EXPANDING THE REALM OF POSSIBILITY

North-Central MEPDG User Group
February 19, 2008

MEPDG Overview & National Perspective
(My Perspective)

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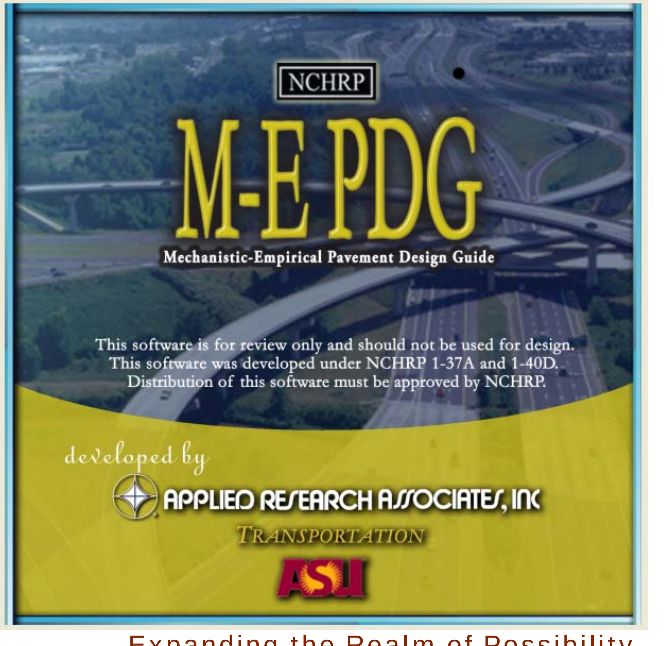
APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

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.

Time, yrs.

-4

10

24

31

45

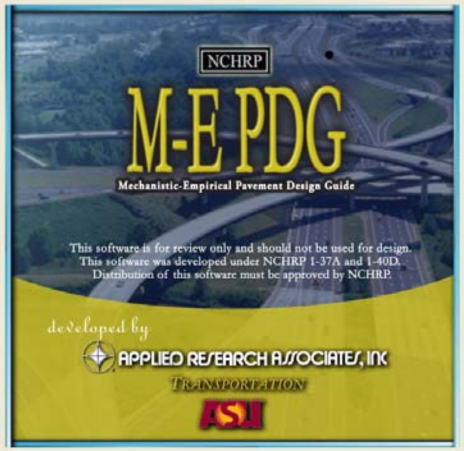
MEPDG

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

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!

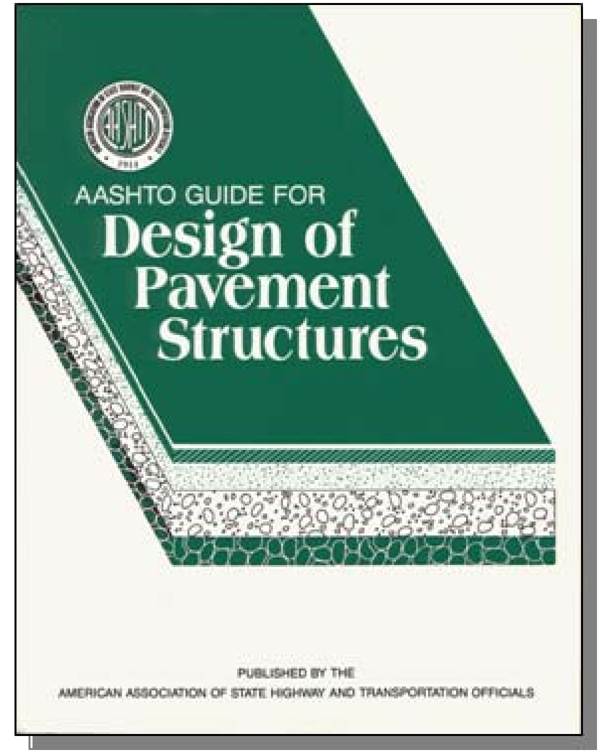


The Beginning

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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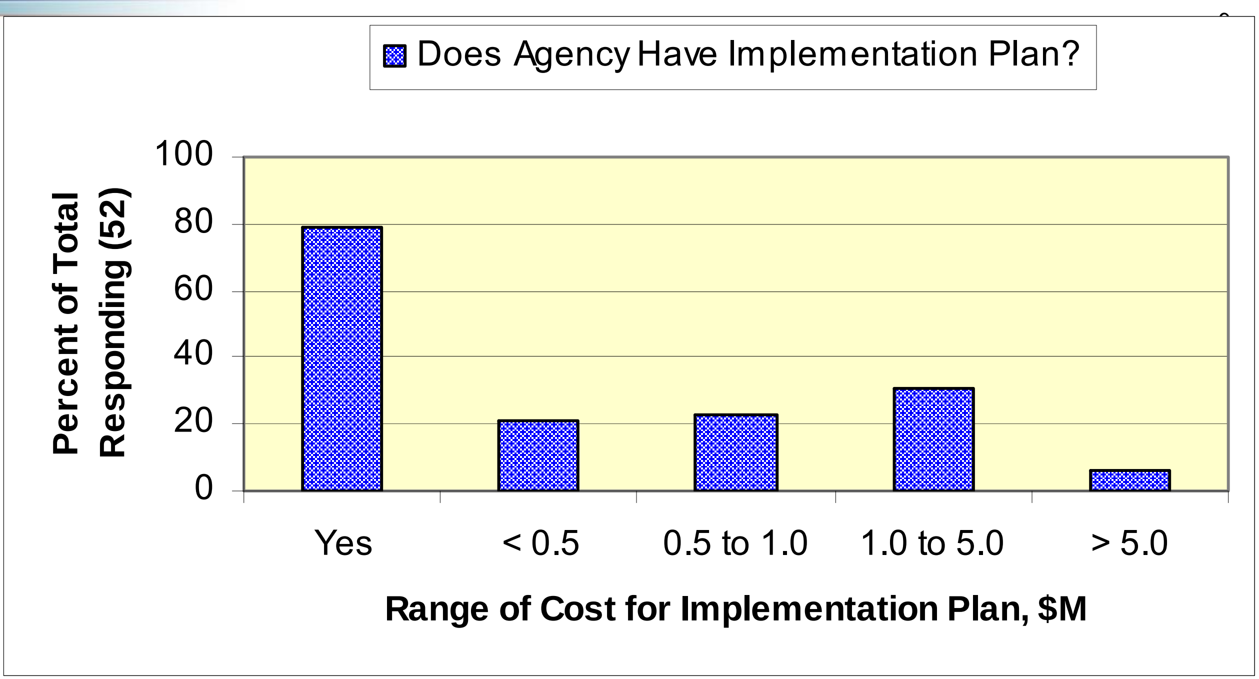
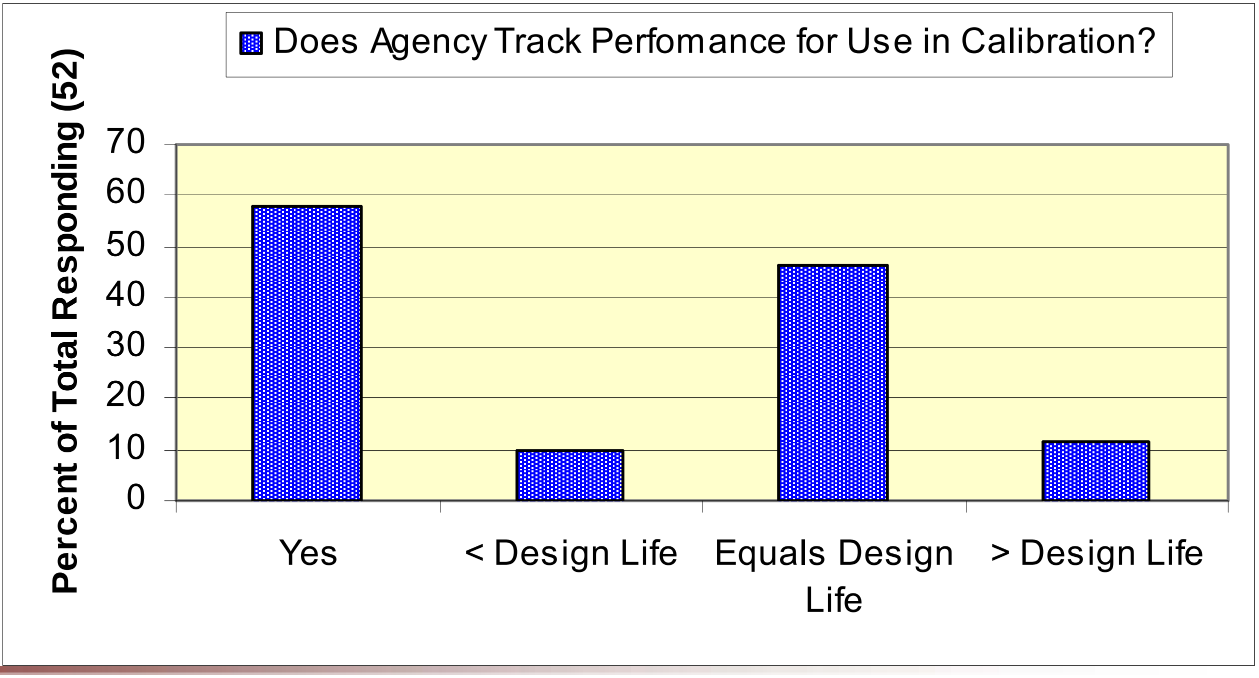
FHWA Summary of Agency Plans



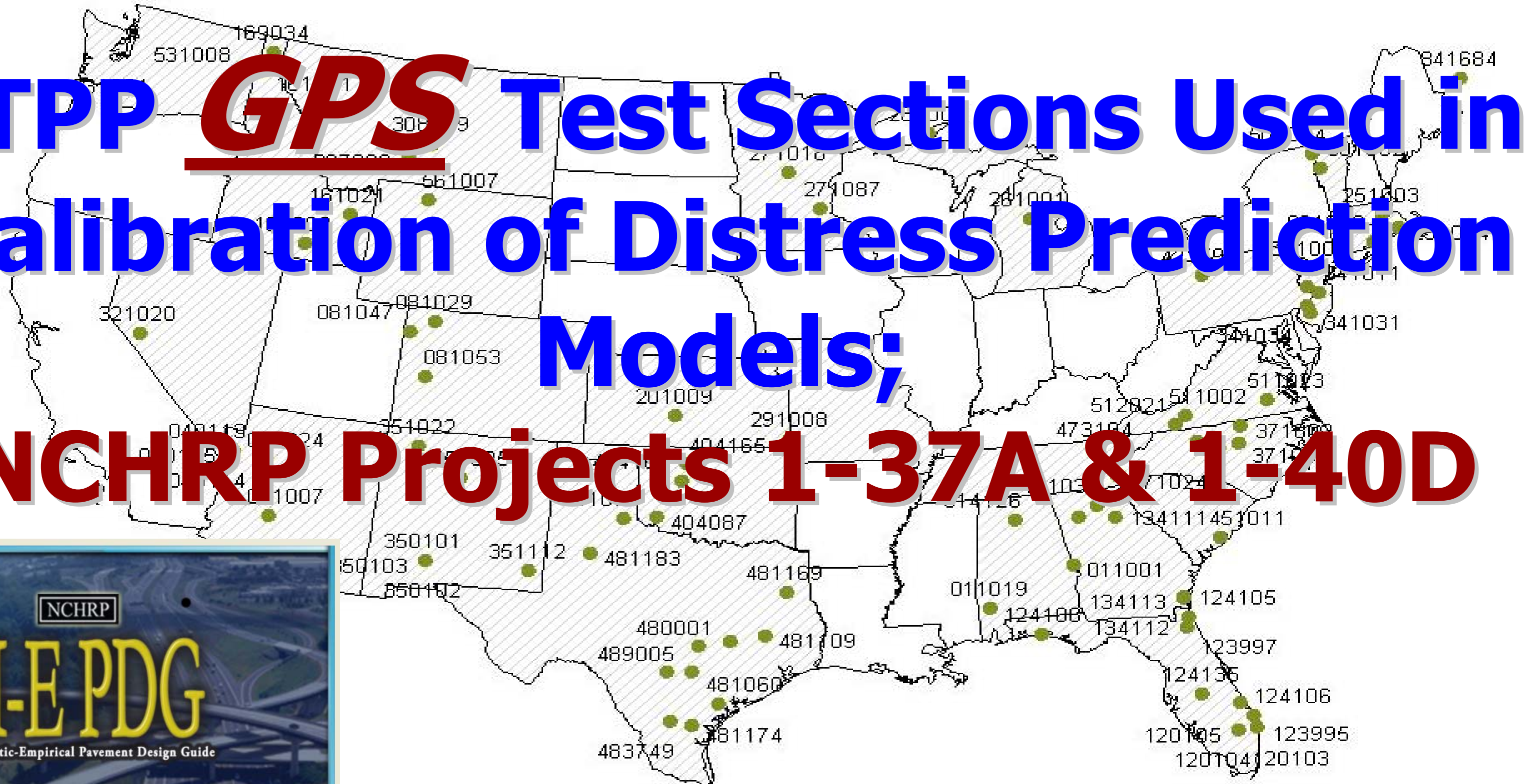
Efforts to Implement MEPDG 2007

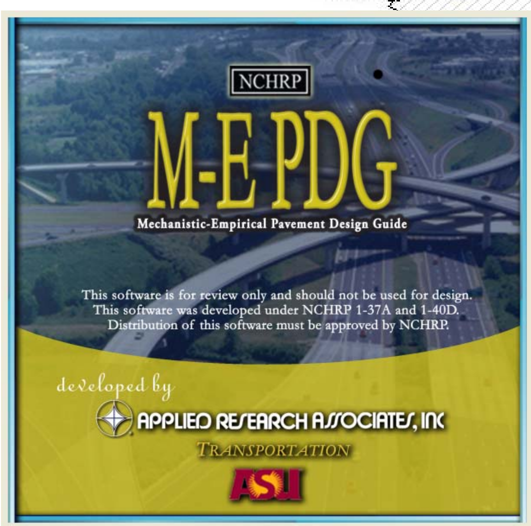


MEPDG Global Calibration

LTPP ***GPS*** Test Sections Used in Calibration of Distress Prediction Models;

NCHRP Projects 1-37A & 1-40D

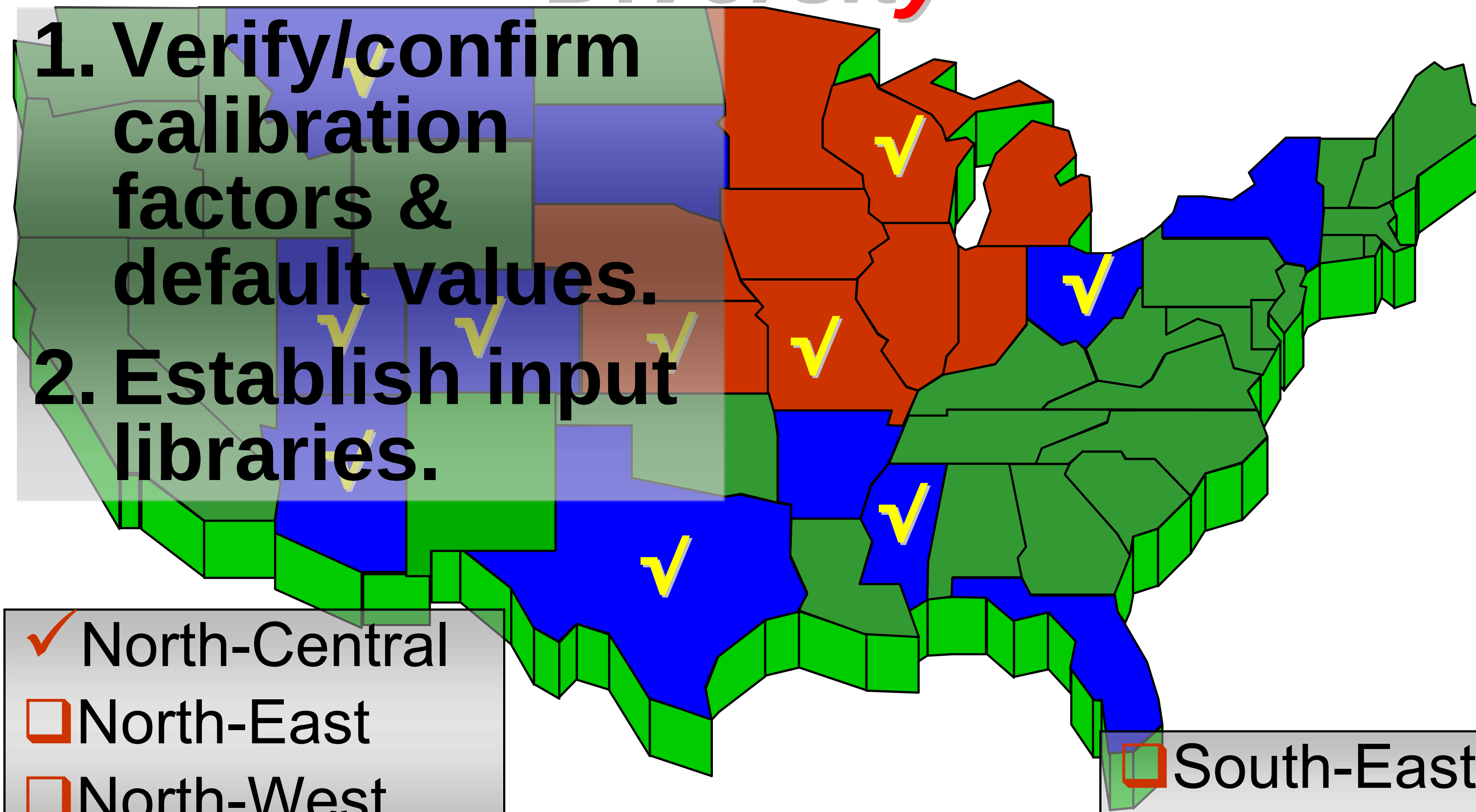




- Many assumptions used.
- Many inputs estimated.

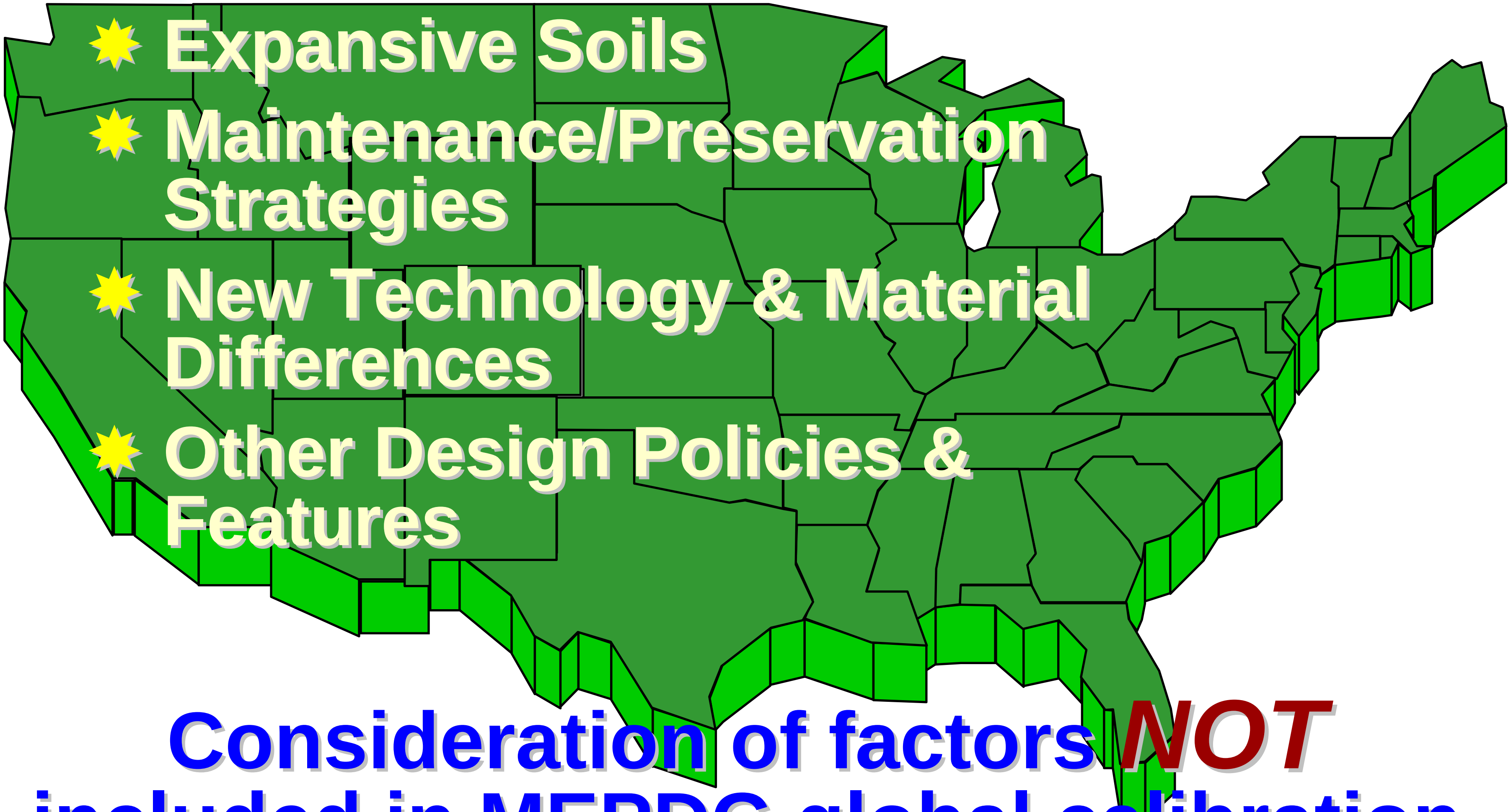
Local Implementation Efforts—*Diversity*

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



- ✓ North-Central
- ☐ North-East
- ☐ North-West
- ☐ South-East
- ☐ South-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

1. **NCHRP 9-30** – *Experimental Plan for Calibration & Validation of HMA Performance Models for Mix & Structural Design*.
2. **NCHRP 9-30(001)** – *Conduct Pre-Implementation Studies & Database Enhancement.*
3. **NCHRP 1-40D** – *A review of the M-E PDG software & prediction methodology; & Correcting errors/blunders in the software*.
4. **NCHRP 1-40B** – *Local Calibration for the Recommended Guide for M-E Design of New and Rehabilitated Pavement Structures.*

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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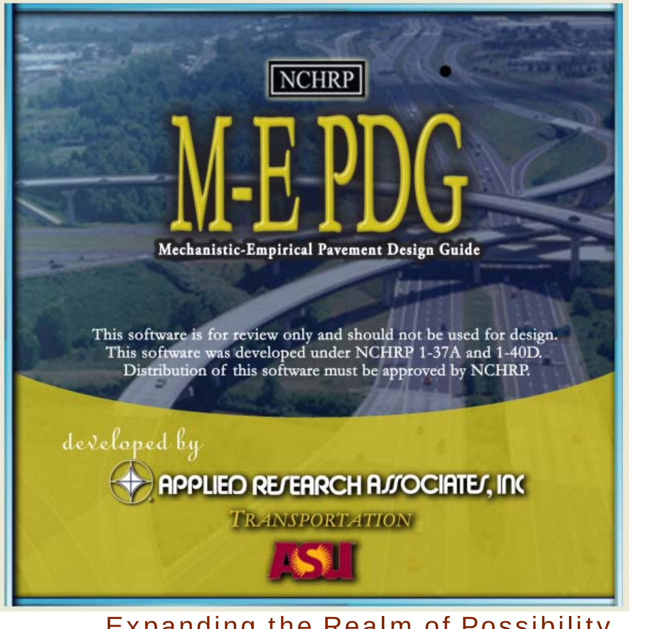
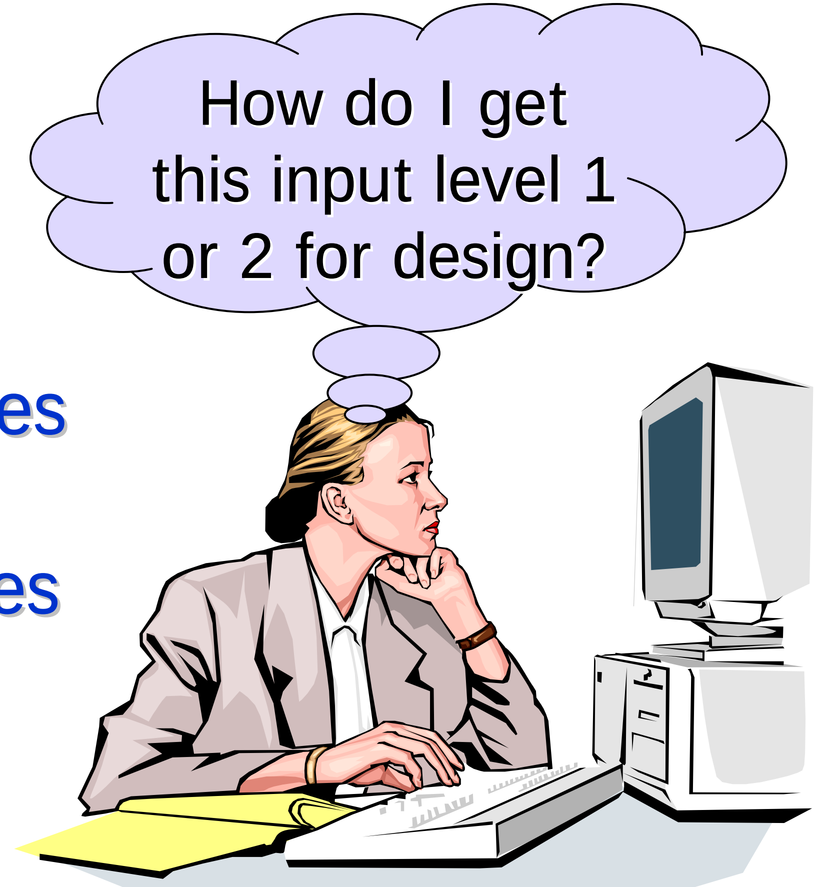


Integration into Practice

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

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

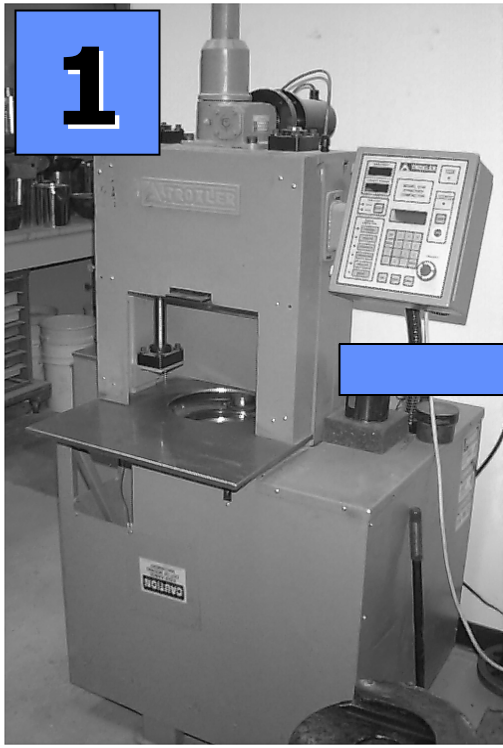
Data integration: an automated process?

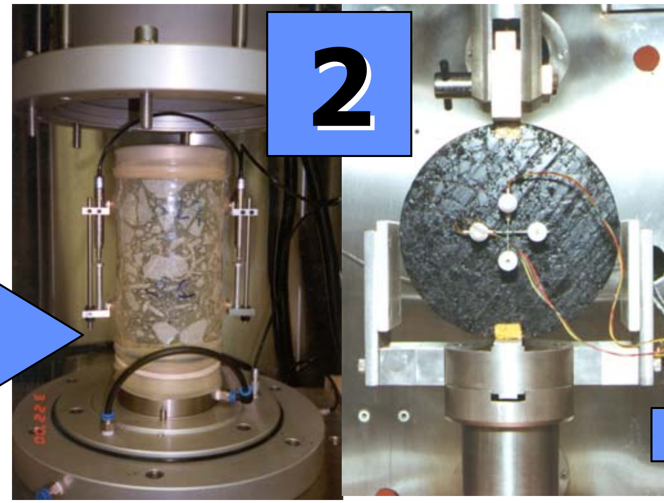
Probably ***NOT!***

PMIS Database

Project Level Data

Structural – Mix Design Compatibility





Mixture design & material specifications determine the inputs.

ARA

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

Outline

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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).

Outline

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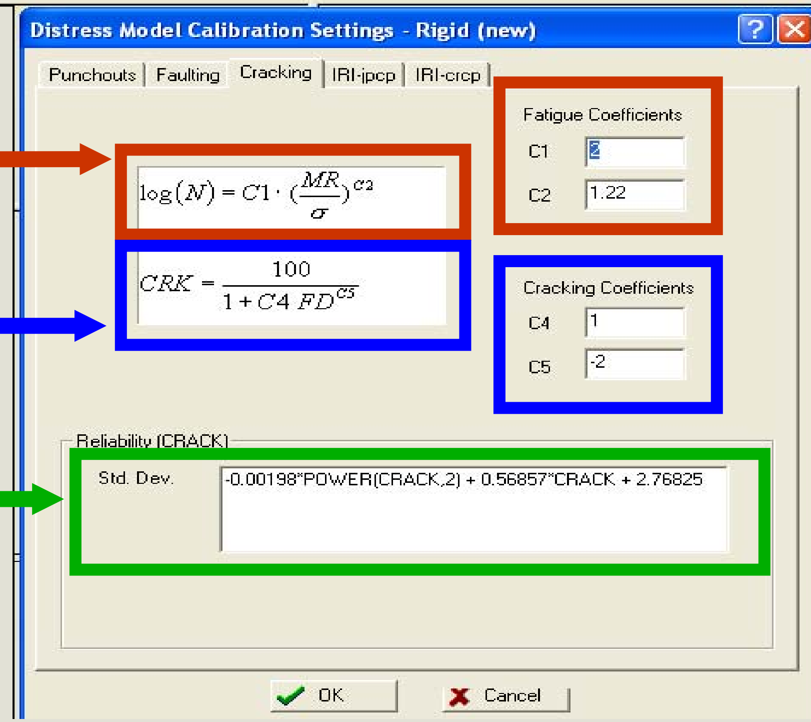
Summary

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.

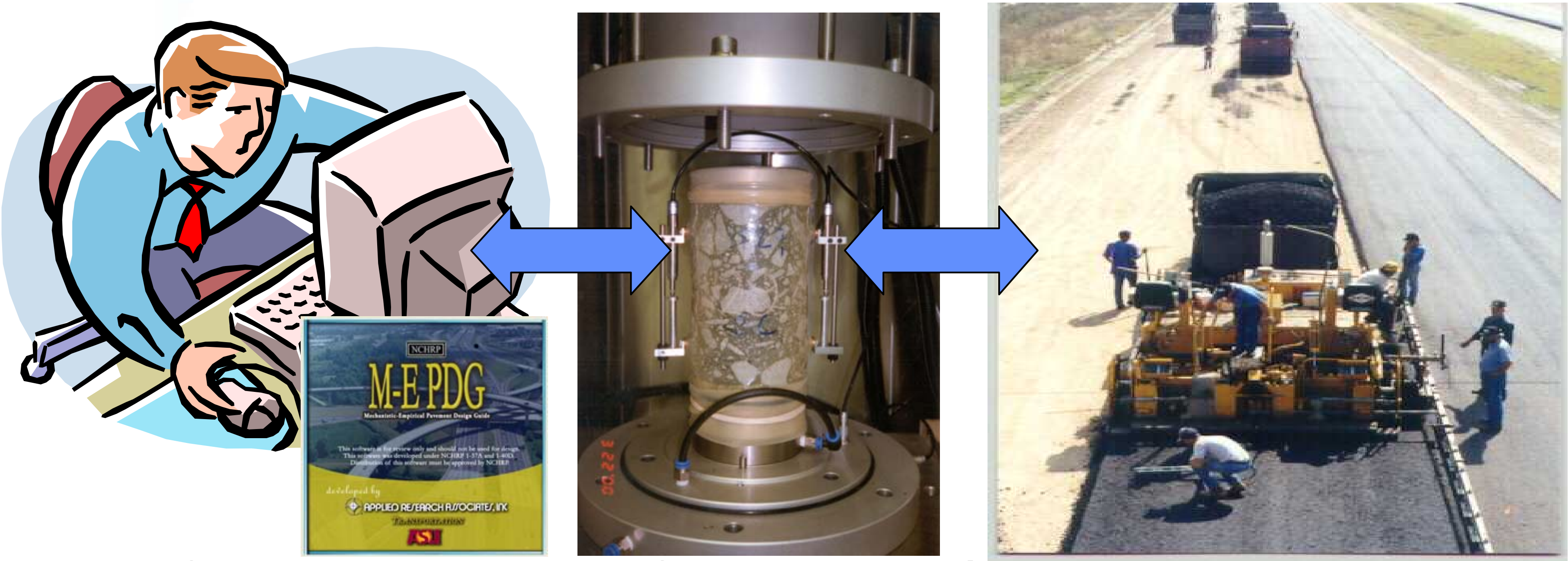
Summary

- 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?

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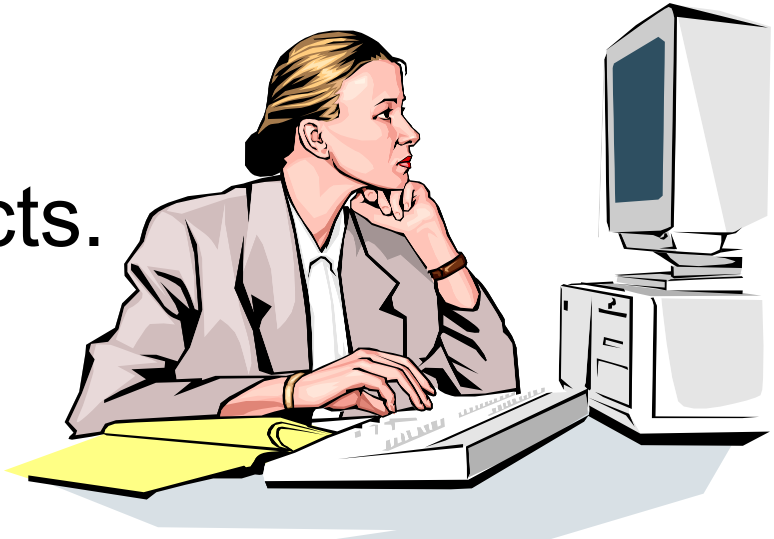
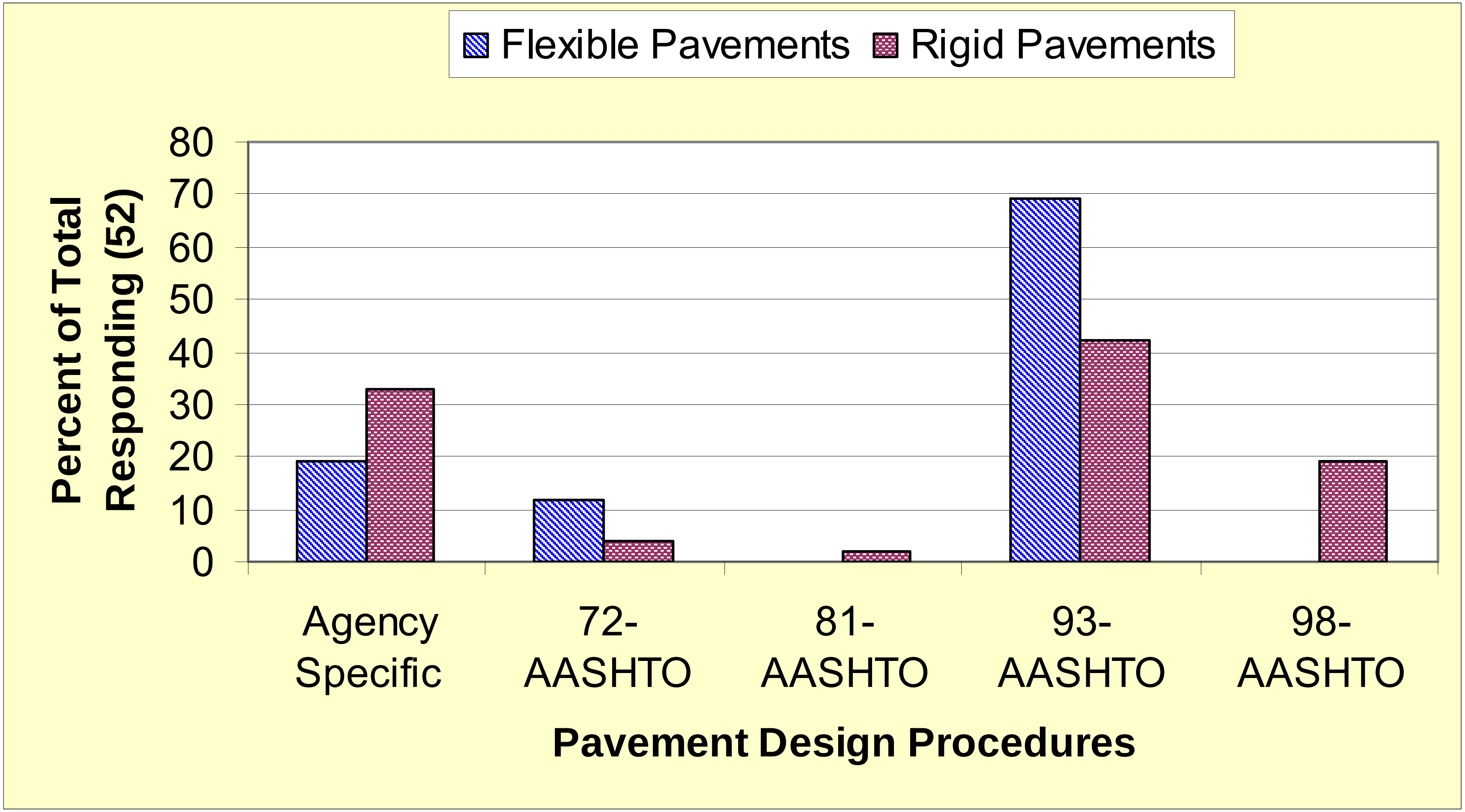
Questions!

Advanced Pavement Design

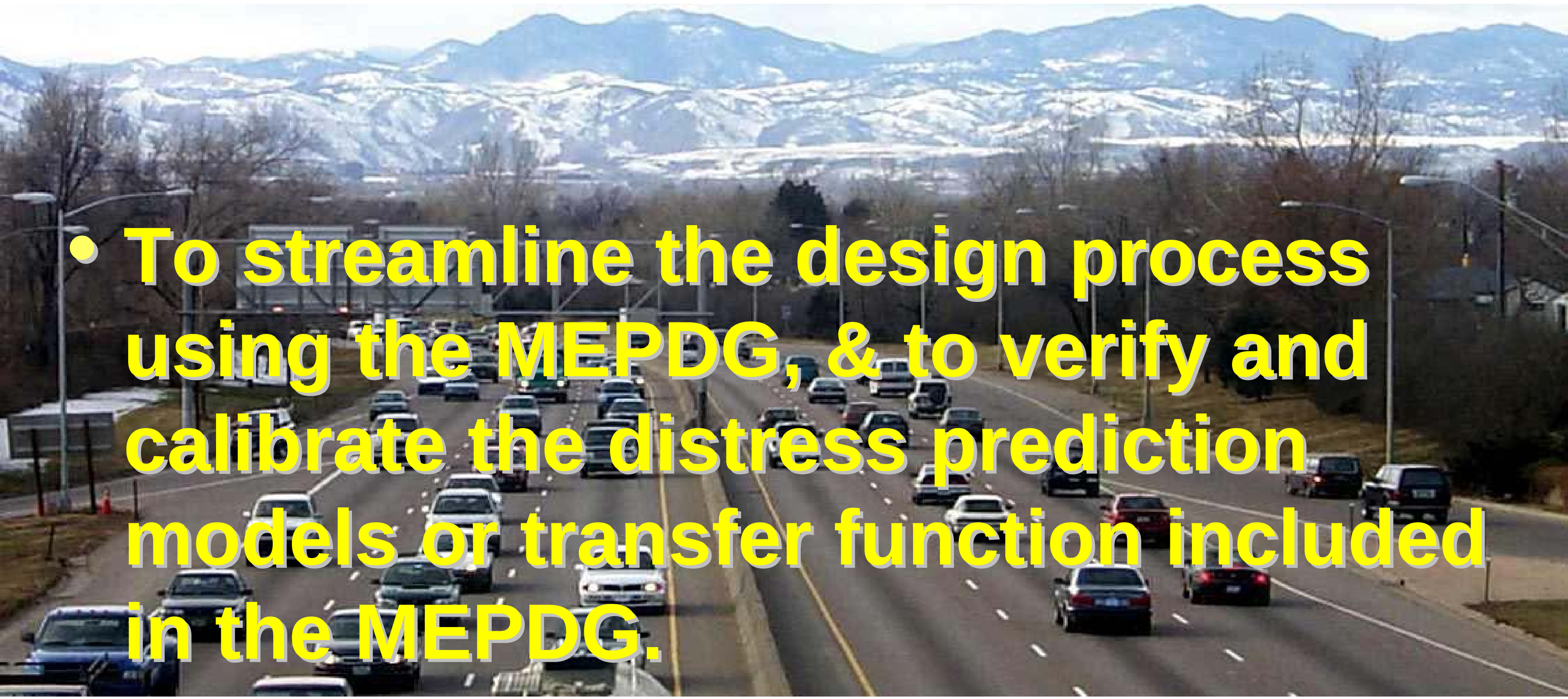
- Distress specific—defines what controls the design.
- Design features—considers many more design features and what effect they have on distress.
- Smoothness
- Construction defect effects.



Current Pavement Design Procedures



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.
3. Cost/Value of design & construction.

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

Layer Thickness, Type & Properties

Mixture Design & Confirm Properties

Implementation Areas & Technology Transfer

- Training & communications within & between departments
- Traffic
- Materials
- Construction
- Calibration

Structural – Mix Design Integration

Design, more than just volumetrics.

8. As-Built Plans & Performance Confirmation

7. Construction

6.HMA Mixture Design

Volumetric & SPT

5. Bid Letting

4. Plan Preparation

3.Structural Design

2. Planning

1. Project Selection

Design Values:

E* > ?

S_{IDT} > ?

D(t) < ?

Library of Mix Properties:

Dynamic Modulus

Flow Number

IDT Strength

IDT Creep

VMA

Technology Transfer & Implementation Products

Remember Products:

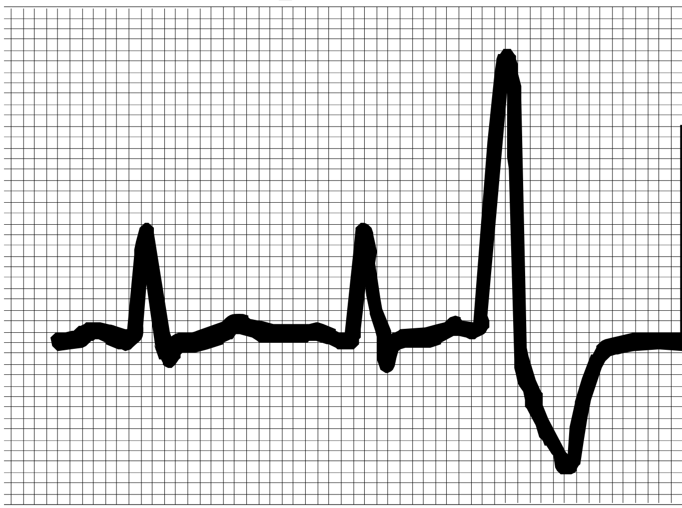
- Management video
- Interactive CD for software
- Implementation notes
- Training course
- Guide text & appendices.
- User's Manual in support of software.

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

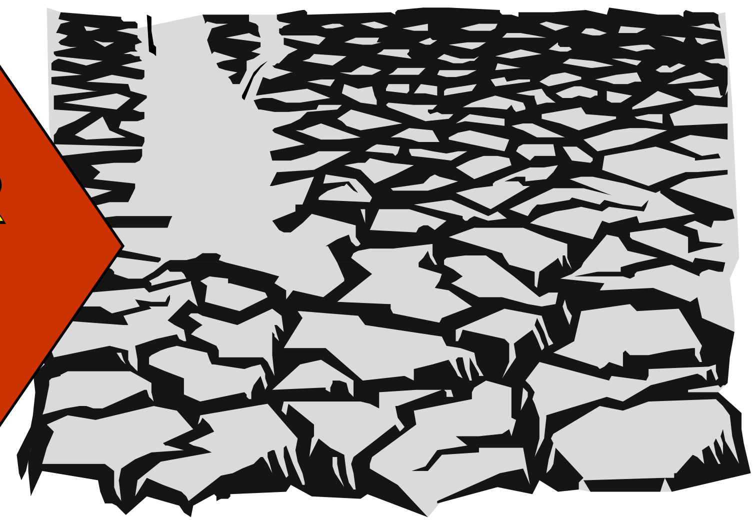


- Stresses
- Strains
- Deflections

TRANSFER FUNCTION

Calibration is a key.

Distress



- Cracking
- Distortion
- Roughness

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 calibratio coefficier
- Demonst 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

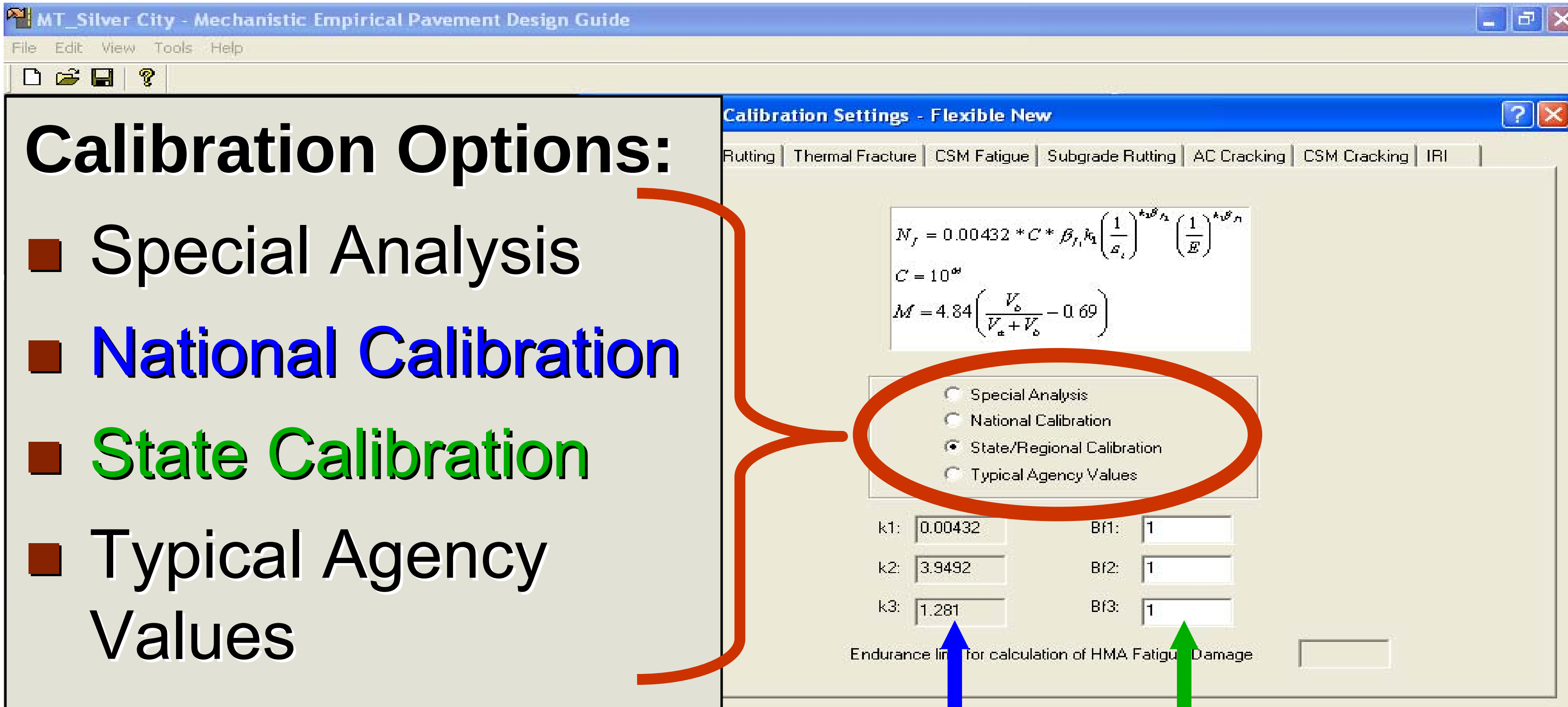
- LTPP
- Special Agency Test Sections
- PMIS Sections – A quick check:
  - Do the distress predictions match our local experience for traditional designs?
  - What is the primary failure mode triggering rehabilitation?

NCHRP 9-30 Database for M-E Based Models

Calibration: Ease of Use

Calibration Options:

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



$$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_t}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$$

$$C = 10^M$$

$$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$$

National/Global Calibration;

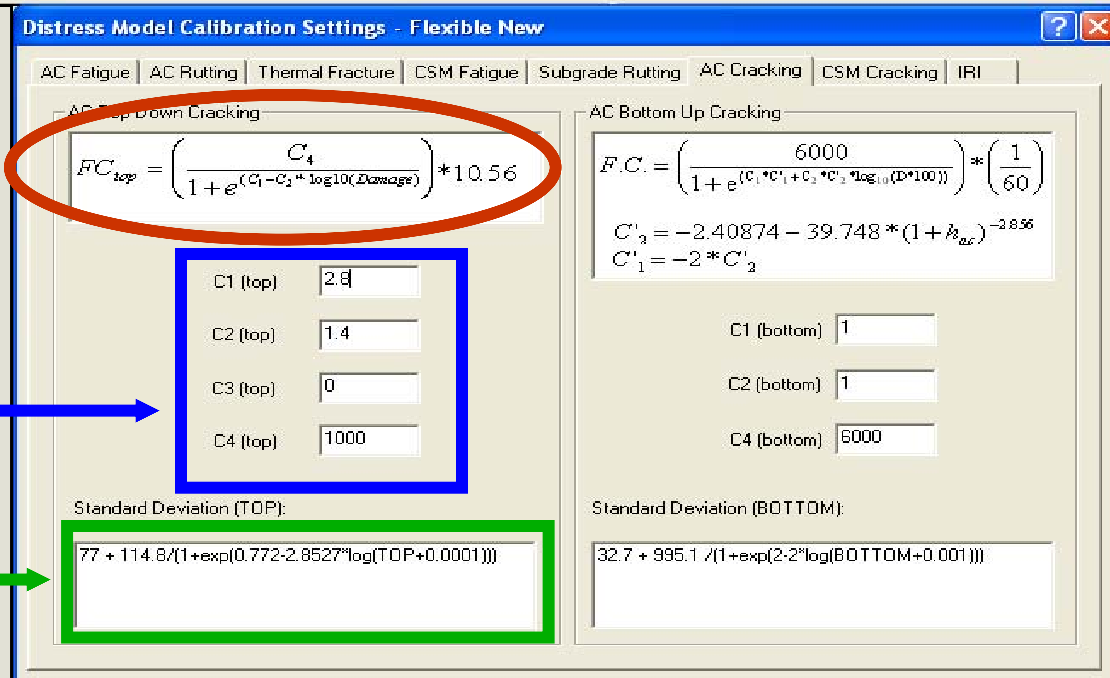
k- or C-Values

State/Regional Calibration;

β- or C-Values

Calibration: Ease of Use

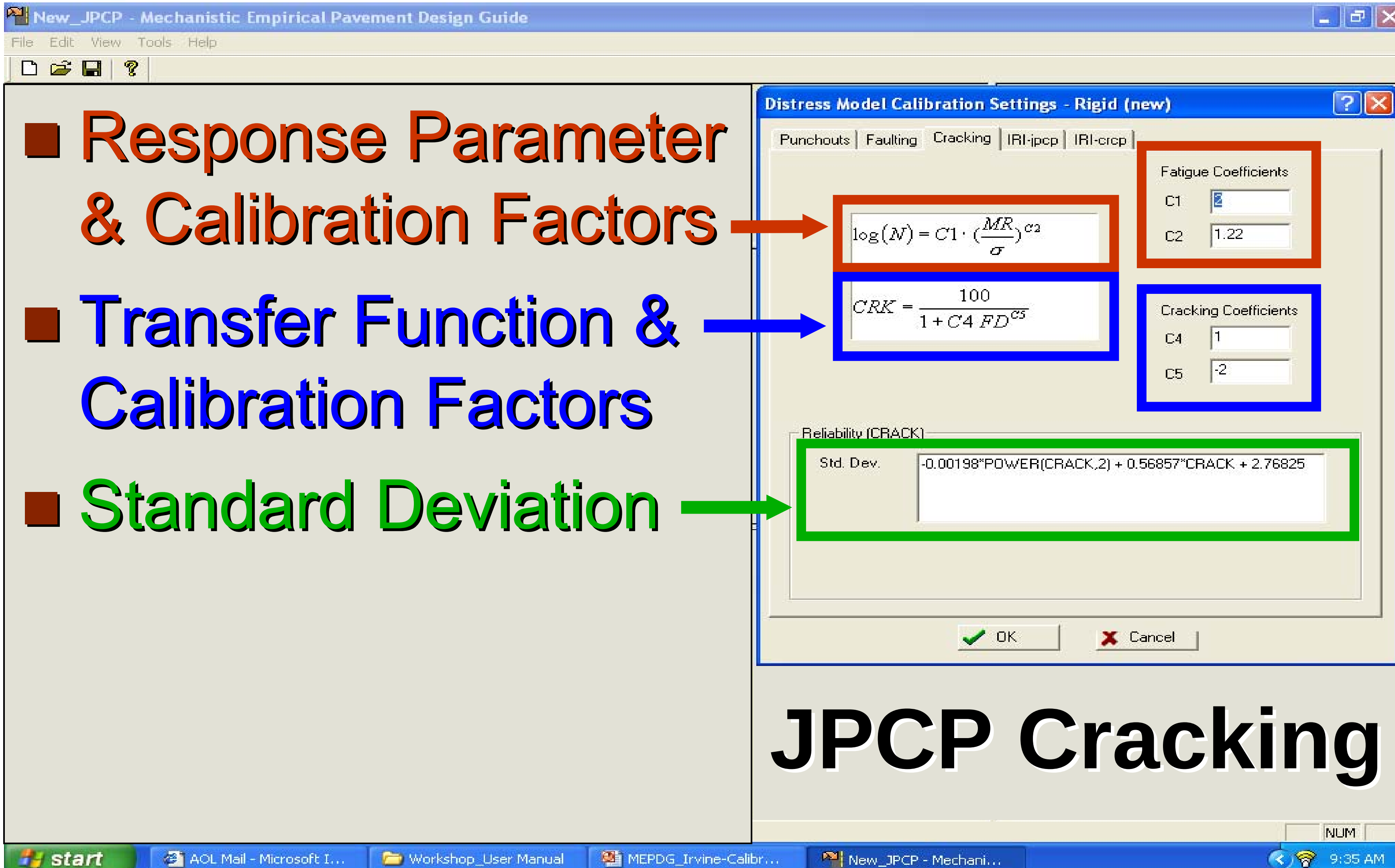
- **Transfer Function**
- **C- Values**
- **Standard Deviation**



HMA Alligator Cracking

Calibration: Ease of Use

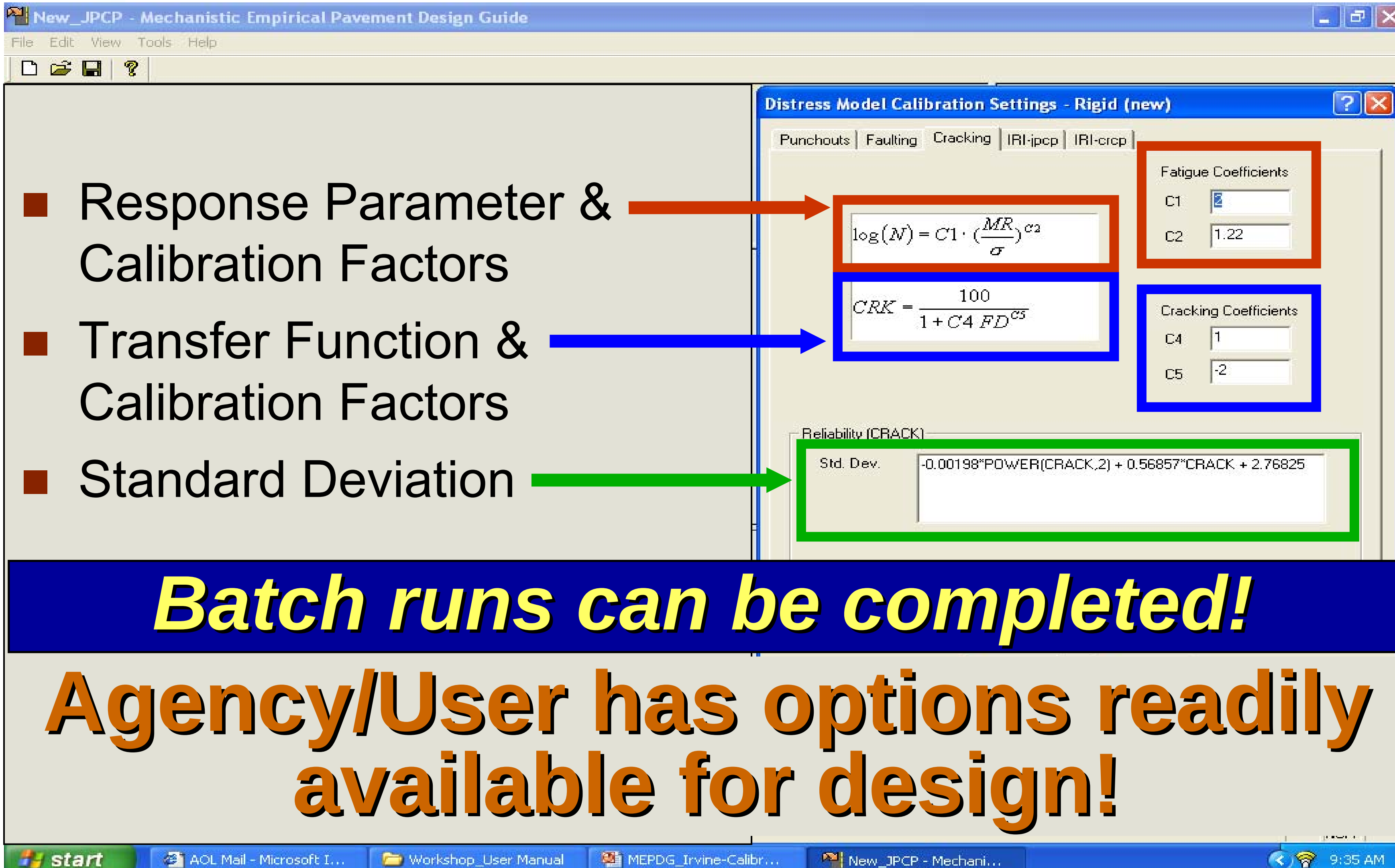
- Response Parameter & Calibration Factors
- Transfer Function & Calibration Factors
- Standard Deviation



JPCP Cracking

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

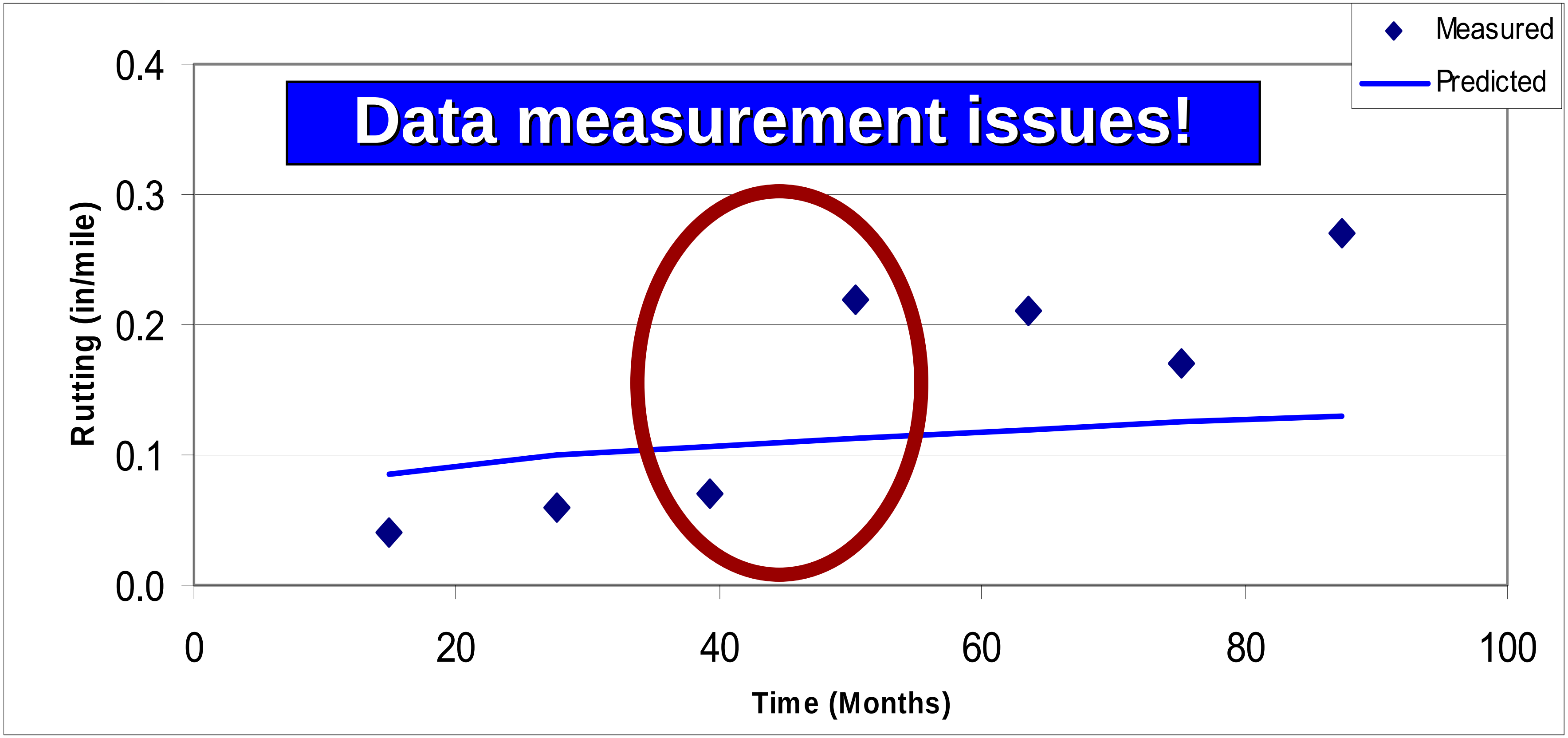
1. Traditional Split-Sample Approach
2. Jack-Knife Testing Approach

Validate/Calibrate MEPDG

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

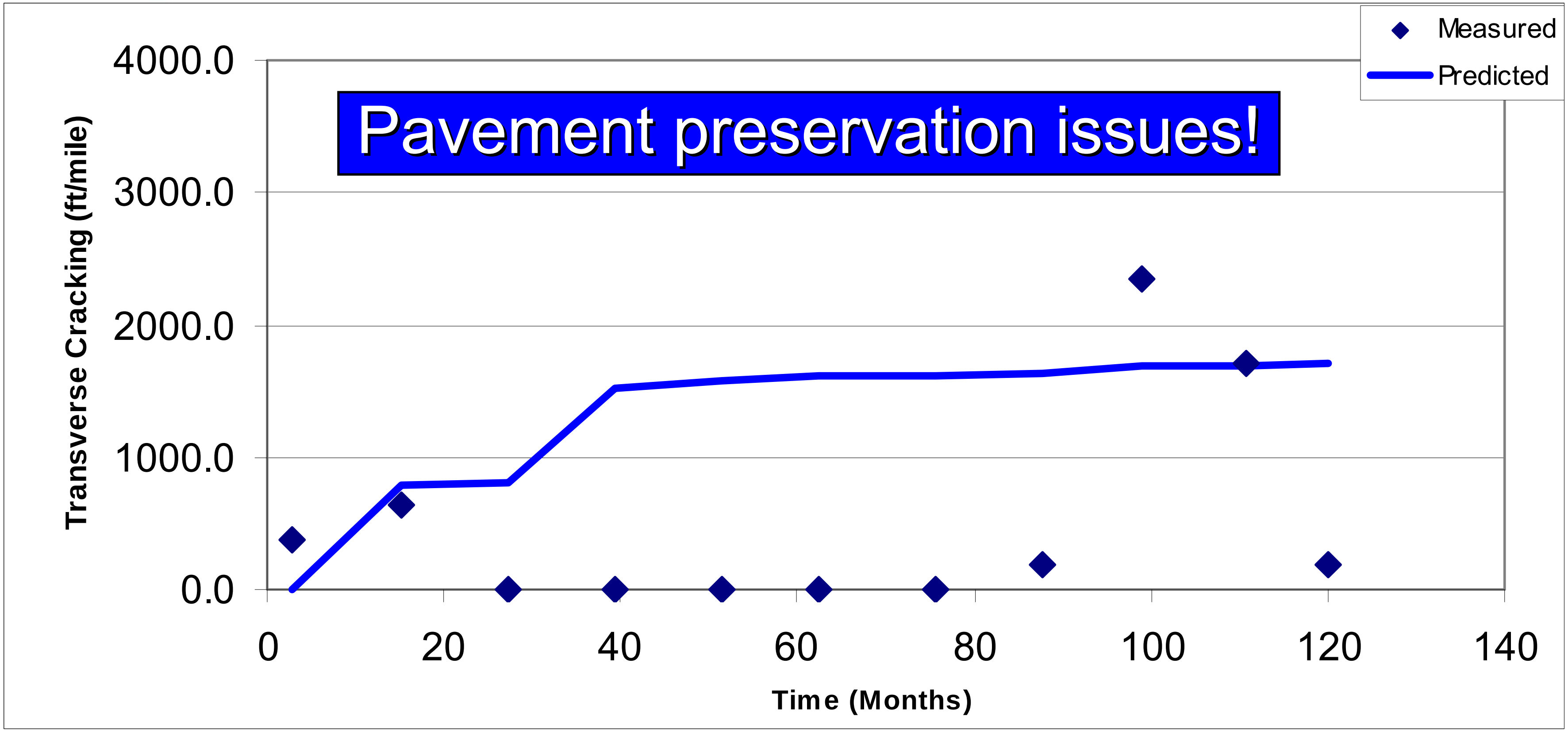
- How many sites?
- Length of roadway segments?
- How many distress observations?
  - Multiple points within segment at any one point in time?
  - Multiple points over time?

Data Quality Review



What caused this increase in measured rutting?

Data Quality Review

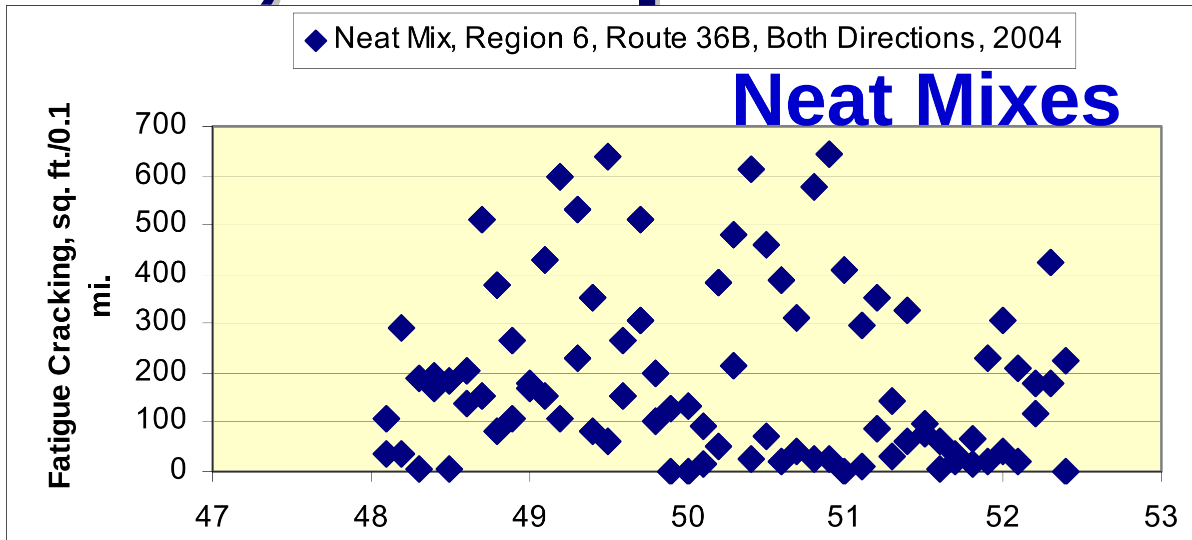


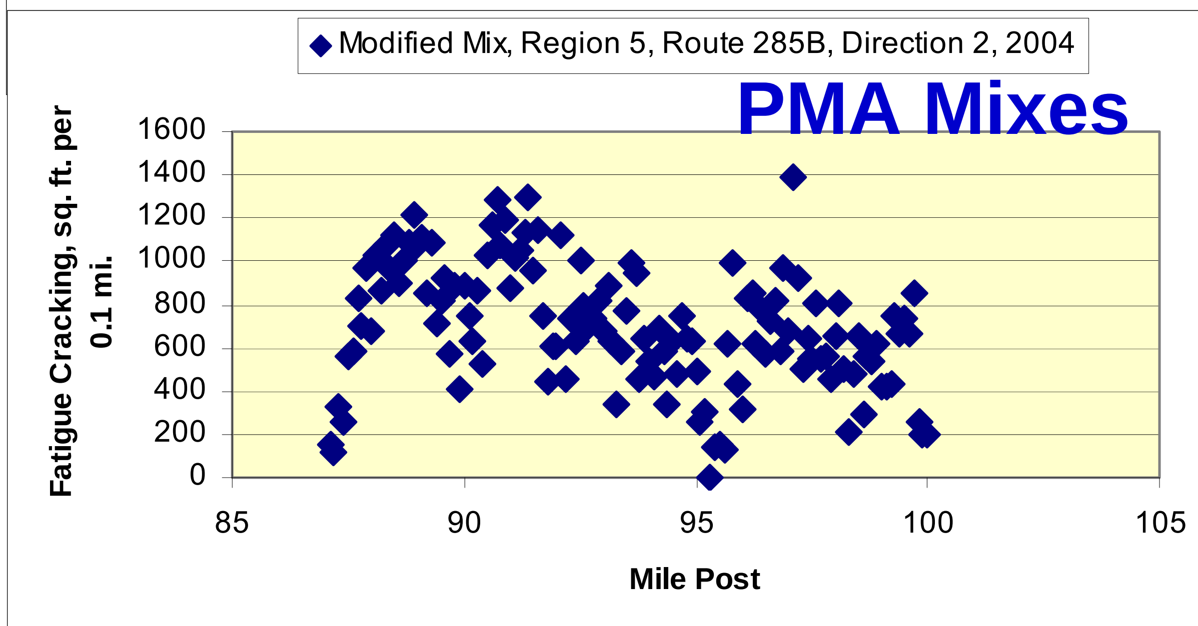
Why are transverse cracking values so diverse?

Distress Data, Example:

Variability; A key data issue.

Example; Fatigue Cracking





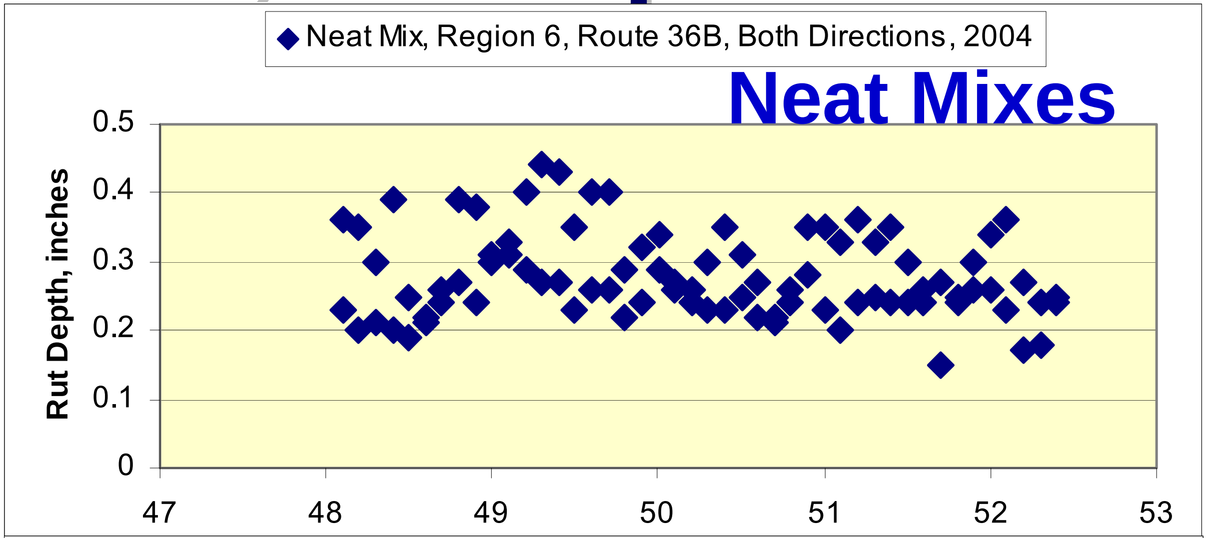
Distress Data, Example:

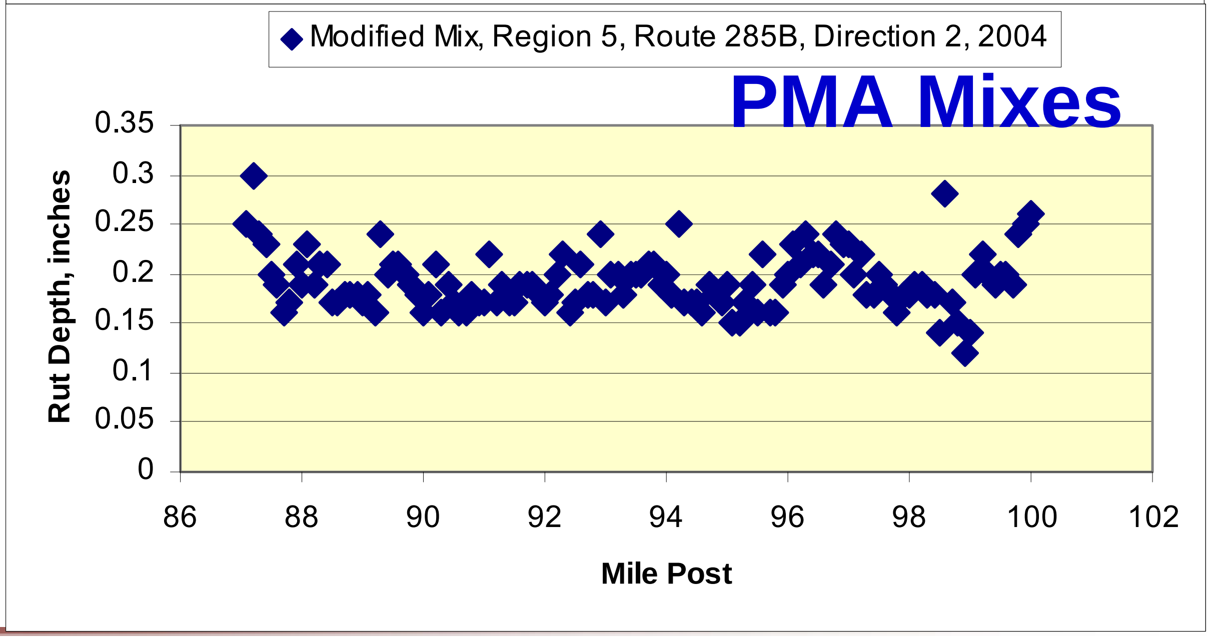
Variability;

A key data issue.

Example;

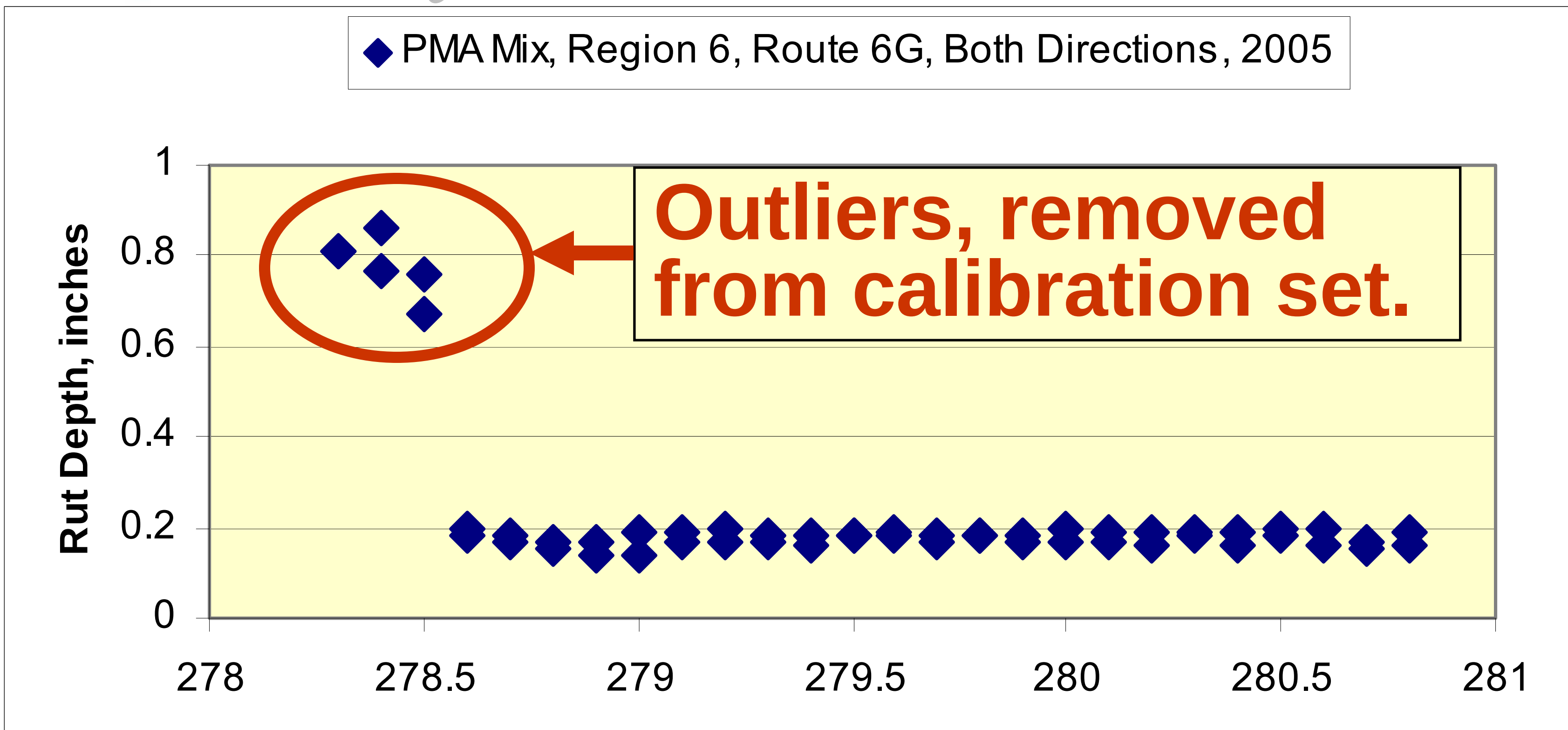
Rut Depth





Distress Data Analyses:

Within Project Variation; Outliers

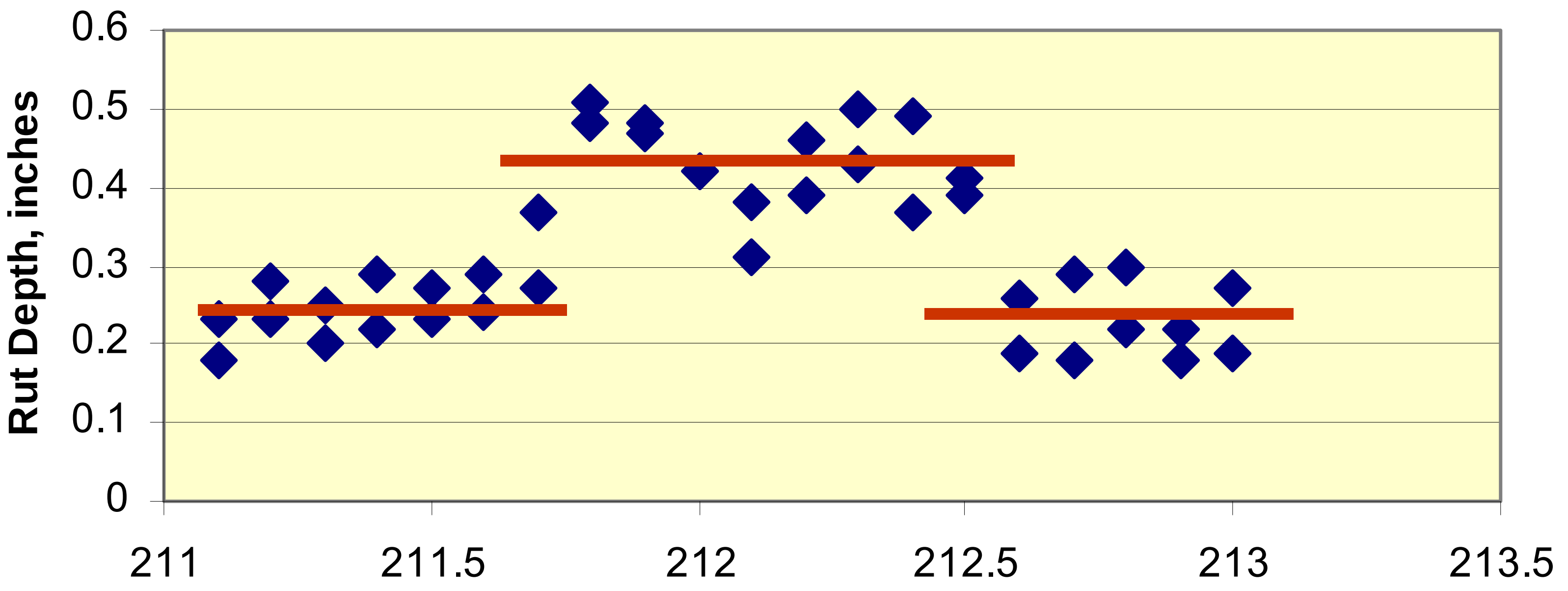


Limited area with significant different distress value within PMIS segment.

Distress Data Analyses:

Within Project Variation; Abrupt Change

Identify reasons for abrupt changes.

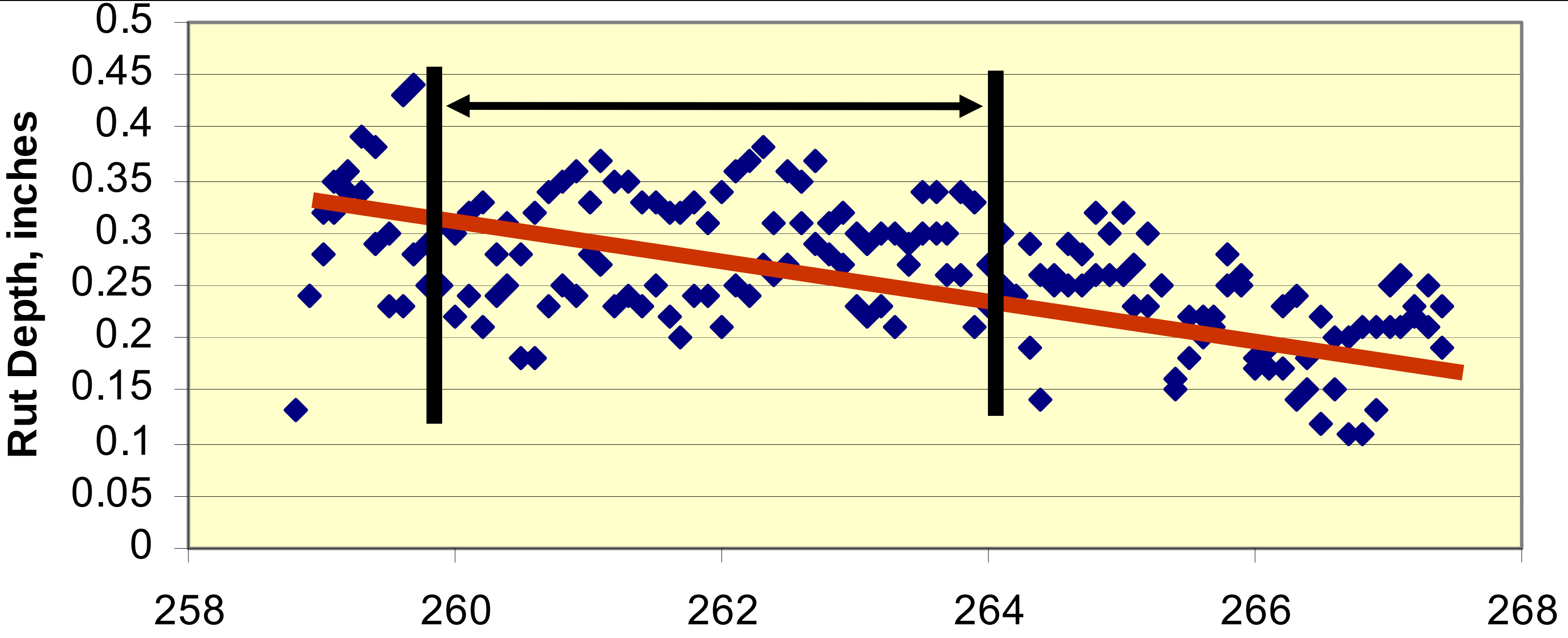


Sudden increase or decrease in distress value within PMIS segment.

Distress Data Analyses:

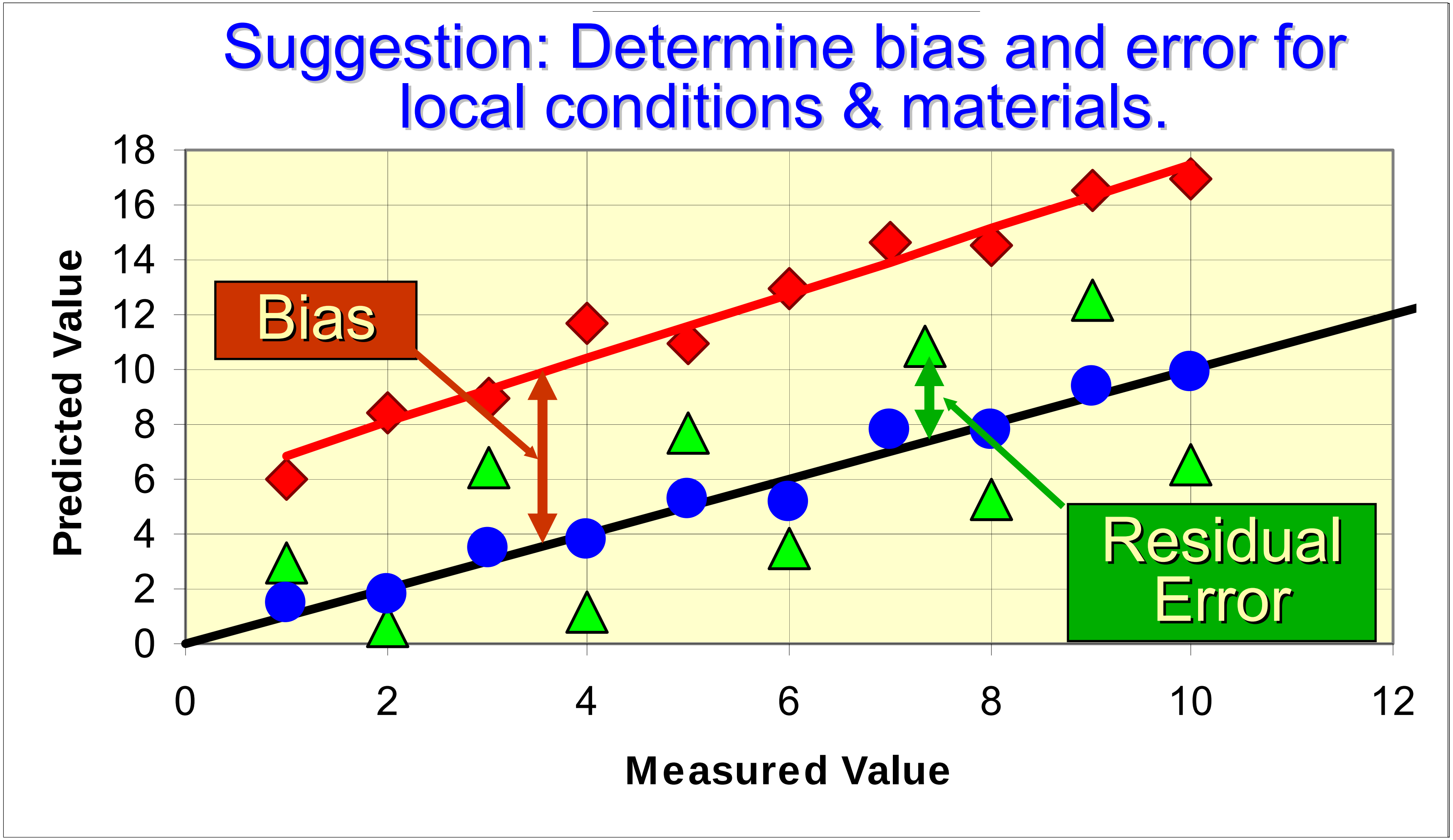
Within Project Variation; Drift

Use segments w/consistent averages.

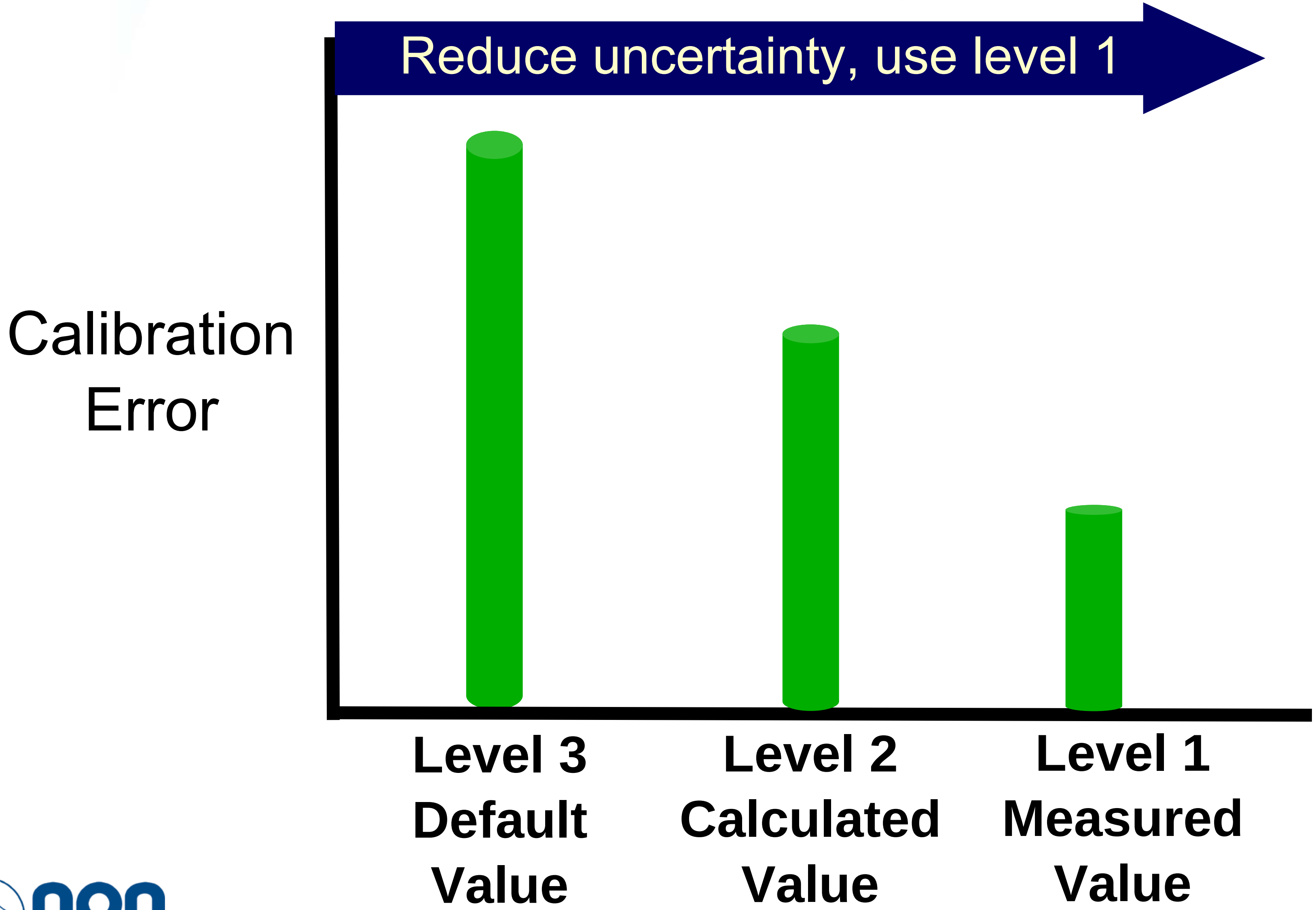


Consistent change in distress over project length, within PMIS segment.

Data Analyses: Bias & Residual Error from Validation/Calibration

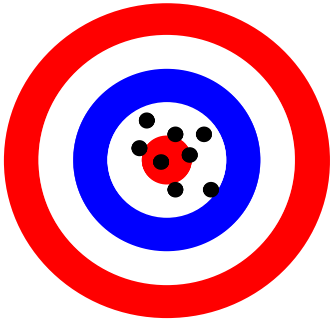


Global Calibration Hypothesis

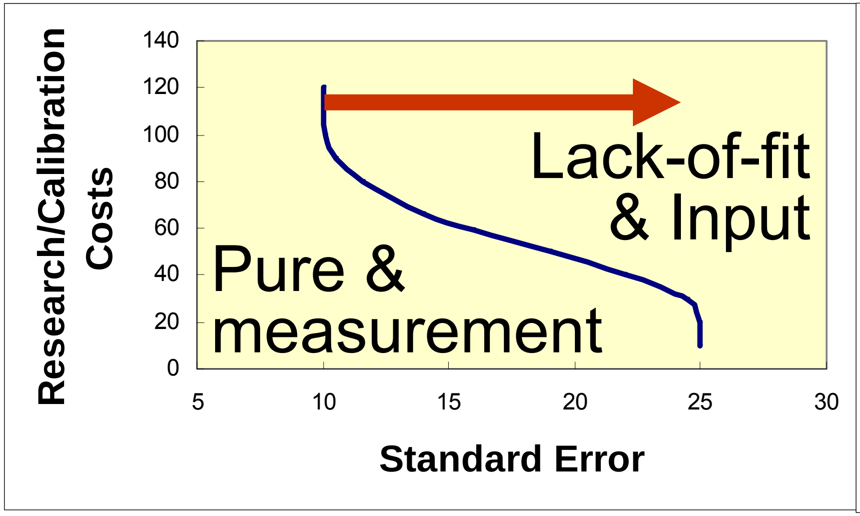


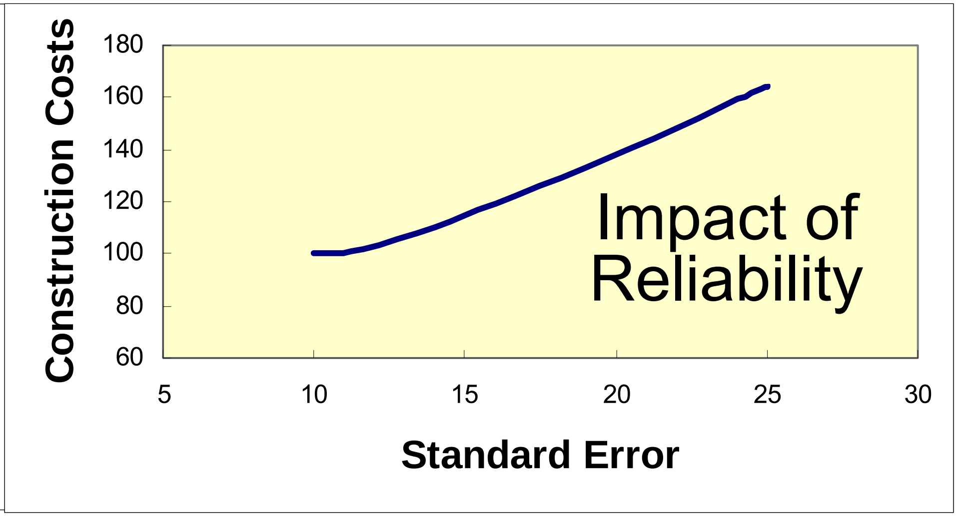
How Close is Close Enough?

$$(\sigma_{Total})^2 = (\sigma_{Measurement})^2 + (\sigma_{Lack-of-Fit})^2 + (\sigma_{Input})^2 + (\sigma_{Pure})^2$$



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.

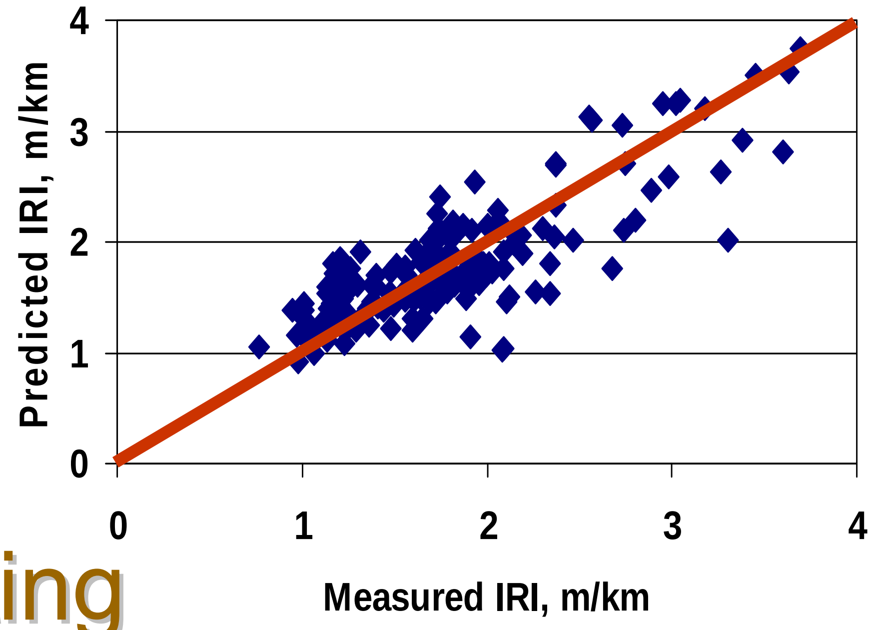
Use of PMIS data for validation/calibration not a simple & quick process!!!!

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

Unbound Mtls.

- Montana – No
- Missouri – No
- Utah - Yes

HMA

- Montana – No
- Missouri – Yes
- Utah - Yes

PCC

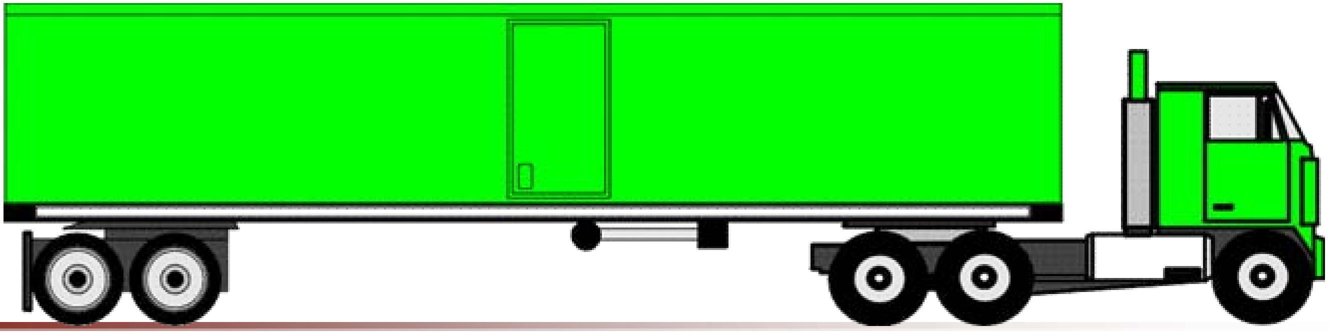
Most agencies have equip.

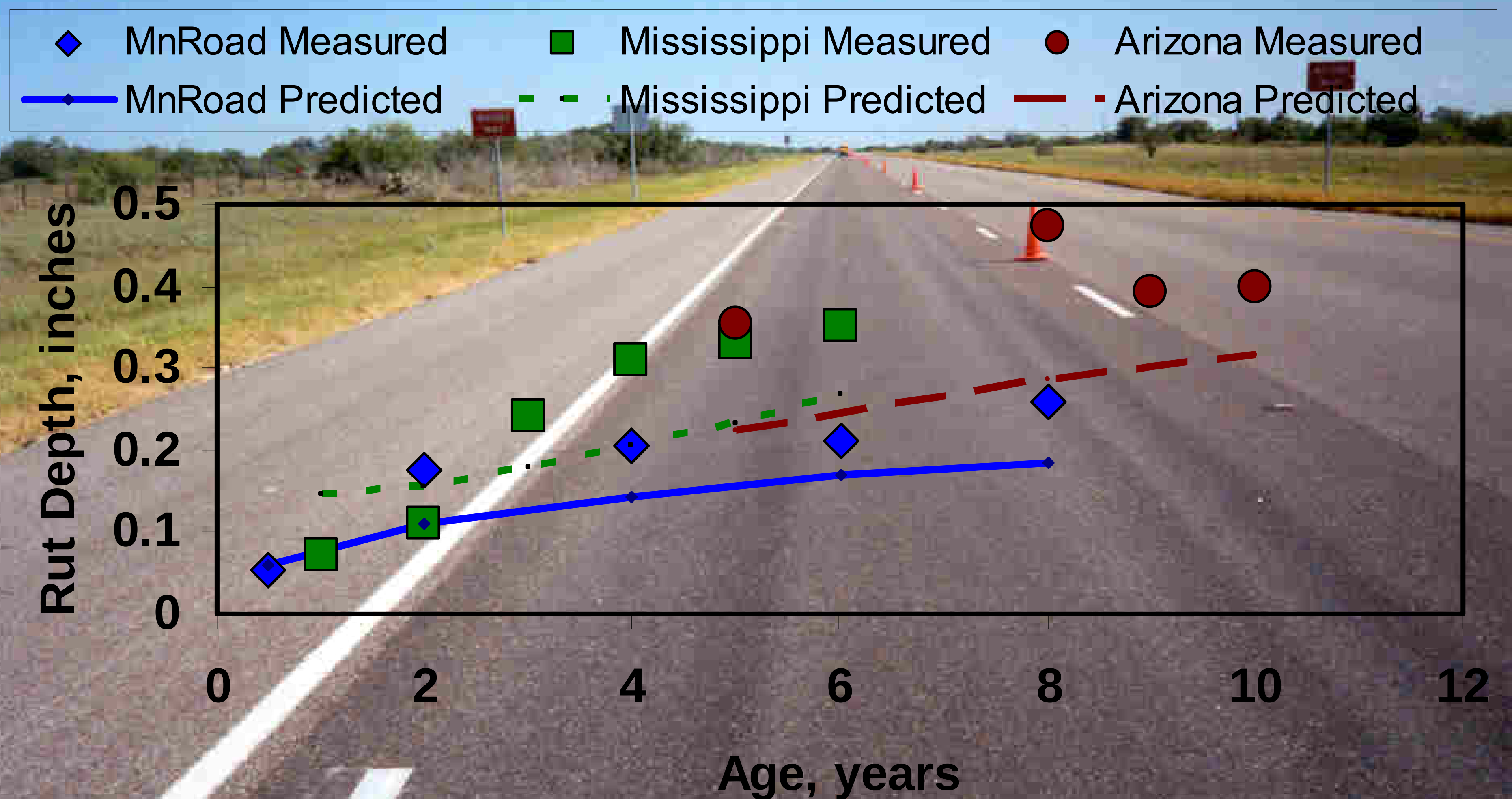
Testing – Lab Testing

- 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?





Time-History Data for Calibration

Local Calibration Hypotheses

- Mathematical models – assumed to be correct.
  - 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.

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. (Step 1)

Level of confidence. (Step 3)

(Step 4)
1. LTPP sections
2. Research sections
3. PMIS segments

Testing & distress definitions (Step 6)

Steps for Local Calibration

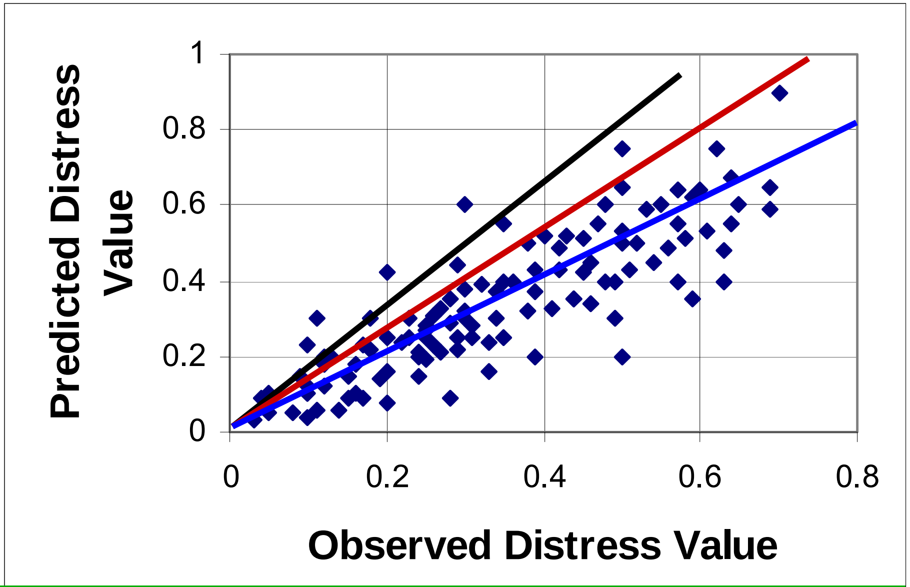
7. Assess bias
8. Eliminate bias
9. Assess standard error
10. Improve model precision
11. Interpretation of results & decide on adequacy of calibration factors

Execute MEPDG & evaluate residual errors.

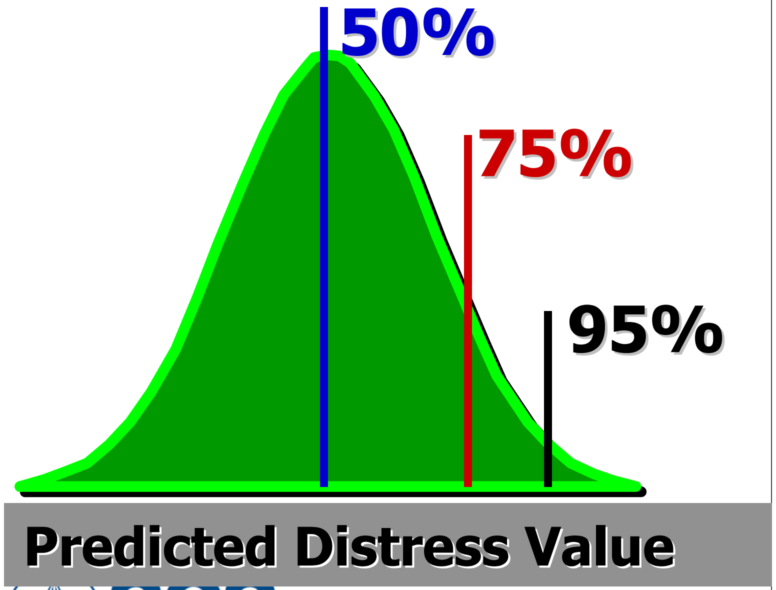
Dispersion around line of equality

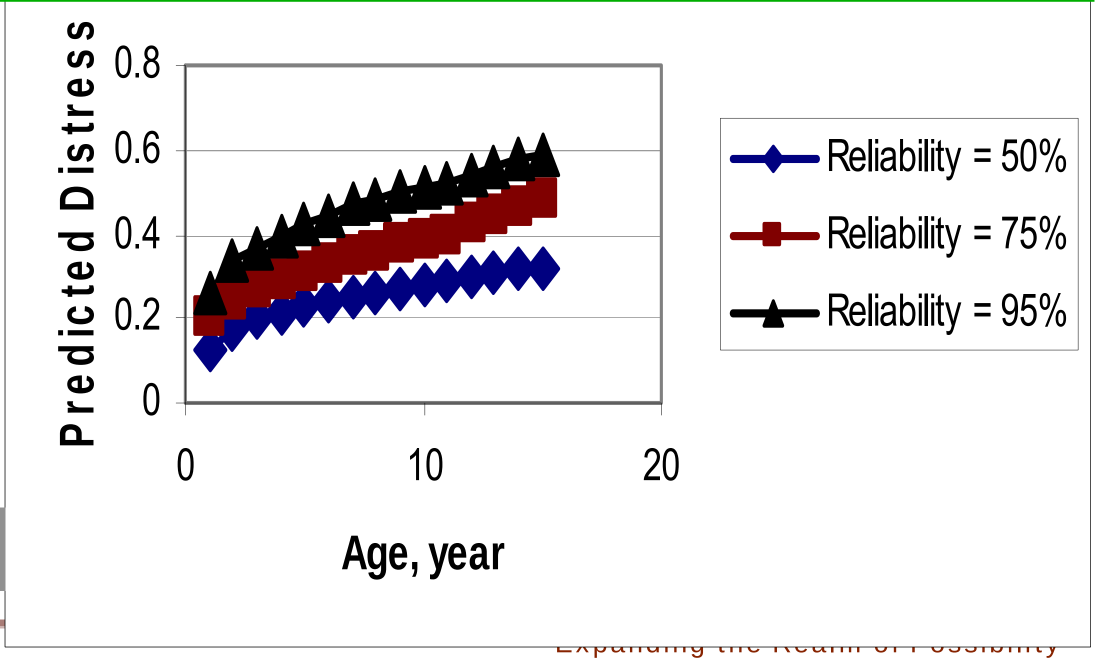
$$D(t)_{CI} = D_{Predicted} + e$$

BUT, where does the error come from?



Design Confidence Interval Concept

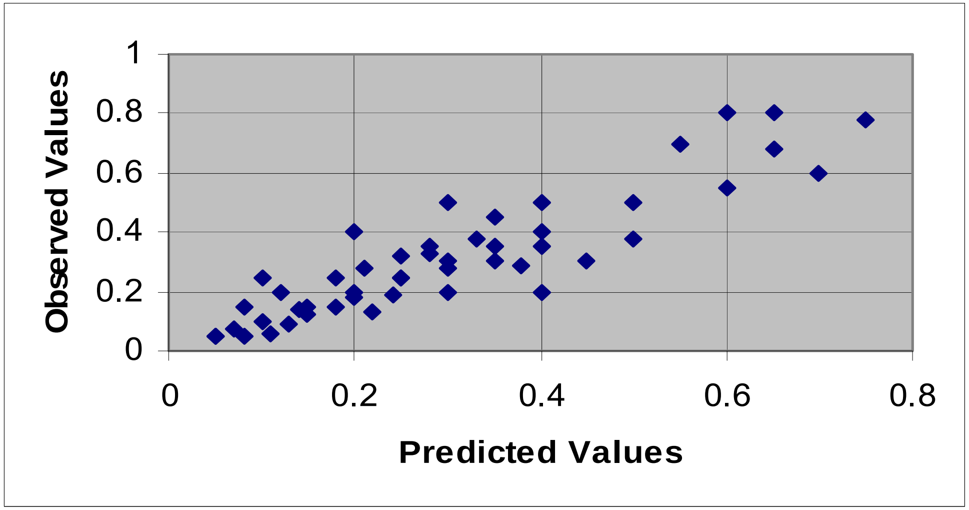




Quantifying the Prediction Error

$$e_{Total} = e_{Lack-of-Fit} + e_{Measurement}$$

$$+ e_{Input} + e_{Pure}$$



Objective:

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

Distress Model Calibration Settings - Flexible New

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

$$\delta_a(N) = \beta_{s_1} k_1 \; \varepsilon_v \; h \left(\frac{\varepsilon_o}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N}\right)^{\beta}}$$

δ_a = permanent deformation for the layer
N = number of repetitions
ε_v = average vertical strain (in/in)
h = thickness of the layer (in)
ε_o, β, ρ = material properties
ε_r = resilient strain (in/in)

Trenches not completed for the LTPP test sections!

- ( ) Special Analysis
- ( ) Nationally Calibration
- (•) State/Regional Calibration
- ( ) Typical Agency Values

Granular:
k1: 2.03   Bs1: 1

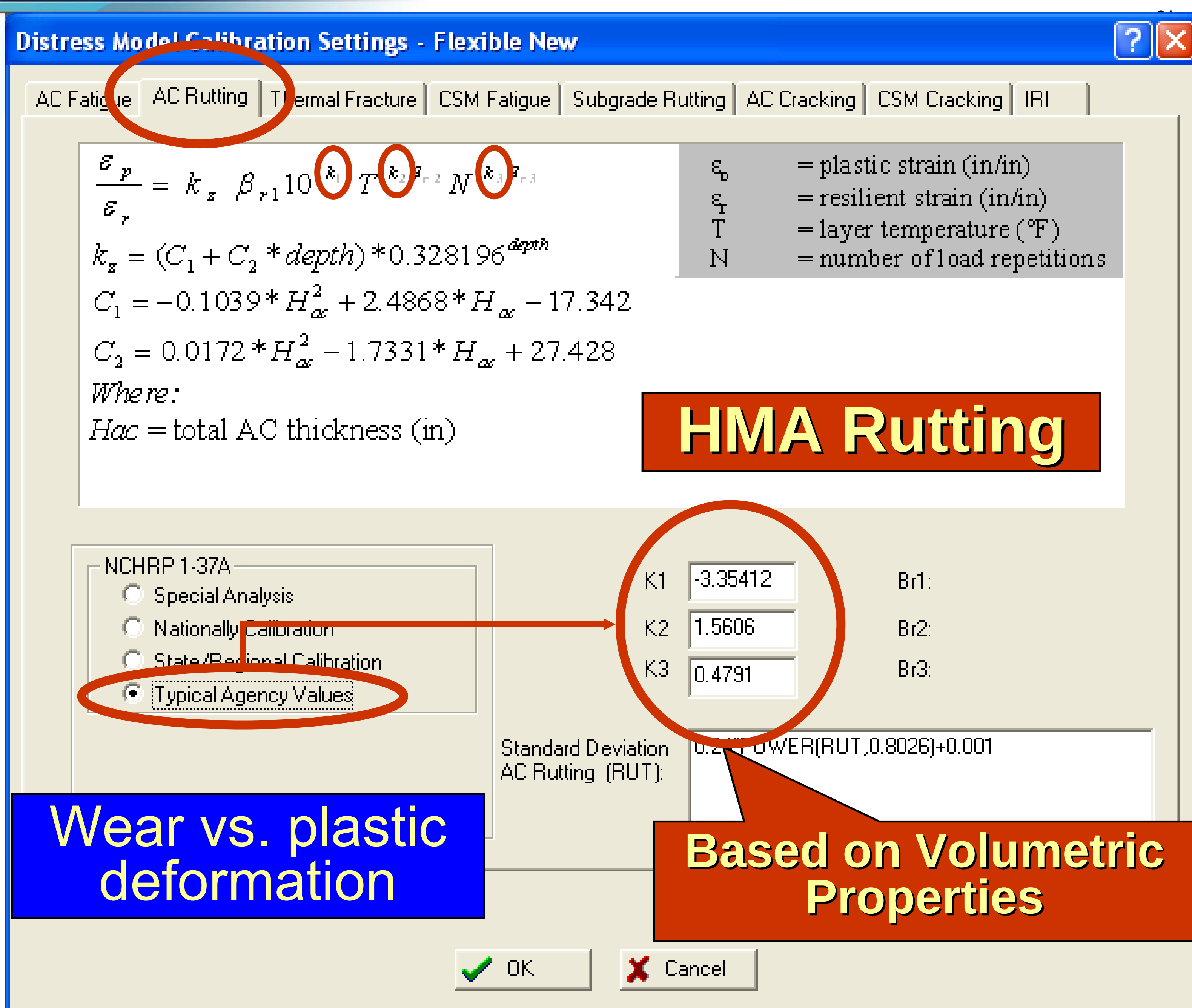
Fine-grain:
k1: 1.35   Bs1: 1

Standard Deviation (BASERUT)
0.1477*POWER(BASERUT,0.6711)+0.001

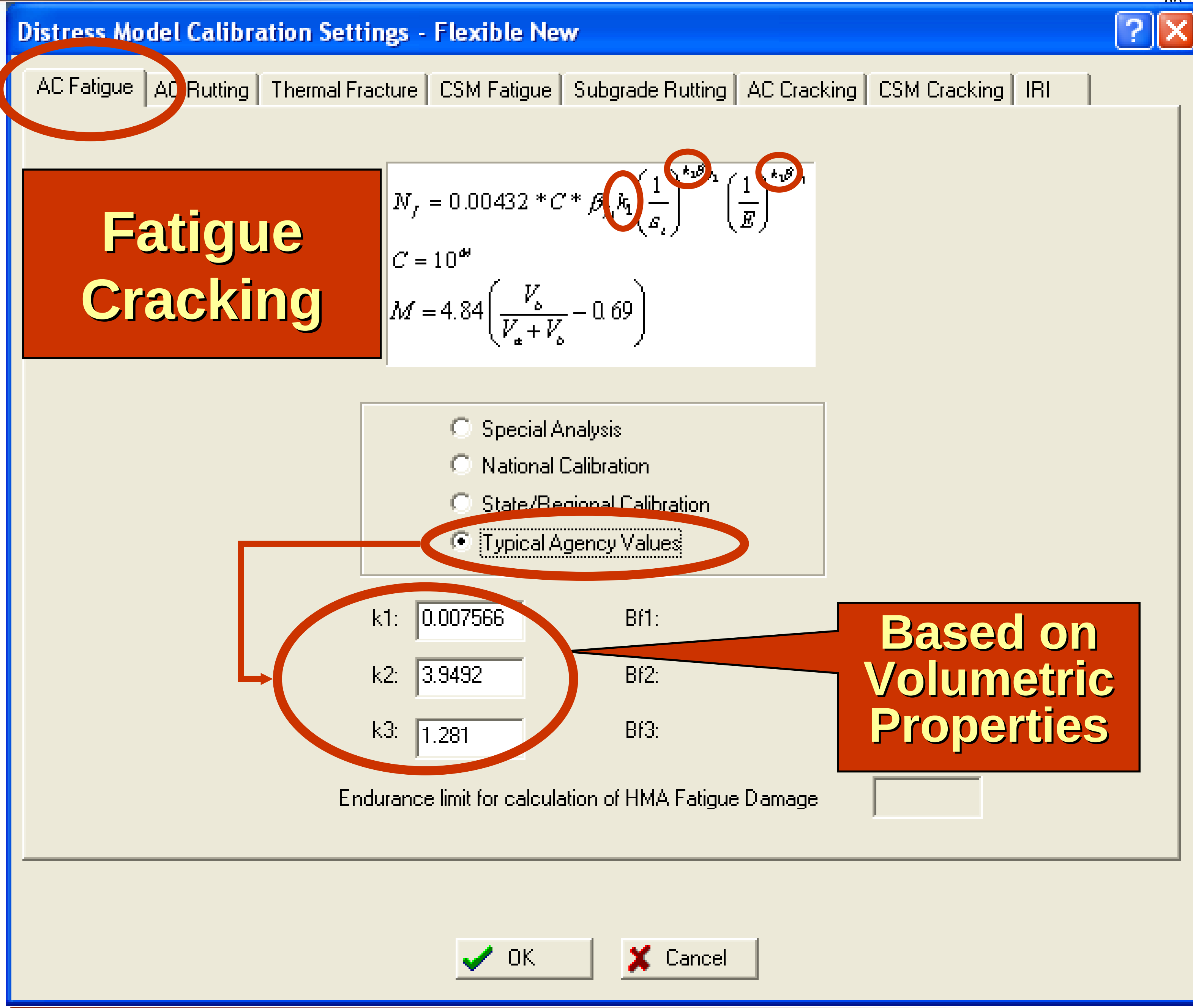
Standard Deviation (SUBRUT)
0.1235*POWER(SUBRUT,0.5012)+0.001

Rutting in Unbound Layers & Subgrade.

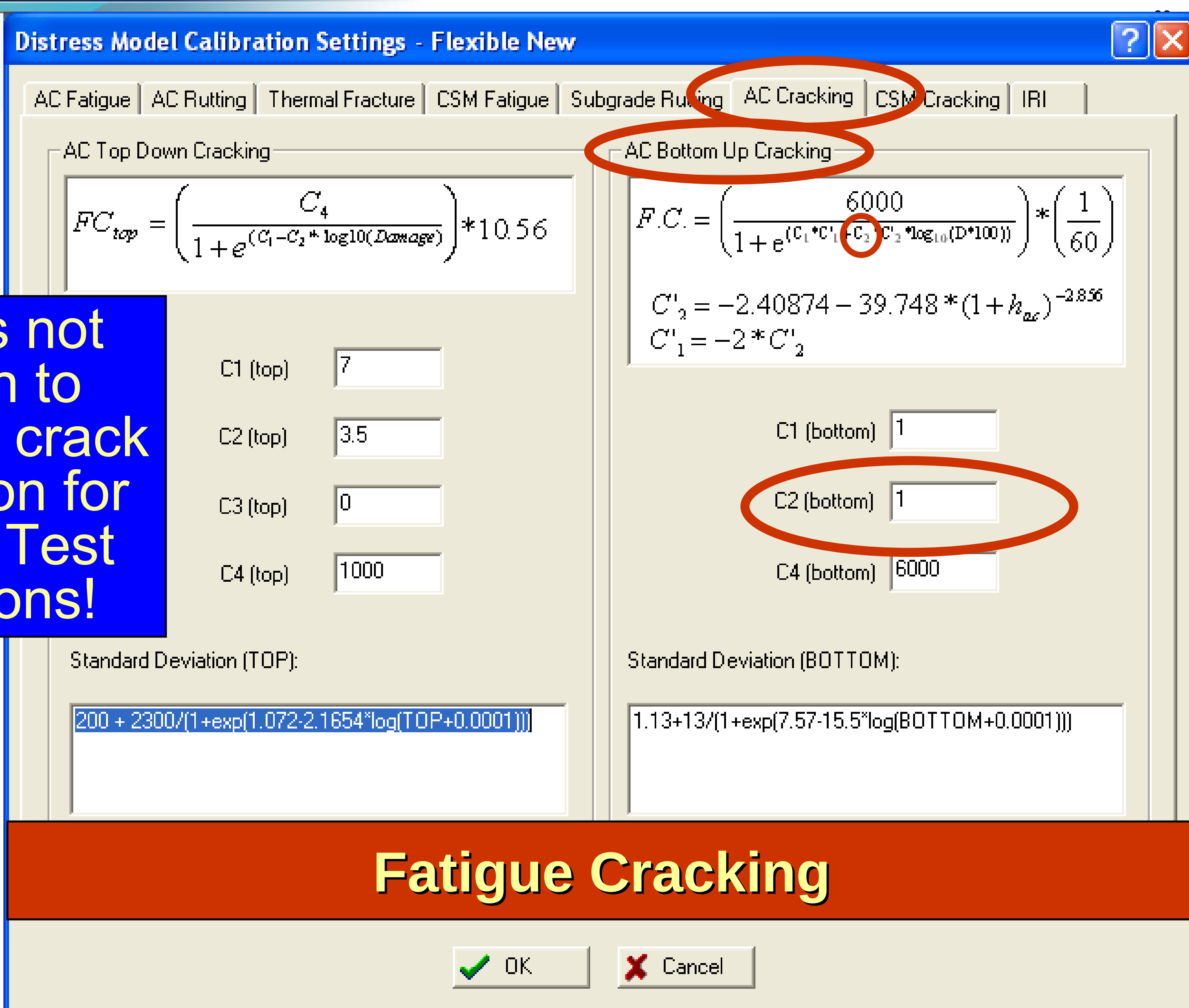
OK   Cancel



Distress Model Calibration Settings - Flexible New
AC Fatigue
AC Rutting
Thermal Fracture
CSM Fatigue
Subgrade Rutting
AC Cracking
CSM Cracking
IRI
$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}}$
$k_z = (C_1 + C_2 * depth) * 0.328196^{depth}$
$C_1 = -0.1039 * H_{ac}^2 + 2.4868 * H_{ac} - 17.342$
$C_2 = 0.0172 * H_{ac}^2 - 1.7331 * H_{ac} + 27.428$
Where:
Hac = total AC thickness (in)
ε_p = plastic strain (in/in)
ε_r = resilient strain (in/in)
T = layer temperature (°F)
N = number of load repetitions
HMA Rutting
NCHRP 1-37A
Special Analysis
Nationally Calibration
State/Regional Calibration
Typical Agency Values
K1 -3.35412
K2 1.5606
K3 0.4791
Br1:
Br2:
Br3:
Standard Deviation AC Rutting (RUT):
0.2*POWER(RUT,0.8026)+0.001
Wear vs. plastic deformation
Based on Volumetric Properties
OK
Cancel

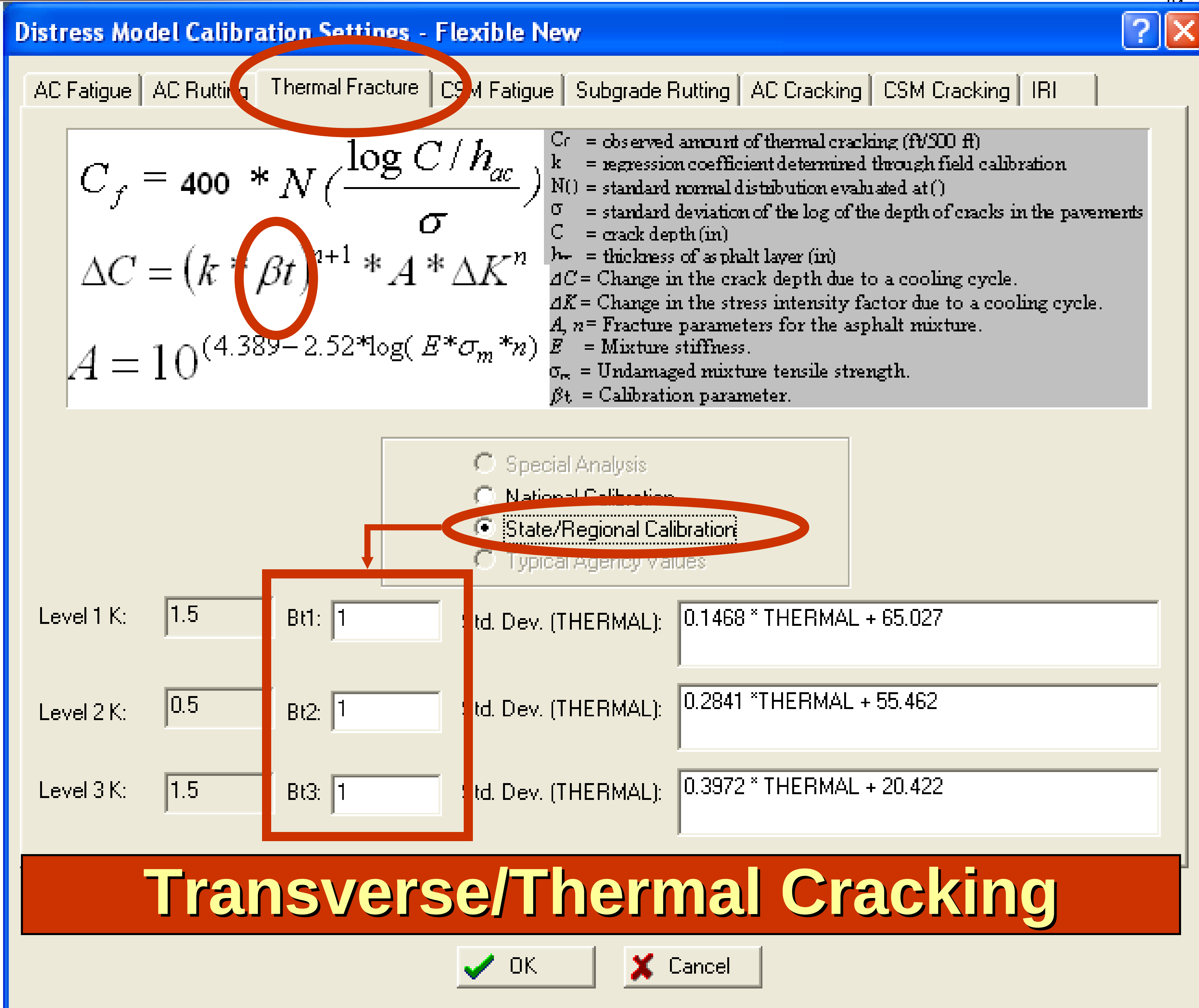

Distress Model Calibration Settings - Flexible New
AC Fatigue
AC Rutting
Thermal Fracture
CSM Fatigue
Subgrade Rutting
AC Cracking
CSM Cracking
IRI
Fatigue Cracking
$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_t}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$
$C = 10^M$
$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$
Special Analysis
National Calibration
State/Regional Calibration
Typical Agency Values
k1: 0.007566
k2: 3.9492
k3: 1.281
Bf1:
Bf2:
Bf3:
Based on Volumetric Properties
Endurance limit for calculation of HMA Fatigue Damage
OK
Cancel

Fatigue Cracking



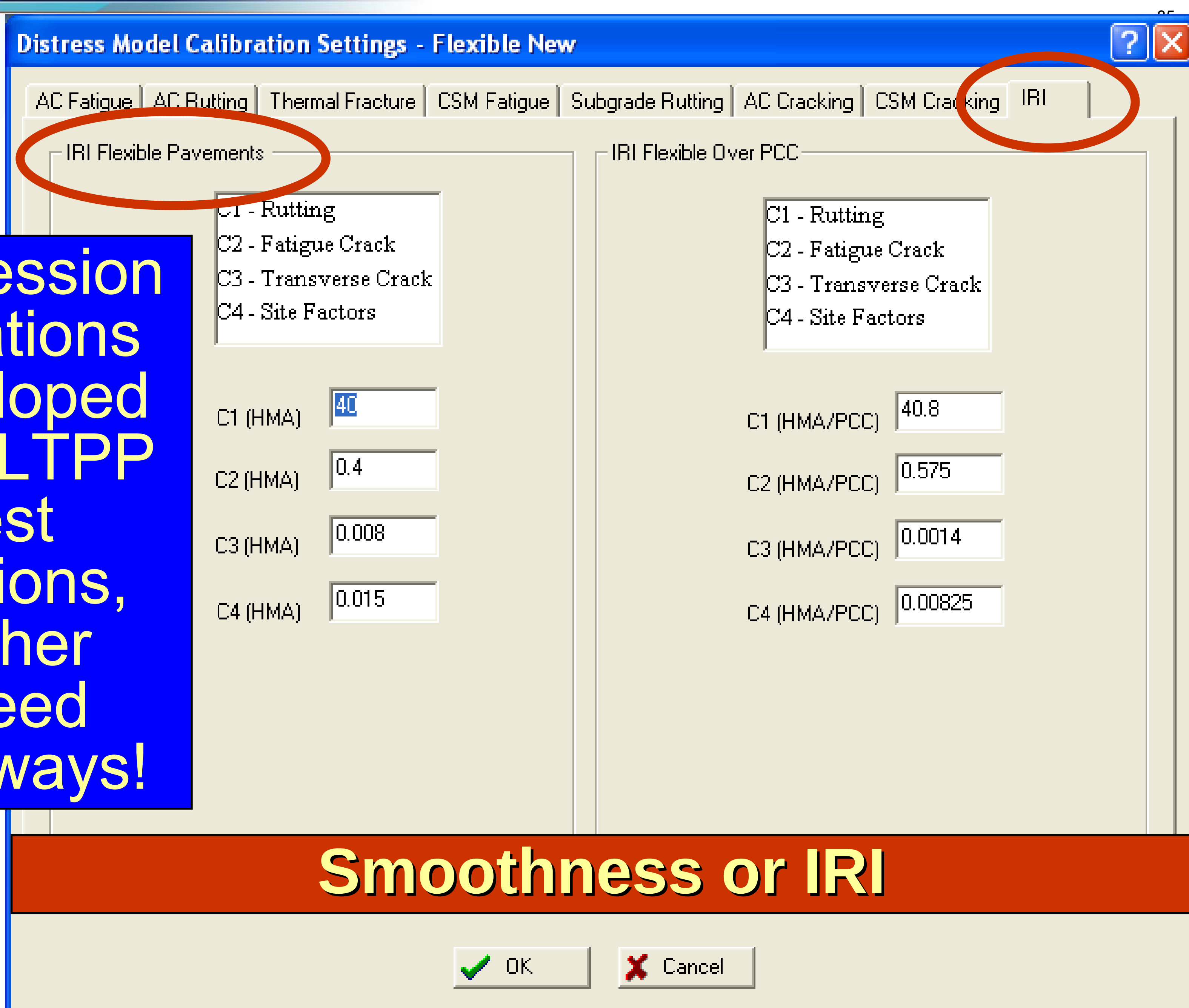
Cores not taken to confirm crack direction for LTPP Test Sections!

Transverse/Thermal Cracking



Smoothness or IRI

Regression equations developed from LTPP test sections, higher speed roadways!



Calibration Data Options