MEPDG Overview & National Perspective (My Perspective)

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Outline

1. The Beginning
2. Local Implementation Efforts
3. Integration of MEPDG into Practice
4. Enhancements
5. Summary
April 2007 Irvine Workshop

It’s Done; In Reality, It’s the Beginning!!
Should we wait until its **PERFECT?**

**AASHTO Guide**
- 1958; Road Test initiated
- 1962; AASHO Road Test complete
- 1972; Interim Design Guide
- 1986; Update
- 1993; Update
- 2007; still not perfect.

**MEPDG**
- 1989; LTPP initiated
- 1998; MEPDG initiated
- 2007; MEPDG delivered

<table>
<thead>
<tr>
<th>Time, yrs.</th>
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</thead>
<tbody>
<tr>
<td>-4</td>
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<td>24</td>
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<tr>
<td>31</td>
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<tr>
<td>45</td>
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</tbody>
</table>
Should we wait until its **PERFECT**?

- If we wait until there are no more changes, *we will never use it.*
- If we wait for perfection, *it will be impractical and cost will restrict its use.*

There is **NO** perfect procedure & it will never be perfect!
The Beginning

We have decided to implement the new MEPDG!

Where do we begin; regional versus agency issues?

What will it cost?

Will we get a better design?

What am I responsible for?

Why, aren’t we doing a good job?

Where do we begin; regional versus agency issues?
Remember where we are coming from, as you use the MEPDG!

- Assumptions used in the Design Guides?
- Calibration of both Design Guides?
- Error in the service life predictions of both Design Guides?
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FHWA Summary of Agency Plans

Efforts to Implement MEPDG 2007
MEPDG Global Calibration

LTPP GPS Test Sections Used in Calibration of Distress Prediction Models;
NCHRP Projects 1-37A & 1-40D

- Many assumptions used.
- Many inputs estimated.
Local Implementation Efforts—

1. Verify/confirm calibration factors & default values.
2. Establish input libraries.

- North-Central
- South-East
- South-West

- North-East
- North-West
Why Local Calibration?

- Expansive Soils
- Maintenance/Preservation Strategies
- New Technology & Material Differences
- Other Design Policies & Features

Consideration of factors NOT included in MEPDG global calibration process.
MEPDG – Local Validation/Calibration Tools

Manual of Recommended Practice for Calibration of M-E Based Models

1. Confirming or adjusting the global calibration factors.
2. Detailed and practical guide to complete local calibration.

MEPDG Software Itself

NCHRP Project 1-40B
Previous & On-Going Studies


3. **NCHRP 1-40D** – A review of the M-E PDG software & prediction methodology; & Correcting errors/blunders in the software.

Previous & On-Going Studies

- Calibration Documents:
  - **NCHRP Digest 284**, December 2003; *Refining the Calibration & Validation of HMA Performance Models: An Experimental Plan and Database.*
  - **NCHRP Digest 283**, December 2003; *Jackknife Testing – An Experimental Approach to Refine Model Calibration and Validation.*

- FHWA: Use of PMS data for local calibration.
- FHWA: Use of deflection basin data in the MEPDG.
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Integration into Practice

A Major Issue – The Unknowns!!

- Determination of properties & other inputs.
- Factors affecting properties needed for design!!!!
  - Source of Materials
  - Contractor
  - Construction Equipment

4-Day NHI Course for MEPDG Software Training

How do I get this input level 1 or 2 for design?
Expanding the Realm of Possibility

Data Integration: Effective use of available but limited local resources.

Data integration: an automated process?

Probably NOT!

PMIS Database

Project Level Data

Expanding the Realm of Possibility
Structural – Mix Design Compatibility

Mixture design & material specifications determine the inputs.
Data Integration into Practice

Develop Designs
- Low-bid; optimize on design features
- Alternate bids; establish equivalent designs
- Design-build & warranties; optimize on performance

Establish Specification Limits
- Quality Assurance
- Performance-Related
- End-Result
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Enhancements: Global & Local

Global
- Distress prediction equations or transfer functions
- Revisions to the software; functionality
- Add additional distresses

Local or Regional
- Revisions to the default values
- Revisions to the transfer function and calibration coefficients
- Build libraries of inputs

NCHRP Project 1-40B
Local Calibration Guide
Previous & On-Going Studies

1. NCHRP 1-40A – Independent Review, prioritize the modifications.
2. NCHRP 9-30A – Calibration of Rutting Models for HMA Structural and Mix Design.
3. NCHRP 9-42 – Top-Down Cracking of HMA.
4. Reflection Cracking of HMA Overlays.
5. NCHRP 9-44 – Application of the Endurance Limit for HMA Mixes.
New Construction Design Strategies

Included:
- Conventional flexible pavements
- Deep strength
- Full depth

Excluded:
- Aggregate surfaced roadways
- Semi-rigid pavements
- Staged construction
- Asphalt treated permeable base
- Geogrids, fabrics, & other strengthening materials
Rehabilitation Strategies

Included:
- HMA overlays with & without milling

Excluded:
- Full depth reclamation
- Hot in place recycling
- Cold in place recycling
- Pavement preservation programs
Site Features Excluded from MEPDG

- Super single tires or single tires.
- Durability & mixture disintegration.
- Volume change in soils (frost heave or expansive soils).
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Summary

Implementation Considerations:

- Regional design features not included in global calibration.
- Regional defaults that are different from global defaults.
- Design criteria as compared to measured values included in calibration.
Summary

- Response Parameter & Calibration Factors
- Transfer Function & Calibration Factors
- Standard Error or Standard Deviation

Agency/User has options readily available for design!
Value of Increased Costs & Time?

If improved performance/longer lasting pavements & reduced life cycle costs;

Then it is worth the effort, time, and cost!!

Assuming enforcement of specifications.
Thank you.
Any Questions?
Questions!
Advanced Pavement Design

- Distress specific—defines what controls the design.
- Design features—considers many more design features and what effect they have on distress.
- Smoothness
- Construction defect effects.
Current Pavement Design Procedures

<table>
<thead>
<tr>
<th>Pavement Design Procedures</th>
<th>Percent of Total Responding (52)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Specific</td>
<td>Flexible Pavements</td>
</tr>
<tr>
<td>72-AASHTO</td>
<td>Rigid Pavements</td>
</tr>
<tr>
<td>81-AASHTO</td>
<td></td>
</tr>
<tr>
<td>93-AASHTO</td>
<td></td>
</tr>
<tr>
<td>98-AASHTO</td>
<td></td>
</tr>
</tbody>
</table>

Flexible Pavements: A shaded column indicating the percentage of responding agencies using flexible pavement design procedures.
Rigid Pavements: A shaded column indicating the percentage of responding agencies using rigid pavement design procedures.

Total respondents: 52
Agency Road Maps for: Implementing the MEPDG

• To streamline the design process using the MEPDG, & to verify and calibrate the distress prediction models or transfer function included in the MEPDG.
Reliability

1993 AASHTO

- Based on traffic level; standard deviation of the design process & applied to traffic level.

MEPDG

- Standard error for each distress prediction model & defined from calibration.

Carefully review and consider the standard errors of the distress prediction equations for application to low volume roadways.
Summary

Remember:
The hierarchical input procedure allows a user to use the MEPDG with **NO** major investment.
Deciding on Design Inputs

- Communications within & between departments
- Traffic
- Materials
- Construction
Decision Factors

1. Cost of validation/calibration.
2. Value of potential improvement in prediction accuracy.

Decision: Yes, validate & calibrate MEPDG to our local conditions!
Preparation of a M-E Design in a Low-Bid Process

Foundation Analysis → Climate EICM → Materials Library → Traffic Library

Design Criteria → Structural Design by Agency

Mixture Design & Confirm Properties → Layer Thickness, Type & Properties
Implementation Areas & Technology Transfer

- Training & communications within & between departments
- Traffic
- Materials
- Construction
- Calibration
Expanding the Realm of Possibility

Structural – Mix Design Integration

Design, more than just volumetrics.

1. Project Selection
2. Planning
3. Structural Design
4. Plan Preparation
5. Bid Letting
6. HMA Mixture Design
7. Construction
8. As-Built Plans & Performance Confirmation

Library of Mix Properties:
- Dynamic Modulus
- Flow Number
- IDT Strength
- IDT Creep
- VMA

Volumetric & SPT

Design Values:
- \( E^* > ? \)
- \( S_{\text{IDT}} > ? \)
- \( D(t) < ? \)

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Technology Transfer & Implementation Products

**Remember Products:**

- Management video
- Interactive CD for software
- Implementation notes
- Training course
- Guide text & appendices.
- User’s Manual in support of software.
Important Activities for Implementation

- Training Courses:
  - Determining inputs & using software

- Communication:
  - Departments need to know what information is needed & how it is used.

- Establish sensitivity of inputs to distress

- Identify problem areas to reduce frustration with software use
Global Calibration of Distress Transfer Functions

Pavement Response

- Stresses
- Strains
- Deflections

Distress

- Cracking
- Distortion
- Roughness

Calibration is a key.
Local Calibration

A difficult & costly issue to resolve!

How close is close enough?
Outline of Recommended Practice for Local Calibration

- Introduction
- Scope of Document
- Referenced Documents
- Definition of Terms
- Significant of Use
- Defining Accuracy
- Standard Error Components
- Step-by-Step Procedure
- Revisions to calibration coefficients
- Demonstration Studies
Validate/Calibrate MEPDG

- How many sites?
- Length of roadway segments?
- How many distress observations?
  - Multiple points within segment at any one point in time?
  - Multiple points over time?
Distress Data Sources

- LTPP
- Special Agency Test Sections
- PMIS Sections – A quick check:
  - Do the distress predictions match our local experience for traditional designs?
  - What is the primary failure mode triggering rehabilitation?

NCHRP 9-30 Database for M-E Based Models
Calibration: Ease of Use

Calibration Options:
- Special Analysis
- National Calibration
- State Calibration
- Typical Agency Values

National/Global Calibration; $k$- or $C$-Values
State/Regional Calibration; $\beta$- or $C$-Values
Calibration: Ease of Use

- **Transfer Function**
  - $F C_{exp} = \frac{C_4}{1 + e^{C_3 - C_2 \cdot \log_2(A_s / 250)}} \approx 10.56$

- **C-Values**
  - $C_1$ (top) = 2.4
  - $C_2$ (top) = 1.4
  - $C_3$ (top) = 0
  - $C_4$ (top) = 1000

- **Standard Deviation**
  - $77 + 114.8 / (1 + \exp(0.772 - 2.6527 \log_2 \text{TOP} + 0.001))$

- **HMA Alligator Cracking**

Expanding the Realm of Possibility
Calibration: Ease of Use

- Response Parameter & Calibration Factors
- Transfer Function & Calibration Factors
- Standard Deviation

JPCP Cracking

Expanding the Realm of Possibility
MEPDG Unique Feature

- Response Parameter & Calibration Factors
- Transfer Function & Calibration Factors
- Standard Deviation

Batch runs can be completed!
Agency/User has options readily available for design!
Local Validation/Calibration Hypotheses

- Mathematical models – assumed to be correct.
  - Pavement response models
  - Climatic model – ICM
  - HMA aging/PCC strength time dependent model

- Statistical or empirical models (transfer functions) may result in bias.
  - Revision of model coefficients to remove bias.
General Approach to Validation & Calibration of M-E Based Models

1. Traditional Split-Sample Approach
2. Jack-Knife Testing Approach
Validate/Calibrate MEPDG

What data do we use?
LTPP/PMIS & other databases!!

- How many sites?
- Length of roadway segments?
- How many distress observations?
  - Multiple points within segment at any one point in time?
  - Multiple points over time?
Data Quality Review

What caused this increase in measured rutting?

Data measurement issues!
Data Quality Review

Why are transverse cracking values so diverse?

Pavement preservation issues!
Distress Data, Example:

Variability; A key data issue.

Example; Fatigue Cracking
Expanding the Realm of Possibility

Distress Data, Example:

Variability; A key data issue.

Example; Rut Depth

Neat Mixes

PMA Mixes
Distress Data Analyses:
Within Project Variation; **Outliers**

Limited area with significant different distress value within PMIS segment.

Outliers, removed from calibration set.
Distress Data Analyses: 
Within Project Variation; Abrupt Change

Identify reasons for abrupt changes.

Sudden increase or decrease in distress value within PMIS segment.
Distress Data Analyses: Within Project Variation; **Drift**

Use segments with consistent averages.

Consistent change in distress over project length, within PMIS segment.
Data Analyses: Bias & Residual Error from Validation/Calibration

Suggestion: Determine bias and error for local conditions & materials.
Global Calibration Hypothesis

Reduce uncertainty, use level 1

Calibration Error

Level 3 Default Value
Level 2 Calculated Value
Level 1 Measured Value
How Close is Close Enough?

\[
\left( \sigma_{\text{Total}} \right)^2 = \left( \sigma_{\text{Measurement}} \right)^2 + \left( \sigma_{\text{Lack-of-Fit}} \right)^2 + \left( \sigma_{\text{Input}} \right)^2 + \left( \sigma_{\text{Pure}} \right)^2
\]

Quantify the total error to answer this question!
Uses of PMIS Data for Validation/Calibration

- Identify factors/site features deviations or anomalies between performance observations.
- Identify bias between observations & predicted distresses for different design features & strategies.

Determination of the standard error – Probably NOT!
Pavement Management Systems Data - A Resource:

- Large time-series database on distress & pavement performance.
- Many dollars expended to develop PMIS and collect data.

Use of PMIS data for validation/calibration not a simple & quick process!!!!!
In Summary

Local validation/calibration:
It’s an important decision but it’s your to make.

🌟 Accuracy
🌟 Costs

Manual of Recommended Practice for Calibrating M-E Based Models.
### Material Testing - Equipment Purchased for Implementation

<table>
<thead>
<tr>
<th>Material</th>
<th>Montana</th>
<th>Missouri</th>
<th>Utah</th>
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</thead>
<tbody>
<tr>
<td>Unbound Mtls.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>HMA</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PCC</td>
<td></td>
<td></td>
<td></td>
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**Note:** Most agencies have equipped.
Testing – Lab Testing

- Build library of material properties
- Build library of default values
Questions for Establishing a Data Collection Plan

1. Is input parameter important for predicting distress?
2. Is the input parameter site/facility specific?
3. Can input parameter be easily/adequately measured?
Expanding the Realm of Possibility

Time-History Data for Calibration

- MnRoad Measured
- Mississippi Measured
- Arizona Measured
- MnRoad Predicted
- Mississippi Predicted
- Arizona Predicted

Rut Depth, inches

Age, years

0 2 4 6 8 10 12

Time-History Data for Calibration

ARA

Expanding the Realm of Possibility
Local Calibration Hypotheses

- Mathematical models – assumed to be correct.
  - Response models
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  - HMA aging/PCC strength time dependent model
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  - Revision of model coefficients to remove bias.
Steps for Local Calibration

1. Select hierarchical input level
2. Develop experimental design & matrix
3. Determine sample size
4. Identify roadway segments
5. Collect & evaluate data for anomalies
6. Conduct field investigations

Policy decision.
Level of confidence.
1. LTPP sections
2. Research sections
3. PMIS segments
Testing & distress definitions
Steps for Local Calibration

7. Assess bias
8. Eliminate bias
9. Assess standard error
10. Improve model precision
11. Interpretation of results & decide on adequacy of calibration factors

Execute MEPDG & evaluate residual errors.

Dispersion around line of equality
Expanding the Realm of Possibility

\[ D(t)_{CI} = D_{\text{predicted}} + e \]

BUT, where does the error come from?

Design Confidence Interval Concept

Predicted Distress Value

| Reliability | Graph
<table>
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<tbody>
<tr>
<td>50%</td>
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<td>75%</td>
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</tr>
<tr>
<td>95%</td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
Quantifying the Prediction Error

\[ e_{Total} = e_{Lack-of-Fit} + e_{Measurement} \]

\[ + e_{Input} + e_{Pure} \]
Objective:

• To streamline the design process using the MEPDG, & to verify and calibrate the distress prediction models or transfer function included in the MEPDG.
Expanding the Realm of Possibility

Rutting in Unbound Layers & Rutting in Unbound Layers & Subgrade...

Trenches not completed for the LTPP test sections!

Rutting in Unbound Layers & Subgrade.
Expanding the Realm of Possibility

Based on Volumetric Properties

HMA Rutting

Wear vs. plastic deformation

Based on Volumetric Properties

HMA Rutting

\[ \frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1}^{10} k_1^{3} k_2^{3} \frac{1}{N} \]

where:

- \( \varepsilon_p \) = plastic strain (in/in)
- \( \varepsilon_r \) = resilient strain (in/in)
- \( T \) = layer temperature (°F)
- \( N \) = number of load repetitions

\[ k_z = (C_1 + C_2 \times \text{depth}) \times 0.328196^{\text{depth}} \]

\[ C_1 = -0.1039 \times H_\alpha^2 + 2.4868 \times H_\alpha - 17.342 \]

\[ C_2 = 0.0172 \times H_\alpha^2 - 1.7331 \times H_\alpha + 27.428 \]

where:

- \( H_\alpha \) = total AC thickness (in)
Expanding the Realm of Possibility

Fatigue Cracking

Based on Volumetric Properties
Cores not taken to confirm crack direction for LTPP Test Sections!
Expanding the Realm of Possibility

### Transverse/Thermal Cracking

The formula for predicting Transverse/Thermal Cracking is given by:

\[
C_f = 400 \cdot N \cdot \left( \frac{\log \left( \frac{C}{h_{ac}} \right)}{\sigma} \right)
\]

\[
\Delta C = (k \cdot \beta t)^{n+1} \cdot A \cdot \Delta K^n
\]

### Model Calibration Settings

- **AC Fatigue**
- **AC Rutting**
- **Thermal Fracture**
- **CSM Fatigue**
- **Subgrade Rutting**
- **AC Cracking**
- **CSM Cracking**
- **IRI**

#### State/Regional Calibration

<table>
<thead>
<tr>
<th>Level 1 K</th>
<th>Bt1</th>
<th>Std. Dev. (THERMAL)</th>
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<tbody>
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<th>Bt2</th>
<th>Std. Dev. (THERMAL)</th>
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<table>
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<th>Bt3</th>
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<tbody>
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<td>1.5</td>
<td></td>
<td>0.3972 * THERMAL + 20.422</td>
</tr>
</tbody>
</table>

*Notes:*  
- **Cr** = observed amount of thermal cracking (ft/500 ft)  
- **k** = regression coefficient determined through field calibration  
- **N()** = standard normal distribution evaluated at ()  
- **\(\sigma\)** = standard deviation of the log of the depth of cracks in the pavements  
- **C** = crack depth (in)  
- **h_{ac}** = thickness of asphalt layer (in)  
- **\(\Delta C\)** = Change in the crack depth due to a cooling cycle.  
- **\(\Delta K\)** = Change in the stress intensity factor due to a cooling cycle.  
- **A, n** = Fracture parameters for the asphalt mixture.  
- **E** = Mixture stiffness.  
- **\(\sigma_m\)** = Undamaged mixture tensile strength.  
- **\(\beta t\)** = Calibration parameter.
Regression equations developed from LTPP test sections, higher speed roadways!
Calibration Data Options

1. Using existing test sections (LTPP & other projects) for calibration
2. Using PMIS segments with detailed distress surveys & LTPP sections.
3. Using PMIS segments for the local calibration