# Role of Pavement Management Data in the Implementation of AASHTO's Pavement ME Design Methodology


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# ROLE OF PAVEMENT MANAGEMENT DATA IN THE IMPLEMENTATION OF AASHTO'S PAVEMENT ME DESIGN METHODOLOGY

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## Abstract

The verification and potential re-calibration of the pavement distress models with agency-specific input and performance data is a recommended critical step in the implementation of AASHTO's mechanistic-empirical (ME) pavement design methodology. Many agencies have sought to address the data needs to fulfill this step through their pavement management data repositories. Because a majority of the pavement management databases are focused on supporting network needs analysis, they capture pavement related data at a coarser resolution than is necessary to support design-level performance models. This has led to some confusion and mixed success with using pavement management data for local calibration. However, if treated carefully and in combination with other ancillary data, pavement management data can certainly be used to verify/calibrate the distress models contained the AASHTO Pavement ME Design software. This paper presents some of the essential considerations in reviewing and applying pavement management system data for ME design model calibration. The commentary is illustrated with some real world case studies and examples drawn from various successful local calibration efforts conducted in the United States using pavement management data such as those in Missouri, Colorado and Utah.

## INTRODUCTION

Many highway agencies in North America are still using a version of the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* for routine pavement designs (*1*). However, if subscription to the *AASHTO's Pavement ME Design* (ME Design) software that supports the *AASHTO Interim Mechanistic Empirical Pavement Design Guide* (MEPDG) is any evidence, the march toward changing this paradigm is well and truly underway. Presently, there are over 35 Canadian provincial and US state highway agencies licensing the ME Design software. These agencies are also in various stages of their efforts to implement the MEPDG. Arizona, Colorado, Indiana, Missouri (the first adopter of the MEPDG), North Carolina, and Utah are examples of state Departments of Transportation (DOTs) in the US that currently allow pavement designs to be performed using the MEPDG as a basis. Through first hand interactions, the authors are aware that at least 10 other agencies are nearing the completion of their implementation efforts and are planning to adopt the MEPDG as their *de facto* pavement design standard in the next two years.

As is well known, the AASHTO 93 procedure is based on the codification of findings from experimental road studies conducted over a 2-year period in the late 1950s at the American Association of State Highway Officials (AASHO) Road Test located in Ottawa, Illinois (*2*). At the completion of the Road Test, the intent was to ratify the procedure using smaller scale satellite studies conducted in other regions of the US to study local influences such as climate, soil support, base type, etc., that were not adequately captured at the Road Test (*3*). This is much like the "local calibration" of the MEPDG that was suggested at the completion of the National Cooperative Highway Research Program (NCHRP) Project 1-37A (*4*). However, unlike the follow-on efforts for the MEPDG, the satellite studies in support of the AASHO Road Test did not get off the ground except for efforts by a few agencies. Hallin et al. (*5*) attribute this to a number of factors including the fact that the focus at the completion of the Road Test moved away from research and was diverted to a bigger priority—building the Interstate highway system in the US. In many ways, the technical completeness of the MEPDG despite its apparent complexity, its emphasis on advanced materials characterization, its ability to integrate climate, materials and structural interaction, its structural mechanics mooring and its central design premise—the use of future predicted performance as an indication of structural service life—drove agencies to simultaneously ratify it (e.g., unanimous decision to adopt the MEPDG as an interim AASHTO practice) as well as devote their resources to verify it. Enabling such verification, commonly referred to as validation and local calibration, is an advanced understanding of materials characterization, environmental impacts, soils characterization and a deeply entrenched pavement management practice which were all firmly in place by the time the MEPDG was launched. A central question that is asked by agencies choosing to adopt the MEPDG is if the global mechanistic-empirical pavement performance models upon which structural design is based, are sufficiently accurate to predict local performance.

Experience of agencies that have completed local calibration suggests that the flow of work depicted in figure 1 is necessary to answer the aforementioned central question of interest. Key activities include defining the scope of the implementation (what pavement design applications are of interest to the agency), identifying pavement sections with adequate data to enable local calibration, defining design inputs through a carefully crafted laboratory and field testing program, validation of the distress and International Roughness Index (IRI models), a re-calibration of the models as necessary, and a number of other technology transfer activities. The role pavement management and other supporting enterprise-level data, e.g., traffic, research, construction quality assurance, construction history, etc., play in all aspects of the implementation workflow shown in figure 1 is self-evident. For example, in the scope definition phase, an inventory of the current pavement and overlay types of interest could come from the pavement management and construction history databases. The experimental factorial for calibration could be set up on the basis of the same information and the factorial could be populated using pavement sections drawn from the pavement management database. The validation and calibration of the models will draw upon (1) inputs from a variety of the sources—construction history information, laboratory and field based testing, as well as the pavement management database (2) performance data for statistical modeling primarily from the pavement management database. Clearly, the importance of pavement management system (PMS) data is apparent and is intimately tied with the MEPDG.

However, PMSs are typically designed to administer a pavement program at the network level using data and models at a lower-level of granularity than those required for project level analysis; this is certainly true when it comes to using pavement management data for calibrating MEPDG. As a result, some initial forays in the use of pavement management data for validating or calibrating the MEPDG have led to disappointing results due to a host of reasons. However, the authors contend that when pavement management and other related data are evaluated and treated appropriately, they can still provide value to the MEPDG implementation process.

## Paper Objective

This paper presents an overview of some of the common challenges faced with the use of pavement management data for validating and calibrating the MEPDG. Through some illustrative examples, the paper also presents how beneficial uses of the data can be found when the data are treated appropriately and combined with other external datasets. The paper advances the argument that pavement management data can be used to validate and calibrate the MEPDG models with good success even if the original intent behind collecting this data does not meet the granularity needed for such analysis.

## COMMENTARY ON CURRENT STATE-OF-THE PRACTICE

A few studies have been conducted to date that have systematically examined the use of data from agency pavement management system (PMS) databases in support of the MEPDG (*6,7*). Based on a survey of practices from 8 state highway agencies and other sources, Hudson et al. (*6*) made a seminal observation that every state agency interested in establishing the MEPDG as a basis for future pavement design should design and develop a "satellite" PMS/Pavement Design (PMS/PD) database. This database would contain more detailed project-level information than the enterprise-wide PMS database and would be linked to it through fields that are typically populated as part of the pavement management function. The database would also be linked to other enterprise-wide datasets, e.g., traffic, as appropriate. Hudson et al. (*6*) proposed that the database (1) preserve the copious as-designed and as-built information on a project-by-project basis, (2) provide a formal interface between pavement management and pavement design functions within an agency (thus restoring the original intent behind advancing a systems engineering approach to managing pavements) and (3) provide a mechanism for an annual follow-up as needed to update the materials and construction data fields. Hudson et al. (*6*) further recommended that states and provinces undertake short-term calibration efforts ahead of setting up this PMS/PD database while holding a long-term view for using it for future calibration efforts.

Pierce et al. (*7*) attempted to formalize the suggestion of Hudson et al. (*6*) through a more focused effort. They developed a framework for the systematic use of PMS data in the local calibration effort and selected one state agency's data and data integration business process to illustrate the application of this framework. Their effort highlighted common issues faced with such efforts faced by others in trying to use PMS data for similar ends, namely: (1) the need for labor-intensive data integration efforts to link PMS data with other required data, structure, traffic, construction history etc. due to a lack of a common referencing system (2) lack of consistency between the units of performance data stored in the PMS database for various distresses with those used in the MEPDG and (3) a paucity of pavement sections with performance data approaching the failure criteria required for proper calibration as suggested by the *AASHTO MEPDG Local Calibration Guide* (*8*).

The issues noted by Pierce et al. (7) are not surprising and have been encountered by several others who have assisted highway agencies in locally calibrating the MEPDG for their local conditions. For example, other researchers including Mallela et al. (*9,10*), Darter et al. (*11*), Hall et al. (*12*), Ceylan et al. (*13*), and Mallela et al. (*14*) have found similar issues with the use of PMS data for the calibration of the MEPDG procedure. The labor-intensive nature of the data integration efforts needed to establish a solid platform for model calibration and validation has limited the use of PMS data for such purposes. Most researchers have focused their efforts on the more readily available information from PMS databases that is compatible with the data demands of the

MEPDG, e.g., calibration of the smoothness or the International Roughness Index (IRI) model as done by several including Hamdi et al. (*15*) and Nassiri et al. (*16*) in Canada.

## RECOMMENDED PRACTICE

This section proposes some effective practice recommendations to better leverage PMS data for local calibration efforts. However, prior to offering these suggestions, the reader is reminded of the following key aspects of the data needs for local calibration as suggested in *AAHSTO's MEPDG Local Calibration Guide* (*8*):

- The central tenets of the validation and local calibration exercise are:
  - To remove any bias in the predictions of the globally calibrated models when used in conjunction with agency approved, best available inputs (i.e., inputs and hierarchical levels that an agency intends to carry forward into routine design after balancing their accuracy needs with resource availability).
  - To establish the minimum possible model standard error within the means available that allows an agency to cost-effectively design pavements for all facility types of interest (i.e., at different levels of desired reliability). Note that model error is dominated by input accuracy and the accuracy of the measured distress data against which it is calibrated. For example, if accurate PMS data are not available, the error term will likely be larger—a fact that needs to be considered during the initial decision making phase.
- At least three historical data points are needed for each distress on each project selected to be included in local calibration to adequately assess the trends in distress progression.
- The magnitudes of pavement distress recorded for each section used in calibration should be close to or above the thresholds values (failure limits) used for the various distresses in design.

The following narrative describes the common challenges faced in using PMS data for local calibration work and provides some suggested effective practices to overcome them. Much of what is presented below is based on the first-hand experience of the authors in implementing the MEPDG in various US state highway agencies.

### Challenge 1: Lack of MEPDG Design Specific information in PMS Databases

#### *Description*

Most agencies attempting to locally validate and calibrate the MEPDG models find that their PMS databases and ancillary databases do not support such efforts.

### *Effective Practice Recommendation*
Because the MEPDG requires inputs from many functions of a highway department, e.g., design, maintenance, traffic, climate, geotechnical, construction, etc., most agencies should anticipate that information to validate and calibrate the MEPDG will not reside in one place. Intra-agency collaboration and labor-intensive effort is required to establish a separate "satellite" database to support the initial validation/calibration effort much like the one suggested by Hudson (*6*). Following the work of Mallela (*9*), such a database should be relational in nature and could have two components to it:

- Library information – which contains advanced materials testing information gathered from literature, laboratory testing, or even field-testing which supports the use of MEPDG in an agency. The information should be referenced using agency specific database fields (i.e., primary or secondary keys) in a manner that it can be used in the future for data merge/join activities.
- Calibration information – which contains all the inventory, testing, traffic, and site information related to each PMS section and research grade section used in the local calibration work.

The database can be modeled after the LTPP information management system and could contain many of its features including separation of data into inventory, testing, and monitoring information. If the local calibration work performed by an agency is outsourced, such a database could become a part of the project deliverable from this effort. This database should be maintained separate from the PMS database and should be updated along with the PMS database. Such a database, if established, will go a long way to aid agencies in refining the MEPDG over time.

## Challenge 2: Inadequate Number of Pavement Sections to Cover Experimental Factorial

### *Description*
Even though a typical agency PMS database contains thousands of unique pavement sections, by the time the data is parsed to fit the design types and design features of interest (i.e., the experimental factor space), the time period of relevance and the availability of adequate historical performance data, surprisingly, most agencies, with even the more sophisticated PMSs in place, find it hard to cover the experimental factor space of interest with more than a handful sections.

### *Effective Practice Recommendation*
The key is to establish the factor space with sections that have the potential to provide the highest quality of data in the future. In this case quality of anticipated data is more important than the quantity of data. Even if existing construction history and performance databases do not support a full-scale calibration immediately, nominating the most appropriate sections is more important because such data can be established in the future using field investigations. Another recommendation for addressing the most

immediate needs is to co-populate the PMS-derived sections with other research grade sections, e.g., from the Long Term Pavement Performance Program (LTPP) or other local research sections, as relevant. Research grade sections tend to have better quality data and can be used in multiple ways to augment the PMS sections.

## Challenge 3: Inadequate Performance History

### *Description*

Inadequate performance history can manifest itself in many ways including (1) the nominated sections are younger and have not developed appreciable pavement distress (2) the data captured by the PMS is not of adequate quality, e.g., large fluctuations in captured distress.

### *Effective Practice Recommendation*

It is possible that some or all of the nominated PMS sections, may not have appreciable amounts of some of the pavement distresses of interest to the model validation/calibration exercise. In such cases, non-statistical approaches such as the one suggested in the *AASHTO MEPDG Local Calibration Guide* (*8*) and used in Mallela et al. (*9*) can be utilized to verify the model accuracy in the short-term. However, it is recommended that the nominated pavement management sections should be tracked in the future for a more robust, long-term local calibration activity. Another approach is to make use of any research-grade or LTPP pavement sections to assess the model accuracy, where feasible and applicable. Note that even though the global models were based on LTPP data, for local calibration purposes, these sections can still be investigated at a much deeper level to gather the necessary design inputs needed to accurately characterize them in the MEPDG. Mallela et al. (*9,10*), Darter et al. (*11*), and Titus-Glover and Mallela (*10*) have shown that LTPP data serve a critical need for local calibration particularly when special emphasis is laid on more accurately characterizing traffic, materials and soils inputs. Performance data can also be more carefully analyzed for these sections in local calibration studies through field visits to identify anomalies (e.g., construction defects) an activity which was not possible in NCHRP Project 1-37A which developed the MEPDG.

If the PMS historical distress data is not consistent, e.g., wildly fluctuating distress data, it can introduce large errors in the final calibrated model. In general, it can be expected that local calibration, purely based on PMS recorded performance data, might lead to larger standard error terms. The quality control of PMS data is therefore paramount and essential. Review of video recorded pavement condition information, windshield surveys of nominated sections, cross-correlation between interdependent distresses, e.g., longitudinal wheel path cracking and alligator cracking, etc. should be considered for data quality review. A leaner, cleaned data set with reliable data is more important than a large data set which has not undergone cursory data quality review.

## Challenge 4: PMS Data does not Capture MEPDG Predicted Distresses

### *Description*

The distress measures used in the MEPDG are different than those used in the PMS database. This can manifest itself in different ways (1) mismatch between the units of PMS-recorded and the MEPDG predicted distress; for example, cracking measured as linear quantity in PMS versus area quantity in the MEPDG (2) methodology used to capture distress introduces a bias between PMS recorded and MEPDG measured distresses, e.g., 3-point or 11-point based laser measurement of rut depth versus LTPP wireline-based rut depth measurements on which the MEPDG models are based (3) PMS uses a composite distress measure, e.g., pavement condition index, in lieu of individual distresses.

### *Effective Practice Recommendation*

For the case where the units are mismatched, it imperative that the units of the calibration database are made consistent through a field survey and re-recording of the distresses in accordance with the MEPDG for the nominated pavement sections. Understandably, this is a labor-intensive process, however, it is a necessary step and is usually limited to a single field visit due to its resource intensiveness. Such re-recording will therefore yield only a limited assessment of distress but is generally intended for short-term, immediate calibration activities and has its advantages. The dataset can be enhanced if the one-time assessment of distresses is combined with a re-survey of video distress data as was done in Missouri by Mallela et al. (*9*) and Colorado by Mallela et al. (*10*).

When the protocol to collect the data or process the data is different than was used at the LTPP but the units of measurement are the same, e.g., rutting or IRI data, statistical correlations can be established to develop regression equations to convert data from one source to the other. For example, Darter et al. (*11*) converted the three-point laser measured rutting data in Utah to an LTPP-equivalent rutting measure by correlating the Utah DOT rut measurements from select PMS sections with LTPP measured data for the same sections.

If the PMS captures a composite index value to represent pavement condition, a common practice in many agencies which use such information for network planning purposes, it is important to understand the business logic and data that underlie the computation of this index value and use that information to ascertain the distresses of interest to the MEPDG calibration exercise. Often, video data provides a good metadata layer from which the MEPDG related distresses can be extracted. Often times, the raw distress calls that make up the composite data are stored on the enterprise mainframes and can be accessed to achieve the same purpose.

In the next section of this paper, some case studies illustrating how some of the challenges of using PMS data in MEPDG local calibration studies were overcome are presented to illustrate the aforementioned commentary.

## CASE STUDIES: SUCCESSFUL APPLICATIONS OF PAVEMENT MANAGEMENT DATA IN SUPPORT OF MEPDG LOCAL CALIBRATION

### Adjusting Arizona DOT Rutting Measurements for Use in Calibration

Arizona DOT (ADOT) collects rut depth data for all PMS sections. The PMS rutting data is available in the dbo_SodaMaster data table. Rut depth measurements in dbo_SodaMaster were made using three-point laser equipment, which is different from LTPP wire or straight-edge rut depth measurements (i.e., LTPP uses a 1.2-m straightedge or wire and recording to the nearest millimeter at 50-ft intervals for each wheel path). Figure 2 illustrates the straight edge method for rut depth measurement. LTPP also uses Dipstick® profiler at 50-ft intervals for determining transverse profiles and rut depth.

In order to use both LTPP and ADOT rut depth data for calibrating the MEPDG rutting models there was a need to ensure that rut depth measurements from both sources were compatible. This was done by following the steps below:

1. Obtain samples LTPP and ADOT PMS rut depth measures from the same temporal and spatial space.
2. Plot rut depth measurements from LTPP and ADOT PMS assembled in (1).
3. Determine extent of bias present.
4. For situations where bias was deemed as significant, develop adjustment factors to mitigate the effect of bias.

The outcomes of the steps above was done as described.

- **Obtain Sample Data**: This was done using rut depth measures from the Arizona LTPP flexible pavement projects as baseline and obtain ADOT PMS rut depth measurements for the same projects within the same measurement timeframe). Same projects was defined as project located within the same milepost and same timeframe was defined as rut depth measurements made within the same year).
- **Plot rut depth measurements from LTPP and ADOT PMS**: See figure 3.
- **Determine Extent of Bias Present**: Bias was defined as the consistent under- or over estimation of rut depth by ADOT when compared to baseline LTPP measurements. Bias was determined by performing linear regression using

Arizona measured and LTPP measured rut depth and performing the following two hypothesis tests (assumed a significance level, α, of 0.05 or 5 percent):

- **Hypothesis 1: Paired t-test.** This test determined whether the Arizona and LTPP measured rut depth represented the same population. The paired t-test consisted of the following:
  - Assume the following null and alternative hypothesis:
    - $H_0$: mean measured ADOT measured rut depth = mean LTPP measured rut depth.
    - $H_A$: mean measured ADOT measured rut depth ≠ mean LTPP measured rut depth.
    - Compute test p-value. Compare computed p-value to predetermined level of significance for this test of 0.05. The null hypothesis H0 was rejected if the p-value was less than 0.05. Rejecting H0 implied that the Arizona and LTPP measured rut depth were essentially from different populations at the 5 percent significance level. Belonging to different populations indicates bias in the ADOT measured rut depth data as the LTPP measurements were considered the "ground truth" for this test analysis.
- **Hypothesis 2.** This set of paired t-test determined whether a linear regression model (ADOT Rut Depth = α*LTPP Rut Depth) has a slope (α) of 1.0 and Intercept of 0 at the 5 percent significance level. The test consisted of the following steps:
  - Using the results of the linear regression analysis, test the following null and alternative hypotheses to determine if the linear regression model Slope is 1.0, Intercept = 0:
    - $H_0$: model slope (α) = 1.0 and Intercept = 0.
    - $H_A$: model slope (α) ≠ 1.0 and Intercept ≠ 0.
  - Compute test p-value for both situations.
  - Compare computed p-value to predetermined level of significance for this test and interpret as done for Hypothesis 1.

  The outcome of the hypothesis testing are presented in table 1.

To eliminate bias in measured ADOT rut depth measurements the correction factor below was applied.

$$ADOT\_RUT_{ADJ} = 0.1544 * 2.918^{(2.4273*ADOT-RUT)} \quad (1)$$

where

| | | |
|---|---|---|
| $ADOT\_RUT_{ADJ}$ | = | ADOT rut depth measurement adjusted to be compatible with LTPP |
| ADOT-RUT | = | ADOT measured rut depth |

Figure 4 presents the relationship between LTPP adjusted ADOT and LTPP rutting measurements. The adjusted ADOT and LTPP rutting measurements were tested for bias. Results presented in table 2 shows no significant bias.

## Adjusting Colorado DOT Rutting Measurements for Use in Calibration

Colorado Department of Transportation (CDOT) Pavement Management Program (PMP) exists to provide the Regions with tools that optimize the use of funding allocated to the Surface Treatment Program (STP). CDOT collects annual condition data for every highway on the network. Condition data collection begins in January and finishes in June. Condition data includes an inventory of every pavement crack, the rutting depth for every highway, the International Roughness Index (IRI) for every highway, pavement types, and various forms of shoulder observations.

Several CDOT PMS sections were selected for use in local calibration of the MEPDG rutting model. Although PMS rut depth data was available, similar to ADOT, they were collected using laser technology that was not compatible with LTPP.

A different approach to adjusting the CDOT PMS rut depth data was adopted as there were resources to conduct a least one visit to the selected PMS section project sites to conduct field studies. The adjustment approach adopted was as follows:

1. Perform field measurement of rut depth as per LTPP measurement protocol.
2. Compared field measured rut depth measurement to PMS measurements.
3. Apply correction factors as need to adjust PMS rut measurements.

Examples of the adjustment procedure for two PMS projects is presented below.

- **Example 1**: A plot of CDOT PMS rut depth versus age is presented in figure 5 for PMS Project 10-12393. Superimposed on this plot is the field measured rut depth (at age = 9 years). A comparison of field measured and PMS rut depth for ages 5, 7, and 9 shows that the PMS data follow a trend that approximately fits the field measure value reasonably. Thus the PMS rut depth values was deemed reasonable and no adjustment was needed. An adjustment factor of 1.0 was thus assumed.
- **Example 2**: A plot of CDOT PMS rut depth versus age is presented in figure 6 for PMS Project 27-13959. Superimposed on this plot is field measured rut depth at

age a section age of 8 years. A comparison of field measured and PMS rut depth for at 8 years shows a PMS rut value of 0.51 in and a field measured value of 0.85 in. The difference in these measures was deemed significant. The plot of PMS rut depth versus age shows that the PMS rut measurement at 8 years was not an anomaly or outlier as it fitted trends from previous measurements well. Thus there was a need to adjust the PMS rut depth to field measurements. This was done by determining an adjustment factor equal to field rut depth divided by PMS rut depth (at age = 8). For this PMS project the ratio was 0.85/0.51 = 1.66667. The adjustment factor was used to adjust PMS rut measurements for this project as shown in figure 7.

### Determining Missouri DOT PMS Projects Historical Alligator Cracking

Missouri DOT (MoDOT) collects profile and visual distress data using Automated Road Analyzer (ARAN). The profile data is converted into IRI while visual distresses are manually interpreted and recorded from ARAN videos of the pavement surface. MoDOT collects ARAN data from all arterial routes once every year.

Several MoDOT PMS pavement projects were identified and selected to augment LTPP projects used for local calibration of the MEPDG alligator cracking and HMA transverse cracking models. The PMS projects were needed as the LTPP pavement test sections did not fully cover the sampling space (representing local Missouri conditions) designed based on pavement site, design, materials, and construction properties. For the identified and selected PMS projected, a key issue was to determine historical distress (alligator cracking and transverse cracking) as per LTPP distress survey protocols. This was done for the PMS projects by:

- Identify the highway ID (route, direction, lane number, and begin/end milepost) for each project of interest.
- Identify sample sections within the project of interest (figure 8).
- Retrieve distress videos from the MoDOT video archives.
- Review distress on the archived distress video and quantify alligator cracking and transverse cracking as per LTPP protocol.
- Develop records of distress patterns and locations on LTPP distress maps.
- Compute alligator cracking and transverse cracking as per MEPDG requirements.

The extracted distresses were then combined with other pavement management information to complete local calibration.

## CONCLUSIONS AND RECOMMENDATIONS

This paper presents some of the common challenges encountered when using PMS data for locally calibrating the MEPDG models. It suggests that PMS data plays a key role in adapting the MEPDG for local conditions and that it needs to be considered along with many other datasets that are essential to initiate a well planned and executed local calibration study. The paper advances the idea that the first effort related to calibration will need to be rigorous and labor-intensive since the detailed information required by the MEPDG is typically not stored in PMS databases. Several challenges with PMS data use are presented. More importantly, the paper also presents case studies where PMS data, when treated along with other research grade or manual data collection, can produce results that will aid in the local calibration efforts.

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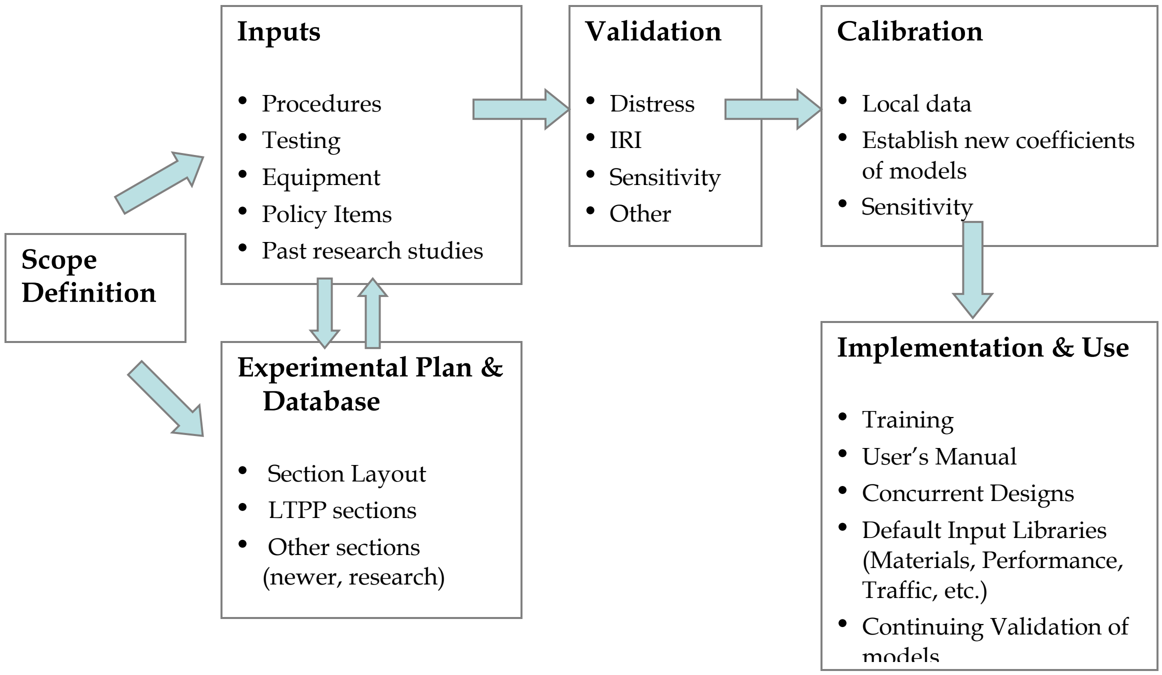


Figure 1. Work flow of activities for implementing the MEPDG.

Figure 2. Straight edge method for measuring rut depth.

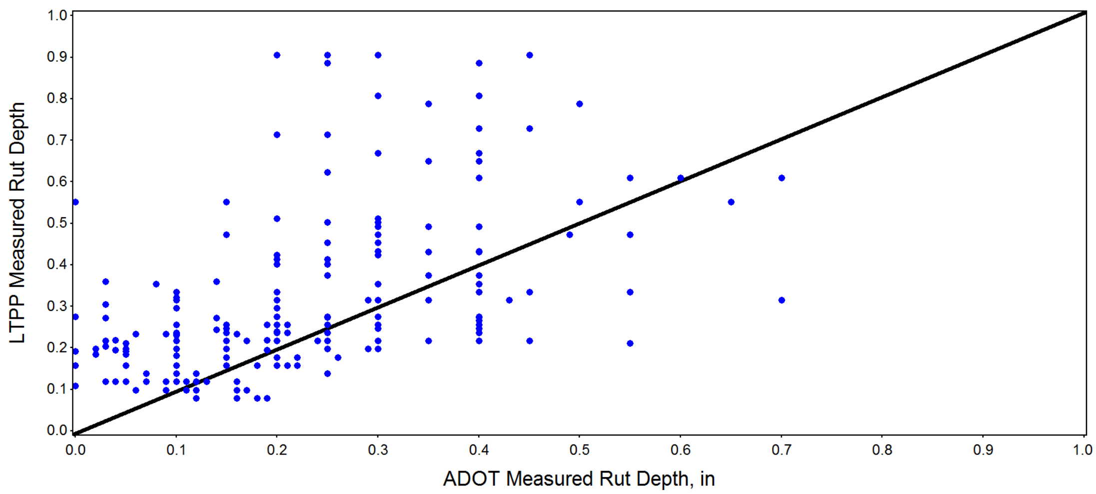


Figure 3. Relationship between ADOT and LTPP Rutting Measurements.

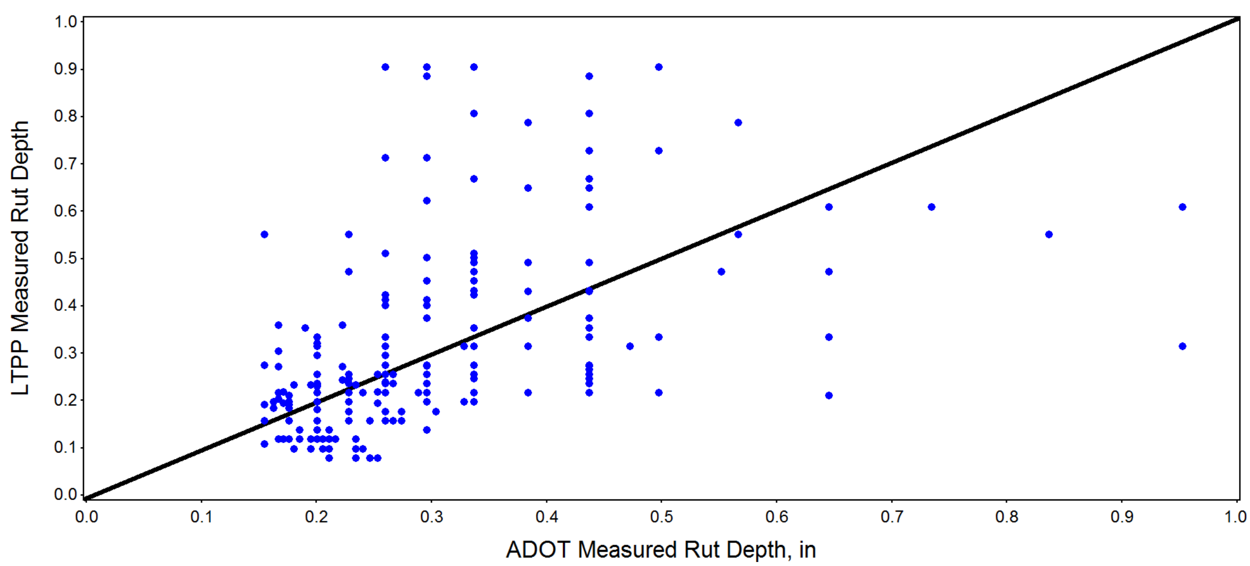


Figure 4. Relationship between LTPP adjusted ADOT and LTPP Rutting Measurements.

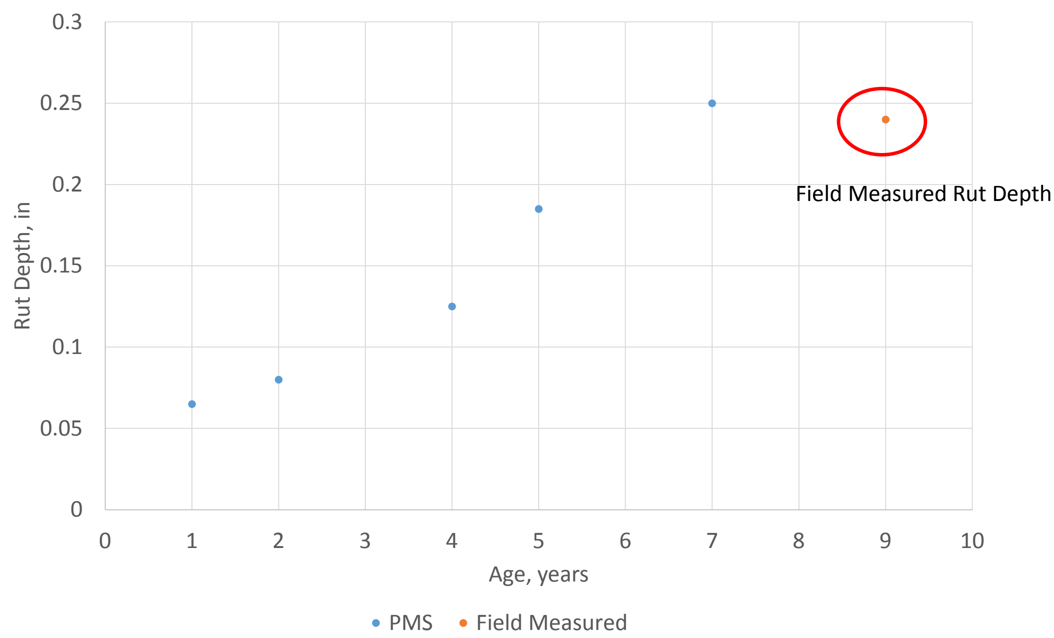


Figure 5. Relationship between field measured and CDOT PMS rut depth measurements for PMS Project 10-12393.

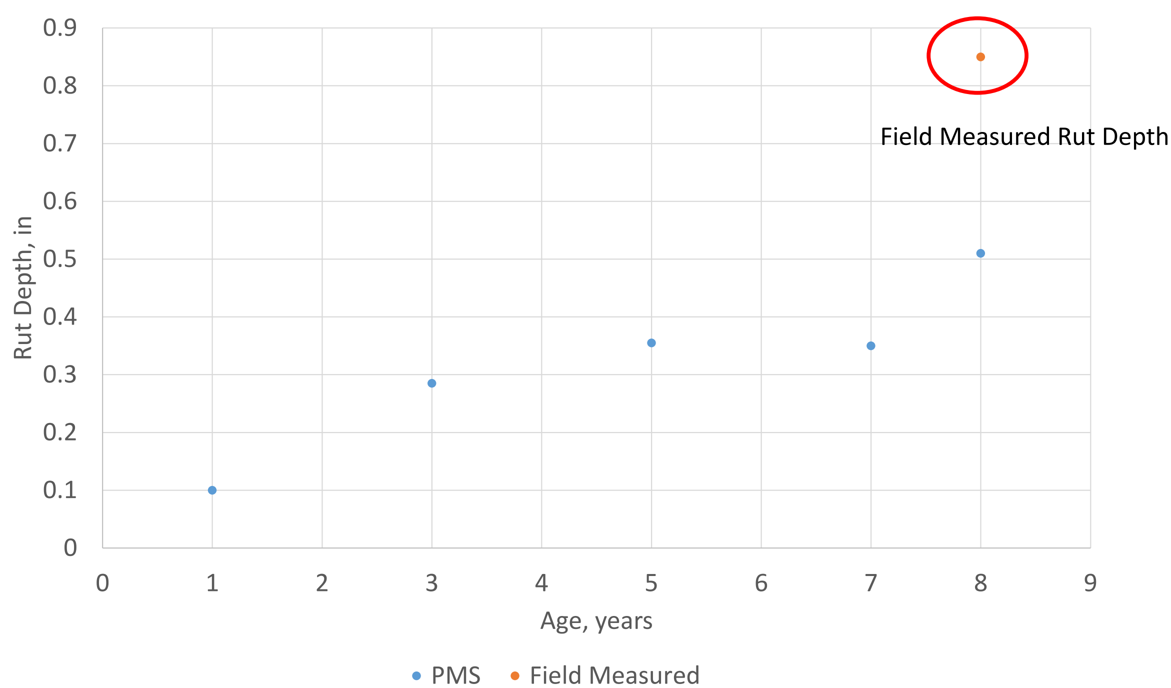


Figure 6. Relationship between field measured and CDOT PMS rut depth measurements for PMS Project 27-13959.

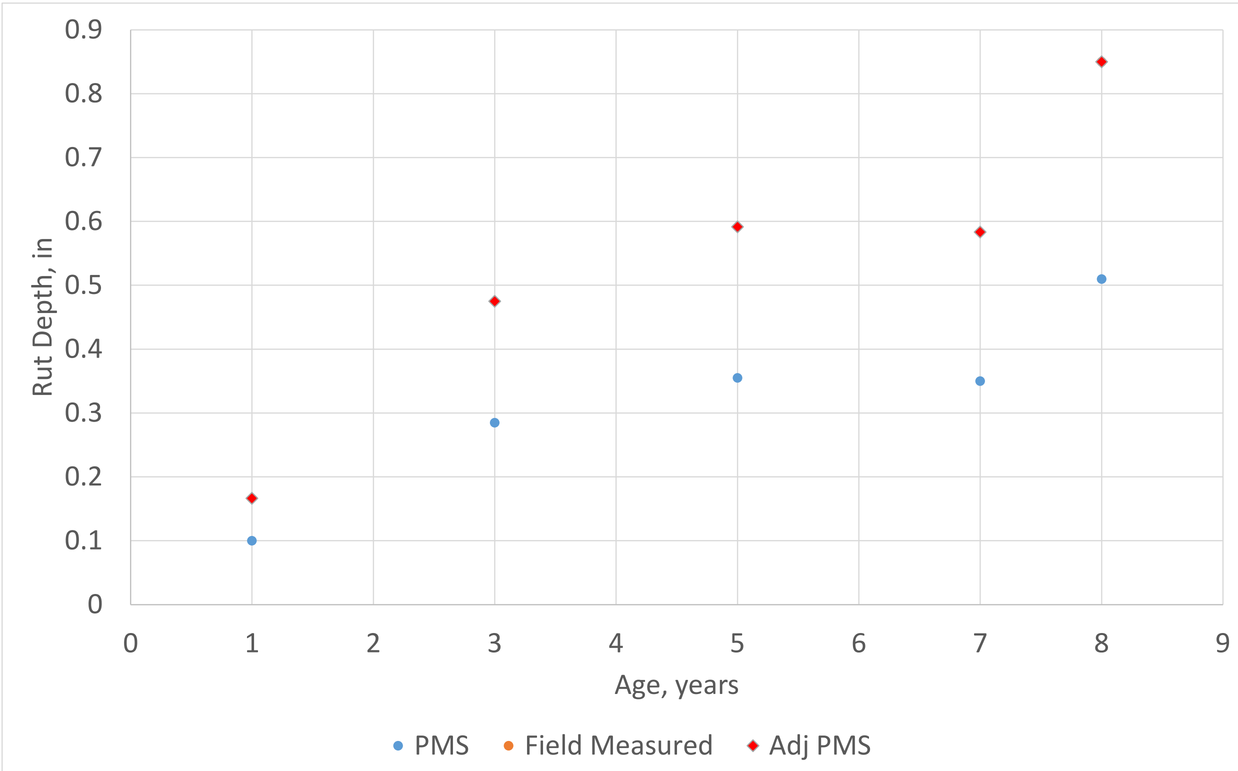


Figure 7. Plot showing adjusted and CDOT PMS rut depth measurements for PMS Project 27-13959.

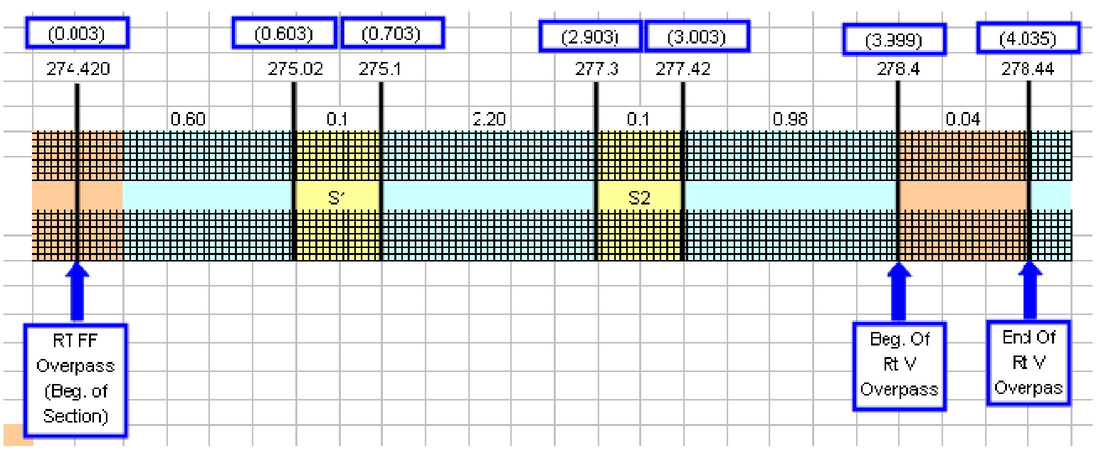


Figure 8. Illustration of a typical MoDOT project and 500-ft sample units.

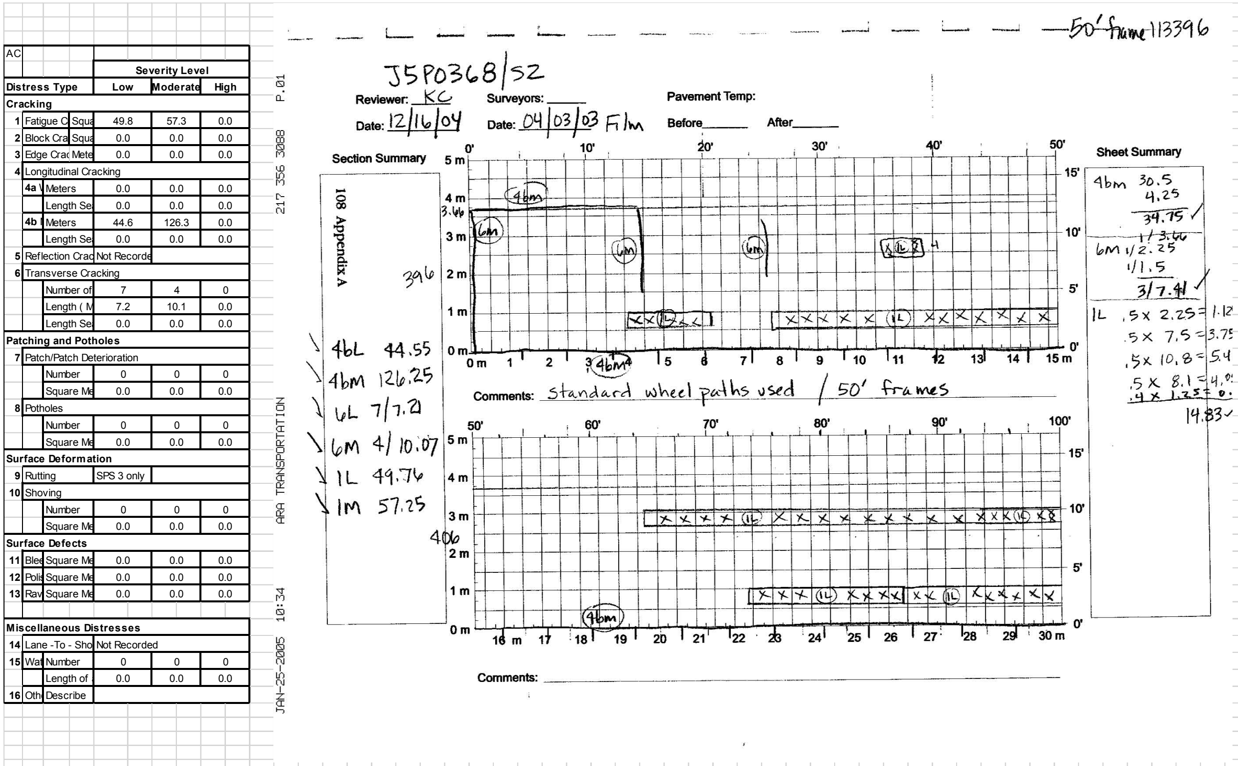

Figure 9. Illustration of a   typical MoDOT project and 500-ft sample units.

Table 1. Summary of the outcome of the hypothesis testing.

| Bias Test | p-value | Accept/Reject Null Hypothesis | Bias |
|---|---|---|---|
| Hypothesis 1 | 0.1530 | Accept | No |
| Hypothesis 2a (Slope) | < 0.0001 | Reject | Yes |
| Hypothesis 2b (Intercept) | < 0.0001 | Reject | Yes |

Table 2. Summary of the outcome of the hypothesis testing.

| Bias Test | p-value | Accept/Reject Null Hypothesis | Bias |
|---|---|---|---|
| Hypothesis 1 | 0.050 | Accept | No |
| Hypothesis 2a (Slope) | 0.1956 | Reject | Yes |
| Hypothesis 2b (Intercept) | 0.050 | Reject | Yes |