they had difficulty in calibrating the flexible IRI model. They used residual plots to compare the rutting and fatigue errors and identified an overprediction of rutting at higher AADTT using this method. Some example designs were performed for different AADTT levels as a final check.

As the next version of the PMED software is expected to incorporate many improvements that will require recalibration, many States will benefit from a new LCGuide that incorporates the needs identified. It is also appropriate to have software that assists in local calibration to provide some consistency in the specific methods and procedures that are best practices to be used in local calibration.

As such, a new Local Calibration Guide is necessary that clearly and concisely describes the intent of the calibration coefficients and also provides an outline to document the local calibration coefficients developed to provide the most benefit to other States and to the State themselves for their future calibrations. The new LCGuide should clearly note:

Calibration coefficients that are mechanistic in nature and should be changed only based on new laboratory studies

Calibration coefficients that should/can be locally calibrated statistically

Calibration coefficients that can be adjusted based on finding a ”best fit” to the field data statistically

Calibration coefficients that can only be adjusted based on trial and error based on PMED software runs

Table 4 Global Calibration Factors and Local Factors by State

	Local Cal Guide recommendation	Arizona DarWIN ME 3.1	Iowa PMED 2.1.24	Kansas PMED 1.3	Louisiana PMED 2.0.19	Michigan PMED 2.0 and Recalibration PMED 2.3	Virginia PMED 1.3
Required N computed	**Min 30 for load related cracking**	Min 18 HMA & 21 JPC	Not noted specifically	Min 18 HMA & 21 JPC	Not noted specifically	Min 16 to 83 HMA and 11 to 101 JPC	Not noted specifically
HMA Sites		58	35 New 60 HMA o/JPC	28	71 New 33 Overlays	25 selected from original 100	52
JPC Sites		48	35	32	43	20 New 8 Rehab	JPC noted as too few to calibrate
Validation	**80/20 split or jackknife**	90/10 split sample	70/30 split	Split samples	80/20 split	Bootstrapped	Split sample & jackknife
National &Local SEE - HMA fatigue cracking	**7%**	L/14.8%	N/0.55 V/0.55	N= N/A L=N/A	N=2.91 L=2.83	**N=7.64 L=6.69	N=3.1 L=3.34
National &Local SEE - HMA rutting	**0.10 inch**	L/0.11 inch	N/0.09 V/0.09	N=.03 to .05 L=0.02	N=0.18 L=0.07	N=0.3425 L=0.0865	N=0.183 L=0.076
National & Local SEE - HMA IRI HMA over JPC	**18.9 in/mile 9.6 in/mile**	L/8.7 in/mile	N/15.21 V/15.09	N=3.4 to 6.5 L= 0.02 to 7.29 in/mi	N=15.20 L=13.15	N=14.7738 L=13.9428	N=23.99 L=27.51
National & Local SEE - JPC cracking	**7%**	L/7.25%	N/28.02% V/8.23%	Did not do cracking	N=29.77 L=8.73	N=6.07 L=4.93	-
National & Local SEE - JPC faulting	**0.05 inch**	L/0.0225 inch	N/0.24 V/0.22	<0.01 inch	N=0.034 L=0.044	N=0.059 L=0.024	-
National & Local SEE - JPC IRI	**17.1 in/mile**	L/9.85 in/mile	N/32.10 V/4.97	N=8.87 L=9.68 in/mile	N=31.36 L=23.58	N=29.89 L=9.83	-

V= Local calibration(Validation set) L= Local calibration, N= National calibration

** The Michigan report included 4 options that used different pavement sections (new, overlays and combinations), Option 1(new) is shown.

Kansas separated the analysis by subgrade modulus for flexible pavements, so 2 values are shown

Table 5- Flexible Pavements, recent State reports calibration factors

Distress	**Transfer Function Coefficient**	**Current Software PMED V 2.4 (Build 2.3.1)**	**Arizona DarWIN ME 3.1 in 2012**	**Iowa PMED 2.1.24**	**Kansas PMED 1.3**	**Louisiana PMED 2.0.19**	**Michigan PMED 2.0**	**Virginia PMED 1.3**
Fatigue Cracking	kf1	0.007566	"		"	"		
	kf2	+3.9492	"		-3.9492	-3.9492		
	kf3	+1.281	"		-1.281	-1.281		
	bf1	1.0	249.0087232	"	.01	"		42.87
	bf2	1.0	"	"	"	"		"
	bf3	1.0	1.233411397	"	"	1.05		"
	C1bottom	1.00	"	"	"	0.892	0.50 | 0.67	0.3190
	C2bottom	1.00	4.5	"	"	0.892	0.56 | 0.56	0.3190
	C3bottom/C4	6000	"	"	"	"		
	C1top	7.00		2.32	0.438 | 4.5	-	3.32 | 2.97	-
	C2top	3.5		0.47	"	-	1.25 | 1.2	-
	C4top	1000		"	36,000	-		-
	C3top	0			0	-		-
AC Rutting	k1r	-3.35412	"		"	0.1		
	k2r	1.5606	"		0.4791	0.4791		
	k3r	0.4791	"		1.5606	1.5606		
	B1r	1.0	0.69	"	0.9	0.8	0.9453	0.687
	B2r	1.0	"	1.1	"		1.3	"
	B3r	1.0	"	"	"	0.85	0.7	"
Unbound Rutting	Coarse-Grained, k_{s1}	2.03	"					
	Coarse-Grained, Bs1	1	0.14	0.001	"		0.0985	0.153
	C: $k_{s1} * Bs1$**	2.03	0.2842	0.00203				
	Fine-Grained, k_{s1}	1.35	"		"			
	Fine-Grained, Bs1	1	0.37	0.001	0.1281 | 0.3251	0.40	0.0367	0.153
	F: $k_{s1} * Bs1$**	1.35	0.4995	0.00135		0.54		

Distress	**Transfer Function Coefficient**	**Current Software PMED V 2.4 (Build 2.3.1)**	**Arizona DarWIN ME 3.1 in 2012**	**Iowa PMED 2.1.24**	**Kansas PMED 1.3**	**Louisiana PMED 2.0.19**	**Michigan PMED 2.0**	**Virginia PMED 1.3**
Thermal Transverse Cracking	Bt1 kt		L1Kt= 1.5 L2Kt= 0.5 L3Kt= 1.5	K3=1.5	K1= 1.5| 1.5 K2= 0.5| 0.5 K3 =120| 3.6	- - -	K1 = 0.75 K3 = 4	
AC IRI	C1	40.0	1.2281	5 | 25	270 | 95	"	50.372|21.43	"
	C2	0.400	0.1175	"	0.04 | 0.04	"	0.4102|0.1600	"
	C3	0.008	"	"	0.001 | 0.001	"	0.0066|0.0049	"
	C4	0.015	0.0280	0.026 | 0.019		"	0.0068|0.0271	"
	Flex o/PCC C1	40.8	-	0.13 | 25	-	-	-	-
	Flex o/PCC C2	0.575	-	"	-	-	-	-
	Flex o/PCC C3	0.0014	-	"	-	-	-	-
	Flex o/PCC C4	0.00825	-	0.02432 / 0.019	-	-	-	-
IRI Site Factor (SF)	See section 1.3.1		MOP 2015	See section 1.3.1	MOP 2015	MOP 2008	MOP 2015	Not identified

*Since the k and b factors simply multiply each other in the transfer equation for unbound rutting, the real factor ends up being k times b. Some fields are blank, in that case they did not identify the factors used.

Table 6-Rigid Pavements, recent State reports calibration factors

Distress	**Transfer Function Coefficient**	**Current Software PMED V 2.4 (Build 2.3.1)**	**Arizona DarWIN ME 3.1 in 2012**	**Iowa PMED 2.1.24**	**Kansas PMED 1.3**	**Louisiana PMED 2.0.19**	**Michigan PMED 2.3**	**Virginia PMED 1.3**
Transverse Cracking	C1	2	"	**2.25**	-	**2.75**	"	-
	C2	1.22	"	**1.4**	-	"	"	-
	C4	0.52	0.19	**4.06**	-	**1.16**	**0.16 | 0.7**	-
	C5	-2.17	-2.067	**-0.44**	-	**-1.73**	**-2.81| -1.34**	-
	Standard Deviation	3.522*POW(CRACK, 0.3415) + 0.75	POW(9.87* CRACK, 0.4012) + 0.5	**-**	**-**	POW(5.3116* CRACK,0.3903) + 2.99	**-**	-
Faulting	C1	.595	0.0355	0.85	*N(M2015)	1.5276	0.4 |0.4	-
	C2	1.636	0.1147	1.39	N(M2015)	N(M2015)	N(M2015)	-
	C3	.00217	0.004436	0.002	0.00164	0.00262	N(M2015)	-
	C4	.00444	1.1 E-07	0.274	N(M2015)	N(M2015)	N(M2015)	-
	C5	250	20000	250.8	"	"	"	-
	C6	0.47	2.0389	0.4	0.15	N(M2015)	N(M2015)	-
	C7	7.3	0.1890	1.45	0.01	N(M2015)	N(M2015)	-
	C8	400	"	"	"	"	"	-
	Standard Deviation	0.07162*POW(FAULT, 0.368) + 0.00806	POW().037 * FAULT, 0.6532) +0.001	-	-	POW(0.0097* FAULT,0.5178) + 0.014	-	-
IRI	C1	0.8203	0.6	0.11/ 0.03	"	"	0.951 |0.42	-
	C2	0.4417	3.48		"	"	2.902 | 9.39	-
	C3	1.4929	1.22	0.04 / 0.01	9.38	"	1.211 | 0.7	-
	C4	25.24	45.20	11.32 / 15.12	70	"	47.056| 33.92	-
	Initial Std Dev	5.4	"	-	-	-	-	-

*N(M2015) denotes the national values in the 2015 MOP, see Appendix A
Kansas did not calibrate transverse cracking and Virginia did not calibrate JPC

Table 7- CRCP, recent State reports calibration factors

	Transfer Function Coefficient	**Current Software**	**Arizona**	**Virginia**
# CRCP sites			**2**	**17**
CRCP Punchouts	C1	2.0	"	N(M2015)
	C2	1.22	"	N(M2015)
	C3	107.73	85	114.76
	C4	2.475	1.4149	N(M2015)
	C5	-0.785	-0.8061	N(M2015)
	Standard Deviation	2.208*POW(PO, 0.5316)	1.5+ 2.9622* POW(PO,0.4356)	
IRI, CRCP	C1	3.15	"	N(M2015)
	C2	28.35	"	N(M2015)
	Standard Error	5.4	"	

2. CURRENT CONTENTS OF THE LOCAL CALIBRATION GUIDE

As part of this project, the existing “Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide” was categorized by content, purpose and understandability. The results of this effort are presented in this section. General/summary comments are provided at the end of this Chapter. Nomenclature used:

- The ‘MOP’ is the 2015 edition of the AASHTO Manual of Practice
- MEPDG is the previous term for the AASHTO PMED software
- SEE is the term used here to describe the standard error of the estimate (also noted as Se in the Local Calibration Guide). It is factor that relates to the difference between the actual and measured values in calibration.

2.1 Categorized Contents of the Local Calibration Guide

- The Headings for each Section in the Local Calibration Guide is noted below in **BOLD**.
- The review of purpose and content are provided under the bolded headings in *italics*.

Guide for the Local Calibration of the Mechanical-Empirical Pavement Design Guide

1.0 INTRODUCTION

The introduction very generally familiarizes the reader to the MEPDG design procedure by presenting the Conceptual Flow chart for the MEPDG Design process. Distress prediction models (transfer functions), calibration and validation are also discussed in a very generic manner. The Introduction also notes that the performance models in the MEPDG were calibrated on a global level.

2.0 TERMINOLOGY AND DEFINITION OF TERMS

2.1 Statistical Terms

Basic statistical terms are introduced alphabetically and defined without use of any graphs or examples or relationships to other terms. One term, Verification, is noted that it is not included in the Local Calibration Guide, but it is defined.

2.2 MEPDG Calibration Terms

This section also is a list of definitions. Five terms are noted, but two simply reference a term in Section 2.1. Terms are alphabetical and no relation between the terms is clearly stated. The MOP is referenced in relation to two of the definitions (Calibration factors and Reliability).

2.3 Hierarchical Input Level Terms

This section is the same as what is in the current MOP as Chapter 4.2. It defines the Input Levels 1, 2 and 3.

2.4 Distress or Performance Indicator Terms

This section is very similar to what is in the current MOP as Chapter 4.5 and 4.6. It defines the different distresses (alligator cracking, longitudinal cracking, etc.). It also provides a reasonable SEE [standard error of the estimate (s_e)] for some of the distresses (which is not in the MOP 4.5 & 4.6).

3.0 SIGNIFICANCE AND USE

The importance of the SEE [standard error of the estimate (s_e)] is discussed in this section. It also notes that only the transfer functions or statistical models are calibrated, the mathematical models are assumed to be accurate.

4.0 DEFINING ACCURACY OF MEPDG PREDICTION MODELS

4.1 Calibration

This section describes bias and precision in a model. It identifies methods to evaluate goodness-of-fit (method of least squares using multiple regression, stepwise regression, principal component analysis and principal component regression analysis) but does not describe them. It references a NCHRP report that describes jackknifing. It notes that two approaches are warranted: one for models that directly calculate magnitude of distress (i.e. rutting) and one for incremental damage models (i.e. HMA fatigue cracking). It does not provide an example of how these would be handled differently.

4.2 Validation

This section describes the basics of validation: an additional and independent set of data to test the calibration. It mentions using chi-square or t-tests on SEE (s_e) to provide a check on validation.
It notes the null hypothesis (predicted values are not statistically different than measured values) should be checked for each performance indicator. It also suggests a 80/20 split sample for calibration/validation.

4.3 General Approach to Local Calibration-Validation
4.3.1 Traditional Approach—Split-Sample
4.3.2 Jack-knife Testing—An Experimental Approach to Refine Model Validation

These sections define standard split sample and jackknife testing separately and then it goes on to recommend a split sample jack-knifing procedure which is not fully described, only referenced as part of NCHRP Project 9-30.

5.0 COMPONENTS OF THE STANDARD ERROR OF THE ESTIMATE

This section introduces 4 sources of model error: measurement error, input error, model or lack-of-fit error and pure error. The relationship between the individual error terms and the dependencies (Distress/IRI, Input Level and Prediction Model) are noted. The errors are further defined in the next sections. This section does not clearly describe how these errors are related to calibration.

5.1 Distress/IRI Measurement Error

This error is Distress/IRI dependent and is different for different distress types based on how the distress is measured (can the measurement be repeated, reproduced, and how variable is the distress). Example: mean rut depth is an estimate of the true mean value)

5.2 Estimated Input Error

The error based on estimating a value, such as using two HMA samples to represent a true mean value. The error is described as being composed of three parts: testing error, sampling error and inherent variation of the material properties.

5.3 Model or Lack-of-Fit Error

Error due to the model (transfer function or mathematical model). Caused by inappropriate assumptions, model simplicity or inadequate form. Example: assuming uniform tire pressure is not reality.

5.4 Pure Error

Normal variation between distress values. Dependent on the input level, distress type and prediction equation. Need replicate sections to compare to identify pure error.

6.0 STEP-BY-STEP PROCEDURE FOR LOCAL CALIBRATION

The local calibration flowchart includes 11 steps which are described in this section. Just the headings are provided here. More detailed examination of these sections are included in Section 3.2 of this document.
Step 1 – Define input levels
Step 2- Develop Sampling Template
Step 3-Estimate sample size
Step 4- Select roadway projects
Step 5- Extract Distress Data
Step 6- Conduct Field and Forensic Investigations
Step 7- Assess Local Bias of Global Calibration Factors
Step 8- Eliminate Local Bias
Step 9- Assess the SEE (S_e)
Step 10- Reduce SEE (S_e)
Step 11- Interpretation of Results

7.0 REFERENCED DOCUMENTS AND STANDARDS

7.1 Referenced Documents

7.2 Test Protocols and Standards

List of 7 Referenced documents, mainly NCHRP reports, and 5 AASHTO Test standards on distress measurements (i.e. faulting, IRI).

APPENDIX: EXAMPLES AND DEMONSTRATIONS FOR LOCAL CALIBRATION

A1: Background

- *This section notes that the MEPDG was globally calibrated but provides reasons why local calibration would be beneficial also. Data for the examples are from Kansas DOT for the flexible example and from Missouri DOT for the JPC example. Specific notes for* *the flexible and JPC examples are noted under each heading, comments related to both examples are noted here:*

- *Both examples are based on an 'expedited time frame' and do not have enough samples.*
- *They each show a 'simplified' sampling template, not a recommended template.*
- *The factorials are unbalanced and do not have replication in either example.*
- *Estimated number of segments needed are noted for both examples but how they were computed was not shown.*
- *The use of 50% reliability as noted in Step 7 is not clearly noted.*
- *Wording in the examples repeats wording found in the Local calibration guide, without adding additional context.*
- *No examples were provided for how statistical parameters were computed. The sections chosen had very little distress in some cases.*

A2: New Flexible Pavements and Rehabilitation of Flexible Pavements

A2.1 Demonstration 1 -PMS Data and Local Calibration

A2.2 Demonstration 2 – LTPP Data and Local Calibration

A2.3 Summary for Local /Regional Calibration Values

- *The example separates PMS data and LTPP data*
- *A value for s_e/s_y was selected as 0.5 without justification, it was just noted as low*
- *A range for observation timing was noted as acceptable, but an unacceptable value is not noted*
- *It appears that the sample size was too small to reject the null hypothesis (A-14), that should have been noted*
- *Color coding of graphs would assist in seeing patterns*
- *ANOVA is noted as being used in Step 8, but the Local Cal Guide does not mention ANOVA*
- *Bf1, bf2 and bf3 noted on A-24 and A-25 is not a calibration coefficient noted in Table 6-1 of the Local Calibration Guide but they are in the MOP*
- *Used different Input levels for the examples and did not discuss reasons for that*
- *A-40 suggests using WINJULEA or an elastic layer program to calculate unbound aggregate stresses- no discussion of this is in the Local Calibration Guide*
- *A-48 provides suggestions on how to adjust bs1 term for rutting- not in the body of the Guide*
- *Table A2-15 shows calibration factors for out of spec material, is that realistic?*
- *A-53 describes how to adjust bf1, bf2, bf3 and c2 for fatigue cracking- not in body of Guide*
- *A-68 notes to use the local calibration values for fatigue but use the global SEE but does not explain why*

A3: New Rigid Pavements- Jointed Plain Concrete Pavements

A3.1 Demonstration 3 -LTPP and PMS Data and Local Calibration

- *The equations noted under Table A3-5 use different nomenclature than the equations in Step 3 of the Guide.*

- *The discussion on the faulting Coefficients (page A-111 and A-114) and what they affect would be more valuable in the body of the report*
- *A-117 recommends a comprehensive sensitivity analysis be performed but provides no references or other recommendations*

2.2 Minimum Information Necessary to Perform Local Calibration

The minimum information necessary to perform local calibration and whether it is in the current Local Calibration Guide (LC Guide) is noted in Table 8:

Table 8- Minimum information necessary to perform Local Calibration

In LC Guide	Partially in LC Guide	Not in LC Guide
Local Calibration Process Flow Chart (current LC Guide Chapter 6)	Calibration factors & transfer equations	Basic description of what all the calibration factors affect/relate to
	Statistical methods and examples	National SEE terms to evaluate local calibration (does not now include the current ones)
	Distress definitions used in PMED	
	Examples of how best to use PMS data that is not exactly as defined	

Not all of the calibration factors are included in the current Local Calibration Guide, and very few of the transfer equations are included. The Manual of Practice (MOP) Chapter 5 includes the transfer equations but does not always define the relationship between the calibration factors, in some cases the original NCHRP 1-37A documents and Appendices are required. The statistics that are included in the Guide could be explained better with figures and consistent nomenclature. Statistics that are mentioned but not shown should be presented with examples for clarity.

2.3 General/Summary Comments on Current Local Calibration Guide

The calibration steps described in the Local Calibration Guide have been used by many researchers and although improvements have been incorporated by others, the basic steps have stood the test of time. With more entities performing local calibration, the relation of practitioners being involved in local calibration to the success of implementation has been acknowledged. Over the last decade, statistical methods and concepts have become more mainstream, and so the terminology needs to be updated to address and engage the non-statistician. The Examples provided in the Guide were based on the best data at the time, but the amount and quality of data that was used in the Examples over 10 years ago is now considered inadequate. Due to these considerations, and since the body of the LCGuide (Sections 1-7) is only 33 pages in length, (only 16% of the volume of the entire document- the entire document is 202 pages, including front matter and back cover) and the Examples make up the bulk of the Guide, it is appropriate to revise and update the Local Calibration Guide.

Some concerns with the current Guide document is that it does not lay out the framework/procedure until almost the last Section (Section 6) and the Guide does not have enough information to perform a local calibration. The Manual of Practice (MOP) is necessary to even set up the equations to do any sort of analysis. The MOP is now included in the AASHTO Pavement ME Software as part of the Help screens but searching for equations and copying them from a help screen is not ideal. It is noted that some calibration factors can be adjusted outside the software and other must be adjusted by running the software, but this is not clearly delineated. Specific concerns:

- Written like a research report, not a Guide.
- Two of the sections are replicated in the MOP (Section 2.3 and 2.4) [It actually appears that when the MOP was updated in 2015 information from these sections from the Local Calibration Guide were added to the MOP]
- Inconsistent format and nomenclature in many places makes it confusing ('Users Manual' and 'Manual of Practice' are both used to describe the MOP on the same page; pavement distress prediction models, transfer functions and performance models all used interchangeably; standard error of the estimate changes from S_e in the body to SEE in the Appendix)
- Does not include all the calibration factors in the software (at the time of print and now)
- Does not include enough information on how best to change calibration factors or enough information on interrelation of the calibration coefficients and models (i.e adjust IRI last)
- Does not include all the transfer function equations that are being calibrated
- Examples both did not have enough samples to match what is recommended
- Examples both noted they were performed in an "expedited manner"

As such the Local Calibration Guide is not a stand-alone document, since it relies on the Manual of Practice (MOP -specifically Chapter 5) and the APPENDICES to the NCHRP 1-37A report, and even though it does reference the MOP and NCHRP 1-37A it does not clearly state that they are absolutely necessary for understanding and performing local calibration correctly.

The statistics noted in Sections 2, 4 and 5 are mainly traditional statistics, but they could be explained better with some simple graphs and consistent nomenclature. The Examples do not provide examples of exactly how the statistics are computed, and in cases the nomenclature is different for the statistical terms in Section 6 and the Examples in the Appendix.

3. PROPOSED SPECIFIC REVISIONS TO THE LOCAL CALIBRATION GUIDE

The following provides recommended revisions to the Guide for Local Calibration of the Mechanistic -Empirical Pavement Design Guide. First, general recommendations are presented, then each section of the proposed revised Local Calibration Guide is covered in detail. The Title of the Guide is also recommended to be revised: 'Guide for the Local Calibration of the AASHTOWare Pavement ME Design Software' is suggested.

NOTE, these are the standard conventions used in the recommendations that follow, others can be used in the Guide, just as long as they are defined and used consistently:

- MOP is used for the Manual of Practice
- LCGuide is used for the Local Calibration Guide
- LCPMED is used for the new, revised Guide for Local Calibration of AASHTOWare Pavement ME Design Software

3.1 GENERAL REVISIONS

In an effort to improve the usefulness of the LCPMED, first it should be reorganized to focus on the calibration steps:

- The Local Calibration Flow Chart (Existing LCGuide Fig 6-1 and 6-2) should be in the Introduction. Each new Section will be one part of the Step-by-Step procedure (or: current Section 6 of the LCGuide turns into new Sections 1-11 of the LCPMED)
    - New Sections 1-11, (which describe the step-by-step procedure) should provide examples of generic tables and matrices, statistical values, with computations or reference location in Appendix with examples
    - Statistical terms should be described for a more general audience (not statisticians) using graphics if possible and including an example of how to specifically compute
    - Statistical terms that are used repeatedly should be in an Appendix (i.e. appendix would describe model error terms, hypothesis testing, calibration and validation and provide a general example of each, if one is not in the Body of the document)
    - The Appendices should include:
        - A. General "Lessons Learned" in performing local calibration
        - B. Statistical definitions and discussions

Existing LCGuide Sections 1-5 are removed. Some parts of these sections can be included in the new Sections as noted specifically below in the Detailed Recommendations, or part of the new Appendix B related to statistical terms. Others, including the Examples in the existing Appendix, will not be included or used.

Each Step in the procedure needs more guidance and some specific examples of what is reasonable or expected. Statistical explanations in the Body and Appendix B of the document should include figures and graphs to better explain their meaning. The three PMED Local Calibration webinars provided some of these types of examples in both generic and State specific cases. A very simple example from the PMED webinar, that is not in the body of the existing LCGuide, is shown in Figure 5.

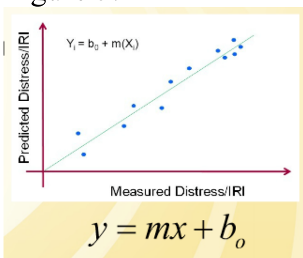

Figure 5 - Hypothesis testing

Generic examples should be used as much as possible in the Guide, since State specific examples may not always translate well to other conditions/States. Consistent nomenclature is imperative for ease of use and understanding. Using the specific terms and calibration constants consistent to what is in the PMED software would provide a needed link to the software. Additional quality control should be performed to assure that the equations and default calibration factors are accurate, as problems with local calibration due to errors in the MOP have been noted in the literature.

Specific State reports are noted in the Detailed Recommendation section below to provide potential examples to be used or considered in the revision (the State is noted in italics and corresponds to the list of State Calibration Reports in the Appendix of the final Review report, these reports will be placed on the AASHTOWARE website for ease of access). Additional guidance should be mined from the three PMED local calibration webinars located on the me-design.com website.

It is also recommended that the rewrite of the Guide only be performed by an entity that has actually completed a local calibration effort. The intricacies and interrelationships of the steps and statistical methods can be underestimated and not fully understood by someone that has not been fully involved in local calibration. The final rewrite should be reviewed by a layperson that is not as familiar with the statistics or the local calibration process.

3.2 DETAILED DESCRIPTION OF NEW LOCAL CALIBRATION GUIDE

The following specific revisions (by proposed new Section) are recommended for the new LCPMED:

New Title:
Guide for the Local Calibration of the AASHTOWare Pavement ME Design Software

Introduction
The current description in paragraph 1 needs to be updated but overall it is appropriate. Other paragraphs need to be revised. Content is too repetitive, too technical/statistical and in places unclear. This section needs to include the Local Calibration Flowchart. The Introduction should include a description of how Steps 1-6 relate to Steps 7-11 and how setting up Steps 1-6 correctly and judiciously could assist in the inevitable redoing of Steps 7-11 when needed (i.e. major software changes). A caution on adding bias into recalibration due to improper site selection is also warranted. A description of how the LCPMED is arranged should be provided.

Section 1 – Select Hierarchical Input Level for Each Input Parameter
The existing description in the LCGuide is acceptable. The input level terms can be described here like in the current Section 2.3 of the LCGuide or preferably the MOP Chapter 4.2 should just be referenced, since the exact same information is located there.
ADD: Sensitivity analysis should also be considered and described here as it relates to a state specific calibration. Local typical pavement sections, the range of traffic levels found in the state, and, any special climatic or materials conditions should all be identified as part of this step, even though they are not used until Step 5. (*Louisiana (Figure 5 and 7)* provides good examples of identifying typical pavement sections.) National sensitivity studies such as NCHRP 1-47 Final Report (or Research Results Digest 372) should be referenced and applicable results noted in this step, especially as related to factors that are sensitive but are not as easy to collect (i.e. HMA E* master curve data was found to be sensitive but requires laboratory testing; JPC slab width was found to be sensitive but relatively easy to get). It should also be noted that NCHRP 1-47 was based on MEPDG Version 1.1 (2009 release), and the models in the latest version of AASHTO Pavement ME Design are different, therefore, if more recent sensitivity studies are available or if a State has a local sensitivity study that should be consulted and referenced. Michigan noted performing a State specific sensitivity study in their calibration report *(Michigan, Section 2.4.1).*

A generic Input Level Table should be presented to provide a relatively constant method to identify all the factors that should be considered for input levels, the Table should also indicate the values that are somewhat set (i.e. tire pressure, tire spacing, traffic wander are almost always going to be input level 3). It should be specifically stated that it is acceptable to mix input levels, since to combine LTPP data and PMS data that would be necessary. Reports from *Colorado (Table 21), Michigan (Table 3-26)*, the MOP (Table 5-1) and NCHRP Synthesis 457 (Table 9) should be reviewed for examples of Tables to use, but a Generic Input Level Table should be provided in the LCPMED.

Section 2- Develop Local Experimental Plan and Sampling Template
The existing description in the LCGuide is acceptable, except for the last two paragraphs (Paragraph 3 that starts with "The sampling template…" and Paragraph/sentence 4 that starts with "Most cells.."). These paragraphs need to be rewritten in less of a "Design of Experiments" verbiage or left in as a note to statisticians and a better description also provided. Blocking or blocked needs to be defined in a more general manner (i.e. grouping conditions that are expected to behave similarly). Sample templates can be used to better describe the idea of a fractional factorial matrix and blocking. An example from the PMED webinar is shown below in Figure 6. Other specific recommendations from the webinar include: try to keep it simple, identify a

primary tier, identify potential unusual factors by looking at your data. The thickness and climate typically lead as primary tiers.

PCC Thick, in	Dowels	Edge Support	Subgrade Type: Coarse (A-1 through A-3)		Subgrade Type: Fine (A-4 through A-7)	
			Base Type: LCB	Granular & ATB	LCB	Granular & ATB
≤ 10	No	No				
		Yes				
	Yes	No				
		Yes				
> 10	No	No				
		Yes				
	Yes	No				
		Yes				

Arizona DOT Template for Rigid Pavements

Figure 6- Example of Sampling Template

Replicate projects should be described as benefitting minimizing error of the model, using the explanation of replicate from Note 2 from the existing LCGuide.
ADD: A generic Sampling Template should be presented for both Flexible and Rigid pavements to provide a relatively consistent method to address sampling design. Reports from states such as *Missouri (Table 1), Arizona (Table 11 & 12)*, *Virginia (Table 4 & 5), Louisiana (Table 5)* should be reviewed for examples of Templates to use, but a Generic Sampling Template or Templates should be provided in the LCPMED. *Kansas (Table 3.13 and 3.14)* had an unusual sampling template based on Subgrade M_r, it would also be good to include an example of an unusual template like this and the reasons behind it.

Section 3-Estimate Sample Size for Specific Distress Prediction Models

The existing description in the LCGuide, paragraph 1 is acceptable. The remainder needs to be rewritten with consistent terminology and an example of how to actually compute the sample size (using theoretical data). The formula and guidance in the Guide, shown below, should also be reviewed and revised if necessary based on the following comments.

$$N \geq \left(\frac{t s_y}{e_t}\right)^2$$ Equation (6-1) from Local Calibration Guide

The equation noted appears related to the classis Cochran's sample size formula (Cochran, William G. (1977) *Sampling Techniques, 3rd Edition*, John Wiley and Sons, New York, NY.), which is based on proportions needed for a representative sample, based on the estimated proportions expected to be encountered. Cochran's sample size is computed by multiplying a Z^2 value to the result of dividing the variability (p*q) squared (which a maximum variability could be construed as a threshold) by the desired precision squared (or tolerable bias), as shown below.

Cochran's Sample size $N = \frac{Z^2 pq}{e^2}$

It is not clear if this value recognizes or is affected by the method of validation (i.e. spilt sample vs jack-knifing). It was shown in one report (Michigan, Table 3-3) that if you use the same value (i.e. 90%) for the confidence interval and reliability (which many State reports did) the equation in 6-1 simplifies to the square of the distress threshold divided by the standard deviation of the distress as noted below.

$$N \sim \left(\frac{distress\ threshold}{S_e\ (standard\ deviation)}\right)^2 \text{ if C.I. interval = reliability} \quad (1)$$

The values that are included in the current LCGuide example (Table A2-5) does not appear to follow this equation, the N values noted are only the threshold values divided by the S_e, they are not squared, making the N values much lower. In all the State reports reviewed the N computed for Flexible pavements IRI is much higher (3 to 4 times) than that needed for the individual distresses of cracking and rutting, but then in most cases the IRI value is noted as being neglected based on the argument that if the distresses are accurately modeled then the IRI will be accurate. This argument needs to be revisited and specifically addressed for reasonableness.

It should also be noted that using equation (6-1) from the LCGuide, if a State has a lower distress threshold than the Nationally calibrated model, the required N for that distress for that State will be lower. At the same time, it has been documented that it is harder to calibrate correctly with low levels of distress, so this result does not appear appropriate and it may require the use of a different equation, or the use of a minimum value for sample size in all cases, like the "standard minimum" 30 samples used in most statistics text books.

ADD: Many State local calibration reports did reference the minimum values shown on Page 6-5 of the current LCGuide. The report that is referenced in the existing LCGuide for these values (Rada, 1999) does not have an example of how these were computed. Since the minimum values given in the LCGuide apparently are being used the most they should also be re-evaluated and any stipulations with using these instead of computing a value should be emphasized. The actual distress values and SEE (S_e)values that were used in calculating the minimum values should also be included in the LCPMED to provide an ability to judge if these are applicable to different situations.

Section 4- Select Roadway Segments

The existing description in the LCGuide needs to be updated to reflect the wording used in new Section 2, it should also refer to the new Section 2 template. Since only one report (Guo, 2013) has been found using accelerated pavement testing in local calibration, the value of including descriptions of experiment test sections 2 and 3 on page 6-6 is questioned and it is recommended to be removed. The factors included in the three bullets on the bottom of page 6-6 and the top of page 6-7 were referenced by many reports and although they should be reviewed and updated as necessary, the information should remain as part of this section.

ADD: Suggestions or example on how to select roadway segments should be included. Some State reports identified sections geographically by selecting a number of sites from each District (*Virginia*), some convened a group of experts (*Missouri),* one did it through a separate research project that looked at data in the existing PMS (*Georgia*) and some did not describe how it was done. Geographic Information Systems (GIS) should also be referenced in this section as a tool to assist in project selection. Important factors should be addressed, such as having high enough distress levels and variability of distress, availability of input values to match desired input levels and how State procedures and policies can affect the factors.

Section 5- Extract and Evaluate Distress and Project Data

The existing description in the LCGuide needs to be updated. The Local Calibration of the MEPDG using Pavement Management Systems (FHWA HIF-11-026) document should be referenced. The three steps (5.1, 5.2, 5.3) are still applicable but the descriptions need to be updated also.

Step 5.1: The AASHTO References need to be reviewed and updated to the current standards. The two options under Step 5.1 need to be updated, with the new HPMS requirements States have already had to identify some method to convert some of their data to LTPP definitions (especially cracking) or they are collecting it specifically in LTPP format for the HPMS sections, either way this section needs to be updated in light of that information.

Step 5.2: The existing description in the LCGuide appears appropriate, but it does not address what to do if the maximum distress values are lower than the threshold values. This was identified in many of the local calibration research reports. Do you reexamine your non-selected pavements to try to identify pavements with higher distress, at a potential cost of more variability of input data? Do you specifically identify pavements that can be left unmaintained to gather additional distress data for the future?
ADD: A recommendation or suggestions should be provided.

Step 5.3: The existing description in the LCGuide is appropriate but does need to be updated and the last three paragraphs, which are heavy on statistical terms needs to be written in a more general manner. Reference to sections that are not included in the new LCPMED (i.e. Section 5) should be revised.
ADD: Chapter 9 of the MOP should be referenced for the field test portion. An additional paragraph should be added recommending the researcher to label any time series graphs used for analysis with location (road number, county), year and age of the pavement section and not just a number label and age. The DOT personnel may be able to assist in analysis of outliers if they have these details easily accessible when viewing the graphs. This also warrants a discussion on the need for the modelers and data owners to discuss and review any anomalies in the data together.

Section 6- Conduct Field and Forensic Investigations

Step 6.1: The existing description in the LCGuide is acceptable.

Step 6.2: The existing description in the LCGuide, in general, is appropriate. Taking cores for HMA cracking initiation was identified in the research reports. An issue with this that should be noted is that it is difficult to confirm bottom-up cracking, but top-down cracking can be confirmed. Potentially due to issues with the rutting model and the changes to the rut model that only recently allowed the rutting to be characterized by layer, or the cost and inconvenience of trenching, trenching was rarely identified in the research reports reviewed. An exception was Colorado. *Colorado (Table 29)* trenched 3 sites and identified 50-70% of the rutting in the asphalt layers, 5-20% in the aggregate base and close to 25% for the top 12 inches of the subgrade.

Step 6.3: The existing description in the LCGuide is acceptable but needs to be updated.

ADD: A new Step 6.4 should be added. This step should recommend that the documentation of the sites, PMED software project designs that are developed, Distress values from Section/Step 5 and any other data related to the local calibration should be organized and a method put in place to maintain and update the performance measurements for these sections in preparation for future recalibrations. It should be recognized, that depending upon future software modeling changes the PMED projects themselves may need to be redone for future calibrations (that is the case with some projects developed with PMED version 1.1) but having all the information readily available will make the entire process much easier.

Section 7- Assess Local Bias of Global Calibration Factors

This section needs to be greatly enhanced and revised and Section 7 and Section 8 should be the meat of the new LCPMED. An example of what this section should contain is in Appendix C. ADD: It should start with a new Table listing the Distresses and Transfer Functions that are used for each pavement type. (*Michigan, Table 4-1)* provides a good example. Nationally calibrated S_e (SEE or standard error of the estimate) values for each distress should also be included in the new Table or a separate Table, like shown in Figure 7 below for flexible pavements.

Global Calibration under NCHRP 1-40D New HMA Pavement Model Statistics; Baseline Values

Performance Model	Model Statistics		
	R^2, %	SEE	Number of Data Points
Rutting	57.7	0.107 inch	334
Alligator Cracking	27.5	5.01%	405
Transverse "Thermal" Cracking	Level 1*: 34.4 Level 2*: 21.8 Level 3*: 5.7	—	—
IRI	56	18.9 inch/mi	1926

Figure 7- Global Calibration Factors (From PMED Local Calibration Webinar 3)

The sentence related to using 50% reliability should be more prominent. A general discussion on bias and errors is warranted here like what is in the existing Section 4, but the details of the statistical components (i.e. existing Section 2 and 5) should be referenced in an Appendix. Parts of the existing Section 4 (which includes calibration and validation) would be appropriate to lead off this section, including a discussion on the different approaches to calibration (direct vs incremental damage), but they need to be rewritten for a more general audience.

Step 7.1 should cover each distress model separately, matching the order of the new 'Distresses and Transfer Function' Table. The definitions noted in the existing LCGuide Section 2.4 should be reviewed/updated and moved to this section, but included with each distress discussion, not all in one place. See the Example for JPC Transverse Cracking distress in Appendix C. ADD: An example of how to compute the residual errors, bias and SEE (Se) should be included, including graphs to support the examples.

Step 7.2 should provide an example of each hypothesis test (Difference =0, Intercept = 0, Slope = 1) for one of the distresses noted in Step 7.1, and it should provide an example of a paired t-test for IRI. The meaning of the p-values should be addressed. A format to document the results should also be provided, like that shown in Figure 8.

Statistical results determining whether hypothesis is accepted or rejected for each distress

Statistical Analysis Type (Statistical Analysis System)					
Goodness of Fit			Bias		
R^2, %	SEE	N	p-value (paired t-test)	p-value (Slope)	Distress Type
45.1	0.134 in	155	< 0.0001	< 0.0001	Rutting
17.5	17.5% lane area	50	0.0059	< 0.0001	Alligator Cracking
39.1	232 ft/mi	21	0.0123	< 0.0001	Transverse Cracking
35.5	15.9 in/mi	343	0.5530	< 0.0001	IRI

Figure 8 - Potential format for Step 7.2 results (From PMED Local Calibration Webinar 3)

Section 8- Eliminate Local Bias

The existing description in the LCGuide should be revised to be clearer. Graphs showing the 3 different possibilities (1. errors biased, 2. high error, but low precision and 3. trends in the errors) would be beneficial. This section should provide an example of how to adjust the calibration factors for each possibility. The current discussion that notes changing the "local calibration coefficient" for case 1 and the "coefficient of the prediction equation" for case 2 is unclear. It appears to relate to the two approaches noted in the LCguide webinar, see Figure 9. An example of what this section should contain for JPS Transverse Cracking is in Appendix C.

Step #8: Statistical Analysis to Eliminate Bias

Two Approaches:

1.The common approach—Accept coefficients of MEPDG distress prediction law and determine local calibration factors.

$$TRUT = \beta_{r1}{*}RUT_{HMA} + \beta_{S1C}{*}RUT_{BASE} + \beta_{S1F}{*}RUT_{SUBG}$$

2.Use laboratory test results to modify coefficients of MEPDG distress prediction law and determine shift factors for local calibration.

$$\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{1r} k_z \varepsilon_{r(HMA)} 10^{k_{1r}} N^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}}$$

Figure 9 - Step #8 clarification

<u>ADD:</u> Clarify the two approaches noted, and when they are appropriate. PMED Webinar 3 did this well for JPC transverse cracking, where the basis of C1 and C2 were defined and it was

recommended to leave those values and only change C4 and C5. (See Figure 10)

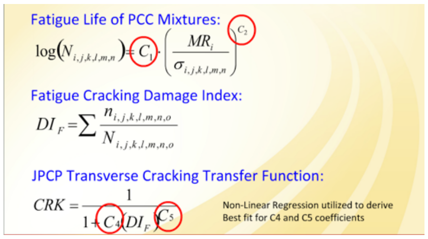

Figure 10 - JPCP Calibration factors from PMED Webinar 3

This section should also include a discussion of using graphing software to look for any trends in the data to assist in identifying cases where potentially different trends are going on that can be seen graphically like the one shown in Figure 11 (Figure A2-17 of the existing LCGuide).

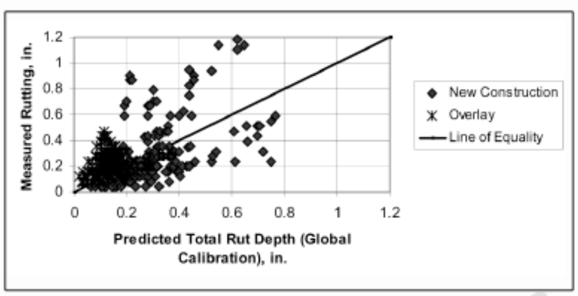

Figure 11 – Identifying Trends in Data

The new construction projects shown as diamonds in Figure 11 appear to have two distinct patterns, one that overpredicts and one that underpredicts rutting. If the individual projects can also be identified graphically by different factors, i.e. thickness, construction date, mix type etc. or the individual projects can be identified and discussed with the DOT personnel involved in their maintenance or construction, it may clearly show the underlying cause for the differences.

This section also needs to cover each distress model separately, in the same order as shown in Section 7, but this time concentrating on the calibration factors that should be adjusted for a certain outcome. Existing Table 6-1 from the existing LCGuide provides some guidance, but additional guidance is needed, like what is found in the existing LCGuide page A-48 for rutting coefficients, page A-53 for fatigue cracking coefficients, page A-111 and A-114 for faulting coefficients and, page A-57 for the fact that IRI needs to be adjusted after adjusting the other distresses. Also, the existing Table 6-1 does not include all the calibration factors, and the difference between coefficients that are used in local calibration (Option 1 in Figure 5) and coefficients (Option 2 in Figure 5) that should only be changed due to material related properties based on laboratory testing needs to be clearly discussed and differentiated.

Computing new standard deviation values for the distresses is not discussed in the current LCGuide. It was discussed in the PMED webinar 3 and the method and reasoning for this should be added to the LCPMED. Figure 12 is from that portion of webinar 3.

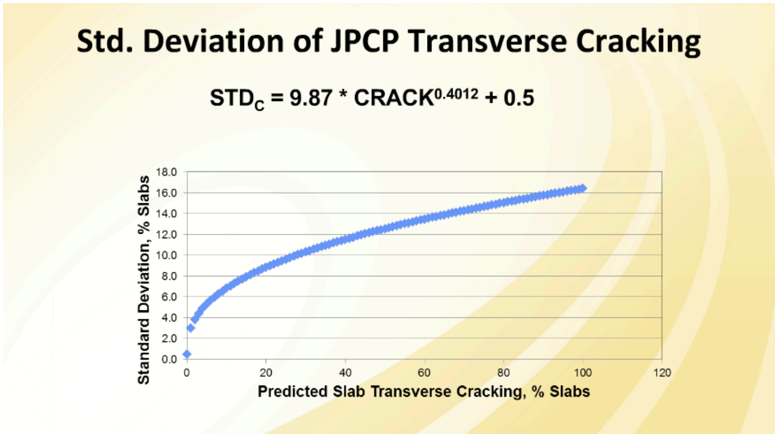

Figure 12 - Computation of standard deviation of the distress (from PMED Webinar 3)

Section 9- Assess the Standard Error, SEE (S_e)

The existing description in the LCGuide needs to be revised to match the verbiage changes made in Section 7. Reference should be made to the new Table in Section 7 that includes SEE (S_e) values. This section should provide an example of a hypothesis test that would be performed. A format to document the results should also be provided, similar but not exactly like that shown in Figure 13. The table should include the National/global values as a comparison.

Step #9: Assess Standard Error

Compare the standard error of the estimate from the local calibration to the global value.

- *Remember, standard error and bias were related to mixture type.*

Construction	New Constr.			Overlay		
Mixture	Marshall	Superpave	PMA	Marshall	Superpave	PMA
Bias	0.009	-0.178	-0.188	0.088	0.094	0.031
Std. Error	0.287	0.140	0.116	0.111	0.126	0.056
Se/Sy	1.14	1.112	2.023	0.912	1.052	1.341

Figure 13 – Table of SEE (Se) values

Section 10- Reduce the Standard Error, SEE (S_e)

The existing description in the LCGuide needs to be revised to match the changes made in Section 7. Potentially an example would make this section clearer. Currently it appears that it recommends that you look at each category in the sampling matrix closer and readjust the calibration factors to see if they get better.

Step 10.1: This step needs to be rewritten and tied to the changes in Section 7.

Step 10.2: This step needs to be rewritten using wording from Section 2 ('blocking' is used here) and tied to the changes in Section 7.

Step 10.3: Not quite sure what Step 10.3 does? Does this mean go back to Step 8 (Section 8) and recalibrate? If so, it should be written that way.

Section 11- Interpretation of Results

The existing description in the LCGuide is unclear. How do you evaluate the SEE (S_e) for each distress at different reliability levels? How do you determine expected design life? It does not say to run a number of sections using the local calibration factors and comparing the results to the national calibrated factors, but that is one way to assess reasonableness in the results. Or running parallel designs with the current method of design for a period of time prior to implementation is another way. In the LCGuide Examples this step appeared to be more of a practical analysis of reasonableness than a statistical analysis. Some clarity of the intent and methods to perform this step are needed in the LCPMED.

Appendix A – Lessons Learned

Appendix A should contain some specific examples based on experiences or novel methods used by States in their Local calibration, such as:

- How local calibration has driven changes in the software models, and therefore sharing local calibration information is a necessary part of continuous improvement of the software
- How State collected cracking for both flexible and rigid pavements has been adjusted to fit the PMED definitions (All States have had to address this, at least for flexible cracking)
- How using cut-off values or defaults in PMS can affect local calibration, such as Louisiana and faulting *(Louisiana, page 55-59)*
- Different specific methods or procedures that have been used in performing local calibration
    - Purdue/Indiana's method of using a Grid Search method to calibrate and identify optimum sample size
    - Iowa's use of a sensitivity index (*Iowa, page 189)*
    - Michigan's use of transverse profiles to assist in rutting prediction *(Michigan, page 96-102)*
    - Louisiana's simplification of the rutting model *(Louisiana, page 65)*)

Appendix B – Statistical Reference

- Calibration and validation methods (do not just use existing Section 4- the pertinent information in existing Section 4 should be here but rewritten in a format that is consistent with new Section 7 and more appropriate for a general audience). This section should also provide a recommendation- it seems that jack-knifing would be more appropriate for small sample sizes like what would be used for Level 1 and 2 inputs and split sampling for large sample sizes that would rely on PMS data and level 2 and 3 inputs – but someone with the necessary statistical knowledge should provide the recommendations that will be provided here, and possibly even consider bootstrapping or the grid search method used by Indiana/Purdue

- Derivation/discussion of the Sample size based on new Section 3
- Hypothesis testing basic discussion
- Regression basics and standard error terms, include graph of measured-predicted and residuals and describe the graphs in relation to new Section 8 (Local bias). NCAT (Figure A) and Michigan (Figure 4-1, page 92) reports both provide a good example of graphically describing error, precision and bias.

REFERENCES

a. References included in Task 422 Report (Alphabetical)

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Wu, Z., Yang, X & Zhang, Z. 2013. Evaluation of MEPDG flexible pavement design using pavement management system data: Louisiana experience, International Journal of Pavement Engineering, 14:7, 674-685, DOI: 10.1080/10298436.2012.723709

b. State Local Calibration Research Reports (by State)

The following 36 states were identified as having either performed a local calibration, being in the process of performing a local calibration, or noted as having a local calibration project in the Transportation Research Board Research in Progress (RIP) database. Under the State name the authors of the latest local calibration research report are noted. The date next to the State name is the published date of the latest report. The software version that was used for local calibration is identified if it was included in the report. The actual local calibration research reports have been located for the states with a Report Icon (19 of the 36). These reports will be placed on the AASHTOWare site for future reference.

ARIZONA (2014) ***REPORT***
ARA(Michael I. Darter, Leslie Titus-Glover, Harold Von Quintus, Biplab B. Bhattacharya, and Jagannath Mallela). Calibration and Implementation of the AASHTO Mechanistic-Empirical

Pavement Design Guide in Arizona. [DARWin-ME, performed in 2012]

ARKANSAS (In TRB RIP database -Survey also noted that it was in process)
University of Arkansas (Kevin Hall) Local Calibration of the MEPDG (TRC-1003)

COLORADO (2013) ***REPORT***
ARA (Jagannath Mallela, Leslie Titus-Glover, Suri Sadasivam, Biplab Bhattacharya, Michael Darter, and Harold Von Quintus). Implementation of the AASHTO Mechanistic Empirical Pavement Design Guide for Colorado. [AASHTO Pavement ME 1.0]

FLORIDA (2008) ***REPORT***
TTI (Jeongho Oh and Emmanuel G. Fernando). Development of Thickness Design Tables Based on the M-E PDG. Tallahassee, Florida. [MEPDG Version 0.8]

GEORGIA (2014) ***REPORT***
ARA (Mr. Harold L. Von Quintus, P.E., Dr. Michael I. Darter, P.E., Dr. Biplab Bhattacharya, P.E., and Mr. Leslie Titus-Glover). Calibration of the MEPDG Transfer Functions in Georgia, Task Order 2 Report. Forest Park, GA. [AASHTO Pavement ME Version 1]

HAWAII (from TRB RIP)
University of Hawaii, Manoa (Archilla, Adrian) Updating of the State Pavement Management System and Calibration of the 2002 Design Guide for Hawaiian conditions. (noted as starting in 2005)

IDAHO (from TRB RIP- in progress)
University of Idaho, Moscow (Bayomy, Fouad) Calibration of the MEPDG Performance Models for Flexible Pavements in Idaho. RP235 (started 2015, in progress)
University of Idaho, Moscow (Bayomy, Fouad, Kassem, Emad and Muftah, Ahmed) Calibration of the MEPDG Performance Models for PCC Pavement in Idaho RP268 (started 2017, in progress)

INDIANA (from TRB RIP – in progress)
Calibration is noted in 2018 survey as being in NCHRP Report. TRB RIP notes two projects:
Purdue University/IDOT (Haddock, John) SPR-4212: Structural Evaluation of Full-Depth Flexible Pavement Using APT.(started in 2018)
Purdue University/IDOT (McCullouch, Bob, Lee, Ju Sang, Nantung, Tommy and Chun, Hyonho) SPR-3711: MEPDG Implementation (Validation/Model Calibration/Acceptable Distress Target/IRI Failure Trigger/Thermal Selection/Binder Selection) and Climate Data Generation (started in 2013, 2018 completion date)

IOWA (2015) ***REPORT***
Iowa State University (Halil Ceylan, Sunghwan Kim, Orhan Kaya, and Kasthurirangan Gopalakrishnan). Investigation of AASHTOWare Pavement ME Design/DARWin-ME Performance Prediction Models for Iowa Pavement Analysis and Design. InTrans Project 14-496. Ames, IA. [AASHTO Pavement ME Version 2.1.24 - Report is an update to a previous calibration that used DARWin-ME Version 1.1]

KANSAS (2015) ***REPORT***
University of Kansas (Xiaohui Sun, Jie Han, Ph.D., P.E., Robert L. Parsons, Ph.D., P.E., Anil Misra, Ph.D., P.E., Jitendra K. Thakur) Calibrating the Mechanistic-Empirical Pavement Design Guide for Kansas. Report KS-14-17. Topeka, KS. [AASHTO Pavement ME Version 1.3]
Also the flexible example in the local calibration guide and 2009 Report KSU-04-4.

KENTUCKY (In TRB RIP database, survey noted they have not calibrated)
University of Kentucky (Graves, L). "Local Calibration and Strategic Plan for Implementation of AASHTO MEPDG", "AASHTO MEPDG Calibration Continuation" and "MEPDG Implementation" (three projects listed in RIP, latest starting date noted as 2009)

LOUISIANA (2016) ***REPORT***
LTRC (Zhong Wu, Ph.D., P.E., and Danny X. Xiao, Ph.D., P.E.) Development of DARWin-ME Design Guideline for Louisiana Pavement Design. Report FHWA/LA.11/551. Baton Rouge, LA. [AASHTO Pavement ME 2.0]

MAINE
(Noted in Survey that they are currently calibrating in-house)

MICHIGAN (2017) ***REPORT***
Michigan State University (Syed Waqar Haider, Gopikrishna Musunuru, M. Emin Kutay, Michele Antonio Lanotte and Neeraj Buch). Analysis of Need for Recalibration of Concrete IRI and HMA Thermal Cracking Models in Pavement ME Design. Report SPR-1668 (AASHTO Pavement ME Versions 2.0, 2.2 and 2.3)
Michigan State University. 2015. (Syed Waqar Haider, Neeraj Buch, Wouter Brink, Karim Chatti and Gilbert Baladi). Preparation for Implementation of the Mechanistic-Empirical Pavement Design Guide in Michigan, Part 3: Local Calibration and Validation of Performance Models. Report RC-1595. Lansing, MI. [Appears to be AASHTO Pavement ME Version 1.3]

MINNESOTA
Noted in survey only calibrated for simplified rigid pavements.

MISSISSIPPI
Survey noted that only a preliminary calibration was performed and the final report is still in review and not yet available

MISSOURI (2009 and ongoing in TRB RIP) ***REPORT***
ARA (Jagannath Mallela, Leslie Titus-Glover, Harold Von Quintus, Michael Darter, Mark Stanley and Chetana Rao). Implementing the AASHTO Mechanistic Empirical Pavement Design Guide in Missouri, Vol II: MEPDG Model Validation and Calibration. MODOT Study R104-002. [Not defined in report but assumed to be original MEPDG 1.0 software due to date of report] Also the PCC example in the local calibration guide.
Existing Project from RIP: RAO Research and Consulting (Rao, Chetana) MEPDG Local Calibration (started in 2016)

MONTANA (2007) ***REPORT***
ARA and Fugro (Harold Von Quintus and James Moulthrop). Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models for Montana. Project HWY-30604 DT. [Not defined in report but assumed to be original MEPDG 1.0 software due to date of report]

NEBRASKA
ARA (Survey noted they are currently calibrating with ARA)

NEVADA
(Noted in the Survey that they had calibrated but that the reports are not available)

NEW MEXICO (2012) ***REPORT***
University of New Mexico (Rafiqul A. Tarefder, Nasrin Sumee, Jose I. Rodriguez, Sriram Abbina, and Karl Benedict). Development of a Flexible Pavement Database for Local Calibration of MEPDG. Report NM08MSC-02. [MEPDG Version 1.0 (MEPDG 2010)]

NORTH CAROLINA (2007) ***REPORT***
North Carolina State University (Y. Richard Kim, Fadi M. Jadoun, T. Hou, and N. Muthadi) Local Calibration of the MEPDG for Flexible Pavement Design. Report FHWA\NC\2007-07. [MEPDG Version 1.1]

NORTH DAKOTA
(Noted in the Survey that they had calibrated but did not provide any other information)

OHIO (2009) ***REPORT***
ARA (Leslie Titus Glover and Jagannath Mallela) Guidelines for Implementing NCHRP 1-37A M-E Design Procedures in Ohio: Volume 4—MEPDG Models Validation & Recalibration. FHWA/OH-2009/9D.Columbus, OH. [MEPDG Version 1.0]

OKLAHOMA (2011)
University of Oklahoma (Hossain, Musharraf Zaman, Curtis Doiron, Steven Cross) Development of flexible pavement database for local calibration of MEPDG final report. ODOT SPR No 2209. Oklahoma City, OK. [AASHTO Pavement ME Version 1.1 based on 2015 TRB paper] {Do Not have copy of report}

OREGON (2013) ***REPORT***
Iowa State University (Dr R. Chris Williams and R. Shaidur) Mechanistic-Empirical Pavement Design Guide Calibration for Pavement Rehabilitation. SPR 718. [DARWin-ME noted in report, appears to have started in 2011]

PENNSYLVANIA ***REPORT to be available in June 2018***
Noted in survey that they would have reports available.

SOUTH CAROLINA (in progress)
University of South Carolina (R. L. Baus, N. R. Stires) Mechanistic-Empirical Pavement Design Guide Implementation FHWA-SC-10-01 [MEPDG Version 1.003 noted as used for rigid and MEPDG 1.10 used for flexible] This report is a Sensitivity analysis and not a full calibration (Noted in Survey that they are calibrating now)

TENNESSEE (2015)
University of Tennessee (Baoshan Huang and Xiang Shu) Summary for RES2013-33 and Thesis located, no report. [Student's Thesis noted that MEPDG Version 1.1 was used]

TEXAS
(Survey noted that the University of Texas/San Antonio and ARA are currently calibrating)

UTAH (2009) ***REPORT***
ARA (Michael I. Darter, Leslie Titus-Glover, and Harold L. Von Quintus) Implementation Of The Mechanistic-Empirical Pavement Design Guide In Utah: Validation, Calibration, And Development Of The UDOT MEPDG User's Guide. UT-09.11 [MEPDG Version 1.0]

VERMONT (from TRB RIP, survey noted a calibration was done with PMS data)
Vermont Agency of Transportation (In-house researcher Nick Meltzer) SPR 711: Correlating ME-PDG with Vermont Conditions, Phase II. (start date is 2010)

VIRGINIA (2015) ***REPORT***
VCTIR (Bryan Smith, P.E., and Harikrishnan Nair, Ph.D., P.E.) Development of Local Calibration Factors and Design Criteria Values for Mechanistic-Empirical Pavement Design. FHWA/VCTIR 16-R1. [AASHTO Pavement ME Version 1.3]

WASHINGTON STATE (2011) ***REPORT***
University of Washington (Jianhua Li, Jeff S. Uhlmeyer, Joe P. Mahoney, Stephen T. Muench) Use of the 1993 Guide, MEPDG and Historical Performance to Update the WSDOT Pavement Design Catalog. Seattle, WA [Recalibrated to DARWin-ME Version 1.0 under this project. Report notes that WSDOT calibrated rigid with MEPDG V 0.6 in 2005 and flexible with Version 1.0 in 2008]

WISCONSIN (2012) ***REPORT***
Marquette University (James A. Crovetti & Kathleen T Hall) Local Calibration of the Mechanistic Empirical Design Software for Wisconsin. Madison, WI. [MEPDG Version 1.1]

WYOMING (2015) ***REPORT***
University of Wyoming (Taylor Kasperick and Khaled Ksaibati) Calibration of the Mechanistic-Empirical Pavement Design Guide for Local Paved Roads in Wyoming. Mountain Plains Consortium MPC 15-294. [DARWin-ME Version 1.1 Build 1.1.32 12/20/2011 identified in software screen shots]

c. National/Other Reports related to Local Calibration (by Area and Date published)

AASHTO Pavement ME National User Group Meetings-2 Denver, Colorado 2017

AASHTO Pavement ME National User Group Meetings- 1 Indianapolis, Indiana 2016

FHWA-HIF-15.021. AASHTO MEPDG Regional Peer Exchange Meetings (Pierce, L. and Smith, K. 2015)

FHWA-HIF-11-026. Local Calibration of the MEPDG Using Pavement Management Systems. (2010)

NCHRP 20-07/Task 327 Report (2014) Developing Recalibrated Concrete Pavement Performance Models for the Mechanistic-Empirical Pavement Design Guide. (Unofficial report)

NCHRP Synthesis 457 (2014) Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide and Software (Pierce, L.M., and McGovern, G.)

NCHRP Report 719 (2012) Calibration of Rutting Models for Structural and Mix Design

NCHRP RRD 308 (2006) Changes to the Mechanistic-Empirical Pavement Design Guide Software Through Version 0.900. NCHRP Project 1-40D.

NCAT 17-07, (2017) Summary of local calibration efforts for flexible pavements

NCAT 17-08, (2017) Impact of local calibration, foundation support, and design and reliability thresholds

d. Thesis Reports Related to Local Calibration

Five different student Thesis (3 Phd and 2 MS) related to local calibration were identified. Their references are provided below.

Abdullah, Ali Qays. (2015) Development Of A Simplified Flexible Pavement Design Protocol For New York State Department Of Transportation Based On AASHTO ME Pavement Design Guide. University of Texas at Arlington. PhD diss.

Guo, Xiaolong. (2013) Local Calibration of the MEPDG Using Test Track Data. Auburn University. MS thesis.

Nabhan, Peter. (2015) Calibration of the AASHTO MEPDG for Flexible Pavements to Fit Nevada's Conditions. University of Nevada, Reno. MS thesis.

Rahman, Md Shaidur. (2014) Local calibration of the MEPDG prediction models for pavement rehabilitation and evaluation of top-down cracking for Oregon Roadways. Iowa State University. PhD diss.. http://lib.dr.iastate.edu/etd/14295

Zhou, Changjun, (2013) Investigation into Key Pavement Materials and Local Calibration on MEPDG. University of Tennessee. PhD diss.. http://trace.tennessee.edu/utk_graddiss/2504

APPENDIX A
Global Calibration Factors (MOP 2008 and MOP 2015) and Equations (MOP 2015)

The values for the global calibration factors over time, and the latest transfer equations affected by these factors are included in this Appendix. Tables A-1 to A-5 show the documented flexible global calibration factor values in the two different versions of the Manual of Practice (MOP) 2008 and 2015 and the values in the current software. Tables A-6 to A-8 show the documented JPC global calibration factor values for the MOP versions and also two values identified for the Task 288 NCHRP recalibration project, the Task 327 version are the same values in the current software. Table A-9 and A-10 show the documented CRC global calibration factor values for the MOP versions and a version found in the Task 327 NCHRP recalibration report. As shown, the values have changed, and calibration values have been added. The changes in individual calibration factors are shown as shaded cells. The cell is only shaded the first time it changes (i.e. in Table A-2, the Coarse-Grained, k_{s1} factor changed from 2008 MOP to the 2015 MOP but is the same for MOP 2015 and the software, so it is only shaded in the MOP 2015 column).

These calibration factor values are included in Chapter 5 of the MOP and somewhat noted in the Examples in the Local Calibration Guide, but they are not summarized as noted here in either document. It is not even clear which factors are important and what their influence is in the Local Calibration Guide, since the equations that use the calibration factors are not included in the Local Calibration Guide document. The Examples in the Appendix of the Local Calibration Guide do provide some insight on the calibration factors and what their influence is, but this information is within the examples and not easily found.

FLEXIBLE PAVEMENTS

Table A1— HMA/AC Rutting

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software*
k1r	-3.35412	-3.35412	-3.35412
k2r	0.4791	0.4791**	1.5606
k3r	1.5606	1.5606**	0.4791
B1r	1.0	1.0	1.0
B2r	1.0	1.0	1.0
B3r	1.0	1.0	1.0

*Current Software has ability to have different values for 3 different layers and it notes a Std Dev of 0.24POW(RUT,0.8062) + 0.001

**MOP 2015 notes in the Preface (Page v1) that these values have changed to what is in the current software, but they are not changed in the body of the document (pg 39)

$$\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{1r} k_z \varepsilon_{r(HMA)} 10^{k_{1r}} n^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}} \tag{5-1a}$$

Table A2— Unbound Layer Rutting

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software*
Coarse-Grained, k_{s1}	1.673	2.03	2.03
Coarse-Grained Bs1			1
Fine-Grained, k_{s1}	1.35	1.35	1.35
Fine-Grained Bs1			1

*Current software also notes two Std Dev values:
Coarse: 0.1477*POW(BRUT,0.6711) + 0.001
Fine:0.1235*POW(BRUT,0.5012) + 0.001

$$\Delta_{p(soil)} = \beta_{s1} k_{s1} \varepsilon_v h_{soil} \left(\frac{\varepsilon_o}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{n}\right)^{\beta}} \tag{5-2a}$$

Table A3— HMA/AC Bottom-Up Alligator/Fatigue Cracking

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software*
kf1	0.007566	0.007566	0.007566
kf2	-3.9492	+3.9492	+3.9492
kf3	-1.281	+1.281	+1.281
bf1	1.0	1.0	1.0
bf2	1.0	1.0	1.0
bf3	1.0	1.0	1.0
C1bottom	1.00	1.00	1.00
C2bottom	1.00	1.00	1.00
C4bottom/C3	6000	6000	6000
C1top	7.00	7.00	7.00
C2top	3.5	3.5	3.5
C4top	1000	1000	1000
C3top			0

*Current software also notes two Std Dev values:
Top: 200 + 2300/(1+ exp(1.072-2.1654*LOG10(TOP + 0.0001)))
Bottom: 1.13 + 13/(1+ exp(7.57-15.5*LOG10(BOTTOM + 0.0001)))

$$N_{f-HMA} = k_{f1}(C)(C_H)\beta_{f1}(\varepsilon_t)^{k_{f2}\beta_{f2}}(E_{HMA})^{k_{f3}\beta_{f3}} \tag{5-4a}$$

$$DI = \sum (\Delta DI)_{j,m,l,p,T} = \sum \left(\frac{n}{N_{f-HMA}} \right)_{j,m,l,p,T} \tag{5-5}$$

$$FC_{Bottom} = \left(\frac{1}{60}\right)\left(\frac{C_4}{1+e^{\left(C_1C_1^* + C_2C_2^* Log\left(DI_{Bottom}*100\right)\right)}}\right) \tag{5-6a}$$

$$FC_{Top} = 10.56\left(\frac{C_4}{1+e^{\left(C_1 - C_2 Log\left(DI_{Top}\right)\right)}}\right) \tag{5-8}$$

Table A4—HMA/AC Thermal Transverse Cracking

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software
Bt1	400	400	
kt	Level 1=5.0 Level 2=1.5 Level 3=3.0	Level 1=1.5 Level 2=0.5 Level 3=1.5	

$$TC = \beta_{t1} N\left[\frac{1}{\sigma_d} Log\left(\frac{C_d}{H_{HMA}}\right)\right] \tag{5-11e}$$

Table A5—HMA IRI

Calibration Factor	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software
C1 (Rut)	40.8	40.0	40.0
C2 (LCracking)	0.575	0.400	0.400
C3 (TCracking)	0.0014	0.008	0.008
C4 (SiteFactor)*	0.00825	0.015	0.015
Flex o/PCC C1		40.8	40.8
Flex o/PCC C2		0.575	0.575
Flex o/PCC C3		0.0014	0.0014
Flex o/PCC C4		0.00825	0.00825
SEE	18.9 in/mile	18.9 in/mile	
SEE (Flex o/PCC)	9.6 in/mile	9.6 in/mile	

*Note SF equation changed from 2008 to 2015 MOP

$$IRI = IRI_o + C_1(RD) + C_2(FC_{Total}) + C_3(TC) + C_4(SF) \tag{5-15a}$$

RIGID PAVEMENTS

Table A6—JPCP Mid-Slab (Transverse) Cracking

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Task 288	NNC*	Current Software
C1	2.0	2.0	2	2	2
C2	1.22	1.22	1.22	1.22	1.22
C4	Not defined (1)	1.00	0.6	0.6	0.52
C5	Not defined (-1.98)	-1.98	-2.05	-2.05	-2.17
Standard Deviation	-0.00198*POW (CRACK,2) + 0.56857 CRACK + 2.76825	POW(5.3116* CRACK,0.3903)+ 2.99	POW(57.08* CRACK, 0.33) + 1.5		3.522*POW(CRACK, 0.3415) + 0.75

*Task 288 values shown are as defined in the Task 327 report, NNC was defined as the Task 288 values in a paper (Mu et al. 2016), current software uses the Task 327 values

$$CRK = \frac{100}{1 + C_4 (DI_F)^{C_5}} \tag{5-16}$$

$$DI_F = \sum \frac{n_{i,j,k,l,m,n,o}}{N_{i,j,k,l,m,n,o}} \tag{5-17a}$$

$$\log\left(N_{i,j,k,l,m,n}\right) = C_1 \cdot \left(\frac{MR_i}{\sigma_{i,j,k,l,m,n}}\right)^{C_2} \tag{5-17b}$$

Table A7—JPCP Faulting

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Task 288*	NNC*	Current Software
C1	1.29	1.0184	0.5104	1.252632	.595
C2	1.1	0.91656	0.00838	1.1273688	1.636
C3	0.001725	0.0021848	0.00147	0.00268755	0.00217
C4	0.0008	0.000883739	0.008345	0.001086951	0.00444
C5	250	250	5999	250	250
C6	0.4	0.4	0.8404	0.4	0.47
C7	1.2	1.83312	5.9293	9.1	7.3
C8	Defined as 400	Defined as 400	400	400	400

Standard Deviation	(0.00761*FAULT(t) + 0.000008099)$^{0.445}$	[0.0097*FAULT(t)]$^{0.5178}$ + 0.014	0.07162*POW (FAULT,0.368) + 0.00806

*Task 288 values shown are as defined in the Task 327 report, NNC was defined as the Task 288 values in a paper (Mu et al. 2016), current software uses the Task 327 values

$$Fault_m = \sum_{i=1}^{m} \Delta Fault_i \tag{5-20a}$$

$$\Delta Fault_i = C_{34} * (FAULTMAX_{i-1} - Fault_{i-1})^2 * DE_i \tag{5-20b}$$

$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=1}^{m} DE_j * Log(1 + C_5 * 5.0^{EROD})^{C_6} \tag{5-20c}$$

$$FAULTMAX_0 = C_{12} * \delta_{curling} * \left[Log(1 + C_5 * 5.0^{EROD}) * Log(\frac{P_{200} * WetDays}{p_s}) \right]^{C_6} \tag{5-20d}$$

$$C_{12} = C_1 + C_2 * FR^{0.25} \tag{5-20e}$$

$$C_{34} = C_3 + C_4 * FR^{0.25} \tag{5-20f}$$

FR = Base freezing index defined as percentage of time the top base temperature is below freezing (32°F) temperature.

Table A8—IRI JPCP

Calibration Factor	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software
C1 (Cracking)	0.8203	0.8203	0.8203
C2 (Spalling)	0.4417	0.4417	0.4417
C3 (Faulting)	0.4929	1.4929	1.4929
C4 (Site Factor)	25.24	25.24	25.24
SEE	17.1 in/mile	0.35 m/km reported (22.2 in/mile)	
Initial Standard deviation			5.4

$$IRI = IRI_I + C1*CRK + C2*SPALL + C3*TFAULT + C4*SF \tag{5-32a}$$

Table A9—CRCP Punchout(All CRCP Applications)

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software
C1	2	2.0	2.0
C2	1.22	1.22	1.22
C3/ A_{po}	195.789	216.8421	107.73
C4/ alphaPO	19.8947	33.15789	2.475
C5/ betaPO	-0.526316	-0.58947	-0.785
Standard Deviation	$-0.00609*PO^2 + 0.56242*PO + 3.36783$	2+ 2.2593*POW(PO, 0.4882)	2.208*POW(PO, 0.5316)
SEE	3.6 in/mile	3.6 in/mile*	

*SEE value for 2015 is suspect since Figure 5-14 (PO resulting from Global Calibration) in the 2015 MOP is exactly the same as the 2008 MOP, but the calibration values are different.

$$PO = \frac{A_{PO}}{1 + \alpha_{PO} \cdot DI_{PO}^{\beta_{PO}}} \quad (5\text{-}26)$$

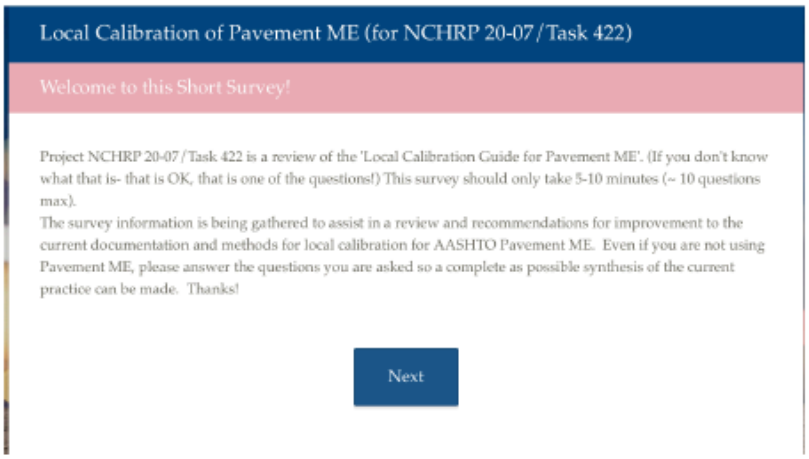
$$\log\left(N_{i,j}\right) = C_1 * \left(\frac{M_{R_i}}{\sigma_{i,j}}\right)^{C_2} - 1 \quad (5\text{-}30)$$

Table A10—IRI CRCP

Calibration Factor	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software
C1 (PO)	3.15	3.15	3.15
C2 (Site Factor)	28.35	28.35	28.35
Standard Error	$(VAR_{IRIi} + C1^2*VAR_{po} + S_e^2)$	7.08 ln (IRI) -11	5.4
SEE (Se)	14.6 in/mile	0.21 m/km (13.3 in/mile)	

$$IRI = IRI_I + C_1 \bullet PO + C_2 \bullet SF \quad (5\text{-}35a)$$

APPENDIX B1.
Local Calibration Survey 2018: Summary


Local Calibration of Pavement ME (for NCHRP 20-07/Task 422)

Welcome to this Short Survey!

Project NCHRP 20-07/Task 422 is a review of the 'Local Calibration Guide for Pavement ME'. (If you don't know what that is- that is OK, that is one of the questions!) This survey should only take 5-10 minutes (~ 10 questions max).

The survey information is being gathered to assist in a review and recommendations for improvement to the current documentation and methods for local calibration for AASHTO Pavement ME. Even if you are not using Pavement ME, please answer the questions you are asked so a complete as possible synthesis of the current practice can be made. Thanks!

Next

1. Thanks in advance for your time! Please provide some contact info for possible follow-up

- Name
- State/Province
- Email Address
- Phone Number

46 States and Ontario responded

*2. Do you currently use AASHTO Pavement ME either for your State/Provinces pavement designs or for comparison designs (parallel effort)?

- Yes-asphalt and concrete designs 15
- Yes- asphalt designs only 1
- Yes-concrete designs only 3
- No- not yet 16
- No- no plans to currently 4
- No- do not plan to 1
- Other (please specify) 7

3. Have you performed (or contracted) any specialty studies/efforts for AASHTO Pavement ME (besides local calibration)?

- Yes- check all that apply
  - Sensitivity Study 20
  - Materials catalog/categorization 25
  - Traffic data analysis 26
  - Climate specific study 11
  - Training on the AASHTO Pavement ME software 18
  - Other/Others (please specify)
- No 6

4. Are you aware of the 2010 'Local Calibration Guide for Pavement ME' available through the AASHTO bookstore?

- Yes 29
- No 2
- Other (please specify) No answer

*5. Have you ever performed (or contracted) a local calibration of AASHTO Pavement ME?

- Yes 29
- No - Thanks again for your time! ***(survey goes to end)*** 12
- Other (please specify) 6 - 3 in progress, 1 only simplified rigid

6. Was the latest calibration completed after 2010?

- Yes 24
- No 7
- Other (please specify)

7. Did they use the Local Calibration Guide to perform the calibration?

- Yes 18
- No 3 Note- these were done by ARA before 2010 or the LGuide was ref. in report
- Don't Know 8
- Other (please specify) Appears all were done with knowledge of Local Calibration Guide

8. Can you share a document or link to documentation for the latest calibration (and for each pavement type, if documented separately)?
Please include principal investigator, if known?
(Open comment field) New reports identified

9. Please indicate any of the conditions you encountered in performing the latest local calibration (Check all that apply):

- Did not have large enough sample size 17
- Needed to perform additional field work to gather needed data 15
- Used our Pavement Management System data directly 7
- Used our Pavement Management System data with conversions to match Pavement ME 13
- Local calibration coefficients gave us unexpected results in design 4
- None of the Above 5
- Other (please explain)

10. Did you encounter any other special situations in local calibration you can share? **(Open comment field)**

Some of the comments:

- *"it was found that the model in the Manual of Practice (MOP) is questionable. for both the alligator and Longitudinal cracking, the standard error increases as the amount of alligator or longitudinal cracking increases."*
- *"cementitious stabilized material base layers were never calibrated at the national level."*
- *"Climatic model (soil PI, passing #200, etc.) is very sensitive to the IRI. The critical pavement performance criteria for pavement design in PavementME is always the IRI, never the fatigue cracks. To local calibrate the soil in the EICM in relation to IRI is close to impossible. "*
- *""borrowed" a couple of LTPP sites from our neighboring states "*
- *"New materials used recently will require different calibration "*
- *"the major distress for new HMA pavement is top-down alligator cracking which is not modeled in MEPDG. "*
- *"JPC-longitudinal cracking and rutting are not modeled in MEPDG. "*
- *"There was either little to no cracking, or a lot of cracking in our calibration sections. "*

(Appendix B2 is Excel spreadsheet containing all survey results, available on request.)

APPENDIX C
Examples for Section 7 and 8 of New Guide

The following examples are intended to provide a format/outline for the changes recommended to Section 7 and Section 8 of the New Local Calibration Guide as described in Section 3.2 of this report. The examples only cover one distress (JPC Transverse Cracking Model) but the intent is that the New Guide will cover each distress in detail like shown here. The distress itself needs to be defined and the equations relating to calibration need to be shown. The specific values that are compared to assess the global values needs to be described like shown here for Section 7. Section 8 needs to clarify which calibration coefficients are mechanistically modeled and which should be identified for local calibration. Specific effects of changing the calibration coefficients need to be discussed, along with an example of how to set up a regression to perform the calibration (if appropriate).

Section 7 - (Step 7.1) Assess Global Calibration Factors

JPCP Transverse Cracking Model

JPCP Transverse Cracking is composed of Bottom-Up and Top-Down Cracking.

Transverse Cracking, Bottom-Up (JPCP)—When the truck axles are near the longitudinal edge of the slab, midway between the transverse joints, a critical tensile bending stress occurs at the bottom of the slab under the wheel load. This stress increases greatly when there is a high positive temperature gradient through the slab (the top of the slab is warmer than the bottom of the slab). Repeated loadings of heavy axles under those conditions result in fatigue damage along the bottom edge of the slab, which eventually result in a transverse crack that propagates to the surface of the pavement. A reasonable standard error of the estimate for total transverse cracking or total percent slabs cracked is seven percent. The PMED predicts the total percent slabs cracked which includes both bottom-up and top-down cracking of JPCP.

Transverse Cracking, Top-Down (JPCP)—Repeated loading by heavy truck tractors with certain axle spacing when the pavement is exposed to high negative temperature gradients (the top of the slab cooler than the bottom of the slab) result in fatigue damage at the top of the slab. This stress eventually results in a transverse or diagonal crack that is initiated on the surface of the pavement. The critical wheel loading condition for top-down cracking involves a combination of axles that loads the opposite ends of a slab simultaneously. In the presence of a high negative temperature gradient, such load combinations cause a high-tensile stress at the top of the slab near the critical pavement edge. This type of loading is most often produced by the combination of steering and drive axles of truck tractors and other vehicles with similar axle spacing. Multiple trailers with relatively short trailer-to-trailer axle spacing are the other source of critical loadings for top-down cracking.

The equations that include the four calibration factors (C1, C2, C4 and C5) for the transverse cracking model are shown as follows:

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$

$$CRK = \frac{100}{1 + C4\, FD^{C5}}$$

Cracking is computed separately for top-down and bottom- up cracking and the total cracking is computed using the following equation:

$$TCRACK = \left(CRK_{Bottom-up} + CRK_{Top-down} - CRK_{Bottom-up} \cdot CRK_{Top-down}\right) \cdot 100\% \qquad (5\text{-}18)$$

where:

$TCRACK$ = Total transverse cracking (percent, all severities),

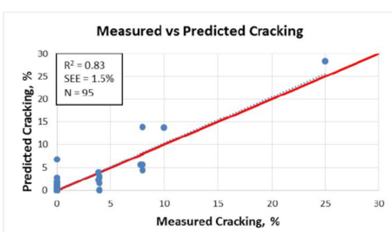
$CRK_{Bottop\text{-}up}$= Predicted amount of bottom-up transverse cracking (fraction), and

$CRK_{Top\text{-}down}$= Predicted amount of top-down transverse cracking (fraction).

Measured Cracking and month: The dates of the measured cracking should be identified, and the month of the measurement is computed by calculating the time from construction date to measurement date. (Note that the equation above is from the MOP 2015 and the typographical error that is in the MOP should be remedied, therefore it should be $CRK_{Bottom\text{-}up}$, not $CRK_{Bottop\text{-}up}$.

Predicted Cracking and month: % Cracking by month is computed in the software and included in the JPCP_Cracking.xls file. The % Cracking used should correlate to the same months defined for the Measured Cracking.

The Measured Cracking and Predicted Cracking are compared by graphing the % cracking and the residual errors as shown below. The measured and predicted cracking should also be statistically compared as described in Appendix B. The Global calibration factors used for the PMED runs, R^2, Standard error and N should all be documented, along with the bias and residual errors, as described in Appendix B.



Section 8.2-Local Calibration

JPCP Transverse Cracking Model-

Adjusting calibration coefficients for JPC Transverse cracking

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$

$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

C1 and **C2** are coefficients based on laboratory testing which determines the number of load repetitions. It is not recommended to adjust the C1 and C2 coefficients unless the **C4** and **C5** calibration factors cannot provide a reasonable regression. Additional laboratory testing can indicate different C1 and C2 coefficients for the conditions being calibrated.

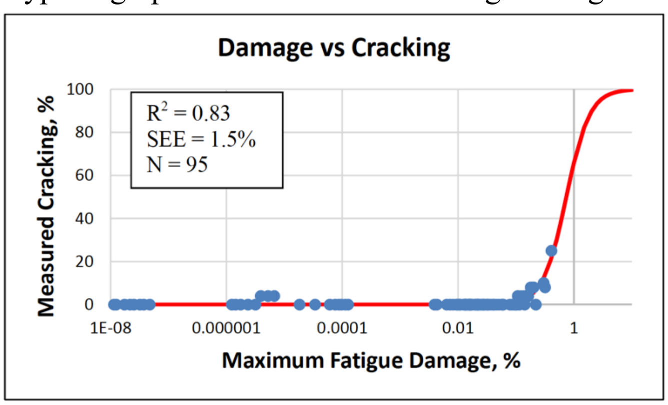
PMEDCracking.xls document from the PMED analysis runs provides Total_BU and Total_TD fatigue damage by month. These values are based on the fatigue damage predictions which then uses the transverse cracking transfer function and then the C4 and C5 coefficients are used to determine the total transverse cracking prediction. The fatigue damage values themselves are not based on C4 and C5, so the values in the PMED runs computed using the global calibration factors from Section 7 can be used directly here. Based on the TCrack equation noted in Section 7 the TCrack predicted is:

TCrack predicted= $\frac{100}{1+C_4 BU^{C5}} + \frac{100}{1+C_4 TD^{C5}} - \left(\frac{100}{1+C_4 BU^{C5}}\right)\left(\frac{100}{1+C_4 TD^{C5}}\right)$

And the regression is:

Ypred = TCrack predicted at month I based on the formula above, and
Ymeas = Measured % transverse cracks at month i, and
X= Total_BU + Total_TD

A typical graph of measured % cracking vs fatigue damage is shown below:

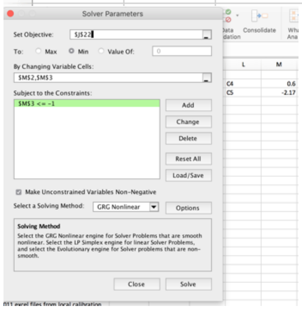


Changes in C4 is expected to reduce the bias and changes in C5 is expected to improve the precision of the model. The values can be adjusted individually based on the needs identified in Section 7 (i.e. if the global values were particularly biased or imprecise), and then at the same time, and the results compared.

An example from an excel spreadsheet (only a portion shown) is below. Microsoft Excel Solver can be used to minimize the Sum of the Squared error by varying calibration coefficients C4 and C5. The resulting calibration factors identified, R^2, standard error and N should all be documented, along with the bias and residual errors, as described in Appendix B.

H2 =SUM(F2,G2,-PRODUCT(F2,G2))

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	BU	TD	Check on x	X	Ymeas	BUCrackvalu	TDCrackvalue	Ypred	Ymeas-Ypred	Squared error			
2	0.01875	0.03769	0.05644	0.05644	0	0.02979423	0.13543889	0.16119782	-0.16119782	0.025984736		C4	0.6
3	0.01789	0.03598	0.05387	0.05387	0	0.29349128	0.12247451	0.38002059	-0.38002059	0.144415647		C5	-2.17
4	0.01705	0.03431	0.05135	0.05135	0	0.26458846	0.11044501	0.345811	-0.345811	0.119585245			



Checking Local Calibration Factors

The YPred vs YMeas relationship from Section 7 should also be reviewed and documented as noted in Section 7, using the calibration factors identified above to calculate YPred, instead of the global calibration factors. The SEE (Se) value that is identified based on the YPred vs YMeas graph is the one to compare to the values computed under Section 7 for the Global calibration coefficients.