LOCAL CALIBRATION OF THE MEPDG USING PAVEMENT MANAGEMENT SYSTEMS

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Final Report
Volume I

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to cor ction 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

AADT	Average Annual Daily Traffic
AADTT	Average Annual Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
CRC	Continuously Reinforced Concrete
CRCP	Continuously Reinforced Concrete Pavement
DOT	Department of Transportation
ESAL	Equivalent Single Axle Loads
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HMA	Hot Mix Asphalt
IT	Information Technology
IRI	International Roughness Index
JCP	Jointed Concrete Pavement
JPCP	Jointed Plain Concrete Pavement
LTPP	Long-Term Pavement Performance
MEPDG	Mechanistic-Empirical Pavement Design Guide
MS	Microsoft
NCHRP	National Cooperative Highway Research Program
PCC	Portland Cement Concrete
PMS	Pavement Management System
SHA	State Highway Agencies

CHAPTER 1. INTRODUCTION

Background

The Mechanistic-Empirical Pavement Design Guide (MEPDG), prepared under NCHRP 1-37A and available from the Transportation Research Board (NCHRP 2004), is a significantly improved methodology for the design of pavement structures. Implementation of the MEPDG is expected to improve the efficiency of pavement designs and enhance the abilities of state transportation departments to predict pavement performance, which will thereby improve their ability to assess maintenance and rehabilitation needs over the life of the pavement structure.

Before the MEPDG can be fully implemented, it has to be calibrated using actual pavement design input and response data to ensure its validity and accuracy. As part of an initial calibration effort, the MEPDG performance models were calibrated and validated primarily using data from the Long-Term Pavement Performance (LTPP) program. Although the LTPP database represents a valuable resource, the enormous variability between the states in terms of geography, climatic conditions, construction materials, construction practices, traffic compositions and volumes, and numerous other pavement design variables make it desirable to calibrate the MEPDG at the local level using local field pavement data. This is not a simple task and requires a great deal of effort to evaluate the inputs needed to accurately reflect the uniqueness of pavement needs for an individual state. Of the three levels of input for MEPDG, the site specific materials, climatic, and traffic data (Level 1 data) most accurately reflects the local situation, the estimated regional data (Level 2 data) are more regionally based but less accurate, and the default data (Level 3 data) are for situations where more specific information is simply not available. The advantage of providing these three levels of input is that the MEPDG can still be used to design pavement structures with acceptable results even if specific Level 1 or Level 2 data are not available. Theoretically, the most accurate pavement design would be the one that used the MEPDG software that was calibrated using Level 1 data and used as many Level 1 and Level 2 data inputs as possible.

One of the first challenges in moving toward the use of the MEPDG is related to the collection of the data needed to support a local calibration effort. Pavement data collection and analysis is expensive, time consuming, and resource intensive, but significant savings could be realized by State Highway Agencies (SHAs) if existing pavement management system data could be used for MEPDG model calibration. An associated benefit of using pavement management data is the inherent improvement in coordination between pavement management and pavement design within each SHA. However, problems that may exist with regard to pavement management data must be resolved before such data can be successfully used to locally calibrate the MEPDG procedure. Some of these issues include:

- The availability of the pavement management system data in the correct format. SHAs use a multitude of different pavement management system approaches and store data in various formats including text files, Microsoft (MS) Excel® workbooks, MS Access® databases, and GIS databases. Some states do not have a dedicated pavement management system database and different types of data are stored in different formats.

For example, the distress data may be in an MS Access® database, but the materials data are in MS Excel® workbooks. Moreover, the type and manner that many states use to collect data (particularly distress data) may not coincide with the exact data requirements of the MEPDG. Another issue is that network-level performance data cannot easily be linked to specific locations where material testing, for example, has been conducted.

- The completeness of the data elements. Many SHA's existing pavement management system data may not be complete enough for the calibration of the MEPDG design approach. It is very possible that some key data elements that are required for calibration will be missing from the state's pavement management data system. For example, many pavement management databases do not contain construction and maintenance information.

- The difficulty in merging data from disparate databases. Databases containing the information needed for calibration may be contained in databases that use different referencing systems for referencing actual locations in the field. Without a common referencing system, it may be difficult to access the information required for calibration.

- The highway agency's plan and schedule for MEPDG implementation. Although most SHAs are interested in moving forward with the MEPDG, many are facing severe budget and staffing shortfalls that may hamper the ability to quickly implement the MEPDG.

In 2006, the FHWA launched a research study to evaluate the potential use of pavement management data for calibration of the MEPDG (FHWA 2006a; FHWA 2006b). Under that study, eight candidate states were selected to participate: Florida, Kansas, Minnesota, Mississippi, New Mexico, North Carolina, Pennsylvania, and Washington. The study concluded that all the participating states could feasibly undertake MEPDG calibration using PMS (Pavement Management System) data (FHWA 2006a; FHWA 2006b). The study went on to say that it seems likely many other states could do the same. One recommendation was that each SHA should develop a satellite pavement management/pavement design database, which should include the regular pavement management data for each project being designed and constructed using the MEPDG. The data used in the design phase would be tabulated in electronic format, transferred, and stored in a satellite database compatible with the pavement management system database. Such an approach would provide a methodology for preserving the design information that is used with the MEPDG on a project-by-project basis. It would also provide a more formal interface between pavement management and pavement design. However, it also requires the duplication of some data typically contained in a pavement management database, which may introduce data conflicts at some point in the future.

Project Objectives

This project was initiated to assist state highway agencies with an important aspect of the MEPDG implementation by building on prior research activities and implementation efforts. In this regard, this projects objective is to develop a framework for using existing pavement management data to calibrate the MEPDG performance models. The feasibility of the framework will be demonstrated using actual data from a SHAs pavement management system. Specifically, the overall objectives of this project include:

- Develop a selecting procedure for identifying three SHAs that could assist in demonstrating the use of pavement management data in the MEPDG calibration process.
- Develop the final screening criteria and select a single SHA.
- Prepare a preliminary framework that identifies the data collection and storage requirements for using data contained within a State's pavement management system for local calibration of the MEPDG.
- Finalize the framework based on the set of actual conditions that exist in the selected state.
- Verify that the framework requirements are understood and the resources are available within the selected SHA to proceed with the calibration process. In addition, verify that all data contained within the developed database (referred to as the MEPDG calibration database in this report) are complete, accurate, and appear to be reasonable.
- Conduct the local calibration of the MEPDG using the SHA supplied pavement sections and data from the pavement management system and other sources as needed (e.g., materials and traffic).

Report Organization

The final report is presented in two volumes: Volume I (Final Report) and Volume 2 (Appendices). This report (Volume 1) documents the entire research effort that was conducted under the project, and contains eight chapters in addition to this introduction. Chapter 2 provides a summary of the process used for identifying three states to be further evaluated for use in this study. Chapter 3 presents the results of the three state selection process. Chapter 4 presents the selection of the single state. Chapter 5 summarizes the preliminary framework development for utilizing pavement management data in the calibration of the MEPDG. Chapter 6 presents the workplan for implementation of the final framework. Chapter 7 discusses the verification of the selected agency's input data for use in the MEPDG calibration process. Chapter 8 presents the calibration results, and Chapter 9 presents specific recommendations on data needs for using pavement management data for calibration of the MEPDG.

CHAPTER 2. THREE STATE SELECTION APPROACH

Introduction

Based on the 2006 FHWA study eight candidate SHAs were identified as being able to feasibly undertake MEPDG calibration using pavement management system data (FHWA 2006a; FHWA 2006b). However, working with eight SHAs in demonstrating how pavement management system data can be used to calibrate the MEPDG would be very time and cost prohibitive. Therefore, this study narrowed the list of eight SHAs down to three. In order to objectively select three of the eight SHAs, the project team identified the following selection criteria:

- Availability of data. The selected SHAs should have as complete as possible the data required for MEPDG calibration. This includes both the pavement management system data and the other required data for calibration.
- Data quality. The availability of high-quality data (correctness, accuracy, reliability, data collection procedures, and quality assurance procedures) is imperative if reliable calibration results are desired.
- Format of the data. For the convenience of data retrieval (query), relational database like MS Access®, MS SQL Server, or Oracle would be ideal. However, other types of electronic data formats (e.g., MS Excel®) can also be used easily. It will take more effort if the data are in paper archives or in mixed format, if they exist on differing types of computer platforms, or if they use non-compatible referencing systems.
- Level of data collection effort. There should be enough data to take into account the seasonal variation of pavement responses, enough coverage to contain all typical pavement types, and the data collection approach should be sufficiently standardized so that the developed framework can be easily expended to most other SHAs. Additionally, the data must be stored in a way that allows the performance data to be linked to the specific locations where destructive or nondestructive tests have been taken.
- The extent of effort required to acquire additional data for the MEPDG calibration. This is related to the data availability and data format mentioned above. If any required data element is missing from the existing data, it will have to be added to the MEPDG calibration database. Depending on the type of missing data, the source of the data available, and the approach needed to re-collect the data, the additional work effort may be significant.

  Anticipated required IT work for linking various databases. To link the pavement management system data and various types of other data, some IT work will be needed. This may include creating a satellite database, creating the primary keys and foreign keys for relational databases, or combining the data from various sources into one logical database. It is possible that a front-end application may be needed to process and combine the data. The anticipated requirements for each of the SHAs will be considered and rated in terms of significance.
- Availability of asphalt, concrete, and composite pavements. The selected SHAs should have good coverage of all the three typical pavement types that are within its PMS data

collection network. It would be helpful if the system covers different pavement types (e.g., hot mix asphalt [HMA], jointed plain concrete pavement [JPCP]) and construction types (new design or rehabilitation design).

<u>Availability of essential data at Level 1 and 2 of MEPDG</u>. Because the availability of Level 1 and Level 2 data increases the accuracy of the resultant calibration, it is desirable to have as much Level 1 and Level 2 data as possible for the key data elements. Most of the eight states involved in the FHWA study showed that the materials data such as the asphalt mix modulus and dynamic modulus of concrete are available at Level 1 (FHWA 2006b). Usually, the traffic volume adjustment factors are Level 3 data.

<u>State's plans to implement the MEPDG</u>. Six of the eight states studied are among the fifteen FHWA Lead States for MEPDG implementation. However, all eight states are active and working to implement the MEPDG within a few years.

The three state selection matrix/criteria proposed and presented herein is designed to permit a realistic assessment of the overall suitability of the eight states to participate in this study. This effort, resulted in the identification of the three SHA that are best suited to contribute to the advancement of the calibration effort nationally using existing pavement management systems.

Selection Concepts

Based on the findings of the two FHWA reports on the use of pavement management system data to calibrate the MEPDG (FHWA 2006a; FHWA 2006b), the research team identified ten primary elements that serve as indicators of a state's readiness to advance the calibration effort using pavement management systems. These indicators fall neatly into four distinct categories of selection criteria, which are discussed in more detail below. The "readiness indicators" are included in a MS Excel® spreadsheet matrix as elements to be rated by an evaluator. Based on the evaluator's findings, a rating of 0 to 10 was assigned to each indicator, with 10 representing the most favorable rating or highest degree of conformity with that element required for calibration. Since the selection criteria categories are not necessarily equivalent to each other in terms of qualifying the state's readiness for calibration, a unique weighting factor has been assigned to each category to reflect their relative importance. For example, the Level of Commitment Category carries a relative weight of 5, whereas the Required Level of Additional Effort Category has been assigned a lesser weight of 3. This permits reflection of the critical importance of a state's willingness and capacity to dedicate necessary resources to the project as compared to the somewhat less critical indication of the need for additional prep work. Table 1 is a spreadsheet that contains all of the above indicators in a matrix format. It represents one state that has been evaluated for illustration purposes only.

The scoring process calls for the completion of one table for each of the eight SHAs. After the evaluator has assigned a rating of 0 to 10 to each of the indicators, a score is then calculated for each indicator by multiplying the rating by the category's relative weighting factor. Four separate category scores were determined by subtotaling the individual scores for all indicators in each category. Finally, a single grand total score was computed for each of the eight states by totaling all four category scores. This approach permitted a more focused comparison among states by category as well as by aggregate total score. The sensitivity of this proposed approach can be evaluated by comparing the evaluation conducted by two or more individual evaluators.

Table 1. Selection Criteria Matrix - One State Example.

State___XY___ Evaluator____MG___ Date__3/12/2008

Category Indicators		**Rating 0 - 10**	**Weight Factor**	**Guideline/Comments**	**Score (Rating * weight Factor)**	**Cat Score, %**	**Grand total, %**
Category I: Level of Commitment	State Plan to Implement MEPDG	6	5	If the state has an existing MEPDG implementation plan, a rating of 10 is assigned. If no plan exists, a rating of 0 is assigned.	30	**73.3**	**71**
	Degree of Commitment to Implementation	7		If the state is committed to and has a plan to implement the MEPDG & the state is willing and able to dedicate the necessary resources, a rating of 10 is assigned. If the state is unable or unwilling to commit the necessary resources, a rating of 0 is assigned. Otherwise, an intermediate rating is assigned based upon the likelihood of future commitment.	35		
	Evidence of Calibration Activity	9		As an indication of the state's commitment to MEPDG implementation, a rating of 10 is assigned if the state has an active calibration effort underway led by a consultant/university or an expert in-house team. If no calibration is underway or planned for the near future, a rating of 0 is assigned.	45		
Category II: Availability and Quality of Data	Availability of Design and Performance Data (for all pavements)	9	4	If the state can demonstrate the availability of design and performance (distress) data for all 3 pavement types (for new and rehabilitation designs), a rating of 10 is assigned. If data exists for two or only one pavement type, a lesser rating is assigned depending on the availability of data.	36	**63.3**	
	Availability of Essential Data (Materials, Traffic, Construction, Climate, Environment) at Level 1 and/or 2	4		If the state can demonstrate the availability of essential calibration data (Materials, Traffic, Construction, Climate, and Environment) at Level 1 and/or Level 2, the state is assigned a rating of 10. If data is only available for some essential data at Level 1 or Level 2 and other data is not available at either of these two levels, the state is assigned a lesser rating depending on the relative amount of data at Levels 1 or 2 in proportion to Level 3 data.	16		
	Data Quality and Objectivity (the state's opinion regarding their data quality)	6		If the state is very confident of their distress data quality and objectivity and demonstrates a solid data QA/QC program, a score of 10 is awarded. Otherwise, the state is assigned a lesser rating depending on their level of confidence in data quality and objectivity. A higher score is awarded to states using automated data collection and analysis technologies.	24		
Category III: Required Level of Effort	Level of Data Collection Intensity (network vs. project level - frequency of coverage)	7	3	Level of ongoing data collection intensity is evaluated with respect to 1) project/ vs. network level data, 2) frequency of coverage (annually vs. bi- or tri-annually), 3)extent of coverage (data per mile, and 4) level of distress detail (actual measurements - see attached table). Rating is dependent on the degree to which state's data collection methods conform to the table (10 = all elements met)	21	**73.3**	
	Anticipated Required IT Work	8		If the anticipated IT work required to support local calibration is judged to be none or very little, the state is assigned a rating of 10. If the anticipated IT work required is judged to be moderate, the state is assigned a score of 5; and if the IT work required is judged to be extensive the state is assigned a score of 1	24		
	Extent of Effort to Acquire Additional Data	7		If the extent of effort required to acquire additional data for local calibration is judged to be none or very little, the state is assigned a score of 10. If the extent of effort required is considered to be moderate, the state is assigned a score of 5; and if the extent of effort required is considered to be extensive the state is assigned a score of 1	21		
Category IV: Data Format	Data Format	9	2	If the state pavement management system and other data required for MEPDG calibration are compatible with MS Excel®, MS Access®, or other type of relational format that can be imported (or exported), the state is assigned a rating of 10. Otherwise, the state is assigned a lower rating depending on the availability of acceptable/workable data format.	18	**90**	

Discussion of Selection Categories

Following is a more complete description of the selection criteria for each of the four categories.

Category I: Level of Commitment

While this category of measure is not technical in nature, it is arguably one of the most important considerations of all. The successful calibration effort is critically dependent on the willingness and the capacity of the SHA to dedicate the resources (time and financial) necessary to see the project through to fruition. A relative weighting factor of 5 was used to compare the importance of this category against the other categories. It is worth mentioning that the original FHWA reports documented varying levels of commitment between the eight states included in the original exploratory study. The level of commitment therefore needed to be assessed through a rational approach. Thus, the Level of Commitment category was comprised of the following three indicators of a state's commitment to MEPDG implementation:

1. State Plan to Implement MEPDG. An existing plan for implementation would be viewed favorably as an indication of a state's intent to move toward implementation. For this indicator, a rating of 10 is assigned if a SHA has an implementation plan in place. If the state is in the process of working on such a plan, a rating of 5 is assigned. If there are no plans for implementation a rating of 0 is assigned.
2. Degree of Commitment. This indicator is intended to provide some measure of a SHAs willingness to fully participate in the effort and its capacity to dedicate the resources needed for MEPDG calibration. While relatively subjective in nature, this rating would shed light on the subject of commitment from the perspective of the responding SHA representatives.
3. Evidence of Calibration Activity. On-going efforts by a SHA to calibrate models were interpreted as a positive indicator of a state's commitment to MEPDG implementation. A higher rating was assigned where evidence of calibration activity by a consultant, university or expert in-house team was demonstrated. It was felt by the contract team that a contractual commitment to the calibration activity would imply a strong desire to get it done within a specified time frame as part of a larger implementation plan.

Category II: Availability of Data

Clearly, the importance of data, complete to the extent possible, cannot be overstated. Design, materials, construction, performance histories, traffic and environmental data at Level 1 and/or Level 2 are essential for successful model calibration. Therefore this category, which carries a relative weighting factor of 4, is comprised of the following two data indicators:

1. Availability of Design and Performance Data. The overall MEPDG implementation effort will eventually require models to be calibrated for all pavement surface types (flexible, rigid, and composite) for both new and rehabilitation projects. Therefore, the availability of both design and performance (distress) data for different projects is considered to be a key indicator of a SHAs preparedness for calibration and eventual implementation.

2. Availability of Essential Data at Level 1 and or Level 2. Materials, traffic, construction and environment data is essential for MEPDG models calibration. The more of this type of available data that conforms to Levels 1 and 2, the less variability is expected in the design output. Therefore, a SHA was assigned a higher rating for this indicator if it was able to demonstrate the availability of a high percentage (relative to the other seven states) of this data that conforms to Levels 1 and/or 2.
3. Data Quality and Objectivity. Based on information provided by the appropriate SHA representative, this provided an indication of the level of confidence the state has in the quality of its pavement management data. Given the enormity of work involved with objectively determining data quality, information supporting these criteria was based to a large extent on the state's own experience and the opinions of its representatives.

Category III: Required Level of Effort

Category III is included in the selection matrix to capture some understanding of the magnitude of additional work (such as supplementing the existing pavement management system data and performing any related IT work) the candidate states would have had to undertake in support of the calibration effort. The Required Level of Effort Category was designed as an attempt to measure the readiness of the states to move forward with calibration in terms of the compatibility of their existing pavement management data, additional data needs to be collected, and IT architecture required for calibration. A relative weighting factor of 3 has been assigned to this category, which is comprised specifically of the following indicators:

1. Level of Data Collection Intensity. This is intended to provide an indication of the suitability of the state's on-going distress data collection activities with regard to project vs. network-level coverage, frequency of condition surveys, extent of coverage in terms of survey sample size, and the degree to which the collected distress data conforms with MEPDG model calibration requirements presented in table 2.
2. Anticipated Required IT Work. This indicator serves to gauge the magnitude of additional IT work above and beyond existing capabilities that would be required to minimally accommodate calibration activities including data linkage and creation of keys for relational databases.
3. Extent of Effort to Acquire Additional Data. This indicator is needed to gauge the amount of additional work required to add any missing data elements. Consideration should be given to the type of missing data and the extent of work that would be required to capture or re-capture that data.

Table 2. MEPDG Required Distresses for Local Calibration.

MEPDG Required Distresses for Local Calibration

HMA
Distress Data

IRI[1]	in/mile
Asphalt top/down (longitudinal) cracking	ft/mile
Asphalt bottom/up (alligator) cracking	% cracked per section length
Low temperature thermal cracking (transverse)	ft/mile
Asphalt rutting[2] (permanent deformation)	inches

JPCP
Distress Data

IRI[1]	in/mile
Transverse cracking	ft/mile
% slab cracked per section	
Mean joint faulting[2]	inches

Continuously Reinforced
Concrete Pavement (CRCP)
Distress Data

IRI[1]	in/mile
Number of punchouts	per/mile
Maximum crack width	in
Minimum crack load transfer (transverse)	LTE%
Minimum crack spacing	ft
Maximum crack spacing	ft

[1] International Roughness Index, typically measured every tenth of a mile
[2] Average, standard deviation, COV, maximum, minimum

Category IV: Data Format

The final category attempts to provide an understanding of the degree of ease with which the necessary data may be manipulated (i.e., relational format). A relative weighting factor of 2 is used to compare the importance of this category against the other three categories. The following indicator comprises Category IV:

1. Data Format. State pavement management data in a relational format such as MS Excel® or MS Access® was viewed as a positive indicator of easy manipulation.

Other Selection Considerations

From the perspective of this study and to generate the maximum benefit possible to the greatest number of states, it was desirable to include those states that are the most representative of the "typical" highway agency. Stated differently, the ultimate selection of the most advanced or mature agency with regard to the status of their MEPDG implementation efforts would not necessarily yield great benefits to a less mature state with an earnest desire to move forward with implementation. For this reason, the selection matrix presented above was augmented with extensive discussion among the research team regarding the advantages and disadvantages of including each state in the study. For example, discussion topics included concerns raised by the team regarding the capacity of a state's pavement management system to objectively support the calibration effort. Or, perhaps the advantages of a particular agency's state-of-the-art distress data collection and analysis methods outweighed some other identified weakness in their pavement management system.

Once the research team reached consensus with regard to the scores of all eight agencies, the three states with scores that most closely approximate the median score for the entire group were selected for inclusion in the study. Based upon the statistical "spread" of the resulting scores, the research team selected a group of three states with scores slightly above or slightly below the median score (i.e., states # 3, 4, and 5 instead of # 4, 5, and 6).

Summary

The described selection criteria provided a rational approach to evaluate the suitability of the eight states in moving forward with MEPDG calibration using data contained within a pavement management system. The selected criteria not only provides an assessment of data availability, data storage format, and data accessibility, but also the willingness and availability of SHA staff to conduct the level of effort needed in the MEPDG calibration process. In addition, selection of the three potential SHAs also included consideration to maximizing the study outcomes by selecting states that represent the "typical" highway agency.

CHAPTER 3. THREE STATE SELECTION RESULTS

Introduction

Using the selection criteria and scoring matrix outlined in Chapter 2, the research team individually evaluated and scored all eight state highway agencies, which included Florida, Kansas, Minnesota, Mississippi, New Mexico, North Carolina, Pennsylvania, and Washington (FHWA 2006a; FHWA 2006b). After completing the individual evaluations, the research team discussed the findings and developed an approach to reach consensus on the state rankings. Following is a summary of the resulting scoring deliberations and comments with regard to perceived strengths and weaknesses of the eight states evaluated.

Scoring Summary

The evaluation of the individual ratings conducted by each research team member began with an in-depth review and discussion of each rater's interpretation of the exercise to provide some standardization or "calibration" of the rating technique. Interestingly, all three raters judged Mississippi, Minnesota, North Carolina, and Florida to be among the most suitable states in accordance with the accepted criteria. While the rankings of these four states differed among raters, each agreed that the differences in scores between the top four states were not substantial. In other words, all raters found the difference between the highest and the fourth highest scores to be small. Kansas, Washington, New Mexico, and Pennsylvania on the other hand, scored significantly lower than the top four states. A detailed comparison of each rater's approach revealed that the largest single factor contributing to the lower ratings for these four states was the level of commitment to the implementation of the MEPDG. According to the information provided in the Hudson, et al. report, these four states had incomplete plans for implementing the MEPDG or had no implementation plans at all. Since the relative weight assigned to this evaluation category was the highest of all four included in the criteria, the incomplete plans for implementation had a strong negative impact on the state's aggregate score. Results of the scores reached by consensus are presented in table 3. Note that the scoring weights assigned to each category to emphasize its relevant importance are included near the top of the table.

Upon reaching consensus with regard to the scores of all eight agencies, the three states with scores that most closely approximate the median score for the entire group were selected for inclusion in this study. This selection approach was developed with the intent of selecting state highway agencies that are representative of typical agencies nationwide rather than state highway agencies that have previously committed excessive resources to calibration activities. However, the pronounced distinction in scores between the top four and bottom four states, which is largely attributed to differences in the levels of commitment to implementation, poses an unanticipated dilemma. That is, those states that are fully committed to implementation will maximize the likelihood of the project's success. For this reason, the research team recommended that the top four states be considered further for participation in the calibration of the MEPDG models that conducted during this study and that the bottom four states be eliminated from further consideration. However, as the research team moved forward with the selection of a single state to work with, the degree to which the agency's pavement management data is representative of information found in other states was taken into consideration.

Table 3. Scoring results.

STATE	**SCORE BY CRITERIA CATEGORY (PERCENT)**				**AGGREGATE SCORE (PERCENT)**
	I. Level of Commitment (weight = 5)	**II. Data Availability and Quality (weight = 4)**	**III. Required Level of Effort (weight = 3)**	**IV. Data Format (weight = 2)**	
MN	93	63	50	60	72
MS	83	57	57	70	68
NC	93	47	40	40	63
FL	73	57	43	70	61
WA	43	53	57	50	50
KS	47	53	47	60	49
PA	23	50	53	60	41
NM	20	47	40	40	34

Discussion and Results

Following are comments pertaining to perceived strengths and weaknesses of the four highest-scoring states highway agencies.

Minnesota

Strengths – Mn/DOT (Department of Transportation) enjoys a mature and highly developed pavement management system. Their plans for implementation are advanced and are being led by the DOT in consort with the University of Minnesota. Their commitment to the effort appears to be very high. Mn/DOT uses digital inspection vehicles to collect distress data annually. They also have detailed, readily accessible construction history information in their Transportation Information System database.

Weaknesses – IT work that would be required to support the calibration effort is judged to be fairly high. Mn/DOT does not yet have experience with traffic spectra data. Records of maintenance work not performed under contract are not available.

Mississippi

Strengths – Mississippi is one of the 14 lead states for implementing the new pavement design guide. The pavement management database is well-developed and contains very detailed information since the database also contains research results. MSDOT has retained the services of a private consultant to advance calibration and implementation on behalf of the DOT. Their approach to implementation is aggressive, and their level of commitment to the effort is judged to be very high.

Weaknesses – Essential data to support calibration (materials, traffic, construction, etc.) is not consistently available at Levels 1 or 2. Many of the input data required in the MEPDG are not yet available in electronic format. Actual pavement layer thickness information is rather scarce. They lack a formal connection between their maintenance operations and their pavement management system.

North Carolina

Strengths – The North Carolina Department of Transportation (NCDOT) has recently enhanced its pavement management system with new software, and they have a contract in place with NC State University to assist with calibration and implementation of the MEPDG. Their pavement management program is well organized, well staffed, and their pavement management system is highly evolved. NCDOT has a fairly comprehensive weigh-in-motion program. Their commitment to the implementation effort appears to be high.

Weaknesses – Essential data to support calibration (materials, traffic, construction, etc.) is not consistently available at Levels 1 or 2. Traffic data are not currently stored in the pavement management system. Maintenance activities are generally not recorded. IT work that would be required to support the calibration effort is judged to be high. The extent of the effort that would be required to acquire additional data for calibration is judged to be fairly high.

Florida

Strengths – FDOT is working with the Texas Transportation Institute to advance their MEPDG implementation effort. There appears to be good cooperation between the relevant databases as much of their data is web-based. Their degree of commitment to the effort appears to be fairly high.

Weaknesses – IT work that would be required to support the calibration effort is judged to be very extensive. They do not have an organized deflection testing program. Distress data collection activities are not automated. The amount of the effort that would be required to acquire additional data for calibration is judged to be high.

States Recommended for Inclusion in the Remainder of the Study

The selection criteria helped the research team identify four state highway agencies that would each be a viable candidate for demonstrating the calibration procedures that was developed under this project. However, the project scope requires the recommendation of only three state highway agencies; each of which would be visited for further discussion. The research team recommended advancement of this MEPDG local calibration project by including the Mississippi, Minnesota and North Carolina Departments of Transportation for the next phases of work with the intent of selecting one of the three to support eventual calibration.

These three states were recommended because they exhibited the highest levels of commitment to the calibration and implementation efforts, and therefore, they are assumed to be most likely to dedicate the time and resources necessary to successfully complete this project. While none of these state highway agencies has all elements in place to locally calibrate the MEPDG at the highest level, they all have reasonably strong pavement management programs and are actively working to resolve their respective pavement management issues (e.g., data integration, software upgrades, data collection improvements). Importantly, the types of issues that Minnesota, Mississippi, and North Carolina are dealing with are shared by many state DOT's throughout the pavement management community nationwide.

In keeping with the goal of selecting a representative agency that is likely to generate maximum potential benefits, the manner in which Minnesota, Mississippi, and North Carolina resolve their pavement design and management issues should be of great interest and utility to typical highway agencies nationwide as they move forward with MEPDG implementation using their pavement management tools.

CHAPTER 4. SINGLE STATE SELECTION

Introduction

In preparing for discussions with the three States (Mississippi, North Carolina, and Minnesota), the project staff sought to confirm the information used during the initial evaluation of the eight States. It was readily recognized that the study done by Hudson et al. was conducted in 2006, and in the two years since that study many things may have changed. For example, several States have been actively involved in evaluation and implementation studies for the MEPDG. The research team sought to explore the current status of work underway in the State as pertaining to the MEPDG implementation, the availability of information in the pavement management database to support the calibration efforts, and the potential level of support that may exist for testing a proposed framework for the use of available State data in calibrating the MEPDG. Specifically, the following factors were considered:

- Level of support in terms of staff requirements.
- Staff availability.
- The State's level of support in terms of budget.
- The computer hardware and operating systems used for related pavement databases.
- The level of IT and database skills the State.
- Level of commitment to this effort by upper management.
- Likelihood of success with the implementation.

The meetings in each of the three States were informal, and were completed in about one and a half business days. The format generally included meeting with all interested personnel to introduce the research effort and the people involved. State agency representatives were asked to discuss, in general terms, the status of their MEPDG implementation efforts. Any university studies that may have been conducted, or are currently under way were discussed, to gain an understanding of the objectives, results, and current status of the work. Discussions were held with representatives of Design, Traffic, and Materials to understand the status of implementation preparedness in each of these areas. Discussions were held with representatives of the Pavement Management group, to assess the availability and format of required data, and the level of effort generally required to access this information.

The likelihood of success with the implementation was primarily gauged by the enthusiasm the State exhibited for the effort, and the existence of a plan for continuation of the effort. Project staff listened for indications of support by upper management, and where necessary queried meeting participants as to the degree of support they received for their efforts.

State Visit Summaries

Following are observations and comments from the meetings with the three State highway agencies.

Minnesota Department of Transportation

Meetings were held with the Minnesota Department of Transportation (Mn/DOT) on Sept. 29-30, 2008. State participants in the meeting included Mr. David Janisch (Pavement Management), Jerry Geib (Pavement Design), Matt Oman (Traffic), and Curt Turgeon (Pavement Engineer). On Day 2 we were joined by Ms. Maureen Jensen, who had worked extensively in the evaluation and implementation of the MEPDG prior to moving to another area in the Department.

Discussions generally confirmed the advantages and disadvantages observed from the earlier work. While Mn/DOT was highly committed to the effort previously, they exhausted their implementation budget while finding a number of apparent problems in the software, and at this point are waiting to take further action once the software is in a more stable position. While the Department continues to collect a great deal of distress and roughness data, the format of the data is not consistent with MEPDG predictions, meaning that the effort required to do meaningful comparisons would be fairly high. While there have been increases in the amount of traffic data collected, staffing shortages have prevented the management and manipulation of data needed to produce the required load spectra information or truck weight road groups.

In general, Mn/DOT feels it has a design process in place that provides an acceptable result, with expected life and actual life in close agreement. As a result there is a lack of justification for making a major change. At this point the cost would be great, with little perceived benefit.

Much of the Mn/DOT implementation work was done in concert with Dr. Lev Kazanovich and the University of Minnesota. An attempt was made to meet with Dr. Kazanovich, but unfortunately he was out of the country during the time of our visit.

Mississippi Department of Transportation

Meetings were held with the Mississippi Department of Transportation (MSDOT) on October 20-21, 2008. State participants in the meetings included Mr. Bill Barstis (Research), Ms. Cindy Drake (Pavement Management), Mr. Jeff Wages (Construction and Materials), and Mr. Trung Trinh (Traffic). Mr. Roger McWilliams of the Division FHWA office also joined us during the meetings. Discussions with Mississippi DOT personnel confirmed the previous findings, and indicated a great deal of advancement in some areas of implementation readiness in the intervening time period. MSDOT sponsored a series of twelve “support studies” as part of their implementation efforts. About half of these involved materials characterizations, which are nearly complete for typical materials used in the State. In these areas they are building libraries of typical material properties for design use.

The State pavement management system is well populated with time series performance monitoring data, and much of that is in the proper format for comparison with MEPDG predictions. Unfortunately the disadvantages previously noted, including a direct link between sections in the pavement management system and material properties still exist, and Mr. Wages reported a great deal of time and effort have gone into locating construction records and obtaining material properties needed from those records. Therefore, it is still believed that the levels of effort necessary to gather required information will be relatively high. It appears that this may be a fairly common characteristic among most State highway agencies.

One thing that impressed the research team during the meetings with MSDOT was the motivation obvious in the implementation support, and the eagerness to meet and work with the team. Mr. Bill Barstis and Ms. Cindy Drake both expressed a desire to participate in the development of the framework, as they felt it would benefit their, and other, implementation efforts. Mr. Barstis indicated that management had generally been very supportive of the efforts thus far, and he felt that they would continue to be supportive as long as forward progress was being made.

In discussing traffic inputs, the research team found that Mississippi DOT is collecting a great deal of traffic data, and had adequate data management facilities in place. However, they had not begun the process of establishing Truck Weight Road Groups or Truck Traffic Classifications yet. References were provided for States that had done this work, in hopes that they could help Mr. Trinh in developing an approach to complete this effort.

North Carolina Department of Transportation

Meetings were held with the NCDOT on October 28-29, 2008. State participants at the initial meeting were Ms. Judith Corley-Lay and Mr. Neil Mastin. The research team had an opportunity to visit with Mr. Clark Morrison (Pavement Design), Mr. Kent Taylor (Traffic), and Mr. Jack Cowsert (Materials) at a later time. Mr. Jim Phelps of the North Carolina FHWA Division office joined us for all of the discussions. The research team learned that NCDOT has a number of support projects under way, generally through Dr. Richard Kim at North Carolina State University. Projects are under way to develop Dynamic Modulus values for typical NCDOT asphalt mixtures, to investigate traffic data status and needs, and to look at statewide calibration needs. All of these projects indicate a fairly high degree of continued interest in the implementation of the MEPDG. Of specific interest was the statewide calibration study, begun in 2007 and scheduled to be completed in August 2009. This study specifically sought to use pavement management and other data for calibration, and found that many estimations and correlations had to be used due to lack of sufficient information.

One important lesson learned during the meetings was that most of the data stored in the NCDOT pavement management database is referenced by County Route and milepoint, meaning that location referencing may be extremely difficult. This may make information location and retrieval nearly impossible, even before the format inconsistencies are considered. Distress data are not stored in a manner consistent with MEPDG predictions, meaning that it will be very difficult to directly relate the two. Still, NCDOT has completed some studies looking at existing roads and MEPDG predictions, and found that performance predictions are poor. They hope that national studies and model improvements as a part of NCHRP 1-40 studies will improve predictive capabilities.

Discussions revealed that while there have been advancements in the area of material characterization, and a study is under way with Dr. Kim on State calibration, it will be difficult to use available information given the current location referencing method and data format. Still, NCDOT remains committed to the effort, and seems genuinely eager to assist if possible.

State Recommended for the Study

The project staff very much appreciated the willingness of DOT staff in all three States to sit and discuss their efforts with the research team. All three of the States exhibited a great deal of interest in the success of this effort. It was clearly obvious that all three States had been deeply involved in the implementation activities for some time, and were well aware of the input needs, and difficulties in developing some of the requirements.

The research team learned something different from each of the State discussions because each of them offered a different perspective on the same problem. Based on our assessment, the NCDOT was recommended and accepted for participation in this study. The NCDOT recommendation was based on the following:

- NCDOT personnel have expressed interest and enthusiasm for the project. They have previously initiated activities in this area that will benefit the project team.
- The Pavement Management Unit is willing to commit engineers to work with our team to populate the MEPDG calibration database required for calibration.
- NCDOT has performed much of the material testing required for Level 1 and 2 data inputs (in particular dynamic modulus values for typical asphalt mixes) and has the resulting data available electronically. The Traffic Surveys group is actively pursuing a research project for determining higher level MEPDG traffic needs.
- In general, all Level 2 inputs can be populated with existing data. Since material sources and suppliers will not be known at the design stage of a project, NCDOT has stated an interest in moving forward with calibration to Level 2 inputs only.
- The Department has the AgileAssets pavement management software in place to provide inventory and performance data needed to calibrate the MEPDG performance prediction models. Pavement deterioration models are in place.
- Data on two pavement types (HMA and PCC) are available at a variety of traffic volumes.

There are several challenges that need to be addressed to successfully test the proposed framework. The challenges identified by the team, and proposed strategies for addressing these challenges, are provided below:

- If IT involvement is required, NCDOT stated that they would not be able to meet the proposed timeframe for completing the project. Although not required under the contract, one of the APTech team members (Stantec) developed a preliminary version of the MEPDG calibration database that stores the inputs outlined in the Preliminary Framework. Because of the availability of this database, NCDOT would be able to populate it using existing data sources without requiring intervention from IT.
- During the interview with NCDOT personnel, some concerns arose because the pavement management database references data by County Route and milepost, which was expected to cause some problems with location referencing. This issue was addressed by selecting specific sections that were used during the calibration study. NCDOT has

already identified 10 HMA projects that were initially constructed in 1995 for which they have construction documents and maintenance histories available. Through the use of known locations, the referencing issues are minimized. Although each of these projects is an asphalt pavement, Ms. Judith Corley-Lay, NCDOT Pavement Engineer, has agreed to identify similar sites for the other surface types that were calibrated during the study.

- NCDOT pavement condition surveys do not conform to the *LTPP Distress Identification Manual* (Miller and Bellinger 2003), which is typical of the majority of state DOTs. As a result, the research team conducted calibration efforts based on the performance data contained within the NCDOT pavement management system and provide discussion on the impacts, if any, of using non-LTPP defined pavement condition distress on the MEPDG prediction models. The findings from this assessment will be useful to other states faced with similar historic pavement condition surveys that are not based on the *LTPP Distress Identification Manual*.

CHAPTER 5. PRELIMINARY FRAMEWORK

Introduction

This chapter identifies the types of information a SHA needs to support its efforts to locally calibrate the MEPDG models using a data contained within a pavement management system. Also included are guidelines for the development of the MEPDG calibration database for storing needed MEPDG inputs. It is envisioned that the developed MEPDG calibration database will not duplicate the information contained in an existing database, but will establish a link for retrieving needed MEPDG input data.

The preliminary framework includes the following five steps:

- Identify the information that can be extracted from the pavement management system, as well as the types of design and as-built information (e.g. thicknesses, material types, as-constructed properties) that are required for calibration activities. Identify sources of information not provided through pavement management.
- Analyze and implement the data storage and backup methodology. The calibration of the MEPDG models will require the collection of additional data that is not typically included in a State pavement management system. A simple relational database table is recommended for storing the additional needed data.
- Link the created MEPDG calibration database with the State pavement management system database.
- Link the created MEPDG calibration database with other SHA databases.
- Outline how missing data related to traffic, climate, materials, and performance parameters could be obtained to support the local calibration effort of a single State.

The application of the framework to a SHA requires consideration of the following factors:

- Based on the results of previous research, the preliminary framework builds on the recommendation to develop a satellite database that combines pavement management and pavement design information on sections that are designed and constructed using the MEPDG. This approach is illustrated in figure 1. The framework identifies information that is expected to be extracted from a pavement management system, as well as the types of design and as-built information that should be obtained from other sources for calibration activities. Specific data requirements for annual measurements (including supplemental materials evaluation testing, actual climate data, maintenance histories, and observed traffic volumes) are also outlined in the preliminary framework.
- A data storage and backup scheme is required. Of all the data required for MEPDG calibration, only a portion of the data is typically stored within a State pavement management system database. These include, but are not limited to, the county, route, milepost, pavement layer descriptions (pavement types and thicknesses), treatment histories, and pavement condition survey data. The rest of the data, such as the construction related (e.g. air voids, compressive strength) data, materials and mix design

data, and climatic data, are not typically contained within a State's pavement management system database. To simplify the process of calibration, it is preferable to combine the various data into one MEPDG calibration database or establish a process for linking them together. For some types of relational databases, database links can be created so that the various databases can work like a single logic database.

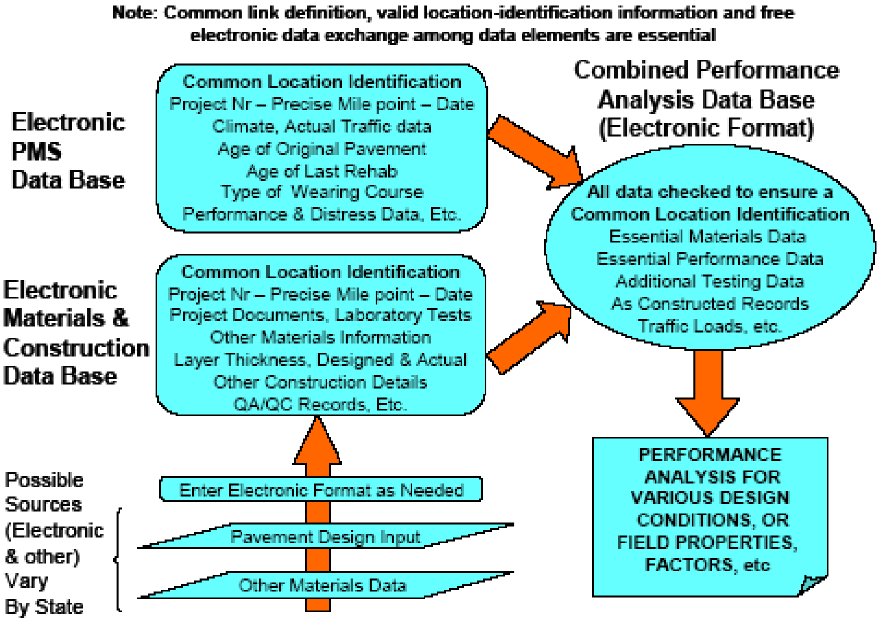

Figure 1. Supplemental database approach for MEPDG calibration activities (FHWA 2006a).

- An approach for linking the created MEPDG calibration database with the State pavement management system database must be included. Generally, there are two different approaches to combine one relational database with another relational database or spreadsheet. The first method is to import the data from the other database or spreadsheets files. The second method is to link the data without importing them. The advantages and disadvantages of each approach are described later in this section. In general, databases are more useful for linking data and for retrieving records. However, many individuals are more comfortable using spreadsheets, which are especially useful for numeric computations. A disadvantage to the use of spreadsheets is that they can only handle simple data relationships.
- The approach to link the created MEPDG calibration database with other SHA databases (e.g., materials databases) needs to be analyzed and the most effective strategy determined. Because some of the required data may be stored as flat text files, a front-end application may be needed to process and import any data into the MEPDG calibration database.
- Guidelines for standard database management and maintenance techniques (e.g. quality control of data inputs, security, backups) are needed. In addition, since the MEPDG is an evolving software program, existing models may be modified and new models may be added. Guidelines for database modification to incorporate future models (and potential changes in data inputs), enhancements, and additions will be necessary.

- The use of a common referencing system will be critical for obtaining applicable data across multiple databases. It is recognized that the various departments within a SHA (such as pavement management, traffic, construction) may maintain their records according to different referencing systems. The ability to relate the various referencing systems to a single referencing system will be essential in the calibration process, thereby insuring that all data relates to the same roadway location on the State highway network.

Project Summary Module

The project-specific information used in a typical MEPDG run is presented in table 4. This information is not used directly in the calibration process but is necessary to define performance parameters (e.g., distresses) and reliability levels. The majority of this information should be available within a typical State pavement management system; however, some information (e.g. traffic opening date, design life) may need to be obtained from alternate sources.

Table 4. Project summary information.

Description	Variable	HMA	PCC		Typical Data
			JPCP	CRCP	
Design properties	Project name and description	X	X	X	Yes
	Design life (years)	X	X	X	Assumed
	Base/subgrade construction (date)	X	X	X	Maybe
	Restoration/Overlay				
	Existing pavement construction (date)	X	X	X	Yes
	Pavement restoration/overlay (date)	X	X	X	Yes
	Traffic opening (date)	X	X	X	No
Site/project identification	Location	X	X	X	Yes
	Project ID	X	X	X	Yes
	Section ID	X	X	X	Yes
	Stationing (format, beginning and end)	X	X	X	Yes
	Traffic direction	X	X	X	Yes
Analysis parameters (limit and reliability)	Initial IRI (in/mi)	X	X	X	Yes
	Terminal IRI (in/mi)	X	X	X	Yes
	AC surface down cracking (ft/mi)	X			No
	AC bottom up cracking (%)	X			Yes
	AC thermal fracture (ft/mi)	X			Yes
	Chemically stabilized layer fatigue fracture (%)	X	X		No
	Permanent deformation – total (in)	X	X		No
	Permanent deformation – AC only (in)	X	X		Yes
	Transverse cracking (% slabs cracked)		X		Yes
	Mean joint faulting (in)		X		Yes
	Existing punchouts			X	Yes
	Maximum crack width (in)			X	No
	Minimum crack load transfer efficiency (%)			X	No
	Minimum crack spacing (ft)			X	No
	Maximum crack spacing (ft)			X	No

Traffic Module

The MEPDG utilizes axle load spectra as an input to the analysis process. The axle load spectra represent the hourly, daily, monthly, and seasonal distributions of the traffic with respect to axle type/load of various vehicle classes. This represents a major departure from the equivalent single axle loads (ESAL) concept that was used in previous American Association of State Highway and Transportation Officials (AASHTO) methodologies. Table 5 lists the required MEPDG traffic inputs and the availability of this information in a typical pavement management system database.

Table 5. Traffic data inputs.

Description	Variable	HMA	PCC[1]	Typical Data
Design properties	Initial two-way average annual daily truck traffic (AADTT)	X	X	No
	Number lanes in design direction	X	X	Yes
	Trucks in the design direction (%)	X	X	No
	Trucks in the design lane (%)	X	X	No
	Operational speed	X	X	No
Traffic volume adjustment factors	Monthly adjustment factors	X	X	No
	Vehicle class distribution (%)	X	X	No
	Truck hourly distribution factors (%)	X	X	No
	Traffic growth factors (%)	X	X	No
Axle load distribution factors	Axle load distribution factors by axle type	X	X	No
General traffic inputs	Mean wheel location (inches from lane marking)	X	X	No
	Traffic wander standard deviation (in)	X	X	No
	Design lane width (in)	X	X	Yes
	Number axles per truck class	X	X	No
	Axle configuration (axle width, dual tire spacing, tire pressure, axle spacing)	X	X	No
	Wheel base distribution (axle spacing and percent of trucks)	X	X	No

[1] Data required for both JPCP and CRCP

Based on the way that traffic is characterized in the MEPDG, most pavement management databases will not contain the needed traffic information. Therefore, most of this information will need to be provided by other sources within the SHA. Table 6 provides additional details regarding the data collection or measurement requirements for each of the MEPDG input levels. Additional (more detailed) information on the traffic module and axle load spectra is available in the NCHRP report, *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, Final Report, Part 2, Chapter 4, Traffic (NCHRP 2004).

Table 6. Traffic data estimation.

Variable	Level	How to acquire and/or measure
Initial two-way AADTT	1	Site specific WIM, AVC or traffic forecasting models
	2	Regional WIM, AVC, vehicle counts or traffic forecasting models
	3	National WIM, AVC, vehicle counts or traffic forecasting models
Trucks in the design direction	1	Site specific WIM, AVC or vehicle counts
	2	Regional WIM, AVC or vehicle counts
	3	National WIM, AVC or local vehicle counts/experience
Trucks in the design lane	1	Site specific WIM, AVC or vehicle counts
	2	Regional WIM, AVC or vehicle counts
	3	National WIM, AVC or local vehicle counts/experience
Operational speed	N/A	Direct measurement of site specific segment or calculate based on Highway Capacity Manual
Monthly adjustment	1	Site specific WIM or AVC
	2	Regional WIM or AVC
	3	National WIM or AVC
Vehicle class distribution	1	Site specific WIM, AVC or vehicle counts
	2	Regional WIM, AVC or vehicle counts
	3	National WIM, AVC or local vehicle counts/experience
Hourly distribution	1	Site specific WIM, AVC or vehicle counts
	2	Regional WIM, AVC or vehicle counts
	3	National WIM, AVC or local vehicle counts/experience
Traffic growth rate	N/A	Continuous or short duration AADTT counts
Axle load distribution factors	1	Site specific WIM or AVC
	2	Regional WIM or AVC
	3	National WIM or AVC
Mean wheel location	1	Direct measurement of site specific segment
	2	Regional/statewide average
	3	National average or local experience
Traffic wander standard deviation	1	Direct measurement of site specific segment
	2	Regional/statewide average
	3	National average or local experience
Design lane width	N/A	Direct measurement of site specific segment
Number of axles per truck	1	Site specific WIM, AVC or vehicle counts
	2	Regional WIM, AVC or vehicle counts
	3	National WIM, AVC or local vehicle counts/experience
Axle configuration	N/A	Measure directly, obtain information from manufacturers, national average or local experience

Environmental/Climatic Model

The MEPDG uses detailed climatic information in the analysis of pavement performance by predicting distress quantities over time for each of the different pavement types. This is a significant enhancement over the previous approach, which merely specifies a climatic region. The MEPDG considers the impacts of seasonal, daily, and hourly moisture and temperature distributions on pavement performance. The climatic data used in the MEPDG is shown in table 7.

Table 7. Environment/climatic parameters.

Description	**Variable**	**HMA**	**PCC[1]**	**Typical Data**
Design properties	Climatic data file[2]	X	X	No
	Latitude (degrees, minutes)	X	X	No
	Longitude (degrees, minutes)	X	X	No
	Elevation (ft)	X	X	No
	Depth of water table (ft)	X	X	No

[1] Data required for both JPCP and CRCP

[2] Climatic data file can be imported (previously generated) or generated

The climatic data files developed for use with the MEPDG are available for downloaded at the NCHRP website (http://www.trb.org/mepdg/climatic_state.htm). The downloaded climatic files can be supplemented with files developed by the SHA based on available weather station data using hourly temperature, wind speed, percent sunshine, precipitation, and relative humidity. Other needed climatic information (as shown in table 7) is typically available from design personnel or other internal sources. In order to model thermal and moisture conditions within the pavement structure, numerous data inputs are required. Detailed information on the necessary inputs is available in the NCHRP report, *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, Final Report, Part 2, Chapter 3, Environmental Effects (NCHRP 2004).

Pavement Structure Model

The pavement structure module allows for the creation of a basic pavement structure (HMA or PCC) for new or rehabilitation design and analysis. In addition, the pavement structure module requires detailed material properties data. A summary of the necessary basic pavement structure information used with the MEPDG is provided in table 8.

Table 8. Pavement structure summary.

Description	Variable	HMA		PCC[1]		Typical Data
		New	Overlay	New	Overlay	
Structure properties	Layer type	X	X	X	X	Maybe
	Layer material	X	X	X	X	Yes
	Layer thickness (in)	X	X	X	X	Maybe
	Rehabilitation level		X			Yes
	Milled thickness (in)		X		X	Maybe
	Pavement rating		X		X	Yes
	Total rutting (in)		X			Yes
	Surface short-wave absorptivity	X	X	X	X	No

[1] Data required for both JPCP and CRCP

The information required for the basic pavement structure section is typically available within a pavement management system with a few exceptions. For instance, the surface short-wave absorptivity of the pavement surface is not typically included in a pavement management database. Table 9 identifies how the surface short-wave absorptivity can be estimated for various MEPDG levels. Other information that may be missing from a pavement management database, such as layer type and layer thickness, may be obtained from cores or from design records.

Table 9. Determining surface short-wave absorptivity.

Variable	Level	How to acquire and/or measure
Surface short-wave absorptivity	1	Estimate through laboratory testing
	2	N/A
	3	Default values

Material Characterization

Significant material characterization is required to support the MEPDG, especially at Level 1 and Level 2. The required HMA, PCC, chemically stabilized, unbound, and bedrock material input parameters are presented in table 10 through table 14. These input parameters are typically not found in most pavement management systems. However, this information may be obtained from records in a SHA materials laboratory, construction records, and from field cores.

Table 10. HMA layer characterization.

Description	**Variable**	**HMA**		**Typical Data**
		New	**Overlay**[1]	
Design properties	HMA E* predictive model	X	X	No
	HMA rutting model coefficients	X	X	No
	Fatigue analysis endurance limit	X	X	No
	Include reflective cracking in analysis		X	N/A
Mix properties	Aggregate gradation (% retained, % passing)	X	X	No
	Asphalt binder type	X	X	No
	Asphalt binder grade	X	X	No
General properties	Reference temperature (°F)	X	X	No
	Effective binder content (%)	X	X	No
	Air voids (%)	X	X	No
	Total unit weight (pcf)	X	X	No
	Poisson's ratio	X	X	No
Thermal properties	Thermal conductivity (BTU/hr ft °F)	X	X	No
	Heat capacity (BTU/lf °F)	X	X	No
Thermal cracking	Average tensile strength at 14°F (psi)	X	X	No
	Creep compliance (1/psi)	X	X	No
	Coefficient of thermal contraction (in/in/°F)	X	X	No
Rehabilitation (HMA overlay of PCC)	Poisson’s ratio of PCC		X	No
	Elastic resilient modulus of fractured slab		X	No
	Type of slab fracture		X	No
	Thermal conductivity of PCC slab		X	No
	Heat capacity of PCC slab			
	Slabs with transverse crack before restoration (%)		X	Yes
	Repaired slabs after restoration (%)		X	Yes
	Dynamic modulus of subgrade reaction (psi/in)		X	Yes
	Month measured		X	Yes

[1] HMA overlays include: overlays of HMA, and overlays of JPCP and fractured JPCP

Table 11. PCC layer properties.

Description	Variable	JPCP		CRCP		Typical Data
		New	Overlay[1]	New	Overlay[1]	
Design properties	Permanent curl/warp effective temperature difference (^{o}F)	X	X	X	X	No
	Joint spacing (ft)	X	X			Yes
	Sealant type	X	X			No
	Dowel diameter and joint spacing	X	X			No
	Edge support - tied PCC (% LTE)	X	X	X	X	No
	Edge support - widened slab (ft)	X	X			No
	PCC-base interface	X	X			No
	Base erodibility index	X	X	X	X	No
	Steel reinforcement (%)			X	X	No
	Diameter of steel reinforcement (in)			X	X	No
	Depth of steel reinforcement (in)			X	X	No
	Base/slab friction coefficient			X	X	No
	Crack spacing (in)			X	X	No
General properties	Layer thickness (in)	X	X	X	X	Maybe
	Unit weight (pcf)	X	X	X	X	No
	Poisson's ratio	X	X	X	X	No
Thermal properties	Coefficient of thermal expansion (per ^{o}Fx10^{-6})	X	X	X	X	No
	Thermal conductivity (BTU/hr ft ^{o}F)	X	X	X	X	No
	Heat capacity (BTU/lf ^{o}F)	X	X	X	X	No
Mix properties	Cement type	X	X	X	X	No
	Cementitious material content (lb/yr^{3})	X	X	X	X	No
	Water/cement ratio	X	X	X	X	No
	Aggregate type	X	X	X	X	No
	PCC zero-stress temperature	X	X	X	X	No
	Ultimate shrinkage at 40% R.H. (microstrain)	X	X	X	X	No
	Reversible shrinkage (% of ultimate shrinkage)	X	X	X	X	No
	Time to develop 50% of ultimate shrinkage	X	X	X	X	No
	Curing method	X	X	X	X	No
Strength properties	28-day Elastic modulus (psi)	X	X	X	X	No
	28-day Modulus of rupture (psi)	X	X	X	X	No
	Compressive strength (psi)	X	X	X	X	No
	Splitting tensile strength (psi)			X	X	No
Rehabilitation	Slabs with transverse cracks before restoration (%)[3]		X	X	X	Yes
	Repaired slabs after restoration (%)		X	X	X	Yes
	CRCP existing punchouts (per mi)			X	X	Yes
	Dynamic modulus of subgrade reaction (psi/in)		X	X	X	No
	Month measured		X	X	X	No

[1] JPCP/CRCP overlays include: bonded and unbonded overlays and overlays of flexible pavements

Table 12. Stabilized layer inputs.

Description	Variable	Typical Data
General properties	Material type (cement and lime alternatives)	Yes
	Layer thickness (in)	Maybe
	Unit weight (pcf)	No
	Poisson's ratio	No
Strength properties	Elastic/resilient modulus (psi)	No
	Minimum elastic/resilient modulus (psi)	No
	Modulus of rupture (psi)	No
Thermal properties	Thermal conductivity (BTU/hr ft ^{o}F)	No
	Heat capacity (BTU/lf ^{o}F)	No

Table 13. Unbound layer inputs.

Description	Variable	Typical Data
General properties	Material type	Yes
	Layer thickness (in)	Maybe
	Poisson's ratio	No
	Coefficient of lateral pressure	No
Strength properties[1]	Modulus (psi)	No
	CBR	No
	R-value	No
	Layer coefficient (a_i)	No
	Penetration DCP	No
	Plasticity index and gradation	No
ICM properties	Gradation (% passing)	No
	Plasticity index	No
	Liquid limit	No
	Compacted layer (Yes/No)	No

Table 14. Bedrock layer inputs.

Description	Variable	Typical Data
General properties	Material type	Yes
	Layer thickness (in)	Maybe
	Unit weight (pcf)	No
	Poisson's ratio	No
	Resilient modulus (psi)	No

As indicated previously, most of the required materials input data is not typically contained in a SHA pavement management database. However, other sources, such as construction records, materials laboratories, or other SHA databases should be explored. A coring program may also be used to obtain missing pavement layer type, thickness, and material characterization information. Missing materials information can be addressed following the MEPDG proposed guidelines included below in tables 15 through 19.

Table 15. Estimating HMA layer parameters.

Variable	Level	How to acquire and/or measure
Dynamic Modulus	1	AASHTO TP62
	2	Predictive equation using G*-D Ai-VTSi calculated values
	3	Predictive equation using typical Ai-VTSi values
Aggregate gradation	1	AASHTO T27
	2	N/A
	3	N/A
Effective binder content	1	AASHTO R35
	2	N/A
	3	Agency historical data or typical values
Air voids	1	AASHTO 269
	2	N/A
	3	Agency historical data or typical values
Total unit weight	1	AASHTO T166 and AASHTO T209
	2	N/A
	3	Agency historical data or typical values
Poisson's ratio	1	N/A
	2	Regression equation based on 'a' and 'b' values
	3	Agency historical data or typical values
Thermal conductivity	1	ASTM E1952
	2	N/A
	3	Agency historical data or typical values
Heat capacity	1	ASTM D2766
	2	N/A
	3	Agency historical data or typical values
Average tensile strength	1	AASHTO T322
	2	N/A
	3	Regression equation based on NCHRP 1-37a
Creep compliance	1	AASHTO T322
	2	AASHTO T322
	3	Regression equation based on NCHRP 1-37a
Coefficient of thermal contraction	1	N/A
	2	Correlation based on HMA volumetric properties
	3	N/A
Dynamic modulus of subgrade reaction	1	AASHTO T307
	2	Correlation based on CBR, R-value, a_i, and DCP
	3	Agency historical data or typical values

Table 16. Determining PCC layer values.

Variable	Level	How to acquire and/or measure
Unit weight	1	AASHTO T121 or T271
	2	N/A
	3	Agency historical data or typical values
Poisson's ratio	1	ASTM C469
	2	N/A
	3	Agency historical data or typical values
Coefficient of thermal expansion	1	AASHTO TP60
	2	Correlation based on aggregate and paste CTE values
	3	Agency historical data or typical values
Thermal conductivity	1	ASTM E1952
	2	N/A
	3	Agency historical data or typical values
Heat capacity	1	ASTM D2766
	2	N/A
	3	Agency historical data or typical values
Ultimate shrinkage	1	AASHTO T160
	2	Correlation based on PCC mix parameters
	3	Level 2 correlation
Reversible shrinkage	1	AASHTO T160
	2	As per Level 1
	3	As per Level 1
Elastic modulus	1	ASTM C469
	2	Correlation based on compressive strength
	3	ASTM C469, historical data, or typical values
Modulus of rupture	1	AASHTO T97
	2	Correlation based on compressive strength
	3	AASHTO T97, historical data, or typical values
Splitting tensile strength	1	AASHTO T198
	2	Correlation based on compressive strength
	3	AASHTO T198, historical data, or typical values
Compressive strength	1	AASHTO T22
	2	N/A
	3	AASHTO T22, historical data, or typical values

Table 17. Characterizing stabilized layer inputs.

Variable	Level	How to acquire and/or measure
Unit weight	1	AASHTO T121 or T271
	2	N/A
	3	Agency historical data or typical values
Poisson's Ratio	1	N/A
	2	N/A
	3	Agency historical data or typical values
Elastic/resilient modulus[1] (PCC surface)	1	ASTM C469 and AASHTO T307
	2	Correlation based on strength
	3	Agency historical data or typical values
Elastic/resilient modulus[1] (HMA surface)	1	AASHTO T307 and ASTM D3497
	2	Correlation based on strength
	3	Agency historical data or typical values
Thermal conductivity	1	ASTM E1952
	2	N/A
	3	Agency historical data or typical values
Heat capacity	1	ASTM D2766
	2	N/A
	3	Agency historical data or typical values

[1] Test method depends on type of stabilized base

Table 18. Characterizing unbound layer inputs.

Variable	**Level**	**How to acquire and/or measure**
Poisson's ratio	1	N/A
	2	Correlation based on local knowledge and experience
	3	Agency historical data or typical values
Coefficient of lateral pressure	1	N/A
	2	Correlation based on material properties
	3	Agency historical data or typical values
Modulus	1	AASHTO T307
	2	Correlation based on CBR, R-value, a_i, and DCP
	3	Agency historical data or typical values
CBR	1	AASHTO T193
	2	N/A
	3	Agency historical data or typical values
R-value	1	AASHTO T190
	2	N/A
	3	Agency historical data or typical values
Layer coefficient	1	AASHTO Guide for the Design of Pavement Structures
	2	N/A
	3	Agency historical data or typical values
Penetration DCP	1	ASTM D6951
	2	N/A
	3	Agency historical data or typical values
Gradation	1	AASHTO T27
	2	N/A
	3	N/A
Plasticity index	1	AASHTO T90
	2	N/A
	3	N/A
Liquid limit	1	AASHTO T89
	2	N/A
	3	N/A

Table 19. Characterizing bedrock layer inputs.

Variable	Level	How to acquire and/or measure
Unit weight	1	AASHTO T121
	2	N/A
	3	Agency historical data or typical values
Poisson's Ratio	1	N/A
	2	N/A
	3	Agency historical data or typical values
Resilient modulus	1	AASHTO T307
	2	Correlation based on strength
	3	Agency historical data or typical values

It is important to note that additional State-specific material characterization data may also be extracted from the LTPP database to supplement missing information that cannot be obtained through direct testing or an agency specific historical/typical values. State research reports may also be an excellent source for historical/typical data.

Detailed information on materials characterization requirements for MEPDG Level 1(data associated with specified test protocols), Level 2 (correlation equations), and Level 3 (typical default values) are available in the NCHRP report, *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, Final Report, Part 2, Chapter 2, Material Characterization (NCHRP 2004).

Pavement Distress Prediction and Measurements

The key pavement performance indicators used by the MEPDG are summarized in table 20. These performance indicators (pavement distresses), associated limits, and reliability levels are used to predict the performance of a typical pavement design using the MEPDG models. The MEPDG models were calibrated using national data; however, each agency should consider calibration of the distress models to local State conditions. There are expected to be some difficulties in calibrating the models, since some distress (such as HMA top-down cracking) are not included in most network-level condition surveys conducted as part of an agency's pavement management activities. Therefore, each agency must determine which models will or will not be calibrated with the pavement management survey information.

Table 20. Pavement performance indicators.

Description	Variable	HMA	PCC		Typical Data
			JPCP	CRCP	
Observed distresses	Initial IRI (in/mi)	X	X	X	Yes
	Terminal IRI (in/mi)	X	X	X	Yes
	AC surface down cracking (ft/mi)	X			No
	AC bottom up cracking (%)	X			Yes
	AC thermal fracture (ft/mi)	X			Yes
	Chemically stabilized layer fatigue fracture (%)	X			No
	Permanent deformation – total pavement (in)	X			No
	Permanent deformation – AC only (in)	X			Yes
	Transverse cracking (% slabs cracked)		X		Yes
	Mean joint faulting (in)		X		Yes
	CRCP existing punchouts			X	Yes
	CRCP crack width (in)			X	No
	Crack load transfer efficiency (%)			X	No
	Crack spacing (ft)			X	No

The majority of the pavement performance indicators (pavement distresses) specified in table 20 are available in a typical pavement management system. However, performance indicators that are not currently collected can be obtained using automated or visual distress surveys. Using caution will ensure compatible performance indicators (definition and format) between the MEPDG and the pavement management system. The condition definitions used in the MEPDG are based on the *LTPP Distress Identification Manual.* Differences between SHA pavement condition definitions and those identified in the *LTPP Distress Identification Manual* will need to be considered in the MEPDG calibration process. One option to consider is incorporating these differences as part of the calibration process. A second option is to calibrate the MEPDG to each State's LTPP sites and then calibrate the MEPDG results to the State's pavement condition survey. For those States with limited LTPP sites, it may be advisable to identify appropriate pavement sections, conduct the pavement condition survey according to the *LTPP Distress Identification Manual*, and calibrate the MEPDG accordingly. In addition, occasionally one or more distress types are combined under a single pavement management system classification; therefore, it will be important to identify the distress classification and measurement units in a State pavement management system before a local calibration effort is attempted. During the calibration process, States are highly recommended to review the *Recommended Practice for Local Calibration of the ME Pavement Design Guide* (anticipated AASHTO publication in 2010) for details related to selection of calibration sections, estimation of needed sample size, and determination of standard error and bias.

Database Development Framework

The development of a simple database or series of spreadsheets is required to store additional MEPDG related/specific traffic, climate, material, and pavement performance data that currently does not exist within a State pavement management system. MS Access® was selected by the research team to create the MEPDG calibration database and associated tables to support the local calibration of MEPDG models by a SHA. A database system is proposed instead of a spreadsheet-based system due to the distinct benefits of database systems. The comparison between databases and spreadsheets is shown in table 21.

Table 21. Differences between databases and spreadsheets.

Database	**Spreadsheet**
• Easier to store, organize and retrieve data • Data links to minimize redundancies, which results in smaller file sizes, faster speeds for data access and reduced errors • Supports complex searches • Supports multiple user access	• Easy to use and familiar to many users • Good for numerical computations and developing graphs • Strength is in calculations and not organizing records • Can only handle simple data relationships • Challenging to manipulate large quantity of records

The differences between databases and spreadsheets demonstrate that the use of a database is much more versatile and functional for capturing data from existing databases and incorporating additional information needed for MEPDG operation and calibration. The selection of a database system is recommended for implementation by SHAs interested in performing local calibration for MEPDG models. The preliminary framework includes a series of MS Excel® files that might be partially or fully developed by a SHA for some MEPDG related inputs and are linked together by the engine of the MS Access® database program. The MS Access® database program is user-friendly, does not require extensive training, and the associated database tables are simple to develop, as highlighted in the next section.

Figure 2 illustrates that the general structure of the MEPDG calibration database and the tables proposed in the preliminary framework closely follow the structure of the MEPDG software program. This framework allows the MEPDG inputs to be populated in a logical manner for MEPDG design and analysis runs and the subsequent local calibration of MEPDG models. The proposed MEPDG calibration database consists of five main modules:

- The Project Module contains the project summary input information and is also used to link one or more modules together. This table is referred to as the "master table."
- The Traffic Module contains all MEPDG traffic input data.
- The Climate Module contains all necessary MEPDG environmental related inputs data.
- The Material Module contains both structure (thickness and material types) and material characterization inputs data.
- The Performance Module contains all distress measurement data and the distress limits for each distress type or trigger values for rehabilitation design.

All proposed input data is specified and required for MEPDG design, analysis, and subsequent local calibration of the MEPDG models. The proposed MEPDG calibration database structure will allow SHAs, over time, to develop a catalogue of agency typical/specific design input values when site-specific information is not readily available. This will allow for an improved characterization of the local conditions/environment resulting in increased accuracy of the performance models.

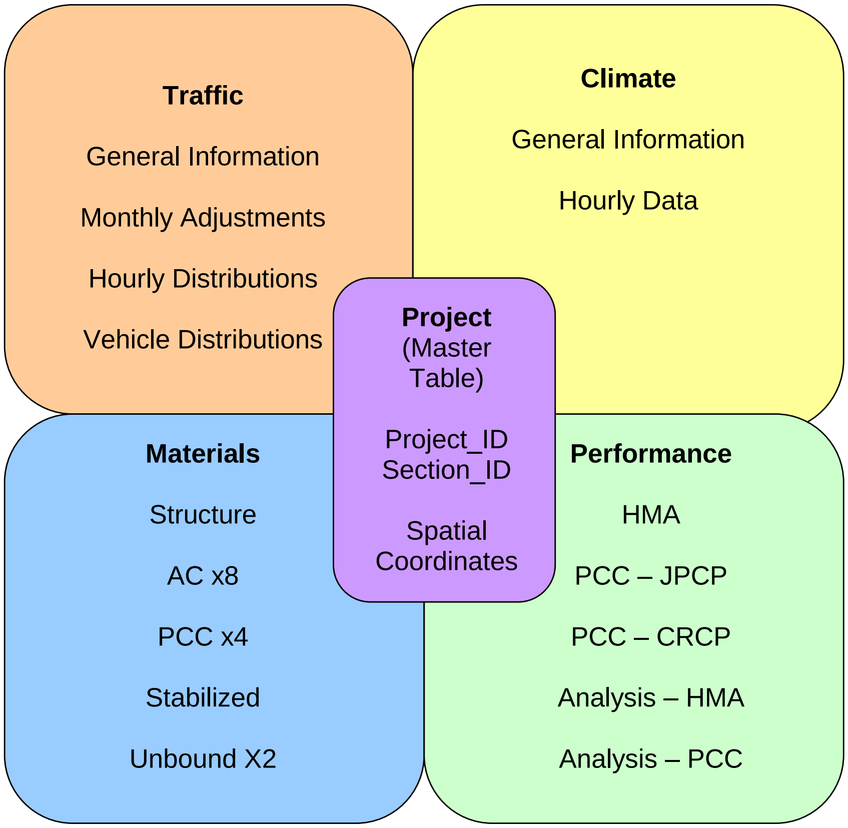

Figure 2. General MEPDG calibration database structure.

The following sections further describe each of the proposed database elements, which are presented in more detail in appendix A.

Project

The project element of the database serves as the "master table" and is linked to the other elements by project and site specific information. This table contains the MEPDG project summary information (design properties, project/site identification) and spatial coordinates for each site. Analysis limit and associated reliability parameters are stored within the performance tables.

Traffic

The traffic element contains nine tables for storing the required data for the MEPDG. These tables cover traffic design properties, traffic volume adjustments, axle load distribution based on axle type, and general traffic inputs as outlined in the NCHRP report, *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, Final Report, Part 2, Chapter 4, Traffic (NCHRP 2004). Traffic files can be compiled as detailed in Chapter 3 of this report.

Climate

The climate element contains two tables that store site-specific weather station data necessary to create hourly climatic database files and other environmental related information. Similarly, climatic information can be compiled as detailed in Chapter 4 of this report.

Material

The material element contains 17 tables to describe the material properties for each pavement layer. These tables are broken down into five material areas: HMA, PCC, stabilized, unbound, and bedrock. Within each of these five main areas, additional tables are required to describe design properties, mix properties, thermal properties, thermal cracking, and materials strength properties. The information contained in these tables is discussed in Chapter 5 of this report.

Performance

The performance element contains six tables to summarize the observed distresses for each pavement type, analysis trigger limits, and rehabilitation overlay data (including project history data for use with rehabilitation projects).

Other Tables

Those items not readily available in the pavement management system, but available in other State maintained databases or files (e.g. construction history, traffic data, GPS referencing system).

Future Enhancements

The MEPDG is an evolving pavement analysis tool. It is fully anticipated that future modifications will be made to the existing models, as well as the potential for the inclusion of entirely new models and design features, all of which may require additional sources of data (e.g. performance prediction and material characteristics). As these additions come to fruition, comparable modifications to the MEPDG calibration database will need to occur. Though this study will not resolve the issues (such as quantifiable performance data, material characterization, and impact of the existing pavement condition on preventive maintenance treatment performance, and so on) surrounding the incorporation of preventive maintenance treatments into a pavement design/analysis procedure, table 22 lists the potential data needs (assuming pavement performance prediction models have been developed) to analyze these activities.

Table 22. Example of data needs for preventive maintenance treatments.

Description	Variable	Typical Data
Design properties	Project name and description	No
	Design life (years)	No
	Traffic opening (date)	No
Site/project identification	Location	No
	Project ID	No
	Section ID	No
	Stationing (format, beginning and end)	No
	Traffic direction	No
Analysis parameters (limit and reliability)	Initial IRI (in/mi)	Yes
	Terminal IRI (in/mi)	Yes
	AC surface down cracking (ft/mi)	No
	AC bottom up cracking (%)	Yes
	AC thermal fracture (ft/mi)	Yes
	Permanent deformation - total pavement (in)	No
	Permanent deformation - AC only (in)	Yes
	Transverse cracking (% slabs cracked)	Yes
	Mean joint faulting (in)	Yes
	Existing punchouts	Yes
	Maximum crack width (in)	No
	Minimum crack load transfer efficiency (%)	No
	Minimum crack spacing (ft)	No
	Maximum crack spacing (ft)	No
Structure properties	Treatment type	No
	Layer material	No
	Layer thickness (in)	No

Summary

Local calibration is an integral part of the implementation of the MEPDG for any SHA. This is necessary because the default MEPDG calibration coefficients are based on national information and may not accurately describe the local traffic conditions, climatic environment, materials, and construction/maintenance practices.

State pavement management system databases will be able to provide basic input parameters required to support the local calibration of the MEPDG. However, there is a need to look outside the pavement management system to as-built construction records, material testing databases or records, and other SHA databases for the necessary traffic, climate, material characterization, and performance/distress measurements. Identifying how the missing data requirements can be obtained will allow SHAs to focus their resources to successfully calibrate the MEPDG to local conditions.

The developed MEPDG calibration database structure will allow for the storage of necessary MEPDG inputs that are not currently in the pavement management system. Having this information in a centralized location, SHAs can effectively extract the necessary data for MEPDG implementation and identify areas that need further characterization and development to better model local traffic, environment, and material conditions.

CHAPTER 6. FINAL FRAMEWORK

Introduction

The final framework itemizes specific activities (e.g., links to other data sources, establishing roles and responsibilities) that are needed prior to populating the MEPDG calibration database. The following summarizes the data and process for finalizing the framework for integrating state pavement management data for calibration of the MEPDG. The majority of the MEPDG input data were extracted from the NCDOT pavement management system. Input data associated with materials and traffic was acquired from other NCDOT files and/or databases.

NCDOT is interested in calibrating the MEPDG to Level 2 only. There are several reasons for this. Typically, NCDOT pavement designs occur one to two years prior to letting and the ability to obtain material specific data is not a reality until the project has been awarded. In addition, NCDOT is unable to justify the expense for collecting data according to Level 1 standards; data collection to Level 2 inputs is more justifiable and realistic at this time.

The NCDOT highway network is comprised of primarily HMA pavements, with a lower percentage of PCC pavements. The NCDOT PMS contains sufficient pavement sections, construction history, and performance data for the HMA pavements that no major issues are anticipated for calibrating the MEPDG. For PCC pavements (of which NCDOT only constructs JPCP), the quality and existence of construction and performance data is similar to that of HMA pavements; however, the number of PCC pavement sections and the length of in-service life is considerably less. At a minimum, the framework will provide NCDOT with the step-by-step calibration process as additional pavement history is obtained on PCC pavements.

As a first step, data contained in the NCDOT pavement management system was identified (table 23 through table 31) for applicability with the preliminary framework. In addition, where appropriate, MEPDG default values were established (e.g. analysis parameters, surface short-wave absorptivity, coefficient of thermal expansion).

Table 23. Project summary information.

Description	Variable	HMA	PCC
Design properties	Project name and description	PMS[1]	PMS[1]
	Design life (years)[2]	20	30
	Base/subgrade construction (date)[3]	Assumed	Assumed
	Restoration/overlay		
	Existing pavement construction (date)	PMS[1]	PMS[1]
	Pavement restoration/overlay (date)	PMS[1]	PMS[1]
	Traffic opening (date)	PMS[1]	PMS[1]
Site/project identification	Location	PMS[1]	PMS[1]
	Project ID	PMS[1]	PMS[1]
	Section ID	PMS[1]	PMS[1]
	Stationing (format, beginning and end)[4]	PMS[1]	PMS[1]
	Traffic direction	PMS[1]	PMS[1]
Analysis parameters[6]	Initial IRI (in/mi)	60	75
	Terminal IRI (in/mi)	170	170
	AC surface down cracking (ft/mi)[5]	n/a	n/a
	AC bottom up cracking (%)[5]	10	n/a
	AC thermal fracture (ft/mi)[6]	n/a	n/a
	Chemically stabilized layer fatigue fracture (%)[7]	n/a	n/a
	Permanent deformation – total (in)[8]	n/a	n/a
	Permanent deformation – AC only (in)[8]	¾	n/a
	Transverse cracking (% slabs cracked)[9]	n/a	10
	Mean joint faulting (in)	n/a	¾

[1] Data contained within the NCDOT PMS.
[2] Based on current NCDOT pavement design practice.
[3] Data is typically not collected and will be assumed to be equivalent to the opening to traffic date.
[4] NCDOT PMS uses a referencing system based on milepost. Latitudes and longitudes will also be determined for each project for locating weather and soils data.
[5] NCDOT does not distinguish between surface down (longitudinal) and bottom up (alligator) cracking. Distress is collected by NCDOT as alligator cracking.
[6] Distress not present on NCDOT highways.
[7] Distress not collected by NCDOT.
[8] Based on NCDOT pavement investigations', rutting is almost exclusively confined to the top or second lift of the HMA surface. Therefore, total pavement rutting will default to the rut depth of the HMA surfaces.
[9] NCDOT does not distinguish between various forms of PCCP cracking.

Table 24. Traffic data.

Description	Variable	Data Location
Design properties	Initial two-way AADTT	PMS[1/], Project Plans
	Number lanes in design direction	PMS[1]
	Trucks in the design direction (%)	Project Plans
	Trucks in the design lane (%)[2]	Project Plans, Variable
	Operational speed	DOT Universe/, Project Plans, PMS[1]
Traffic volume adjustment factors	Monthly adjustment factors	Traffic[3]
	Vehicle class distribution (%)	Traffic[3]
	Truck hourly distribution factors (%)	Traffic[3]
	Traffic growth factors (%)	Traffic[3]
Axle load distribution factors	Axle load distribution factors by axle type	Traffic[3]
General traffic inputs	Mean wheel location (inches from lane marking)	Default[4]
	Traffic wander standard deviation (in)	Default[4]
	Design lane width (in)	Default[4]
	Number axles per truck class	Default[4]
	Axle configuration	Default[4]
	Axle width (ft)	Default[4]
	Dual tire spacing (in)	Default[4]
	Tire pressure (psi)	Default[4]
	Axle spacing (ft)	Default[4]
	Wheel base distribution	Default[4]

[1] Data contained within the NCDOT PMS.
[2] Based on current AASHTO lane distribution factors.
[3] Data contained within the NCDOT Traffic database.
[4] MEPDG default values (level 3, where applicable).

Table 25. Existing pavement structure.

Description	Variable	Data Location			
		HMA		PCC	
		New	Overlay	New	Overlay
Structure properties	Layer type	PMS[1]	PMS[1]	PMS[1]	PMS[1]
	Layer material	PMS[1]	PMS[1]	PMS[1]	PMS[1]
	Layer thickness (in)	PMS[1]	PMS[1]	PMS[1]	PMS[1]
	Milled thickness (in)	n/a	PMS[1]	n/a	PMS[1]
	Pavement rating[2]	n/a	PMS[1]	n/a	PMS[1]
	Total rutting (in)	n/a	PMS[1]	n/a	PMS[1]
	Surface short-wave absorptivity[3]	Default	Default	Default	Default

[1] Data contained within the NCDOT PMS.
[2] NCDOT PMS rating based on a scale of 0 – 100; the MEPDG condition categories, ranging from very poor to excellent, will be defined in increments of 20 points.
[3] MEPDG default values (Aged PCC: 0.70-0.90; weathered asphalt: 0.80-0.90; new asphalt: 0.90-0.98).

Table 26. HMA layer characterization.

Description	Variable	Data Location	
		New	Overlay[1]
Design properties	HMA E* predictive model	MATS[2]	MATS[2]
	HMA rutting model coefficients	MATS[2]	MATS[2]
	Fatigue analysis endurance limit	MATS[2]	MATS[2]
	Include reflective cracking in analysis	n/a	MATS[2]
Mix properties	Aggregate gradation (% retained, % passing)	MATS[2]	MATS[2]
	Asphalt binder type	MATS[2]	MATS[2]
	Asphalt binder grade	MATS[2]	MATS[2]
General properties	Reference temperature (°F)	MATS[2]	MATS[2]
	Effective binder content (%)	MATS[2]	MATS[2]
	Air voids (%)	MATS[2]	MATS[2]
	Total unit weight (pcf)	MATS[2]	MATS[2]
	Poisson's ratio	MATS[2]	MATS[2]
Thermal properties	Thermal conductivity (BTU/hr ft °F)	MATS[2]	MATS[2]
	Heat capacity (BTU/lf °F)	MATS[2]	MATS[2]
Thermal cracking	Average tensile strength at 14°F (psi)	MATS[2]	MATS[2]
	Creep compliance (1/psi)	MATS[2]	MATS[2]
	Coefficient of thermal contraction (in/in/°F)	MATS[2], Project files	MATS[2], Project files
Rehabilitation (HMA overlay of PCC)[3]	Poisson's ratio of PCC	n/a	n/a
	Elastic resilient modulus of fractured slab	n/a	n/a
	Type of slab fracture	n/a	n/a
	Thermal conductivity of PCC slab	n/a	n/a
	Heat capacity of PCC slab	n/a	n/a
	Slabs with transverse crack before restoration (%)	n/a	n/a
	Repaired slabs after restoration (%)	n/a	n/a
	Dynamic modulus of subgrade reaction (psi/in)	n/a	n/a
	Month measured	n/a	n/a

[1] HMA overlays include: overlays of HMA, JPCP, and fractured JPCP.
[2] Data contained within the materials database developed by North Carolina State University.
[3] Due to incomplete data contained within the NCDOT PMS, this rehabilitation treatment will not be included in the calibration process.

Table 27. PCC layer properties.

Description	**Variable**	**JPCP**	
		New	**Overlay**
Design properties	Permanent curl/warp effective temperature difference (°F)	Default[1]	Default[1]
	Joint spacing (ft)	15	15
	Sealant type	Silicone	Silicone
	Dowel diameter (in)	CD[2]	CD[2]
	Dowel bar spacing (in)	12	12
	Edge support - tied PCC (% LTE)[3]	n/a	n/a
	Edge support - widened slab (ft)[4]	n/a	n/a
	PCC-base interface	Full	Full
	Base erodibility index	Resistant	Resistant
	Loss of full friction (age in months)	360	360
General properties	Layer thickness (in)	PMS[5]	PMS[5]
	Unit weight (pcf)	150	150
	Poisson's ratio	0.20	0.20
Thermal properties	Coefficient of thermal expansion (per ^{o}Fx10^{-6})	Project Files	Project Files
	Thermal conductivity (BTU/hr ft °F)	MATS[6]	MATS[6]
	Heat capacity (BTU/lf °F)	MATS[6]	MATS[6]
Mix properties	Cement type	Type II	Type II
	Cementitious material content (lb/yd^3)	526	526
	Water/cement ratio	0.559	0.559
	Aggregate type	?	?
	PCC zero-stress temperature	Default[1]	Default[1]
	Ultimate shrinkage at 40% R.H. (microstrain)	Default[1]	Default[1]
	Reversible shrinkage (% of ultimate shrinkage)	Default[1]	Default[1]
	Time to develop 50% of ultimate shrinkage	Default[1]	Default[1]
	Curing method	Compound	Compound
Strength properties[7]	28-day Elastic modulus (psi)	n/a	n/a
	28-day Modulus of rupture (psi)	n/a	n/a
	Compressive strength (psi)	4500	4500
	Splitting tensile strength (psi)	n/a	n/a
Rehabilitation[8]	Slabs with transverse cracks before restoration (%)[3]	n/a	n/a
	Repaired slabs after restoration (%)	n/a	n/a
	Dynamic modulus of subgrade reaction (psi/in)	n/a	n/a
	Month measured	n/a	n/a

[1] MEPDG default values.
[2] Dowel bar diameter varies with pavement thickness, use construction drawings for selecting dowel bar diameter.
[3] NCDOT does not use tied shoulders.
[4] NCDOT does not use a widened slab.
[5] Data contained within NCDOT PMS.
[6] Data contained within the materials database developed by North Carolina State University.
[7] Only one strength property is required.
[8] Due to the relatively young age of NCDOT PCC pavements, rehabilitation has not been conducted and will not be included in the calibration process.

Table 28. Stabilized layer inputs.

Description	Variable	Data Location
General properties	Material type (cement and lime alternatives)	PMS[1], Project Files
	Layer thickness (in)	PMS[1]
	Unit weight (pcf)	MATS[2]
	Poisson's ratio	MATS[2]
Strength properties	Elastic/resilient modulus (psi)	MATS[2]
	Minimum elastic/resilient modulus (psi)	MATS[2]
	Modulus of rupture (psi)	MATS[2]
Thermal properties	Thermal conductivity (BTU/hr ft °F)	MATS[2]
	Heat capacity (BTU/lf °F)	MATS[2], Project Files

[1] Data contained within NCDOT PMS.

[2] Data contained within the materials database developed by North Carolina State University.

Table 29. Unbound layer inputs.

Description	Variable	Data Location
General properties	Material type	MATS[1]
	Layer thickness (in)	MATS[1]
	Poisson's ratio	MATS[1]
	Coefficient of lateral pressure	MATS[1]
Strength properties[2]	Modulus (psi)	MATS[1]
	CBR	MATS[1]
	R-value	MATS[1]
	Layer coefficient (a_i)	MATS[1]
	Penetration DCP	MATS[1]
	Plasticity index and gradation	MATS[1]
ICM properties	Gradation (% passing)	MATS[1]
	Plasticity index	MATS[1]
	Liquid limit	MATS[1]
	Compacted layer (Yes/No)	Yes

[1] Data contained within the materials database developed by North Carolina State University.

[2] Only one strength property is required.

Table 30. Bedrock layer inputs.

Description	**Variable**	**Data Location**
General properties	Material type	MATS[1]
	Layer thickness (in)	MATS[1]
	Unit weight (pcf)	MATS[1]
	Poisson's ratio	MATS[1]
	Resilient modulus (psi)	MATS[1]

[1] Data contained within the materials database developed by North Carolina State University.

The key pavement performance indicators, and source of NCDOT data, used by the MEPDG for HMA and PCC are summarized in table 31 and 32, respectively.

Table 31. HMA pavement performance indicators.

Description	**MEPDG Variable**	**Data Location**	**Comment**
Performance Indicator	IRI (in/mi)	PMS	Collected and summarized in 0.1 mile increments.
	Surface down cracking (ft/mi)	PMS	Collected as alligator cracking in accordance with severity level (light, moderate, and severe) and as a percentage of roadway area – conversion to feet of cracking per mile will be necessary.
	Bottom up cracking (%)	PMS	Distress not specifically collected by NCDOT.
	Thermal fracture (ft/mi)	---	Distress generally not present on NCDOT highways.
	Chemically stabilized layer fatigue fracture (%)	PMS	Distress not collected by NCDOT.
	Permanent deformation - total pavement (in)	---	Based on NCDOT pavement investigations', rutting is almost exclusively confined to the top or second lift of the HMA surface. Therefore, total pavement rutting will default to the rut depth of the HMA surfaces.
	Permanent deformation - AC layers only (in)	PMS	Collected with three point laser and summarized on 0.1 mile increments.

Table 32. PCC pavement performance indicators.

Description	MEPDG Variable	Data Location	Comment
Performance Indicator	Terminal IRI (in/mi)	PMS	
	Transverse cracking (% slabs cracked)	PMS	Cracking (all types) is collected according to severity level (light, moderate, and severe). Calculation as a percent of slabs will be necessary.
	Mean joint faulting (in)	PMS	

Integration of Input Data into the MEPDG Calibration Database

The following work was conducted by NCDOT Pavement Management staff and the APTech project team to integrate the NCDOT PMS and other database(s) information into the MEPDG calibration database:

- Customize the relational MEPDG calibration database to meet the data definition (e.g. integer, decimal) format of NCDOT data fields;
- Provide step-by-step details for integrating MEPDG input data into the MEPDG calibration database which is not currently contained within the PMS (e.g. traffic, materials)
- Document the process for collecting data to populate the MEPDG calibration database for at least one pavement section. The allowed NCDOT and the research team the ability to evaluate and ensure that proper definitions were being used for all input values, to determine if there was any missing or needed data, and to provide insight for integration of the larger data set.
- Populate the MEPDG calibration database with all intended NCDOT pavement sections.

Summary

This section documented the implementation of the final framework using data contained within a single state highway agency. This demonstration showed that the majority of the data can be obtained from a pavement management system; however, some of the needed input data, such as material properties and construction data will require an interface with other data sources. The importance of having a common referencing system also became evident during this activity. A common referencing system becomes important when data is being retrieved from specific project locations amongst the various data sources. Additionally, the availability of a database to store the information that would be used for calibration proved beneficial.

CHAPTER 7. DATABASE VERIFICATION

Introduction

The overall success of this project is in large part linked to the successful completion of the verification process. Several forms of coordination were conducted with NCDOT to ensure data quality and applicability to MEPDG calibration. As NCDOT populated the MEPDG calibration database, the APTech team contacted the NCDOT staff to discuss progress approximately every two to three weeks. The APTech team worked with the NCDOT staff to verify that proper procedures were being followed for storing the data, ensuring that the framework was being tested and any problems with the framework were identified and adjusted. Specifically, the following details were confirmed with NCDOT:

- Are all the data items that were specified in the framework being collected or are plans in place for collecting any missing data?
    - To minimize variability (e.g., construction, pavement performance, traffic loadings), pavement projects were selected from the North Carolina interstate and/or primary system.
    - Climate stations currently contained within the MEPDG was used for all selected pavement sections.
    - Pavement condition assessment is based on the NCDOT pavement condition definitions, which is not necessarily based on the *LTPP Distress Identification Manual*, as recommended in the MEPDG documentation. NCDOT pavement condition assessment is shown in table 33 and Appendix B (flexible survey manual) and Appendix C (rigid survey manual).

Table 33. NCDOT pavement distress types.

Flexible Pavement	**Rigid Pavement**
Alligator cracking	Cracking
Transverse cracking	Corner breaks
Rutting	Joint seal damage
Raveling	Spalling of joints
Bleeding	Shoulder drop-off
Patching	Patching
Oxidation	

- Have the data gone through the required quality control procedures to verify their correctness, accuracy, and reliability? If not, what procedures will be used to verify the accuracy of the data?
    - NCDOT assured that all the data incorporated into the MEPDG calibration database had received the necessary quality control checks to ensure data accuracy.

- Does the data cover all the three typical pavement types, including both new design and rehabilitation activities? Are all distress types represented?
  - Since the NCDOT highway network is comprised of primarily HMA pavements, with a lower percentage of portland cement concrete (PCC) pavements, only project data for these two pavement types was provided. In addition, the MEPDG calibration database contains several HMA pavements that have received an HMA overlay.
- Can the data from various sources be integrated in a single database so that performance data can be linked to material, traffic, construction, and climatic data and can the data be easily extracted for use in calibrating the models?
  - NCDOT stated that all the necessary data was available, though not necessarily contained within one database or possibly in electronic format. NCDOT worked with other divisions (e.g., Materials, Construction, and Traffic) to obtain the necessary data. In addition, much of the available materials information was assembled into a database by the North Carolina State University (NCSU) as part of a NCDOT sponsored research project. NCDOT obtained the NCSU database and transferred the data into the MEPDG calibration database.

The final verification activity was conducted to ensure the data provided by the state appeared reasonable. Although it is difficult for the APTech team members to check the validity of the data, reasonableness checks were used to determine the overall soundness of the data. Distress data was compared to the construction data to verify that the level of deterioration was reasonable for the specific pavement design and age. Similarly, material test results were reviewed to check that they are within reasonable ranges of acceptance. From this review, the APTech team determined that the data provided by NCDOT appeared to be reasonable.

Project Selection

As previously described, NCDOT selected pavement sections for use in the calibration process based on representative pavement structural section, section uniformity (e.g., pavement type, pavement thickness, materials), and availability of traffic, material, and pavement performance data. As outlined in the NCHRP 1-40B report (NCHRP 2004) the minimum number of total pavement sections, by distress, that should be selected for performance prediction model calibration includes (see table 34):

Table 34. Minimum sample size for MEPDG calibration.

Distress	**Minimum number of roadway segments**
Total rutting or faulting	20
Load related cracking	30
Non-load related cracking	26
Reflection cracking (HMA surfaces only)	26

The research team recommended that NCDOT preferably select 20 to 30 pavement sections, for each pavement type, to be used in the calibration process. NCDOT stated that they would do their best to comply with this request, but also noted finding this number of sections, especially for the PCC pavement sections, may be challenging.

MEPDG Calibration Database

In March 2009, the APTech team delivered a preliminary MEPDG calibration database to NCDOT for data population. As part of this process, NCDOT was also asked to evaluate and comment on the application of the MEPDG calibration database to meet the data requirements. In addition, NCDOT was asked to provide any additional information that was needed for operation of the MEPDG calibration database by the APTech team. The following provides a summary of comments received from NCDOT on the MEPDG calibration database.

- The preliminary MEPDG calibration database was developed using MS Access 2003®; however, NCDOT is currently using MS Access 2007®. NCDOT updated the MEPDG calibration database to the newer version of MS Access.

- The MEPDG calibration database contains thirty-one NCDOT projects consisting of a mix of older asphalt, newer asphalt, rehabilitated/resurfaced asphalt, and JPCP. The listing of projects, according to pavement type, is shown in table 35.

Table 35. Projects by pavement type.

Pavement Type	No. of Projects
New asphalt (constructed in1993)	9
New asphalt (constructed in 1999)	10
Asphalt (thin layer thickness)	3
Asphalt (overlay projects)	3
Concrete	6

- NCDOT developed and provided to the APTech team all of the MEPDG project files (*.DGP) for each project identified in table 34. These files allowed the project team the ability to verify or clarify the project input data as needed.

- NCDOT also provided the APTech team all climate files (*.HCD) for the state of North Carolina. The climatic files were generated for all identified projects based on the latitude and longitude of the projects midpoint location. Hourly climate data was unavailable and therefore excluded from the MEPDG calibration database.

- Upon review of the Highway Construction and Materials System (HiCAMS), it was discovered that much of the detailed construction and material data had been deleted three years after project completion for the majority of the projects; this is especially true for the concrete pavement projects. Though this data may be available in other NCDOT paper records, it was determined that it would require an unreasonable time commitment to obtain these files for this project.

- NCDOT determined that the MEPDG calibration database template originally provided by the APTech team was not conducive to data entry and did not adequately follow relational database design. All database fields were set to integer values, where many of the inputs also included text or decimal fields. Significant time was required to modify and improve the MEPDG calibration database to meet NCDOT data entry and relational database design requirements. The modified MEPDG calibration database by any means is not perfect; ideally NCDOT would like to have coded a few behaviors in that would have simplified the data entry and viewing process.

- NCDOT populated the MEPDG calibration database with the best available pavement condition data.

- Water table data is not available and therefore was not included in the MEPDG calibration database.

- Based on the work conducted for this project, NCDOT is discussing the possibilities of capturing additional materials data in the pavement management system. Currently, NCDOT only captures mix type and depth of each layer.

- Asphalt design files were obtained from NCSU. All information in the files had been entered by graduate students at the university as part of a separate NCDOT local calibration research project.

- Many of the values used are MEPDG defaults; however were applicable project specific traffic and material data has been included.

- Very little dynamic modulus (E^*) data and no subgrade moduli (M_R) data for asphalt projects was available.

- Material data is essentially non-existent for the NCDOT concrete pavement projects. This data was either filed in such a way as to be impossible to find or destroyed due to age. Therefore, the concrete design files were assembled with default values for nearly all inputs.

- AADTT counts for all projects was available; however, default traffic distributions were used on all projects.

- Soil type for each project was available from the pavement design files; however, all other soils data consisted of default values.

Review of NCDOT Data

Upon review of the NCDOT populated MEPDG calibration database, the APTech project team identified the following:

1. The MEPDG calibration database was mainly populated with data to conduct calibration at Level 2 for asphalt and JPC pavements. This is a policy decision taken by NCDOT. Other SHAs may formulate similar decisions based on the common pavement types. It may be difficult for a SHA to obtain Level 1 project specific data prior to construction; however, other similar materials sources may be used by a SHA to obtain the data needed for Level 1 calibration.

2. The MEPDG calibration database lacks data required for the calibration of CRCP and composite pavements (asphalt over JPCP or CRCP). Both of these pavement types are commonly in the United States (and abroad).

3. The MEPDG calibration database contains information on new and rehabilitated asphalt pavements and only newly constructed JPCP (i.e., no JPCP rehabilitation projects).

4. The MEPDG calibration database contains traffic data that includes AADT, truck count, and twenty year traffic projection. NCDOT is in the process of assembling MEPDG traffic data on newly constructed projects as part of a separate study.

5. As noted previously, the NCDOT collected pavement performance data (i.e., pavement distresses) is not in accordance with the LTPP *Distress Identification Manual* (FHWA 2003).

MEPDG Calibration Database

The following describes the data contained in the MEPDG calibration database. Though this data is specific to the data definitions contained within the NCDOT pavement management system, it is believed to be applicable to other SHAs since it illustrates the level and amount of data needed for calibration of the MEPDG performance models.

Table 36 describes the data contained in the project reference information table. This table is replicated in all other database tables to ensure that a consistent referencing process is maintained for all data elements.

Table 36. Project reference information.

Label	Description
PRJCT_ID	Unique number that identifies each project
SCTN_ID	Unique number that identifies the section within each project
Latitude	Latitude (degree, minute) of the mid-point of each project
Longitude	Longitude (degree, minute) of the mid-point of each project
Elevation	Elevation (ft) of the mid-point of each project
H20_Tbl_Dpth	Depth to water table (ft)
Stationing_Type	Describes the units of measure used for stationing (ft)
Stationing_Start	Stationing of the project begin location (ft)
Stationing_End	Stationing of the project end location (ft)
Design_Life	Original pavement design life (years)
Construct_Date	Date of original pavement construction
Overlay_Date	Date of HMA overlay placement (where applicable)
Traffic_Date	Date roadway was opened to traffic
Pavement Type	Type of pavement (asphalt, JPCP, or CRCP)

Based on discussion with NCDOT, it was determined that the climatic data contained within the MEPDG would be sufficient for use in the MEPDG calibration process. Therefore, the climatic data for North Carolina that is contained within the MEPDG *.hcd files was not repeated in the MEPDG calibration database. However, if a SHA was interested in adding additional climatic data, the needed data elements are described in table 37.

Table 37. Climatic input descriptions.

Label	Description
Year	Year climate data was recorded
Month	Month climate data was recorded
Day	Day climate data was recorded
Hour	Hour climate data was recorded
Temperature	Mean hourly temperature (°F)
Wind_Speed	Mean hourly wind speed (mph)
Percent_Sun	Mean hourly percent sunshine
Precipitation	Mean hourly precipitation (in)
Relative_Humidity	Mean hourly relative humidity

Table 38 includes a description of each AC material data element.

Table 38. AC materials input descriptions.

Name	Description
LYR_NBR	Layer number
Effctv_Bndr_Cntnt	Effective binder content (by weight)
Poisson_Ratio	Poisson’s ratio
Existing_Layer	Existing layer as opposed to a new layer
Layer_Thickness	Layer thickness (in)
Air_Voids	Percent air voids
Thermal_Cndctvy	Thermal conductivity. (BTU/hr-ft-°F)
Ref_Temp	Reference temperature (°F)
Unit_Weight	Total unit weight (pcf)
Heat_Capacity	Heat capacity (BTU/lb-°F)
E*	**Dynamic modulus of asphalt mixture (Level 1)**
Temperature	Temperature (°F)
E*_0_1	Dynamic modulus (psi) at 0.1 Hz
E*_1	Dynamic modulus (psi) at 1 Hz
E*_10	Dynamic modulus (psi) at 10 Hz
E*_25	Dynamic modulus (psi) at 25 Hz
RTFO_SP	**Superpave binder test data (Level 1 and Level 2)**
Temperature	Temperature (°F)
G*	Binder dynamic modulus (Pa)
Delta	Phase angle

Table 38. AC materials input descriptions (continued).

Name	Description
RTFO_Conv	**Conventional binder properties (Level 1 and Level 2)**
Temp	Temperature (°F)
Softening_Pnt	Softening point (P)
Abslt_Vscsty	Absolute viscosity (P)
Knmtc_Vscsty	Kinematic viscosity (CS)
Spcfc_Grvty	Specific gravity
Penetration	Penetration
Brkfld_Vscsty	Brookfield viscosity
Gradation	**Gradation properties of asphalt mixture (Level 2 and Level 3)**
Retained_3/4	Cumulative percent retained on the ¾ in sieve.
Retained_3/8	Cumulative percent retained on the ⅜ in sieve.
Retained_ No_4	Cumulative percent retained on the #4 sieve.
Passing_No_200	Percent passing the No. 200 sieve.
Creep	**Creep compliance properties (thermal cracking).**
Load_Time	Loading time (sec).
Creep_-4F	Low temperature (-4 °F).
Creep_-14F	Mid temperature (14 °F).
Creep_-32F	High temperature (32 °F).
Binder	**Asphalt binder properties (Level 3).**
Binder_Type	Binder Type
Binder_Grad	Binder grade
Therm Crk	**Thermal cracking properties**
Tnsl_Strngth	Average tensile strength at 14 °F (psi)
VMA	Mixture voids in mineral aggregate (%)
Aggrgt_CTC	Aggregate coefficient of thermal contraction (in/in/°F)
Mix_CTC	Mix coefficient of thermal contraction (in/in/°F)

Table 39 includes descriptions of each PCC material data element. For much of the PCC materials inputs, NCDOT has limited data. As a result, much of the PCC material (JPCP, NCDOT did not provide any CRCP projects) inputs used the default values provide within the MEPDG.

Table 39. PCC materials input descriptions.

Name	Description
LYR_NBR	Layer number
Layer_Thickness	Layer thickness (in)
CTE	Coefficient of thermal expansion (per °F x 10^{-6})
Existing_Layer	Existing layer as opposed to a new layer
Unit_Weight	Unit weight (pcf)
Therm_Conduct	Thermal conductivity (BTU/hr-ft-°F)
Poisson_Ratio	Poisson's ratio
Heat_Capacity	Heat capacity (BTU/lb-°F)

Table 39. PCC materials input descriptions (continued).

Name	Description
Design	**Concrete pavement design features**
Curl/Warp_Effective_ Temperature_Difference	Permanent curl/warp effective temperature difference (°F)
Joint_Spacing	Joint spacing (ft)
Sealant_Type	Joint sealant type
Dowel_Diameter	Dowel bar diameter (in)
Dowel_Spacing	Dowel bar spacing (in)
Tied_PCC	Identifies the presence of a tied concrete shoulder
Tied_LTE	Load transfer efficiency of the tied concrete shoulder
Widened_Slab	Identifies the presence of a widened lane
Slab_Width	Width of the widened slab (ft)
PCC-Base_Interface	Level of friction between the base and PCC
Base_Erodobility_Index	Base erodobility index
Loss_of_Friction	Loss of full friction (age in months)
Steel_Reinforcement	Percent steel (%)
Reinforcement_Steel_Diameter	Bar diameter (in)
Depth_of_Reinforcement	Steel depth (in)
Base/Slab_Friction_Coefficient	Base/slab friction coefficient
Crack_Spacing	Mean crack spacing (in)
Mix	**Mix design properties**
Cmnt_Typ	Cement type
Cmntitious_Cntnt	Cementitious content
W/C_Ratio	Water-cement ratio
Ultimate_Shrinkage	Ultimate shrinkage
Reverse_Shrink	Reverse shrinkage
Curing_Type	Curing type
Strength	**Strength properties**
Age	Age (yrs)
Elstc_Modulus	Elastic modulus (psi)
Modulus_of_Rupture	Modulus of rupture (psi)
Comp. Strength	Compressive strength (psi)
Splt_Tnsle_Strngth	Split tensile strength (psi)

Table 40 includes a description of each PCC maintenance data element.

Table 40. PCC maintenance input descriptions.

Name	Description
Slabs_Transverse_Cracking_Before_Restoration	Number of transverse cracks prior to restoration
Repaired_Slabs_After_Restoration	Number of transverse cracks after restoration
CRCP_Existing_Punchouts	Number of existing punchouts
Dynamic_Modulus_Subgrade_Reaction	Dynamic modulus of subgrade reaction

Table 41 includes a description of each unstabilized/stabilized material data element.

Table 41. Unstabilized/stabilized materials input descriptions.

Name	**Description (and measure where applicable)**
LYR_NBR	Layer number
Layer_Thickness	Layer thickness (in)
Layer_Type	Layer type (aggregate base, bedrock, soil, or stabilized subgrade)
Last_Layer (semi-infinite)	Identifies layer as the last layer of the pavement section
Bedrock	**Bedrock layer inputs**
Type	Soil type
Unit_Weight	Unit weight (pcf)
Poisson_Ratio	Poisson's ratio
Resilient_Modulus	Resilient modulus (psi)
Gradation (for each layer)	**Gradation inputs for each unstabilized/stabilized layer**
Passing_3_5	Mean percent passing 3-½ in screen
Passing_3	Mean percent passing 3 in screen
Passing_2_5	Mean percent passing 2-½ in screen
Passing_2	Mean percent passing 2 in screen
Passing_1_5	Mean percent passing 1-½ in screen
Passing_1	Mean percent passing 1 in screen
Passing_3/4	Mean percent passing ¾ in screen
Passing_1/2	Mean percent passing ½ in screen
Passing_3/8	Mean percent passing ⅜ in screen
Passing_#4	Mean percent passing #4 screen
Passing_#8	Mean percent passing #8 screen
Passing_#10	Mean percent passing #10 screen
Passing_#16	Mean percent passing #16 screen
Passing_#20	Mean percent passing #20 screen
Passing_#30	Mean percent passing #30 screen
Passing_#40	Mean percent passing #40 screen
Passing_#50	Mean percent passing #50 screen
Passing_#60	Mean percent passing #60 screen
Passing_#80	Mean percent passing #80 screen
Passing_#100	Mean percent passing #100 screen
Passing_#200	Mean percent passing #200 screen
Passing_0_02mm	Mean percent passing 0.020 mm screen
Passing_0_002mm	Mean percent passing 0.002 mm screen
Passing_0_001mm	Mean percent passing 0.001 mm screen
PI	Plasticity index
LL	Liquid limit
Compacted_Layer	Compacted layer
Stabilized	**Inputs for stabilized layer**
Unit_Wght	Unit weight (pcf
Poisson_Ratio	Poisson's ratio
Elastic/Resilient_Mod	Elastic/resilient modulus (psi)
Minimum_Mod	Minimum elastic/resilient modulus (psi)
Mod_of_Rupture	Modulus of rupture (psi)
Therm_Cndctvty	Thermal conductivity (BTU/hr-ft-°F)
Heat_Capacity	Heat capacity (BTU/lb-°F)

Table 41. Unstabilized/stabilized materials input descriptions (continued).

Name	Description (and measure where applicable)
Strength (for each layer)	**Strength inputs for each unstabilized/stabilized layer**
k1	Regression constants (used for Level 1 calculation of M_R)
k2	Regression constants (used for Level 1 calculation of M_R)
k3	Regression constants (used for Level 1 calculation of M_R)
Poisson_Ratio	Poisson's ratio
Ltrl_Pressure	Lateral pressure
Modulus	Resilient modulus (psi)
CBR	California Bearing Ratio
R_Val	R-Value
Lyr_Coefnt	AASHTO layer coefficient
DCP	Dynamic Cone Penetrometer (mm/blow)

Table 42 includes a description of the pavement performance data elements for HMA pavements and table 43 includes the PCC pavement performance data elements.

Table 42. Pavement performance input descriptions – HMA.

Name	Description
HMA Analysis	**Analysis parameters for flexible pavement**
IRI_Limit	Terminal IRI limit (in/mi)
IRI_Reliability	Terminal IRI reliability (%)
Surface_Down_Limit	Surface down longitudinal cracking limit (ft/mi)
Surface_Down_Reliability	Surface down longitudinal cracking reliability (%)
Bottom_Up_Limit	Bottom up alligator cracking limit (%)
Bottom_Up_Reliability	Bottom up alligator cracking reliability (%)
Thermal_Fracutre_Limit	Thermal fracture limit (ft/mi)
Thermal_Fracture_Reliability	Thermal fracture reliability (%)
Stabilized_Fatigue_Limit	Chemically stabilized layer fatigue fracture limit (%)
Stabilized_Fatigue_Reliability	Chemically stabilized layer fatigue fracture reliability (%)
Total_Deformation_Limit	Permanent deformation – total pavement limit (in)
Total_Deformation_Reliability	Permanent deformation – total pavement reliability (%)
AC_Deformation_Limit	Permanent deformation – AC only limit (in)
AC_Deformation_Reliability	Permanent deformation – AC only reliability (%)

Table 43. Pavement performance input descriptions – PCC.

Name	Description
PCC Analysis	**Analysis parameters for rigid pavements**
IRI_Limit	Terminal IRI limit (in/mi)
IRI_Reliability	Terminal IRI reliability (%)
Transverse_Crack_Limit	Transverse cracking limit (% slabs cracked)
Transverse_Crack_Reliability	Transverse cracking reliability (%)
Joint_Fault_Limit	Mean joint faulting limit (in)
Joint_Fault_Reliability	Mean joint faulting reliability (%)
Punchouts_Limit	CRCP existing punchout limit (number of punchouts)
Punchouts_Reliability	CRCP existing punchout reliability (%)
Crack_Width_Limit	Maximum CRCP crack width (in)
Crack_LTE_Limit	Minimum crack load transfer efficiency (%)
Min_Crack_Spacing_Limit	Minimum crack spacing (ft)
Max_Crack_Spacing_Limit	Maximum crack spacing (ft)
Maintenance	**Rigid rehabilitation**
Transverse_Crack_Before	Before restoration, percent of slabs with transverse cracks plus percent of previously repaired/replaced slabs (%)
Transverse_Crack_After	After restoration, total percent repaired/replaced slabs (%)
CRCP_Punchouts	Number of existing punchouts (per mile)
Subgrade_Dynamic_Modulus	Dynamic modulus of subgrade reaction (psi/in)
	Month modulus of subgrade reaction measured

Table 44 includes a description of each traffic data element. NCDOT has recommended the use the MEPDG default values for the monthly adjustments factors; therefore, this information is not shown in table 44.

Table 44. Traffic input descriptions.

Name	Description
AADTT	Initial two-way average annual daily truck traffic
Direction	Direction of traffic
No_Design_Lane	Number of lanes in the design direction
%_Trcks_Dsgn_Dir	Percent of trucks in the design direction (%)
%_Trcks_Dsgn_Lane	Percent of trucks in design lane (%)
Speed	Operational speed (mph)
Growth_Rate	Traffic growth rate (%)
General Traffic Inputs	
Wheel_Location	Mean wheel location (inches from the lane marking)
Trffc_Wander_Stdev	Traffic wander standard deviation (in)
Design_Lane_Width	Design lane width (ft)
Axle Configuration	
Avg_Axle_Width	Average axle width (edge-to-edge), outside dimension (ft)
Dual_Tire_Spacing	Dual tire spacing (in)
Tire_Pressure	Tire pressure (psi)
Axle_Spcing_Tandem	Tandem axle spacing (in)
Axle_Spcing_Tridem	Tridem axle spacing (in)

Table 44. Traffic input descriptions (continued).

Name	Description
Axle_Spcing_Quad	Quad axle spacing (in)
Wheelbase	
Wheelbase_Short	Average short axle spacing (ft)
% Trucks_Short	Percent of trucks – short axle spacing (%)
Wheelbase_Medium	Average medium axle spacing (ft)
% Trucks_Medium	Percent of trucks – medium axle spacing (%)
Wheelbase_Long	Average long axle spacing (ft)
% Trucks_Long	Percent of trucks – long axle spacing (%)
Axle/Truck	*Number of axles/truck*
Class	FHWA truck class 4 – 13
Single	Average number of single axles per truck class
Tandem	Average number of tandem axles per truck class
Tridem	Average number of tridem axles per truck class
Quad	Average number of quad axles per truck class
Traffic Volume Adjustment Factors	
Hour Distrib	Hourly distribution
Midnight – 11:00 PM	Hourly truck traffic distribution by hour (%)
Total	Sum of hourly distribution (must total 100%)
Monthly Adjust	Monthly adjustments
Month	Month of the year (January – December)
Class_1 – Class_13	Monthly adjustment factor for each FHWA truck class 1 – 13
Vehicle Distrib	Vehicle class distribution
Class_1 – Class_13	AADTT distribution by vehicle class (%)
Total	Sum of AADTT distribution (must total 100%)
Axle Load Distribution Factors	
Single	Single axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
3000 – 41000	Percent of axles in each load interval (1000 lb increments)
Tandem	Tandem axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
6000 – 82000	Percent of axles in each load interval (2000 lb increments)
Tridem	Tridem axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
12000 – 102000	Percent of axles in each load interval (3000 lb increments)
Quad	Quad axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
12000 – 102000	Percent of axles in each load interval (3000 lb increments)

Table 45 through table 47 includes a description of each agency data element (HMA, JCP, and CRC, respectively).

Table 45. Agency data input descriptions – HMA.

Name	**Description (and measure where applicable)**
CNTY_NBR	NCDOT county number – value ranges from 1-100 and is based on the alphabetical order of counties
RTE_NBR	NCDOT eight digit route number
DIR	Direction
BGN_MLPST_NBR	Begin milepost number
BGN_DES	Begin description
SCTN_LEN	Length of the survey section
END_MLPST_NBR	End milepost number
END_DES	End description
SRVY_YR_NBR	Survey year number (condition data year)
ALGTR_NONE_PCT	Percent of route with no alligator cracking – stored number is percent/10
ALGTR_LOW_PCT	Percent of route with no low severity alligator cracking – stored number is percent/10 **Measure** – Hairline cracks about ⅛" wide
ALGTR_MDRT_PCT	Percent of route with moderate severity alligator cracking – stored number is percent/10 **Measure** – May be slightly spalled, about ¼" wide
ALGTR_HGH_PCT	Percent of route with no high severity alligator cracking – stored number is percent/10 **Measure** – Pieces appear loose, severely spalled, about ⅜" to ½” wide
TRNSVRS_CD	Transverse cracking distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = ¼" wide, no spalling; M = may be spalled, ¼ to ½" wide, 5 to 20 ft apart; S = may be severely spalled, > ½" wide, 1 to 2 ft apart
RUT_CD	Rutting distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = ¼” to < ½" deep; M = ½" to < 1" deep; S = > 1" deep
RVL_CD	Raveling distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = small amounts of stripping, aggregate starting to wear away; M = some stripping is evident and in small areas or aggregate broken away; S = stripping very evident, aggregate accumulation
OXDTN_CD	Transverse cracking level – (N)one, (S)evere **Measure** – N = not present; S = present
BLD_CD	Bleeding distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = present on 10 to 25% of section; M = present on 26 to 50% of section; S = present on > 50% of section
PTCH_CD	Patching distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = present on 6 to 15% of section; M = present on 16 to 30% of section; S = present on greater than 30% of section

Table 45. Agency data input descriptions – HMA (continued).

Name	Description (and measure where applicable)
RIDE_CD	Ride distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = minimum tire noise, isolated bumps/dips (up to ¼ of the section); M = ¼ to ½ of section is uneven with bumps/dips/ruts; S = more than ½ section is uneven and bumpy
ADT_NBR	Average daily traffic for the section
FAS_CD	Federal aid status (largely a deprecated field)
RTG_NBR	NCDOT composite rating number – calculated from the above distress fields
SYS_CD	Route type
RSRFC_YR_NBR	Last known resurface year (not used for interstates)
RSRF_THCKNS_NBR	Last known resurface thickness (not used for interstates)
SBDVSN_RRL_CD	Subdivision or rural route CD
SCTN_CST_AMT	Estimate treatment cost to repair section based on current distresses
LANE_MILE_CST_AMT	Estimated treatment cost per lane mile to repair section based on current distresses
PVMT_TYP_CD	Pavement type code **Measure** – P = plant mix, B = bituminous surface treatment, S = slurry seal
PVMT_WID	Pavement width
LANE_NBR	Number of lanes
SHLDR_CD	Shoulder type **Measure** – P = plant mix, B = bituminous surface treatment, S = slurry seal, U = unpaved
SHLDR_WID	Shoulder width
CURB_GTR_CD	Curb and gutter indicator **Measure** – Y = on both sides; N = on one side only
MIN_IRI_NBR	Minimum IRI number in the section
MAX_IRI_NBR	Maximum IRI number in the section
AVG_IRI_NBR	Average IRI number in the section
IRI_YR_NBR	Year IRI data was collected

Table 46. Agency data input descriptions – JCP.

Name	Description (and measure where applicable)
CNTY_NBR	NCDOT county number – value ranges from 1-100 and is based on the alphabetical order of counties
RTE_NBR	5 digit route number
DIR	Cardinal direction
BGN_MLPST_NBR	Begin milepost number
END_MLPST_NBR	End milepost number
SRVY_YR_NBR	Survey year number (condition data year)
BGN_DES	Begin description
END_DES	End description
LANE_NBR	Number of lanes

Table 46. Agency data input descriptions – JCP (continued).

Name	**Description (and measure where applicable)**
CURB_GTR_CD	Curb and gutter indicator **Measure** – Y = on both sides; N = on one side only
JNT_SPCG_NBR	Joint spacing (ft)
SLAB_NBR	Number of slabs surveyed
PVD_SHLDR_CD	Paved shoulder type **Measure –** P = plant mix, B = bituminous surface treatment, S = slurry seal
PVD_SHLDR_WID	Paved shoulder width
PVD_SHLDR_CNDTN_CD	Paved shoulder condition Code (N, L, M, S) **Measure** – Asphalt: L = good condition; M = acceptable condition, some cracking ¼" to ½" wide; S = unacceptable condition, cracking > ¼" wide, edge breaking away Concrete: L = good condition; M = Cracks < ⅛" wide, light to moderate spalling; S = cracks over ⅛" wide, unstable material, faulting > ¼"
UNPVD_SHLDR_WID	Unpaved shoulder width (ft)
SRFC_WEAR_NONE_PCT	Percent of pavement with no detectable surface wear
SRFC_WEAR_LGHT_PCT	Percent of pavement with low levels of detectable surface wear **Measure** – Texture worn away with < 25% visible aggregate, small popouts may be visible
SRFC_WEAR_MDRT_PCT	Percent of pavement with moderate levels of detectable surface wear **Measure** – Texture worn away with 25 to 50% visible aggregate, small extensive popouts may be present
SRFC_WEAR_SVR_PCT	Percent of pavement with high levels of detectable surface wear **Measure** – Texture worn away with > 50% visible aggregate, large extensive popouts may be present
PMPG_NBR	Number of joints exhibiting pumping
LNGTDNL_LGHT_NBR	Number of slabs with low severity longitudinal cracking **Measure** – Crack widths < ⅛", no spalling or faulting
LNGTDNL_MDRT_NBR	Number of slabs with moderate severity longitudinal cracking **Measure** – Crack widths ⅛" to ½", spalling less than 3", or faulting up to ½", may be sealed
LNGTDNL_SVR_NBR	Number of slabs with high severity longitudinal cracking **Measure** – Crack widths > ½", spalling greater than 3", or faulting greater than ½"
CRNR_LGHT_NBR	Number of slabs with low severity corner breaks **Measure** – Cracks well sealed or hairline, no faulting, spalling or break-up
CRNR_MDRT_NBR	Number of slabs with moderate severity corner breaks **Measure** – Low to medium severity spalling, faulting < ½", no pieces broken
CRNR_SVR_NBR	Number of slabs with high severity corner breaks **Measure** – Moderate to severe spalling, faulting > ½", broken into two or more pieces
SPLL_LGHT_NBR	Number of slabs with low severity spalls **Measure** – Spalls < 3" wide

Table 46. Agency data input descriptions – JCP (continued).

Name	Description (and measure where applicable)
SPLL_MDRT_NBR	Number of slabs with moderate severity spalls **Measure** – Spalls 3" to 6" wide
SPLL_SVR_NBR	Number of slabs with high severity spalls **Measure** – Spalls > 6" wide
TRNSVRS_LGHT_NBR	Number of slabs with low severity transverse cracking **Measure** – Crack widths < ⅛", no spalling or faulting
TRNSVRS_MDRT_NBR	Number of slabs with moderate severity transverse cracking **Measure** – Crack widths ⅛" to ½", spalling less than 3", or faulting up to ½", may be sealed
TRNSVRS_SVR_NBR	Number of slabs with high severity transverse cracking **Measure** – Crack widths > ½", spalling greater than 3", or faulting greater than ½"
SEAL_LGHT_NBR	Number of seals exhibiting light deterioration **Measure** – Exists on < 10% of joint
SEAL_MDRT_NBR	Number of seals exhibiting moderate deterioration **Measure** – Exists on 10 to 50% of joint
SEAL_SVR_NBR	Number of seals exhibiting severe deterioration **Measure** – Exists on > 50% of joint
FALT_NBR	Average faulting in the survey section
ADT_NBR	Average daily traffic for the section
RTG_NBR	NCDOT composite rating number – calculated from the above distress fields
RIDE_CD	Ride distress level – (N)one, (L)ight, (M)oderate, (S)evere **Measure** – L = few bumps and dips, joints are fairly smooth; M = some joints appear faulted, joints or cracks cause bumps and unevenness; S = most joints severely faulted, cracks cause unevenness and surface may be broken, cracked or worn away
MIN_IRI_NBR	Minimum IRI number in the section
MAX_IRI_NBR	Maximum IRI number in the section
AVG_IRI_NBR	Average IRI number in the section
IRI_YR_NBR	Year IRI data was collected

Table 47. Agency data input descriptions – CRC.

Name	Description
SRVY_YR_NBR	Survey year number (condition data year)
CNTY_NBR	NCDOT county number. Value ranges from 1-100 and is based on the alphabetical order of counties
RTE_NBR	5 digit route number
DIR	Cardinal direction
BGN_MLPST_NBR	Begin milepost number
BGN_DES	Begin description
END_MLPST_NBR	End milepost number
END_DES	End description

Table 47. Agency data input descriptions – CRC (continued).

Name	Description
LANE_NBR	Number of lanes
CURB_GTR_CD	Curb and gutter indicator
PVD_SHLDR_CD	Paved shoulder type **Measure** – P = plant mix, B = bituminous surface treatment, S = slurry seal.
PVD_SHLDR_WID	Paved shoulder width
PVD_SHLDR_CNDTN_CD	Paved shoulder condition code (N, L, M, S)
UNPVD_SHLDR_WID	Unpaved shoulder width
UNPVD_SHLDR_CNDTN_CD	Unpaved shoulder condition code (N, L, M, S)
SHLDR_DRPOFF_CD	Shoulder drop-off severity (N, L, M, S)
SHLDR_LANE_JNT_CD	Shoulder and travel lane joint condition (N, L, M, S)
CNCRT_PTCH_GOOD_NBR	Number of good quality concrete patches in the survey section
CNCRT_PTCH_FAIR_NBR	Number of fair quality concrete patches in the survey section
CNCRT_PTCH_POOR_NBR	Number of poor quality concrete patches in the survey section
ASPHLT_PTCH_NBR	Number of asphalt patches
SRFC_WEAR_NONE_PCT	Percent of pavement with no detectable surface wear
SRFC_WEAR_LGHT_PCT	Percent of pavement with low levels of detectable surface wear
SRFC_WEAR_MDRT_PCT	Percent of pavement with moderate levels of detectable surface wear
SRFC_WEAR_SVR_PCT	Percent of pavement with high levels of detectable surface wear
PMPG_NBR	Number of joints exhibiting pumping
RIDE_GOOD_PCT	Percent of pavement with good ride quality
RIDE_FAIR_PCT	Percent of pavement with fair ride quality
RIDE_POOR_PCT	Percent of pavement with poor ride quality
LNGTDNL_LGHT_LEN	Total length of low severity longitudinal cracking in the survey section
LNGTDNL_MDRT_LEN	Total length of moderate severity longitudinal cracking in the survey section
LNGTDNL_SVR_LEN	Total length of high severity longitudinal cracking in the survey section
TRNSVRS_MDRT_NBR	Number of moderate severity transverse cracks
TRNSVRS_SVR_NBR	Number of high severity transverse cracks
PNCH_LGHT_NBR	Number of low severity punch-outs
PNCH_MDRT_NBR	Number of moderate severity punch-outs
PNCH_SVR_NBR	Number of high severity punch-outs
NRW_CRCK_NBR	Total length of narrow cracks in the survey section
Y_CRCK_NBR	Total length of y-cracks in the survey section
ADT_NBR	Average daily traffic for the section
RTG_NBR	Not calculated for CRC pavements
MIN_IRI_NBR	Minimum IRI number in the section
MAX_IRI_NBR	Maximum IRI number in the section
AVG_IRI_NBR	Average IRI number in the section
IRI_YR_NBR	Year IRI data was collected

Summary

The development of a MEPDG calibration database is essential for the calibration and validation of the MEPDG performance models using pavement management data. This is necessary not only for the initial calibration/validation process, but will be critical for future updates and modifications.

A preliminary MEPDG calibration database was provided to NCDOT by the APTech research team that contained all of the data elements identified in the preliminary framework. The NCDOT pavement management group reviewed the preliminary MEPDG calibration database and determined that a number of changes (e.g., storage of input values, addition of NCDOT specific data, database structure) would be necessary to adequately address the various data collection/storage needs of the NCDOT. Based on discussion with the APTech research team, it was determined that it would be more efficient for the NCDOT pavement management group to modify the MEPDG calibration database to meet the data and formatting needs of the NCDOT.

This chapter has documented the verification of input and pavement performance data for NCDOT pavement sections to be used in the MEPDG calibration process. A total of thirty-one projects, consisting of nineteen new asphalt pavement sections, three thin asphalt pavement sections, three asphalt overlay sections, and six new JPCP sections, have been entered into the MEPDG calibration database. In addition, NCDOT has populated the MEPDG calibration database with all available project, materials, construction, and traffic data. NCDOT has also determined that the climatic files contained within the MEPDG are sufficient for the calibration process.

The APTech team has reviewed the MEPDG calibration database and found that it meets the framework for this project.

CHAPTER 8. MEPDG MODEL CALIBRATION

This chapter describes the research team's efforts in calibrating the MEPDG performance models to North Carolina conditions. Calibration of NCDOT flexible and rigid pavements using the most current version of the MEPDG software available at that time (version 1.100) was conducted. The research team executed the MEPDG design software using the inputs provided within the MEPDG calibration database, although MEPDG default values were selected where NCDOT specific data elements were not available. A minimum of three NCDOT pavement sections were used in the calibration of each of the MEPDG performance prediction models.

MEPDG design inputs were prepared for all pavement sections used in the calibration process and the MEPDG was run to obtain the resulting pavement performance distress profiles. The MEPDG predicted pavement performances were then plotted against the field measured performance as noted in the NCDOT pavement condition surveys. Based on how well the predicted performance meet the measured performance determined whether or not modification of the calibration coefficients was necessary. Figure 3 illustrates the general procedure used in the calibration process.

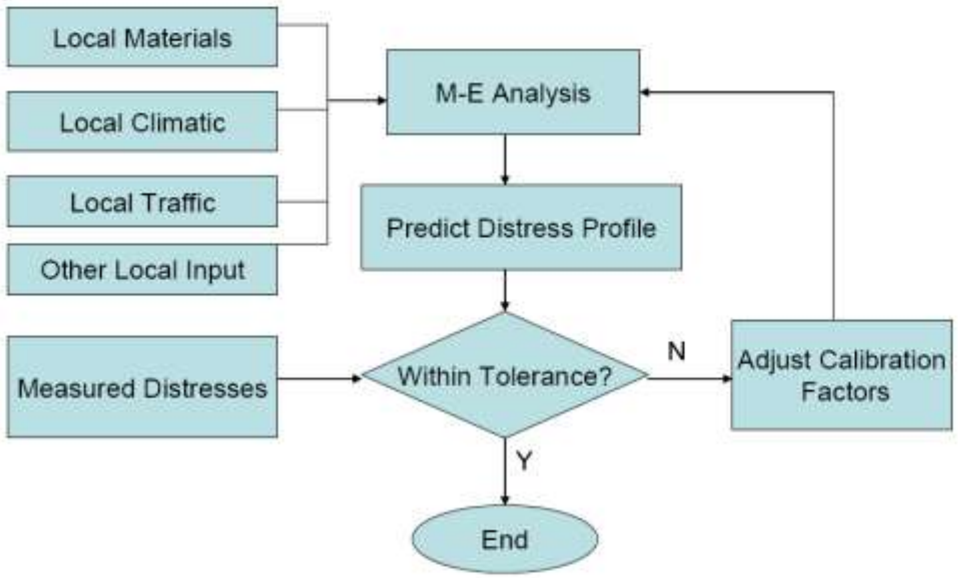

Figure 3. Flowchart for calibration.

Performance Models

The premise behind any mechanistic-empirical design procedure is the ability to relate key structural response variables (i.e., deflection, stress, and strain) to observed performance. This process hinges on the use of robust pavement performance models, which are typically regression equations that relate a material property, such as HMA stiffness, to an observed distress, such as rutting or cracking. The following briefly summarizes the pavement response models used within the MEPDG.

- HMA pavements—the performance criteria included in the MEPDG software includes rutting, load-related cracking (alligator and longitudinal), thermal cracking, reflective cracking in HMA overlays, and smoothness (IRI). The MEPDG HMA pavement performance prediction models are presented in appendix D (tables D-1 through D-7) of volume 2.
- JPCP—the performance criteria included in the MEPDG software includes cracking, faulting, and IRI. The MEPDG JPCP pavement performance prediction models are presented in appendix D (tables D-8 through D-10) of volume 2.
- CRCP—the performance criteria included in the MEPDG software includes punchouts and smoothness. The MEPDG CRCP pavement performance prediction models are presented in appendix D (tables D-11 through D-12) of volume 2.

Quantifying Pavement Condition

The development of calibrated models for use in the MEPDG is highly dependent on the data contained within the LTPP database, primarily since it is the only database of its kind providing material properties, traffic, pavement condition data and so on, for a wide variety of pavement sections under a broad range of climate and traffic loadings. However, a survey conducted by McGhee (2004) determined that approximately 5 percent of respondents were using the *LTPP Distress Identification Manual* for assessing pavement condition. Furthermore, although the majority of SHAs collect pavement smoothness, rutting, and cracking data, the collected data may be based on different distress definitions or data collection procedures from those contained in the *LTPP Distress Identification Manual*. The challenge, therefore, is to be able to convert SHA historical pavement condition data that has been collected in accordance with the different criteria to the definitions contained within the *LTPP Distress Identification Manual*. Each SHA should assess the differences between the LTPP and their state pavement distress collection protocols in order to determine how these differences may influence the MEPDG calibration activities.

NCDOT Pavement Condition Assessment Methodology

NCDOT assesses pavement condition through the use of windshield surveys and pavement profilers. Pavement condition surveys are conducted on all flexible and rigid pavement sections every 2 years. A 100 percent survey is conducted on all flexible pavement sections, while a 20 percent sample is conducted on rigid pavement sections. Pavement condition surveys are conducted by trained personnel traveling at 15 to 20 mi/hr who note the presence of a variety of observed pavement distresses. NCDOT also collects rutting and IRI data using a high-speed profiler outfitted with a three-sensor rut bar (one sensor in each wheelpath and one sensor centered between the wheelpaths). Faulting measurements are obtained either by a faultmeter, the profiler, or other hand measurement methods.

In relation to correlating the LTPP based pavement condition assessment to that of the NCDOT, Corley-Lay et al. (2010) conducted a study to determine if any disparities exist between the two data sets in North Carolina. For asphalt-surfaced pavements, NCDOT compared pavement condition data for all LTPP monitored sites (flexible pavement, general pavement study sites only) to those contained in the NCDOT pavement condition survey for corresponding roadway segments. Conclusions from this comparison included the following observations (Corley-Lay et al. 2010):

- The LTPP walking survey revealed higher amounts of distress than the NCDOT windshield survey.
- The LTPP walking survey indicated almost twice the amount of alligator cracking as noted by the NCDOT windshield survey. NCDOT currently rates the presence of alligator cracking in either or both wheelpaths as equivalent amounts. For example, a pavement section rated as 100 percent alligator cracking can have a fatigue cracking length that ranges from 5,280 ft (1610.4 m) (one wheelpath) to 10,560 ft (3220.8) (two wheelpaths).
- Greater rut depths were measured using the LTPP method than those measured using NCDOT's high-speed profiler.
    - Regardless of the measurement technique, rutting on NCDOT sections was less than 0.33 in. (8.32 mm) for all sites.
    - NCDOT is in the process of increasing the number of rut bar sensors, from 3 to 5, on agency high-speed profilers.
    - Profile data will be collected on all National Highway System routes annually. NCDOT has determined that it would not be practical to collect profile data on the entire network and believe that the current rating system is adequate.
- A comparison of IRI results were not reported in the NCDOT study.

Discrepancies in the data collection process between LTPP and NCDOT were noted by the research team during the calibration process. Any resulting challenges due to differences in pavement condition definitions (or procedures) have been noted in the calibration section of this report.

Asphalt-Surfaced Pavements

The current NCDOT survey procedures report the presence of the following distress types on asphalt-surfaced pavements:

- Alligator cracking.
- Transverse (thermal) cracking.
- Rutting.
- Oxidation (weathering).
- Bleeding.
- Ride quality (subjective).
- Patching.

Though all of the above distresses have been included in the MEPDG calibration database, the following discussion will only include flexible pavement distress types that are considered in the MEPDG, which include rutting, load-related cracking, and thermal cracking.

Rutting

Table 48 includes the definition for rutting for both LTPP and NCDOT. Rutting is measured as the actual rut depth for the LTPP method, while NCDOT categorizes rutting according to the three severity levels shown in table 48.

Table 48. LTPP and NCDOT HMA distress definition – rutting.

Severity Level	LTPP	NCDOT
Low	• No severity level established • Actual measure of rut depth	• 1/4 to 1/2 in deep
Moderate		• 1/2 to 1 in deep
High		• > 1 in deep

Alligator Cracking

Table 49 includes the definition for alligator cracking for both LTPP and NCDOT. For the most part, the LTPP and NCDOT alligator crack definitions are very similar and only differ in that NCDOT provides a measure of crack width for each level of severity.

However, the procedures for measuring the extent of alligator cracking are significantly different between LTPP and NCDOT. For LTPP, the actual area of alligator cracking is determined, resulting in a square-foot measure of alligator cracking for each severity level. NCDOT measures the amount of alligator cracking as the percent of total area; however, as noted previously, the presence of alligator cracking in one wheelpath is considered to have the same extent as if the alligator cracking was in both wheelpaths. Corley-Lay et al. (2010) identified the need to evaluate the impact of the current NCDOT methodology for quantifying HMA alligator cracking in the MEPDG. The impacts of the NCDOT alligator cracking methodology on the calibration conducted is beyond the scope of this project.

Table 49. LTPP and NCDOT HMA distress definition – alligator cracking.

Severity Level	LTPP	NCDOT
Low	• No or only a few connecting cracks • Cracks are not spalled or are sealed • Pumping is not evident	• Longitudinal disconnected parallel hairline cracks • Cracks are approximately 1/8 in wide • Cracks have been sealed, sealant in good condition
Moderate	• Interconnected cracks • Cracks may be slightly spalled • Cracks may be sealed • Pumping is not evident	• Longitudinal cracks forming an alligator pattern • Cracks are approximately 1/4 in wide • May be slightly spalled • Cracks have been sealed, sealant in poor condition
High	• Moderately or severely spalled interconnected cracks • Pieces may move under traffic • Cracks may be sealed • Pumping may be evident	• Severely spalled • Pieces appear loose • Approximately 3/8 to 1/2 in wide • Potholes may be present

Thermal Cracking

Table 50 includes the LTPP and NCDOT definitions for thermal cracking. The LTPP and NCDOT thermal crack definitions are similar, but differ in that NCDOT includes block and reflective cracking, and that moderate and high severity levels differ by the width of the defined crack. In this case, NCDOT uses a slightly more stringent requirement in that moderate-severity thermal cracking occurs at a crack width of 0.25 to 0.50 in and high-severity cracking is defined as a crack width greater than 0.50 in, while LTPP defines moderate- and high-severity cracking as between 0.25 and 0.75 in and greater than 0.75 in, respectively.

Table 50. LTPP and NCDOT HMA distress definition – thermal cracking.

Severity Level	LTPP	NCDOT
Low	• Unsealed crack with mean width ≤ 0.25 in or • Sealed crack with sealant in good condition, width cannot be determined	• < 0.25 in wide • No spalling • Cracks spaced more than 20 ft apart • Sealed crack, sealant in good condition
Moderate	• Any crack with mean width > 0.25 in and ≤ 0.75 in or • Crack with a mean width ≤ 0.75 in and adjacent to low severity random cracking	• 0.25 in to 0.50 in wide • May be spalled • Cracks spaced 5 to 20 ft apart • Sealed crack, sealant in poor condition
High	• Any crack with mean width > 0.75 in or • Any crack with mean width ≤ 0.75 in and adjacent to moderate to high severity random cracking	• 0.50 in wide • May be severely spalled • Cracks spaced 1 to 2 ft apart

Procedures for measuring thermal cracking extent also differ significantly between LTPP and NCDOT. LTPP recommends measuring the number and length of the thermal cracks at each severity level, while NCDOT rates only the condition that represents the majority of the segment (Corley-Lay et al. 2010).

Smoothness

Smoothness is quantified by LTPP according to IRI. Historically, NCDOT has quantified ride condition using a subjective rating scheme that includes:

- Low severity – minimum tire noise, isolated bums or dips (up to one-quarter of the pavement section).
- Moderate severity – one-quarter to one-half of the pavement section is uneven with bumps, dips, or ruts.
- Severe severity – more than one-half of the section is uneven and bumpy.

NCDOT began collecting profile date for determination of IRI beginning in 2001.

Concrete-Surfaced Pavements

As with asphalt-surfaced pavements, NCDOT reports the presence of a number of distresses for jointed concrete pavements (JCP) that include:

- Shoulder type and condition.
- Shoulder-lane drop-off.
- Shoulder-lane joint seal condition.
- Surface wear.
- Pumping.
- Ride quality (subjective).
- Patching.
- Longitudinal cracking.
- Transverse cracking.
- Corner breaks.
- Spalling.
- Joint seal damage.
- Faulting.

The following comparisons will only include rigid pavement distress types that are considered in the MEPDG, which for JCP include transverse cracking and joint faulting.

Transverse Cracking

As shown in table 51, for the most part, the transverse cracking definition for LTPP and NCDOT are essentially the same. The difference in the transverse cracking definition is in terms of the allowable crack width that defines moderate and high severities. However, none of the pavement sections used in the analysis had cracking above the low severity level; the majority of the pavement sections reported no cracking. There is also a difference in the definition of allowable spalling; NCDOT specifies the spall width, while LTPP evaluates the percent of the joints spalled. This difference is not considered to be significant and the NCDOT measurement is considered to be the same as the LTPP measurement.

Table 51. LTPP and NCDOT PCC distress definition – transverse cracking.

Severity Level	LTPP	NCDOT
Low	• Crack width < 1/8 in • No spalling • No measureable faulting or • Well-sealed cracks, width cannot be determined	• Crack width < 1/8 in • No spalling or • No faulting
Moderate	• Crack width ≥ 1/8 in and < 1/4 in or • Spalling < 3 in or • Faulting < 1/4 in	• Crack width 1/8 to 1/2 in • Spalling less than 3 in or • Faulting up to 1/2 in • May be sealed
High	• Crack width ≥ 1/4 in or • Spalled ≥ 3 in or • Faulting ≥ 1/2 in	• Crack width > 1/2 in • Spalling > 3 in or • Faulting greater than 1/2 in

Faulting

As shown in table 52 the faulting definition for LTPP and NCDOT are exactly the same. NCDOT obtains faulting measurements through the use of a faultmeter, profiler, or manual methods and LTPP manual uses the FHWA-modified Georgia Faultmeter. LTPP specifies that the fault should be recorded within the outside wheelpath; however, NCDOT provides no specific guidance on the location of fault measurement. While the accuracies of the collection methods are different, the results are considered to be equivalent.

Table 52. LTPP and NCDOT PCC distress definition – faulting.

Severity Level	LTPP	NCDOT
Low	• No severity level established • Actual measure of fault height	• No severity level established • Actual measure of fault height
Moderate		
High		

Smoothness

Smoothness is quantified by LTPP according to IRI. Historically, NCDOT has quantified ride condition using a subjective rating scheme that includes:

- Low severity – few bumps and dips, joints are fairly smooth.
- Moderate severity – some joints appear faulted, joints or cracks cause bumps and unevenness.
- Severe severity – most joints are severely faulted, cracks cause unevenness and surface may be broken, cracked or worn away.

NCDOT also began collecting profile date for the determination of IRI beginning in 2001.

NCDOT Pavement Sections and Design Inputs

As described previously, projects were selected for use in the calibration process based on pavement type (new HMA, overlaid HMA, and new JCP), uniformity over the entire pavement section (e.g., pavement thickness, material type, traffic), and availability of pavement data (e.g., pavement condition). Figure 4 illustrates the location of each of the pavement sections used in the calibration process. Detailed information on the HMA and JCP projects selected for use in the calibration process are included in appendix E of volume 2.

Figure 4. MEPDG calibration site locations (Mastin 2010).

Climate

Climatic data for all pavement sections was interpolated from the two nearest weather stations using the NCDOT provided project coordinates (latitude, longitude, and elevation). Climatic files were obtained from the updated climate files located on the MEPDG website (http://www.trb.org/mepdg/climatic_state.htm).

Traffic

NCDOT provide traffic data in terms of AADTT and percent trucks for all pavement sections. MEPDG default values were used for all other inputs for all pavement sections.

Materials

For the most part, detailed material properties for all pavement layers were not available for any of the NCDOT pavement sections. Any provided material properties (e.g., layer material type and thickness, subgrade soil type, HMA material properties) have been included in the MEPDG calibration database and used in the calibration process. Due to the previous study conducted by the North Carolina State University, the following HMA material properties have been included in the MEPDG calibration database:

- Effective binder content.
- Poisson's ratio.
- Air voids.
- Thermal conductivity.
- Unit weight.
- Heat capacity.
- Aggregate gradation.
- Creep testing.
- Thermal cracking.

For all other needed inputs not included in the MEPDG calibration database, MEPDG default values were selected. All data inputs for all pavement sections used in the calibration process are included in volume 2 (appendix F for HMA sections and appendix G for PCC sections). In addition, tables 53 and 54 summarize the HMA and PCC pavement sections used in the calibration process, respectively.

Table 53. Summary of HMA pavement sections.

Section No.	Open to Traffic[1]	Route Type	Layer thickness and type[2]			Subgrade Soil Type	AADTT, vpd	Growth Rate
			1	2	3			
1006-3	1982/94	Interstate	1.4 in HMA[3]	9.7 in HMA	n/a	A-1-a	7,700	4.0
1024-2	1980/92	NC	2.3 in HMA[3]	8.0 in HMA	n/a	A-2-4	735	4.0
1802	1985	SR	4.4 in HMA	n/a	n/a	A-1-a	230	4.0
1817	1983	US	4.6 in HMA	n/a	n/a	A-1-b	190	4.0
R2000BB	1994	Interstate	10.5 in HMA	15 in SS	n/a	A-6	575	3.1
R2211BA	1997	NC	6.0 in HMA	8 in AB	8 in SS	A-6	648	3.6
R2232A	1996	US	8.5 in HMA	15 in SS	n/a	A-7-6	4,031	3.2
R2313B	1994	US	6.0 in HMA	8 in AB	8 in SS	A-7-6	506	2.9
U508CA	1993	NC	8.0 in HMA	n/a	n/a	A-2-6	432	2.5

[1] Initial construction/overlay (where appropriate)
[2] AB = aggregate base; SS = stabilized subgrade
[3] overlay application

Table 54. Summary of PCC pavement sections.

Section No.	Open to Traffic	Route Type	Layer thickness and type[1]			Subgrade Soil Type	AADTT, vpd	Growth Rate
			1	**2**	**3**			
A-10CA/DA	2003	Interstate	10 in JCP	4 in ATB	12 in CS	A-6	6,6223	2.9
I-10CC	1989	Interstate	10 in JCP	4 in ATB	12 in CSS	A-6	1,900	3.0
1-1900AC	1989	Interstate	11.5 in JCP	4 in ATB	7 in CSS	A-4/A-6	6,592	3.4

[1] ATB = asphalt treated base; CS = crushed stone subbase; CSS = cement stabilized subbase; LSS = lime stabilized subbase

Local Calibration

The steps for conducting calibration of the MEPDG pavement performance models to location conditions include (NCHRP 2009):

- **Select the hierarchical input level**. Selection of the hierarchical level is an agency by agency decision. The selected hierarchical input level can be the same for all inputs, or preferably is individually selected for each input parameter. The latter is preferable since it allows agencies the flexibility to determine the level of effort needed in the data collection process. For example, a given agency may already have Level 1 traffic data, but only Level 2 material property data. In this example, it would be more beneficial to match the selected hierarchical level based on the availability of data and not on a standard level for all inputs.
- **Develop an experimental plan and sampling template**. The intent of this step of the calibration process is to ensure the selection of pavement section samples are representative of the agency's standard specifications, construction and design practices, and materials. In this manner an agency selects pavement sections that are based on current design or construction practices (e.g., HMA designed using Superpave rather than Hveem or Marshall Mix designs). In addition, to improve the statistical significance of the calibration process, selected pavement sections should also encompass performance data that extends over the entire pavement design life. For example, if the MEPDG is to be used to evaluate 20-year designs, the selected pavement sections used in the calibration process should include 20 years of pavement performance data.
- **Estimate the sample size**. To have the results of the calibration process to be statistically meaningful, the needed number of pavement sections, by distress type, must be determined (see table 34). The intent is to minimize both the bias (which distorts the prediction of actual observations) and precision (repeatability of estimates).
- **Select roadway segments**. This step includes the selection of roadway segments based on the availability of existing data. To minimize costs, agencies should select representative pavement sections that require minimal field sampling and testing. Agencies should also select replicate pavement sections to be used during the validation process. Selected roadway segments should include:
  - Only a few structural layers and material types.

  - Segments with and without overlays to allow for calibration of both new and rehabilitated pavement performance prediction models.
  - Non-conventional mixes or layers (e.g., warm mix, stone matrix asphalt, open-graded friction courses, and high strength PCC mixtures).
  - Selected roadway segments should have at minimum of three pavement condition surveys over a 10-year period.

- **Evaluate project and distress data**. This step validates that all selected roadway segments have the needed data, all data are in the proper format (e.g., distress data is in accordance with LTPP distress definitions), performance data are available over the pavement design life, data are checked for anomalies/outliers, and data are checked for hierarchical level.
- **Conduct field testing and forensic investigation**. As needed, field sampling and testing may be required to complete any missing data elements. For example, the MEPDG HMA performance prediction models include a rutting model that predicts the rut depth within the HMA layer, the unbound layer, and the total pavement section; however, only total rut depth was recorded on the LTPP pavement sections. Similarly, load-related cracking models for HMA and transverse slab cracking for PCC include both a top-down and bottom-up component, yet again this information was not included in the LTPP data collection process. Therefore, ideally, to improve the calibration process, both trenching of HMA pavements (to confirm rut depth in bound and unbound layers) and coring of HMA and PCC pavements (to confirm cracking initiation location) is recommended to better define these factors.
- **Assess bias**. In this step the MEPDG predicted pavement performance is compared to the field performance and the bias and the standard error are determined (using the null hypothesis).
- **Eliminate bias and reduce the standard error of the estimate**. If the null hypothesis is rejected and a significant bias exists, then steps should be taken to eliminate the bias by adjusting the calibration coefficients. Tables 55 and 56 for HMA and PCC distress, respectively, provides guidance on which calibration coefficients should be considered for adjustment to eliminate or reduce bias in the performance prediction (NCHRP 2009).

Table 55. Calibration coefficients to adjust for reducing bias – HMA pavements.

Distress	**Eliminate Bias**	**Reduce Standard Error**
Rutting	k_{r1}, β_{s1} or β_{r1}	k_{r2}, k_{r3}, and β_{r2}, β_{r3}
Alligator cracking	C_2 or k_{f1}	k_{f2}, k_{f3}, and C_1
Longitudinal cracking	C_2 or k_{f1}	k_{f2}, k_{f3}, and C_1
Load related cracking – semi-rigid pavements	C_2 or β_{c1}	C_1, C_2, and C_4
Thermal cracking	β_{t3}	β_{t3}
IRI	C_4	C_1, C_2, and C_3

Table 56. Calibration coefficients to adjust for reducing bias – PCC pavements.

Distress	**Eliminate Bias**	**Reduce Standard Error**
Faulting	C_1	$C_2 – C_8$
JPCP transverse cracking	C_1 or C_4	C_2 and C_5
CRCP fatigue cracking	C_1	C_2
CRCP punchouts	C_3	C_4 and C_5
CRCP crack widths	C_6	C_6
JPCP IRI	C_4	C_1
CRCP IRI	C_4	C_1 and C_2

- **Reduce standard error of the estimate**. If the standard error is determined to be too high, revisions to either the local calibration coefficients or the statistical model may be needed.
- **Interpretation of the results**. In this step the reasonableness of the predicted pavement distress, at a given reliability level, can be determined by comparing the MEPDG predicted pavement distress to actual pavement distress contained within the pavement management system.

Since many of the NCDOT provided pavement sections either had very little distress or had not been in-service for a sufficient period of time (specifically the JCP section), full calibration of the pavement prediction models is limited. Though the number of submitted pavement sections is adequate to demonstrate the calibration process, a larger pavement section sample is required for both the calibration and validation process.

The following describes the results of the calibration process for the NCDOT HMA and PCC pavement sections.

NCDOT HMA Pavement Sections

For new flexible pavement design, the MEPDG performance parameters include rutting, load-related cracking (alligator and longitudinal), thermal cracking, reflective cracking (HMA overlays only), and IRI. The HMA pavement sections listed in table 57 were used in the calibration process.

Table 57. Pavement sections used in the calibration of the HMA performance models.

Model	Pavement Sections
Rutting	1006-3, 1024-2, 1817, R2211BA, and R2232A
Alligator Cracking	1006-3, 1802, 1817, R2211BA, and U508CA
Thermal Cracking	R2000BB, R2211BA, and R2232A

Figures 5 through 7 illustrate the MEPDG uncalibrated predicted distress versus the NCDOT observations for rutting, alligator cracking, and thermal cracking, respectively.

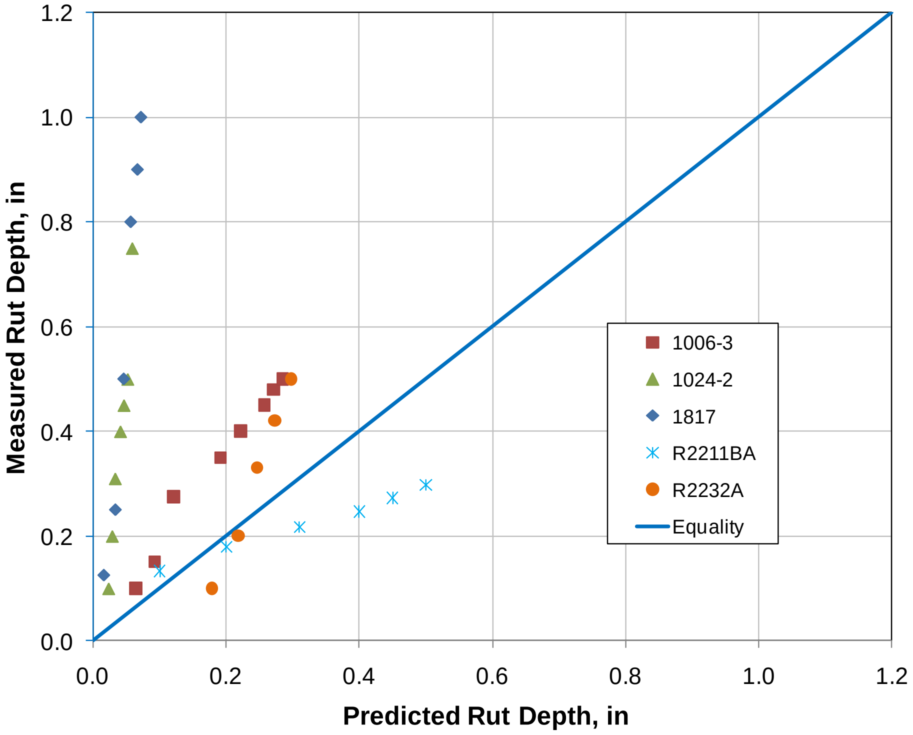

Figure 5. MEPDG predicted (uncalibrated) versus NCDOT distress – rutting.

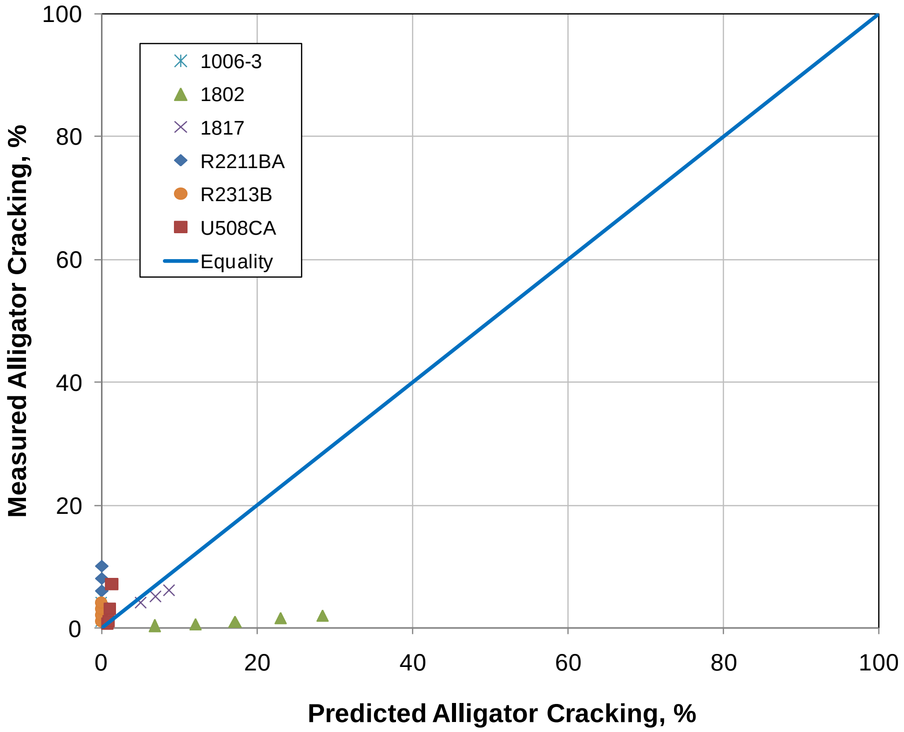

Figure 6. MEPDG predicted (uncalibrated) versus NCDOT distress – alligator cracking.

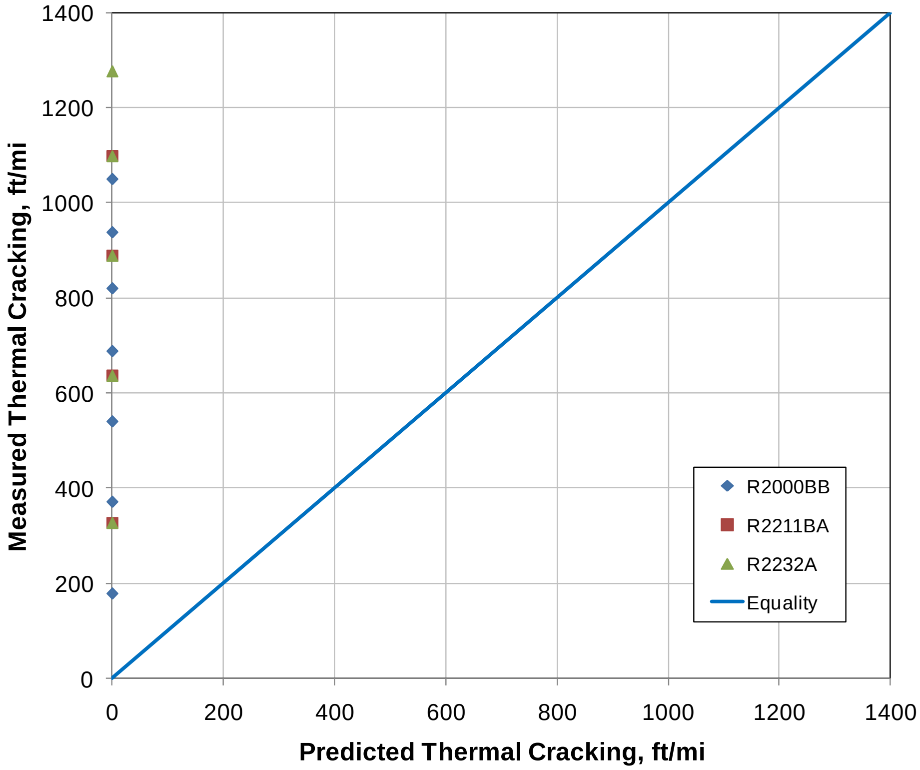

Figure 7. MEPDG predicted (uncalibrated) versus NCDOT distress – thermal cracking.

As shown in figures 5 through 7, the predicted performance using nationally calibrated models under predicts the depth of rutting for all but two projects, over predicts alligator cracking on one project and under predicts alligator cracking on four projects, and under predicts the amount of thermal cracking as compared to the NCDOT measured distresses.

The residual errors (the difference between the predicted value and the actual value) for the calibration sites using the nationally calibrated models for rutting are shown in figure 8. The residual error for rutting on all pavement sections increases with age and are all the same sign (except for early age rutting on pavement sections R2211BA and R2232A). However, on three pavement sections (1006-3, R2211BA, and R2232A), the residual error is relatively low compared to the performance (or failure) criteria (0.75 in); indicating that model prediction may be improved through adjustment of the calibration coefficient. For pavement sections 1024-2 and 1817, the residual error is considered high when compared to the performance criteria, suggesting that some other factor may be influencing the prediction. Based on the data provided, no specific reasoning can be given for the higher residual error on pavement section 1024-2 and 1817.

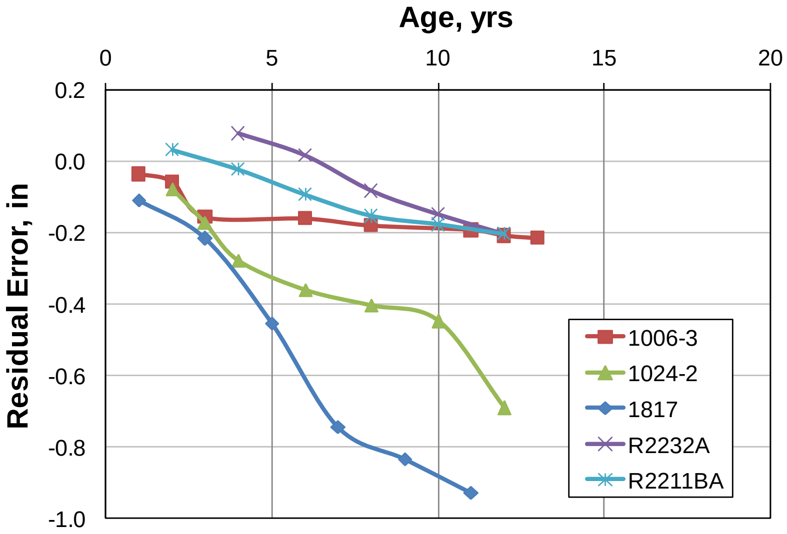

Figure 8. Residual error for rutting predictions (uncalibrated).

The residual errors for alligator cracking are shown in figure 9. For all but two pavement sections (1802 and 1817), the residual error is negative, with a relatively constant slope, and a residual error that is low compared to the performance criteria (25 percent). This indicates that adjustment of the calibration coefficient may improve the performance prediction on these pavement sections. Again, based on the available pavement section information, no specific reasoning can be found for the high residual error for pavement section 1802.

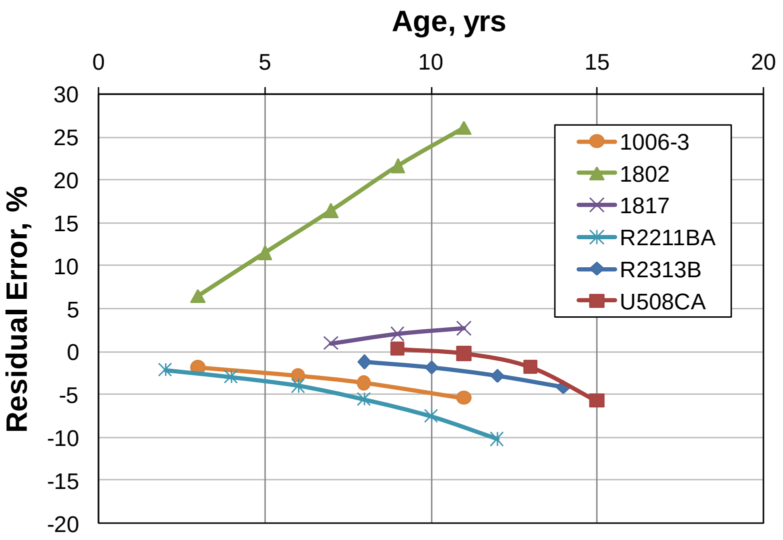

Figure 9. Residual error for alligator cracking predictions (uncalibrated).

The residual errors for thermal cracking are shown in figure 10. The residual errors for each pavement section are negative, the slopes are considered to be high, and the value of the error is high compared to the performance criteria (1000 ft/mi [189.39]). Adjustment of the calibration coefficients may improve the performance prediction.

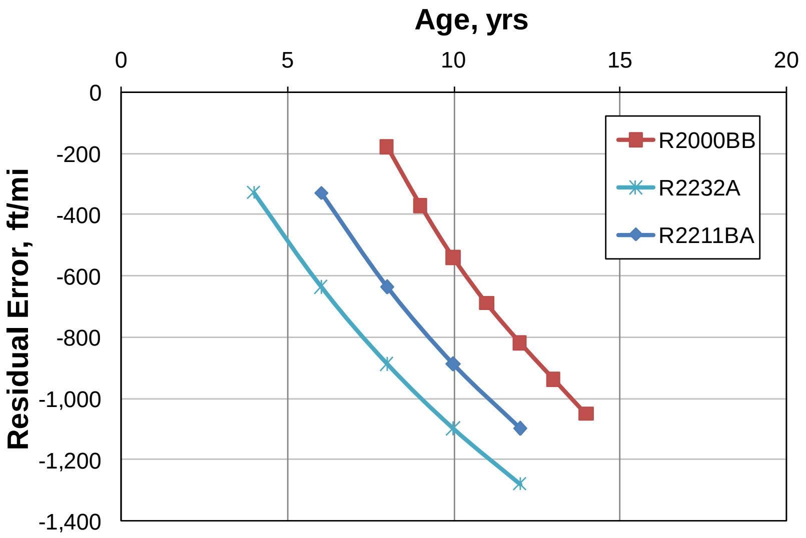

Figure 10. Residual error for HMA thermal cracking predictions (uncalibrated).

The primary goal in the calibration process is to reduce the error between the measured and predicted distress. However, there are a number of limitations in the available data, including the relatively few data points, the required conversion of NCDOT's subjective measure of rutting and thermal cracking to an estimated value, and the limited data available at levels approaching the established failure criteria or at the end of the performance period; all of these pose a significant challenge to the model calibration process. Nevertheless, the data limitations encountered are likely fairly common within other SHAs and some method of model calibration is needed in the interim until additional data can be collected. The MS Excel® solver routine, which employs linear programming optimization techniques, was used to minimize the root square error between the available NCDOT measured and MEPDG predicted values. With this process the beta coefficients were changed until a minimum square root error was reached. This procedure was repeated for each pavement section separately. The final beta coefficients were then obtained by averaging the resulting calibration coefficients for each of the pavement sections. This process was done for each of the key HMA distresses, as described below.

Rutting

As indicated previously, the NCDOT subjective rut depth measurement had to be converted to an estimated measured value. In addition, progression of rut depth over time (e.g., for one year to the next), due to the limited amount of rutting data on the NCDOT pavement sections, was also needed. A number of studies have been conducted that document the development of rut depth development over time (Haddock 1999; Sivasubramaniam et al. 2004; White et al. 2002). These studies, in addition to the MEPDG rutting models, were used to predict rut depth over time for the NCDOT data.

With the absence of actual measured data for rut depth, the research team determined that it would be more realistic to base the rutting severity on the last NCDOT survey year for each section used in the calibration process. The only difference would be on those sections that received an HMA overlay; in those instances, the research team selected the rut condition prior to the applied overlay. In this manner, rutting was assumed to progress from zero to the assumed numeric value over the life of the pavement. The assumed values for rut depth are:

- Low severity – 0.5 in. (12.7 mm).
- Moderate severity – 1.0 in. (25.4 mm).
- High severity – none of the NCDOT pavement sections reported high severity rut depth, so no measured value was assigned to this severity level.

Rut depth progression was based on the number of NCDOT rut depth ratings and distributed over the measurement period to best reflect the slope of the MEPDG predicted rut depth over time. Table 58 and figure 11 (for low severity rating) illustrate the rut progression process.

Table 58. Rut progression – low severity.

Year	**No. of Distress Observations**									
	Low Severity						**Moderate Severity**			
	3	**4**	**5**	**6**	**7**	**8**	**2**	**3**	**4**	**5**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.80	0.65	0.68
2	0.25	0.25	0.20	0.20	0.20	0.15	1.00	0.90	0.80	0.82
3	0.50	0.40	0.33	0.31	0.30	0.28		1.00	0.90	0.90
4		0.50	0.42	0.40	0.38	0.35			1.00	0.95
5			0.50	0.45	0.43	0.40				1.00
6				0.50	0.47	0.45				
7					0.50	0.48				
8						0.50				

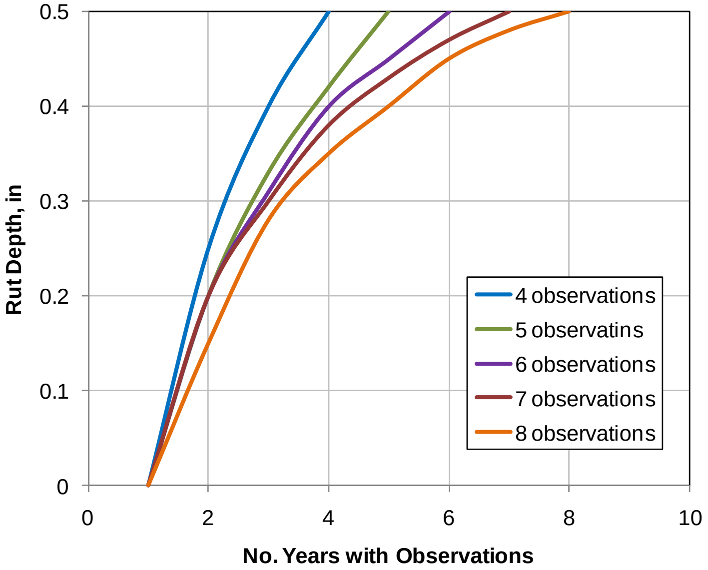

Figure 11. Progression of rut depth for NCDOT low severity rating.

Table 59 includes the estimated value for all projects used in the rutting model calibration process.

Table 59. Estimated rut depth by pavement section.

Age, yrs	**Pavement Section Rut Depth (in)**				
	1006-3	**1024-2**	**1817**	**R2211BA**	**R2232A**
1	0.10	---	0.13	---	---
2	0.15	0.10	---	0.10	---
3	0.28	0.20	0.25	---	---
4	---	0.31	---	0.20	0.10
5	---	---	0.50	---	---
6	0.35	0.40	---	0.31	0.20
7	---	---	0.80	---	---
8	0.40	0.45	---	0.40	0.33
9	---	---	0.90	---	---
10	---	0.50	---	0.45	0.42
11	0.45	---	1.00	---	---
12	0.48	0.75	---	0.50	0.50
13	0.50	---	---	---	---

In addition, rutting was assumed to be totally contained within the HMA layers (i.e., no rutting in the unbound layers). However, this assumption should be validated through coring or more preferably through trench studies.

There are three calibration coefficients for HMA rutting: β_{r1}, β_{r2}, and β_{r3}. Recommended calibration coefficients for the rutting model are shown in table 60 and the resulting calibrated rut prediction models are shown in figures 12 through 16 for the five NCDOT pavement sections.

Table 60. Rutting model calibration coefficients.

Coefficient	**Default Value**	**Adjusted Value**
β_{r1}	1.00	1.52
β_{r2}	1.00	4.24
β_{r3}	1.00	-0.75

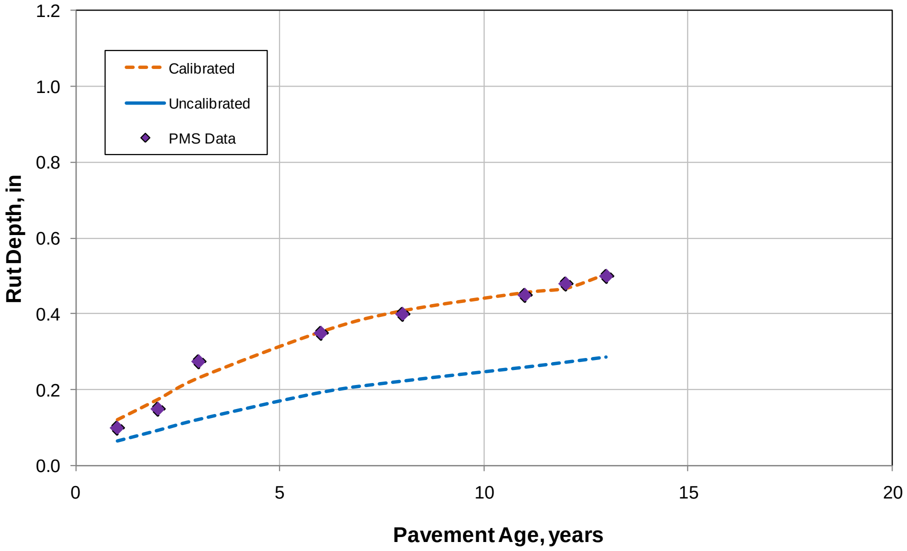

Figure 12. Locally calibrated rutting model – section 1006-3.

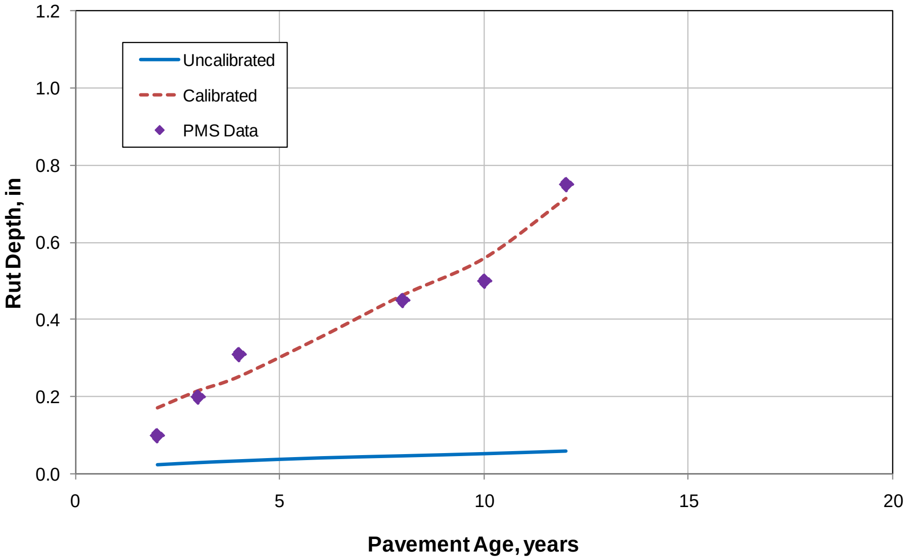

Figure 13. Locally calibrated rutting model – section 1024-2.

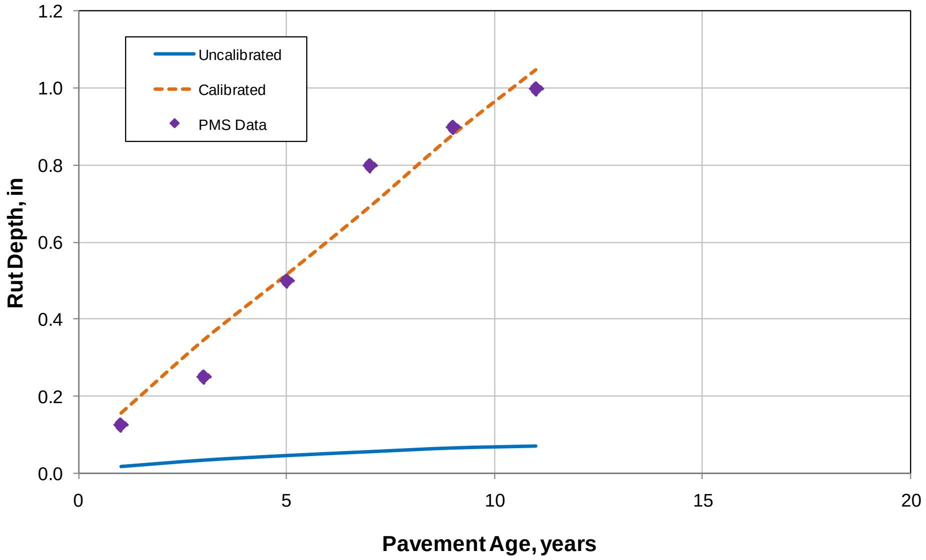

Figure 14. Locally calibrated rutting model – section 1817.

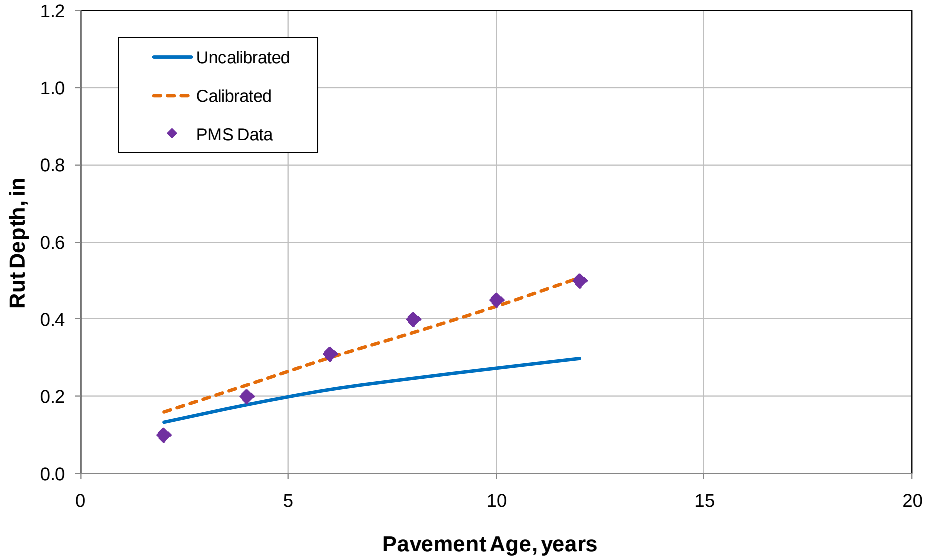

Figure 15. Locally calibrated rutting model – section R2211BA.

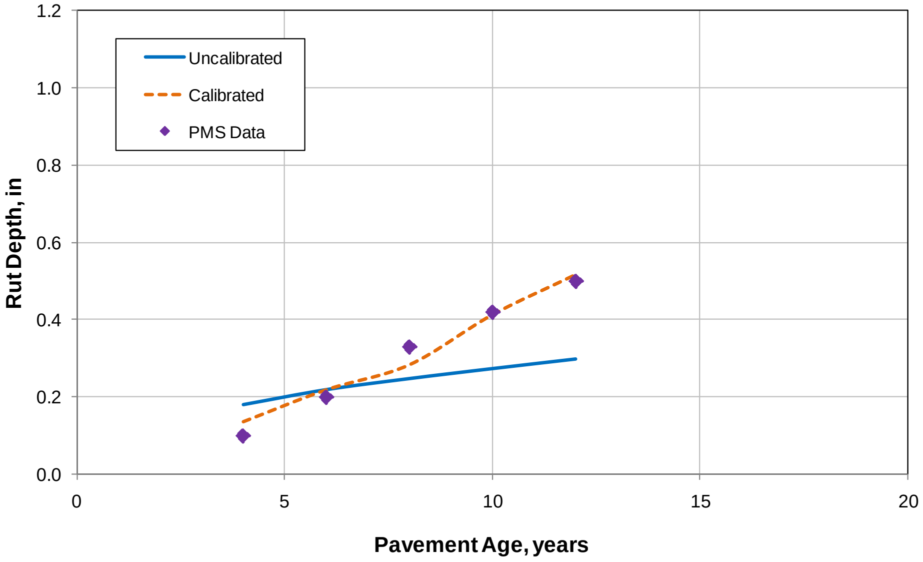

Figure 16. Locally calibrated rutting model – section R2232A.

While the adjustment to the calibration coefficients appears to better characterize the observed performance of NCDOT HMA pavements (see also figure 17), the calibration coefficients should be reviewed and revised to include a larger number of NCDOT pavement sections.

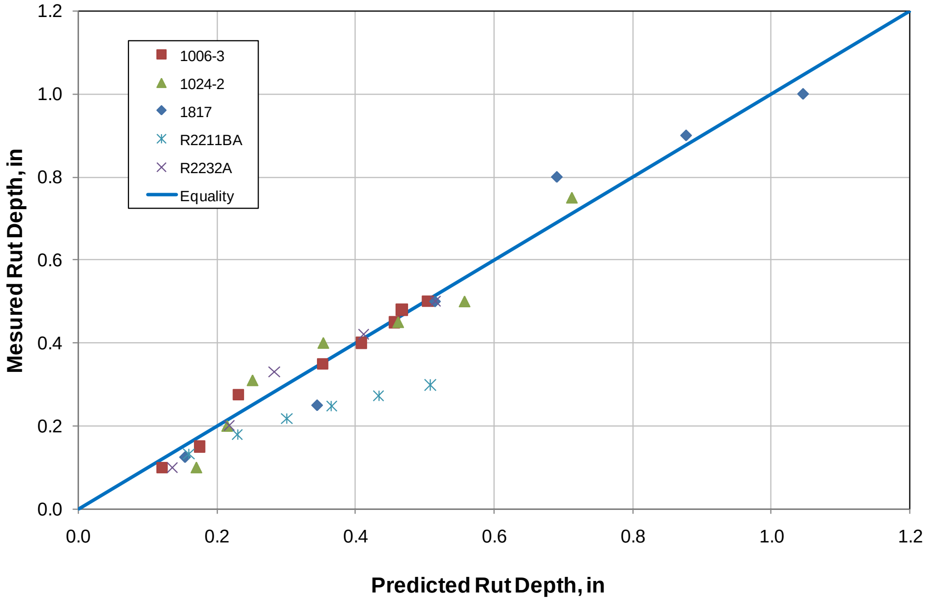

Figure 17. MEPDG predicted (calibrated) versus NCDOT distress – Rutting.

Alligator Cracking

The MEPDG software version 1.100 includes a performance prediction model for longitudinal (or top-down) cracking. However, at the initiation of this study this model was considered to still be a work in progress. In addition, NCDOT only characterizes load-related cracking as alligator cracking. Therefore, calibration of the longitudinal cracking model would require significant field testing and evaluation and therefore is considered beyond the scope of this study. All load-related cracking was considered to initiate from the bottom up and so only the alligator cracking model was calibrated as part of this study. In addition, the calibration of the MEPDG model for alligator cracking took into account the following assumptions (NCHRP 2004; NCHRP 2009):

- A sigmoid function form is the best representation of the relationship between cracking and damage. This is an extremely reasonable assumption as the relationship must be "bounded" by 0 ft^2 (0 m^2) cracking as a minimum and 6,000 ft^2 (558 m^2) cracking as a maximum.
- Alligator cracking is limited to 50 percent cracking of the total area of the lane (6000 ft^2) (558 m^2) at a damage percentage of 100 percent.
- Since alligator cracking is related to loading and asphalt layer thickness, alligator crack prediction is similar for a wide range of temperatures.

Due to the variability of the subjective rating of alligator cracking NCDOT reported over time, the research team decided to use only the most recent distress severity reported at each site in the calibration process. The extent of alligator cracking was then distributed over the age of the pavement section similar to the process used for rutting. In addition, the following assumptions were made:

- A representative asphalt dynamic modulus (function of fatigue temperature) for the total asphalt layer(s) modulus was extracted from the MEPDG output data file for every i^{th} year corresponding to the NCDOT measured alligator distress.
- A layer elastic analysis program was used to compute the tensile strain at the bottom of the asphalt layer. Ranges of tensile strains were obtained at different modulus/temperatures related to fatigue failures. Additional input data used in the layer elastic analysis is shown in appendix E, table E-16, of volume 2.

There are three calibration coefficients for alligator cracking: β_{f1}, $\beta_{f2,}$ β_{f3}. Based on the analysis conducted as part of this study, the recommended calibration coefficients for the alligator cracking model are shown in table 61 and the resulting alligator cracking prediction for the NCDOT pavement sections are shown in figures 18 through 23.

Table 61. Alligator cracking model calibration coefficients.

Coefficient	**Default Value**	**Adjusted Value**
β_{f1}	1.00	1.41
β_{f2}	1.00	-2.82
β_{f3}	1.00	-6.67

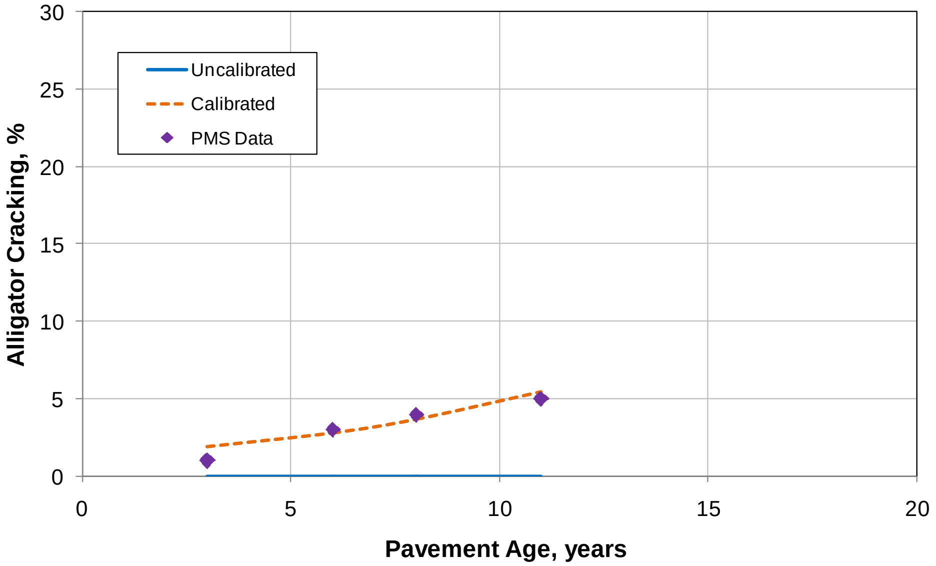

Figure 18. Locally calibrated alligator cracking model – section 1006-3.

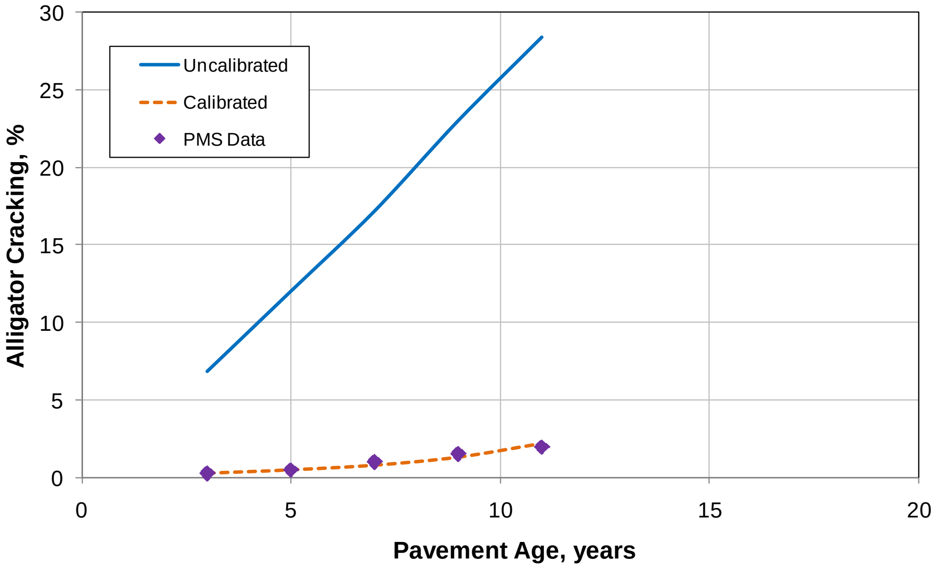

Figure 19. Locally calibrated alligator cracking model – section 1802.

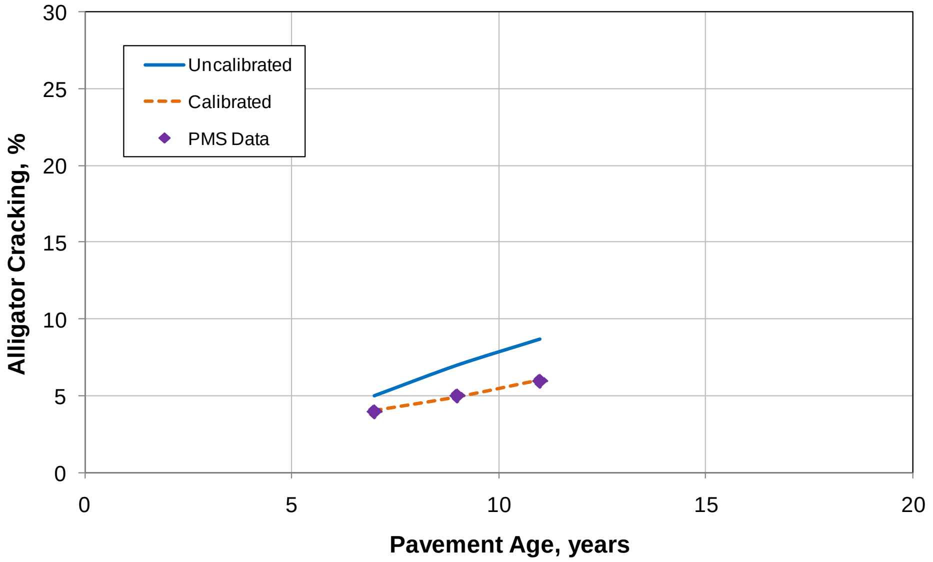

Figure 20. Locally calibrated alligator cracking model – section 1817.

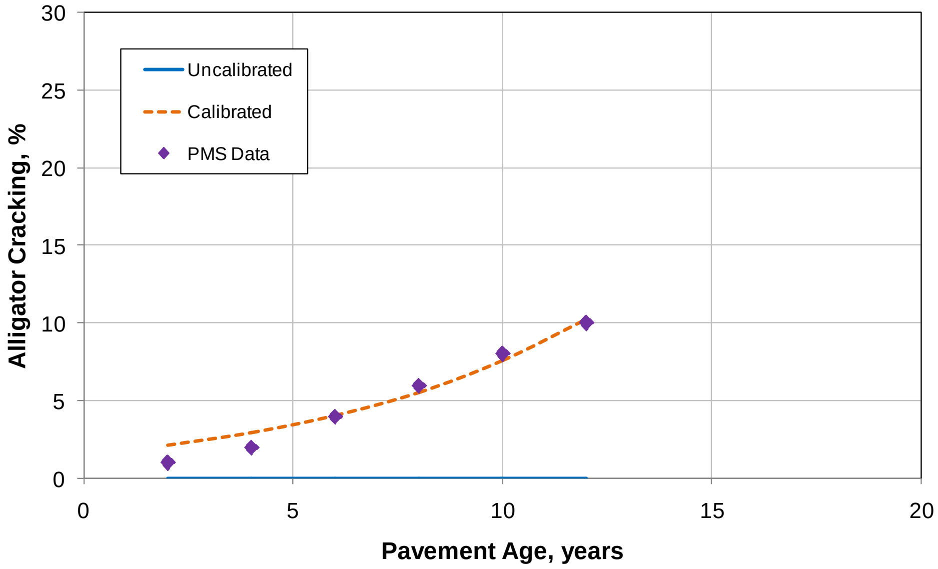

Figure 21. Locally calibrated alligator cracking model – section R2211BA.

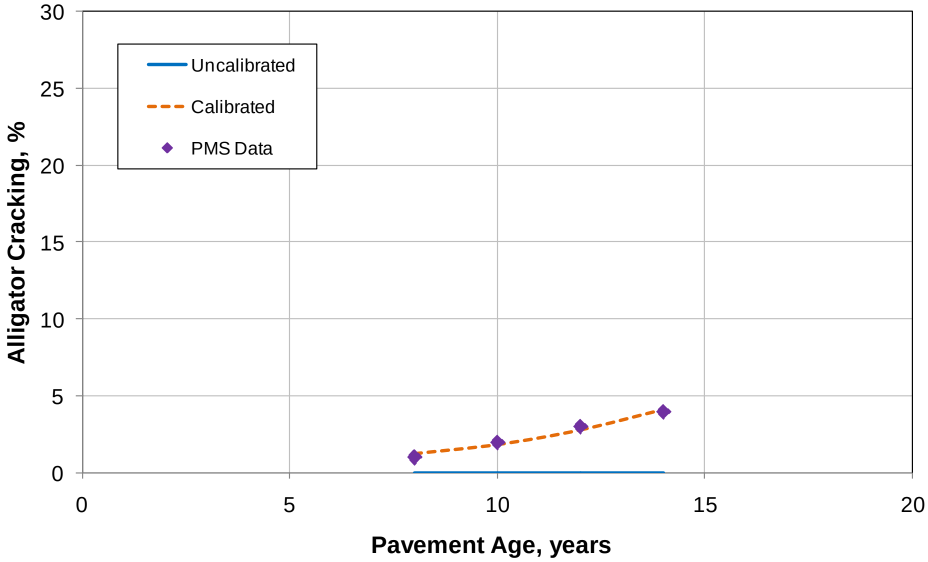

Figure 22. Locally calibrated alligator cracking model – section R2313B.

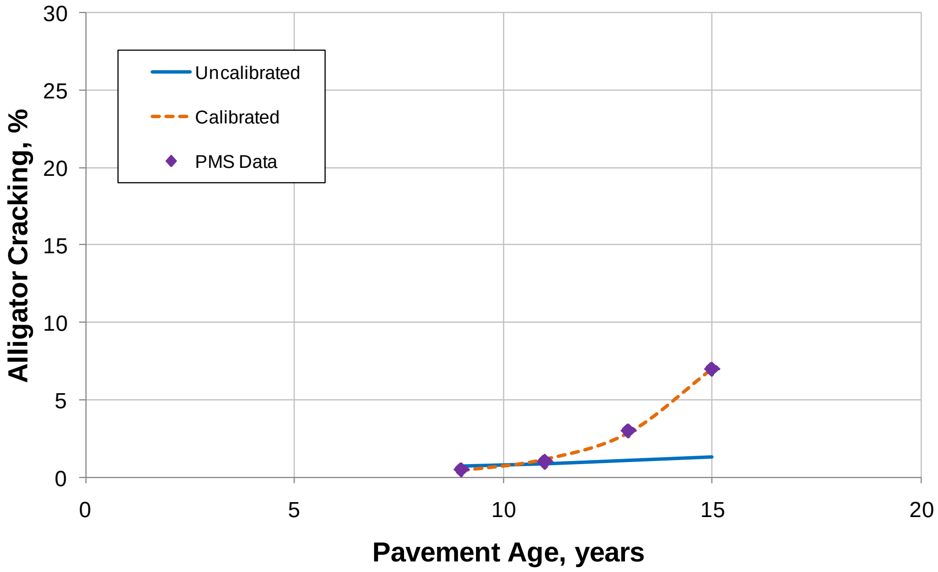

Figure 23. Locally calibrated alligator cracking model – section U508CA.

Figure 24 illustrates the comparison of the predicted versus measured alligator cracking for the NCDOT pavement sections based on the calibrated model. The use of the adjusted calibration coefficients does provide a much better fit of the data, but additional pavement sections should be included in the analysis prior to implementation of the revised model.

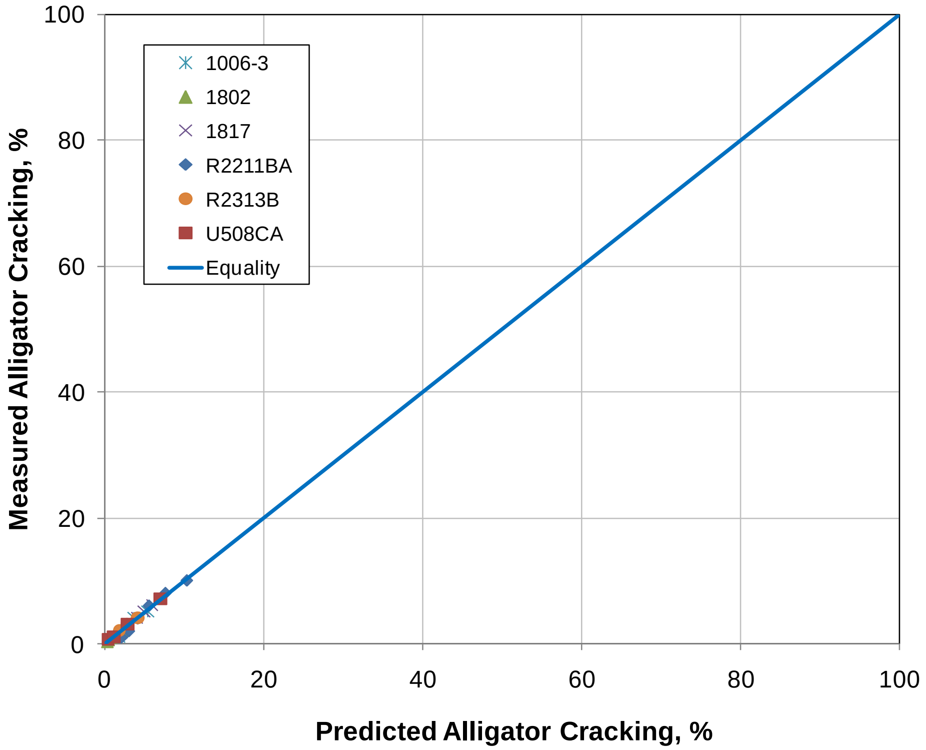

Figure 24. MEPDG predicted (calibrated) versus NCDOT distress – alligator cracking.

Thermal Cracking

Calibration of the thermal cracking model within the MEPDG requires four measurements: crack depth, crack width, crack length, and crack spacing. NCDOT only includes a subjective rating of crack width and crack spacing as part of their distress survey. In order to convert the NCDOT subjective rating into measured values for use in the calibration process, a number of assumptions were necessary, including the following:

- The thermal crack prediction model within the MEPDG has two limitations (NCHRP 2004; NCHRP 2009):
  - The model will not predict thermal cracking on more than 50 percent of the total section length.
  - Thermal cracking is maximized at 400 ft (122 m) per each 500 ft (152.5 m) section.
  - The maximum length of thermal cracking is 4224 ft/mi (800 m/km) (400 ft/500 ft x 5280 ft [122 m/152.5 m x 1000 m]).
- Crack spacing was calculated for each severity level based on the maximum value of the NCDOT specified range. For example, moderate severity thermal cracking has a spacing of 5 to 20 ft (1.53 to 6.1 m). For this study, a crack spacing of 5 ft (1.53 m) was used.
- Cracks were assumed to be full-lane width (i.e., 12 ft [3.66 m]) for all severity levels.
- The thermal crack depths were assumed to progress over time in accordance with the severity level. In addition, thermal crack depths were constrained to not exceed twice the indicated/reported crack width or range. An additional constraint was added to limit the crack depth to thickness of the asphalt surface layer (NCHRP 2004).
- For each pavement section, the section length was divided by the reported NCDOT cracking frequency and multiplied by the crack length (assumed to be 12 ft [3.66 m]) to obtain the total estimated crack length per pavement section.
- As with rutting and alligator cracking, the distress severity from the last NCDOT survey was used to calculate the thermal cracking numeric value.

The adjusted thermal cracking model coefficients are summarized in table 62 and the resulting thermal cracking prediction for the NCDOT pavement sections are shown in figures 25 through 27. For the uncalibrated condition, the MEPDG software predicts no thermal cracking for all NCDOT pavement sites used in the calibration process. The estimated thermal cracking length resulted in a range of 1,045 to 1,278 ft (318.73 to 389.79 m) for the NCDOT pavement sections. This results in a crack spacing of approximately 30 ft (9.15 m), which is considered conservative, but was selected to avoid the MEPDG thermal cracking model limit of 50 percent cracking over the project length.

Table 62. Thermal cracking model calibration coefficients.

Coefficient	Default Value	Adjusted Value
β_{t1}	400	4,224

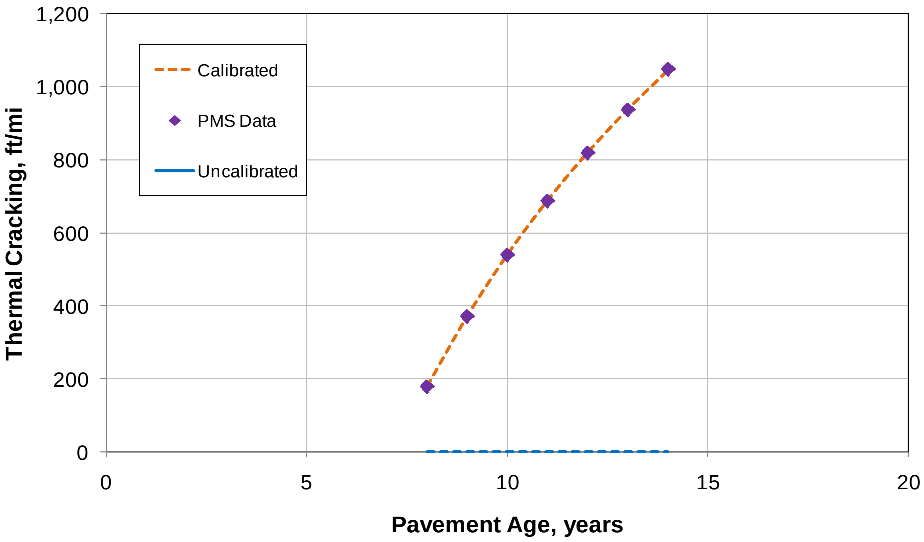

Figure 25. Locally calibrated thermal cracking model – section R2000BB.

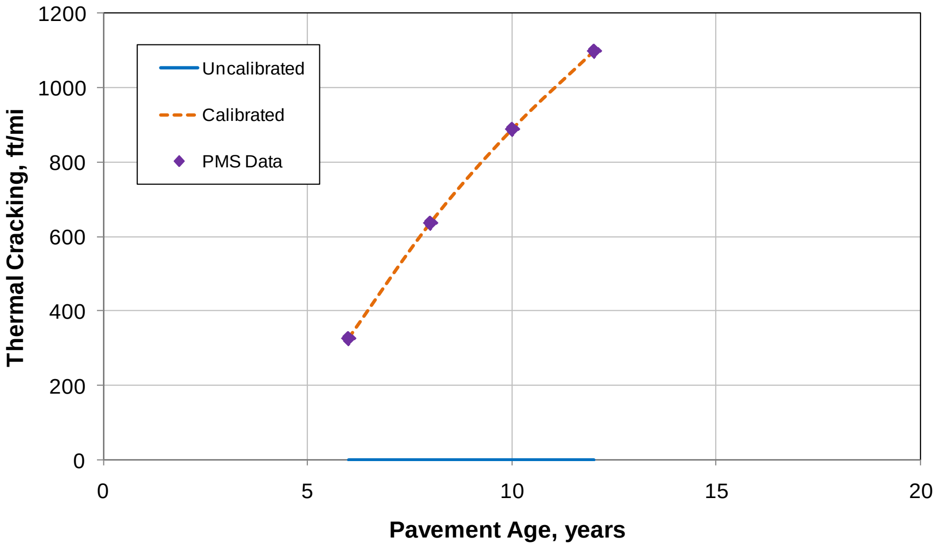

Figure 26. Locally calibrated thermal cracking model – section R2211BA.

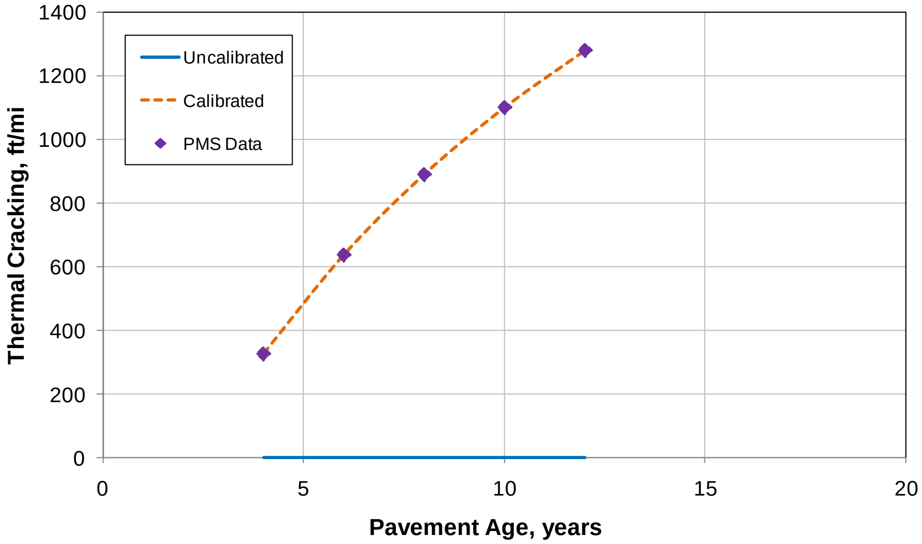

Figure 27. Locally calibrated thermal cracking model – section R2232A.

Figure 28 illustrates the comparison of the predicted versus measured thermal cracking for the NCDOT pavement sections based on the calibrated model. The use of the new calibration coefficients provides a much better fit of the data; however, additional pavement sections should be included in the analysis prior to implementation of the revised model.

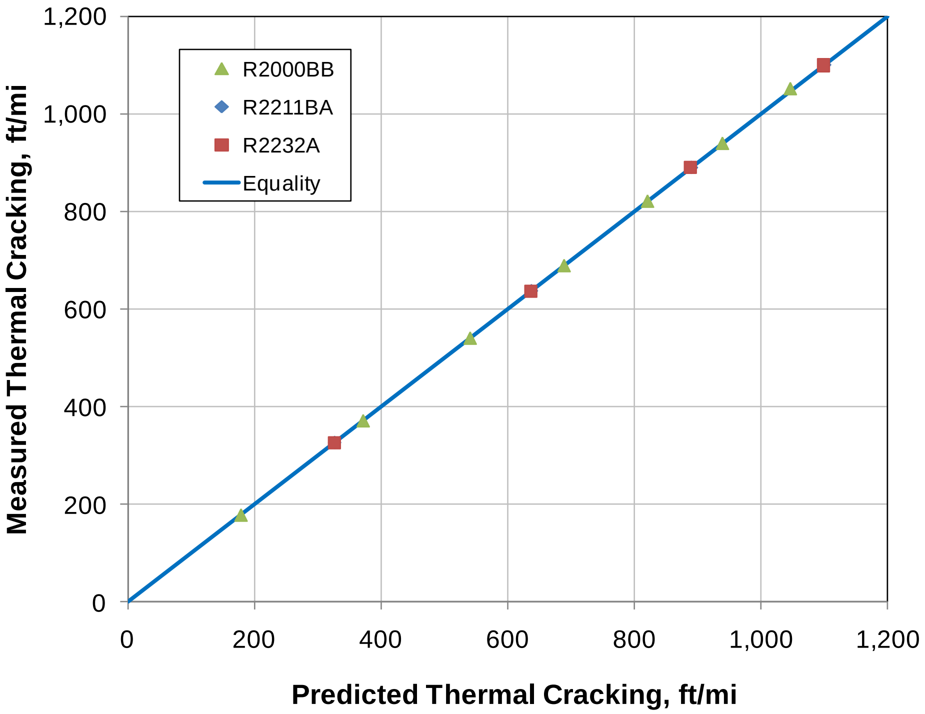

Figure 28. Comparison of residual errors for thermal cracking model.

Reflective Cracking

As with alligator cracking, the reflective cracking model within the MEPDG (version 1.100) was also considered to be a work in progress at the initiation of this project. In addition, NCDOT currently does not include reflective cracking in their pavement condition surveys. Therefore, calibration of the reflective cracking model was not performed.

Smoothness

The MEPDG IRI model consists of a regression equation that is calculated from other distresses. For HMA pavements, the IRI model is a function of the initial IRI, a site factor (which considers pavement age, subgrade soil plasticity index, freezing index, and precipitation), load-related cracking, thermal cracking, and rut depth (see also appendix D, table D-7, of volume 2).

IRI calibration requires an extensive number of pavement sections and years of data collection that would be challenging to obtain under this study. NCDOT had only been collecting IRI data for 8 years, which was considered to be insufficient to accurately develop a calibrated IRI models. Therefore, calibration of the HMA IRI model was not performed.

NCDOT PCC Pavement Sections

As previously noted, for new rigid pavement design the MEPDG performance parameters include transverse cracking, transverse joint faulting, and IRI. Three PCC pavement sections in North Carolina were selected for assessing local calibration coefficients. The three pavement sections selected for calibration include I-10CC, I-2511BB, and I-900AC. Figures 29 and 30 illustrate the MEPDG uncalibrated predicted distress versus the NCDOT observations for cracking and faulting, respectively.

As shown in figures 29 and 30, the predicted performance using nationally calibrated models over predicts the distress development as compared to the NCDOT measured distress. The use of the nationally calibrated models would result in an overdesign and more costly pavement sections than is otherwise suggested by the performance of the three pavement sections.

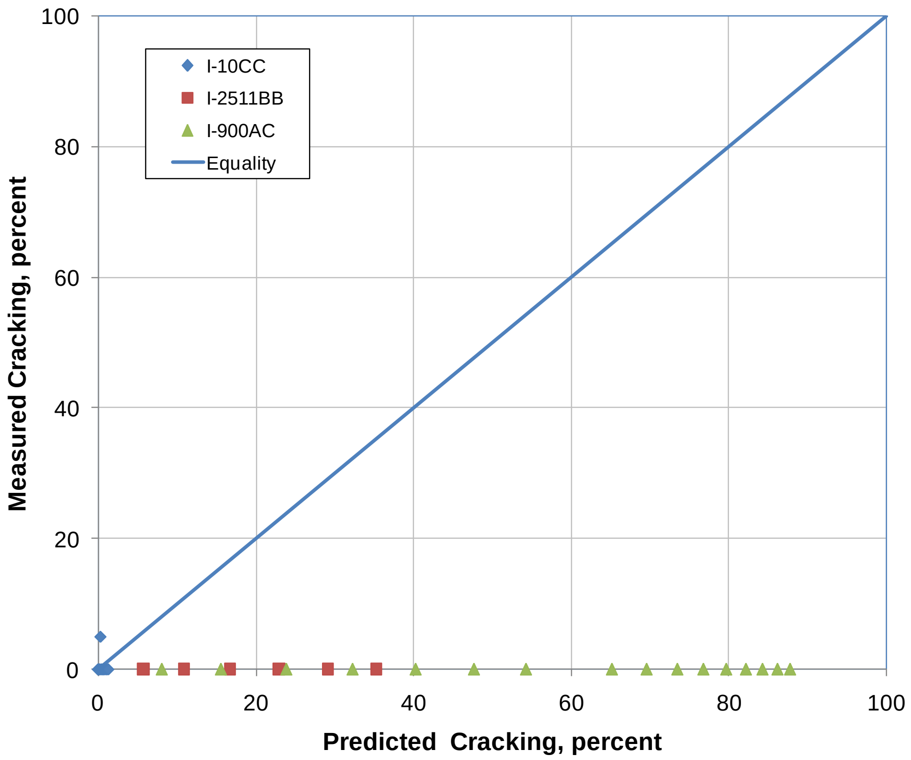

Figure 29. MEPDG predicted (uncalibrated) versus NCDOT distress – transverse cracking.

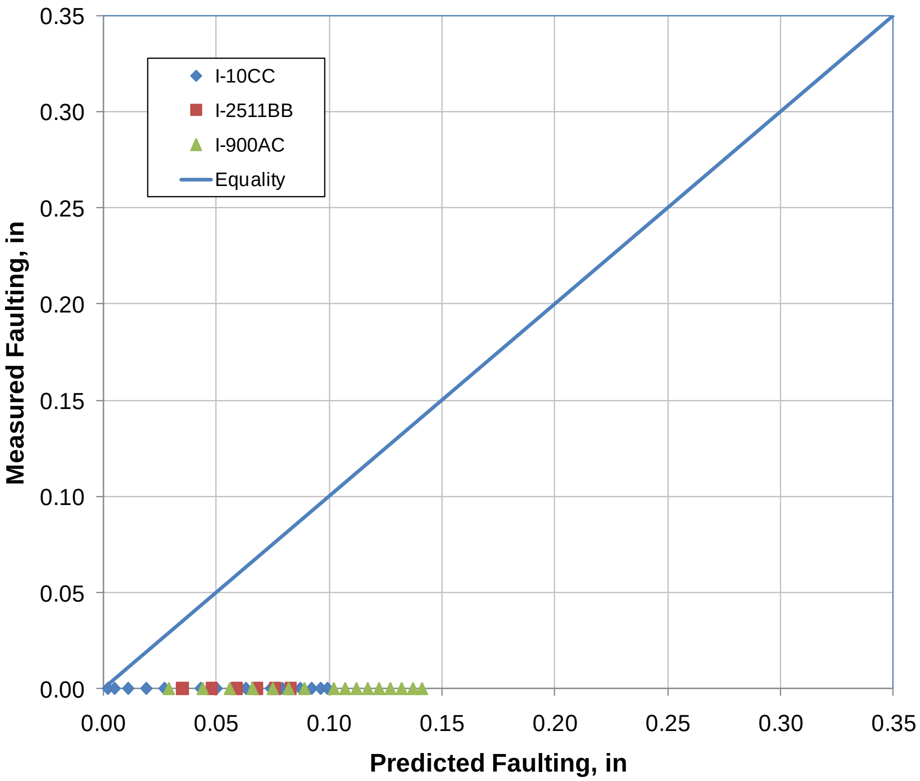

Figure 30. MEPDG predicted (uncalibrated) versus NCDOT distress – Faulting.

The residual errors for transverse cracking are show in figure 31. On two projects (1-2511BB and I-900AC), the residual error increases with age, and are the same sign, but have a relatively high error compared to the performance criteria (15 percent). Even so, adjustment of the calibration coefficients may improve the predicted performance. The third project (I-10CC) has a very low (or zero error), indicating the nationally calibrated model reasonably predicts transverse cracking on this pavement section.

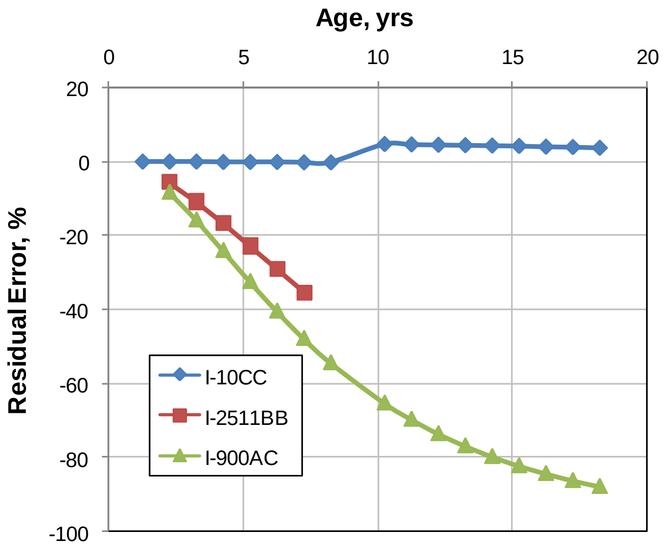

Figure 31. Residual error for transverse cracking predictions (uncalibrated).

The residual errors for faulting are show in figure 32. The residual errors increase with age, are the same sign, and are relatively high compared to the performance criteria (0.12 in [3.05 mm]). Therefore, adjustment of the calibration coefficients may improve the predicted performance.

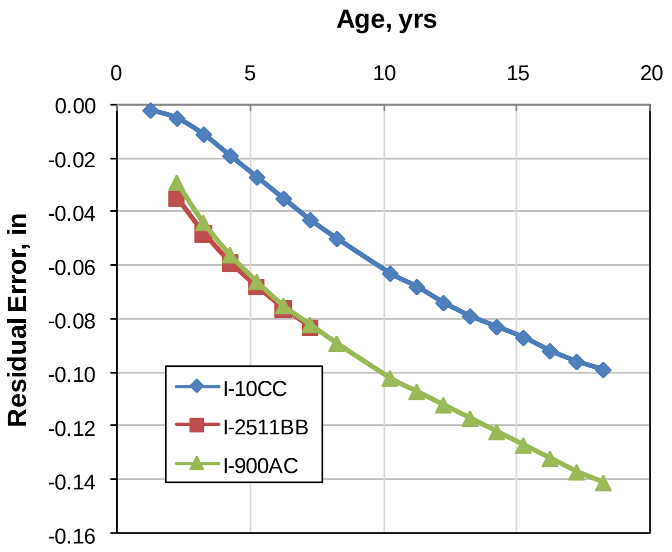

Figure 32. Residual error for faulting predictions (uncalibrated).

As noted previously, the goal in the calibration process is to reduce the error between the measured and predicted distress. As with the HMA pavement sections, there are very few data points, the measured data are primarily zero quantities, and no data are available approaching the established failure criteria or near the end of the performance period, making model calibration challenging. The approach taken by the research team was to minimize the standard error with the available data points. Because there are no data available at later ages, it was assumed that the original pavement designs, on average, meet the selected limiting criteria and reliability. While this is a significant assumption, current project distress levels appear to support this assumption (i.e., actual field performance indicates no faulting and no cracking on the NCDOT pavement sections).

Transverse Cracking

There are four calibration coefficients for transverse cracking: C_1 through C_4. Adjustment of C_1 and C_2 had the greatest influence on reducing the differences in initial cracking estimates; however, how much of an adjustment is needed for characterizing the long-term performance of the NCDOT PCC pavements is unknown since long-term performance data are not available. With no data beyond 18 years, minimizing the error to only the years with data resulted in the prediction of early failure—an average of approximately 42 percent cracking at the selected reliability of 90 percent at the end of 30 years. If it is assumed that the original NCDOT designs will on average perform to the selected design criteria (15 percent slab cracking) at the specified reliability (90 percent), then the calibration coefficients shown in table 63 are obtained. Using the adjusted calibration coefficients, the resulting adjusted transverse cracking model for sections I-10CC, I-2511BB, and I-900AC are shown in figures 33, 34, and 35, respectively.

Table 63. Transverse cracking model calibration coefficients.

Coefficient	**Default Value**	**Adjusted Value**
C_1	2.00	2.696
C_2	1.22	1.22

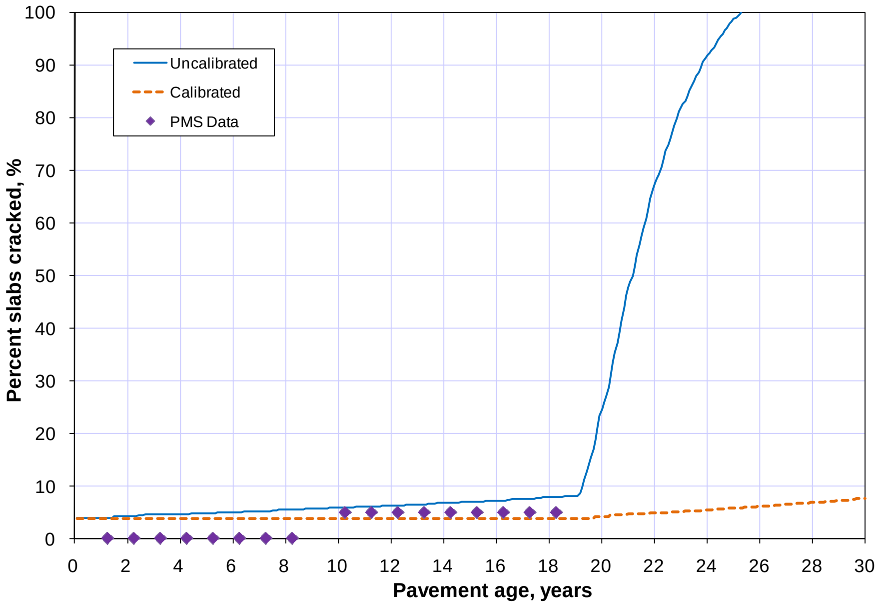

Figure 33. Locally calibrated PCC transverse cracking model – section I-10CC.

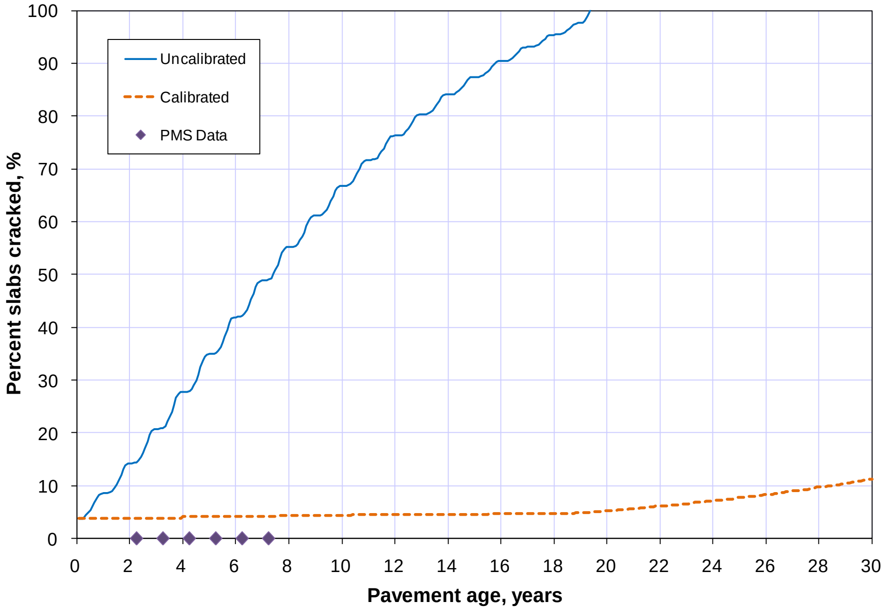

Figure 34. Locally calibrated PCC transverse cracking model – section I-2511BB.

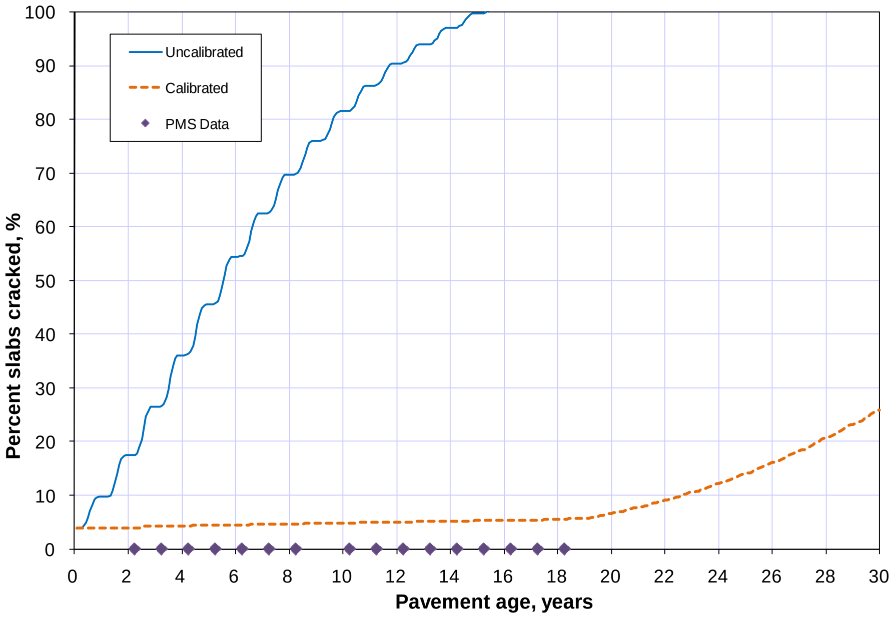

Figure 35. Locally calibrated PCC transverse cracking model – section I-900AC.

While the calibrated model appears to better characterize the observed performance of NCDOT PCC pavements (see also figure 36), the use of the adjusted calibration coefficients also comes with a caution. These coefficients adjust the fatigue damage calculations that, among other inputs, are dependent on the layer material properties and traffic characteristics. The layer properties for these design runs were selected primarily as default values, as were most of the traffic characteristics. While it may very well be that the adjusted calibration coefficients reflect local performance, efforts should be made to ensure that inputs are as accurate as possible for local conditions.

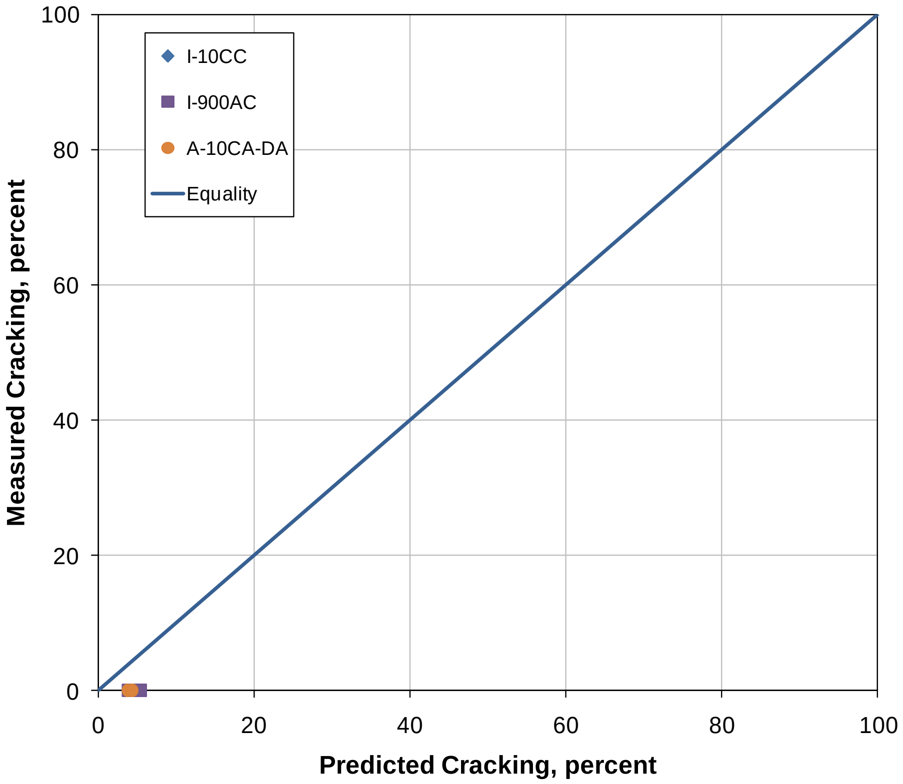

Figure 36. MEPDG predicted (calibrated) versus NCDOT distress – transverse cracking.

Joint Faulting

The faulting prediction model includes eight calibration coefficients, C_1 through C_7. The adjusted faulting model coefficients are summarized in table 64 and figures 37 through 39 illustrated the nationally calibrated models, PMS data, and locally calibrated models using the derived coefficients.

Table 64. Summary of faulting model calibration coefficients.

Coefficient	**Default Value**	**Adjusted Value**
C_1	1.29	0.073
C_2	1.10	1.10
C_3	0.001725	0.001725
C_4	0.0008	0.0008
C_5	250	250
C_6	0.40	0.40
C_7	1.20	1.741

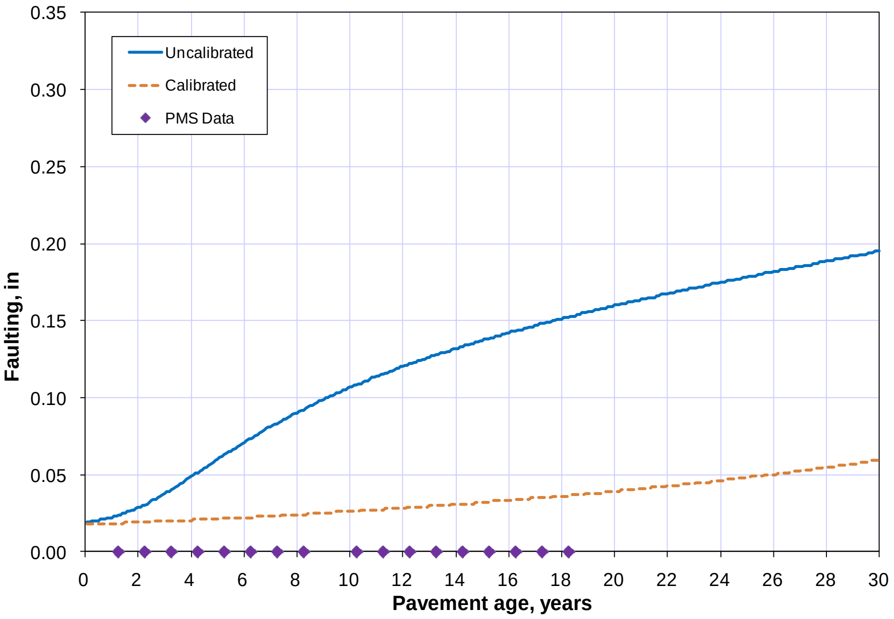

Figure 37. Locally calibrated joint faulting model – section I-10CC.

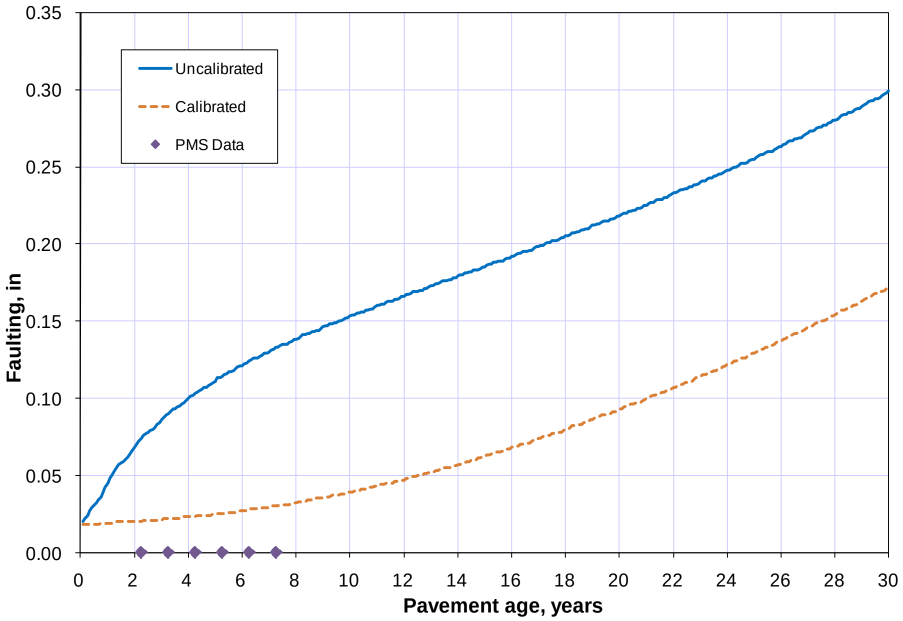

Figure 38. Locally calibrated faulting model – section I-2511BB.

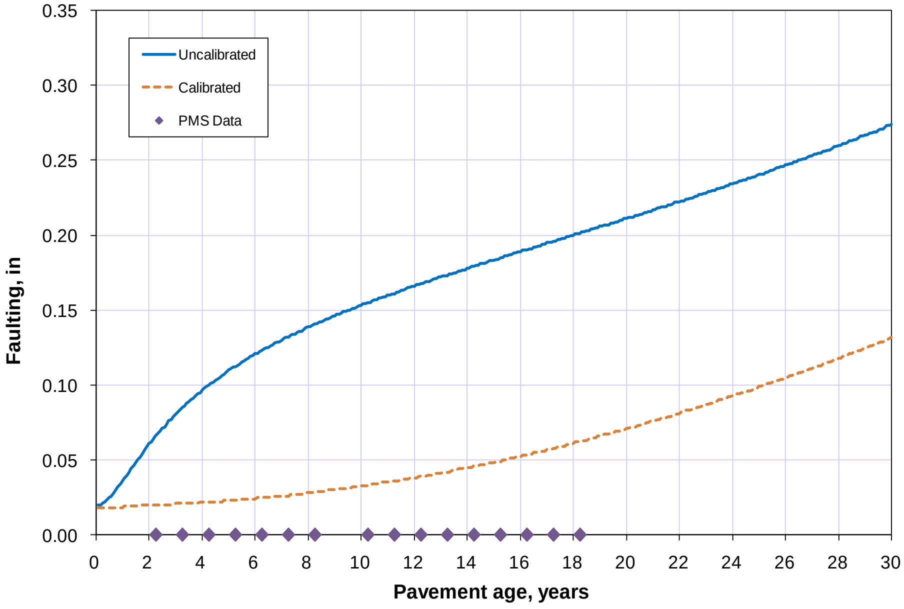

Figure 39. Locally calibrated faulting model – section I-900AC.

The calibrated faulting model appears to better characterize the observed performance of NCDOT PCC pavements (see also figure 40); however, as noted with the transverse cracking model calibration, efforts should be made to ensure that inputs are as accurate as possible for local conditions.

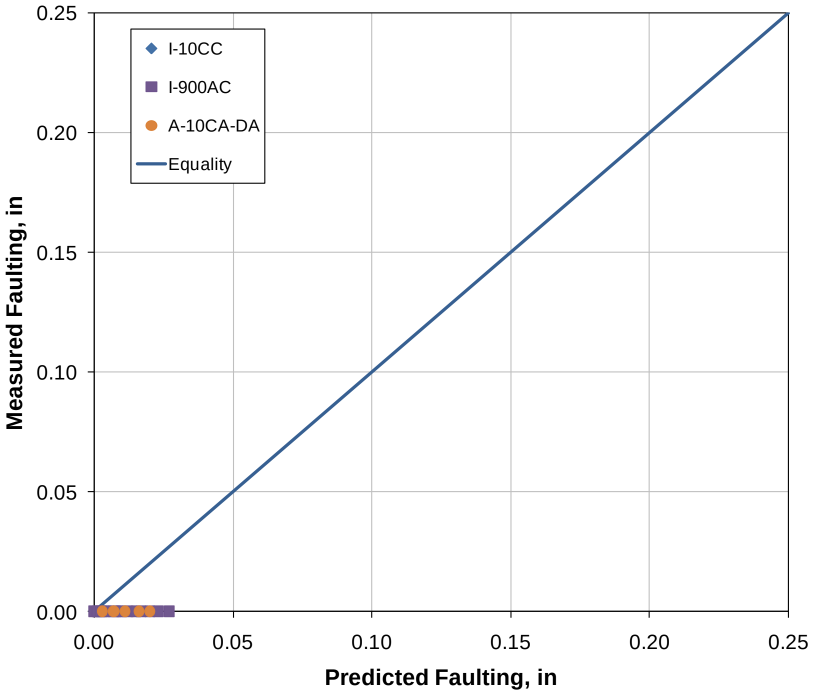

Figure 40. MEPDG predicted (calibrated) versus NCDOT distress – Faulting.

Smoothness

For JCP, the IRI model is a function of initial IRI, percent of slabs with transverse cracks, percent of spalled joints, cumulative joint faulting, and a site factor (which considers pavement age, freezing index, and percent passing No. 200 sieve for the subgrade soil) (see also appendix D, table D-10 in volume 2). As with the HMA IRI model, the extensive number of pavement sections required for a valid calibration was not possible within the scope of this study.

Summary

With a focus on the implementation of the MEPDG over the next decade, many highway agencies will need to characterize existing pavement condition to aid in the local calibration process. One of the major challenges with calibration will be in correlating the pavement condition data collected as part of the LTPP program to that contained within each States pavement management system. There are a number of challenges in this process that include: LTPP sections are comprised of 500 ft (152.5 m) lengths and may not fully represent the project distress, the LTPP data definitions may not completely reflect the distress definitions of each SHA, and many highway agencies may have only limited pavement condition data; the latter is particularly critical because the calibration process requires numerous pavement sections with performance data that extends over the analysis period.

With these limitations, the research team demonstrated how existing pavement data for flexible and rigid pavement sections from the NCDOT could be used to calibrate the pavement distress models contained within the MEPDG. For the HMA pavement sections, a MS Excel® solver was used to iterate the calibration coefficients to result in a minimum error, while an iterative process was used for the JCP pavement sections. In both cases, revisions to the calibration coefficients produced a better fit between predicted and measured distress; however, caution was also noted that additional pavement sections and performance data were needed prior to NCDOT consideration for adoption of the recommended calibration coefficients.

CHAPTER 9. RECOMMENDATIONS

Based on the review and analysis conducted under this study, the research team has the following recommendations to assist in the MEPDG calibration process using pavement management data.

- Evaluate the potential differences between the SHA pavement condition survey methodology and that conducted in accordance with *LTPP Distress Identification Manual*. Since the MEPDG performance prediction models are based on the noted distress of the LTPP pavement sections, differences in pavement condition assessment can influence the accuracy of the distress prediction.
- For this study, many of the design inputs for the included project sections are the default values contained in the MEPDG software. An in-depth review of the inputs should be conducted to make certain the values apply to the design process and materials for the DOT. Recalibration of the models should be performed if additional design information is obtained.
- A larger sample size is needed for a statistically meaningful calibration. However, many agencies are expected to have to deal with limitations to the amount of material properties and traffic data that can be correlated to the condition data within a SHAs pavement management system. For those states that are utilizing data contained within the LTPP, acquiring data from adjacent states could be considered as one way of providing additional data sets.
- NCDOT is currently measuring pavement roughness using a high-speed profiling device; however, results of rut depths measured from the profiler were not provided to the research team. It is recommended that NCDOT, and other SHAs that modify their data collection procedures, evaluate the use of new data in the calibration process. Having additional pavement sections whose performance is monitored over consecutive years is expected to greatly improve the accuracy of the calibrated MEPDG prediction model.
- Although it likely would improve the accuracy of the thermal crack prediction, it is not expected that many SHAs will go to the effort of measuring the depth of all thermal cracks; however, it would be beneficial to at least measure the depth of the transverse crack at each significant change of a cooling cycle. NCDOT currently measures thermal cracking based on the predominant distress severity and extent over the pavement sections. To improve the thermal crack prediction, it is recommended that agencies also consider measuring crack width, crack length, and the number of thermal cracks over the pavement section.
- Asphalt mixtures should be characterized in accordance with dynamic modulus and tensile strength. The dynamic modulus and tensile strength properties are needed to determine the asphalt mixture thermal properties (m, n, and A).
- Recalibration should take place when additional data are available near the end of the pavement service life. Data for the JCP projects only spanned approximately half of the anticipated service life. Data with distress measurements near the end of the performance period are expected to improve the calibration of the performance models.

- Many of the JCP distresses were not observed on the sections included in the calibration study. Model calibration should be reviewed when distress data approaching the selected failure criteria are available. Alternatively, if performance data does not approach the selected design criteria, the selection of this value should be re-assessed for local performance.
- The NCDOT distress surveys are completed by March of each year, but the exact time of the survey is not recorded in the pavement management system. With the MEPDG predicting distresses on a monthly basis, the survey month should be compared. While the difference of 1 month may be minimal in the calculations, having unknown dates adds to the prediction error.
- Due to the requirement of a large number of pavement sections, this study did not calibrate the IRI model for either HMA or PCC pavements. It appears that NCDOT has the necessary measurement equipment and pavement sections to adequately calibrate these models. Calibration of the IRI models appears to be stop

Another challenge with the MEPDG calibration process will be in obtaining, evaluating, and analyzing the large quantity of data inputs. For the NCDOT evaluation, a small number of pavement sections still resulted in a considerable length of time to evaluate, analyze, and format for calibration purposes. The availability of only limited performance data and the presence of data that did not meet the LTPP data definitions required additional efforts by the research team to correlate the two survey approaches. Other agencies that do not use survey procedures that are identical to the LTPP methodology will have to go through similar steps.

Nevertheless, it has been demonstrated that the MEPDG models can be calibrated using pavement management data even if only limited data sets are used for the initial calibration activities. Based on the calibration steps outlined in this report, a suggested timeline for calibrating the MEPDG performance prediction models is presented in table 65. The actual timeline will be dependent on the availability of performance data, the size of the state pavement network, the variation of pavement categories and designs, and the number and experience of personnel.

Table 65. Estimated timeline for local calibration.

Calibration Steps	**Timeline (weeks)**	**Comments (NCHRP 2009)**
Select hierarchical input level	1	This should reflect how an agency intends to use the MEPDG on a day-to-day basis.
Develop experimental plan	2	Determine the number of pavement categories (e.g., full-depth HMA, HMA overlays, PCC, PCC overlays). Consider grouping by similarities in material type, climate, subgrade soil, and traffic loadings.
Estimate sample size	1	Identify which performance models will be calibrated. Establish performance criteria for each distress type (e.g., rut depth, load-related cracking, faulting). Determine acceptable bias. In addition, each pavement category should also include replicate sections.
Select roadway segments	4	Selected segments should have a range of distress for pavements of similar age. Consider excluding pavements with premature failure or extremely superior performance. Selected pavement sections should have similar types and extent of distresses present over a similar length of time. This will help in minimizing the potential for bias.
Evaluate project and distress data	12	Access correlation between LTPP and State pavement distress definitions. Check, confirm, and remove outliers. Confirm that selected pavement sections include values close to the selected performance criteria. Confirm pavement sections have initial IRI data (IRI prediction model is highly dependent on initial IRI), construction history data, traffic data, rehabilitation data, and materials data.
Conduct field testing and forensic investigation	---	Confirm rut depth in various pavement layers through extensive coring or trench studies. Confirm location of crack initiation (top-down or bottom-up). This step should be based on the SHAs acceptance of the assumptions and conditions contained within the MEPDG; therefore, it is difficult to estimate the length of time to conduct this investigation.
Access and reduce/eliminate bias	2	Includes the evaluation of predicted versus measured pavement distress. Adjust calibration coefficients if the model precision is reasonable, but the accuracy is poor. If the prediction is reasonable, but the precision is poor the calibration coefficient is likely dependent on a site feature, material property, and/or design feature. If the precision is poor and the model accuracy is dependent on time or number of load cycles (i.e., poor correlation between measured and predicted distress), the exponent on the number of load cycles needs to be considered.

Table 65. Estimated timeline for local calibration (continued).

Calibration Steps	**Timeline (weeks)**	**Comments**
Assess and reduce standard error	2	Assess the relationship between the standard error from the local calibration process to that in the MEPDG software. If significantly different, determine if the standard error is dependent on some other parameter or material/layer property. If no dependency is determined, accept the local calibration coefficient.
Interpret results	2	Determine whether or not to accept the locally calibrated models or use the nationally calibrated models. Identify any major differences between LTPP projects and SHA standard practice. Determine whether or not the calibration coefficients explain any of these differences. Ensure engineering reasonableness.
Total	26	This is an estimate of maximum length of time required for the calibration process. However, depending on the available data contained within the pavement management system, this process could be shortened considerably.

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