

# Implementation Process of Pavement ME Design in Maricopa County



**Gant Yasanayake** PhD, PE  
Pavement Design Engineer  
MCDOT

**John Shi** PhD, PE  
Materials Engineer  
MCDOT



# Main Objective of this Study

- ☐ Explore the new pavement design software program
- ☐ Find suitable local calibration factors for County conditions
- ☐ Implement the new design method at Maricopa County in the future



## Pavement ME Design in Maricopa County

# Current MCDOT Pavement Design Procedure

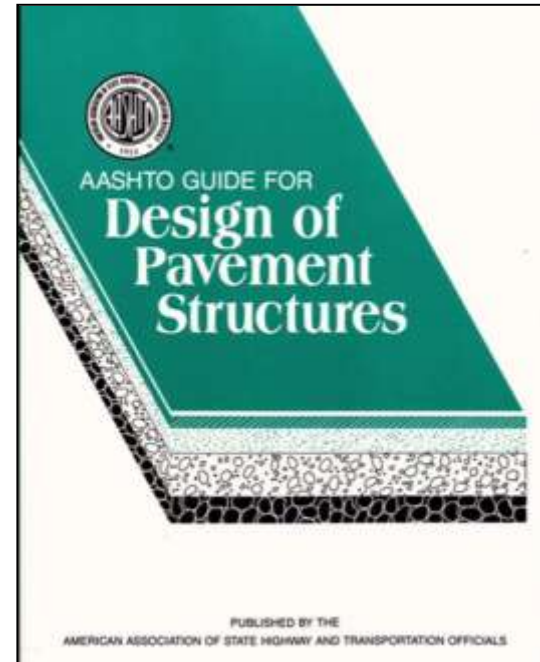


Traffic: AADT & % Trucks  
converted to ESALs



AC and AB:  
 $a_i$  and E

Subgrade:  
R-Value, Sieve and  
PI correlated to  $M_R$



# Current Pavement Design: Pros and Cons

## Roadway Design Manual

Adopted: November 3, 1993  
Updated: February 2016

Maricopa County  
Department of Transportation  
2001 W. Durango Street  
Phoenix, AZ 85009



## Chapter 10

### MCDOT Pavement Design Guide

## PROS

- ☐ Inexpensive testing
- ☐ Simple design
- ☐ layer thicknesses

## CONS

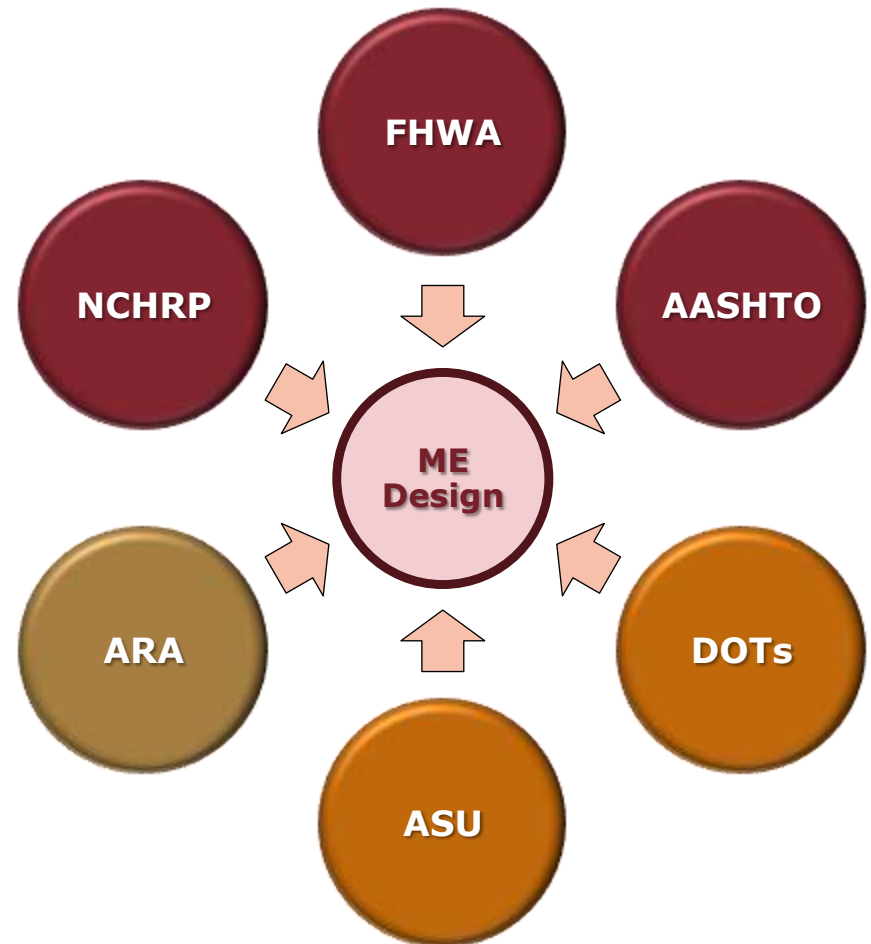
- ☐ Based on one AASHO Road Test conducted in the late 1950s
- ☐ The latest update was in 1993
- ☐ Uses empirical relations



***AASHO Road Test***

# New Pavement ME Design

- ❑ Pavement ME Design is built upon Mechanistic-Empirical Pavement Design Guide (MEPDG)
- ❑ Reflects eight years of research and development by ASU and others
- ❑ Continuous improvement under NCHRP, the FHWA and State Agencies



# New Pavement ME Design: Pros and Cons

## PROS

- ☐ Mechanistic behavior of structure is modeled
- ☐ Based on extensive research effort over many years
- ☐ Predicts pavement performance
- ☐ Hierarchical input levels available
- ☐ Possible to carry out local calibrations

## CONS

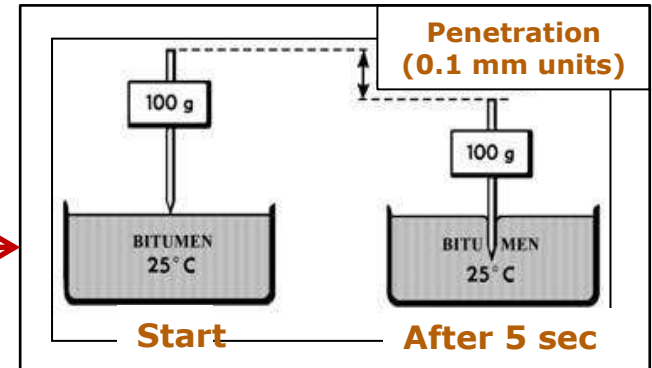
- ☐ Expensive testing is required
- ☐ The design process is not very simple
- ☐ The software is expensive to maintain
- ☐ Users should gain good knowledge to input data, interpret analyses, and make reasonable decisions



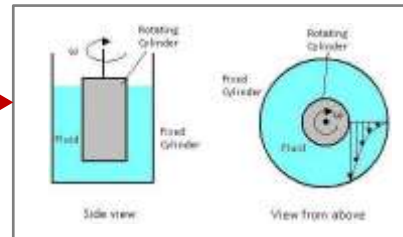
# New Pavement ME Design Laboratory Testing

## Binder Viscosity Testing

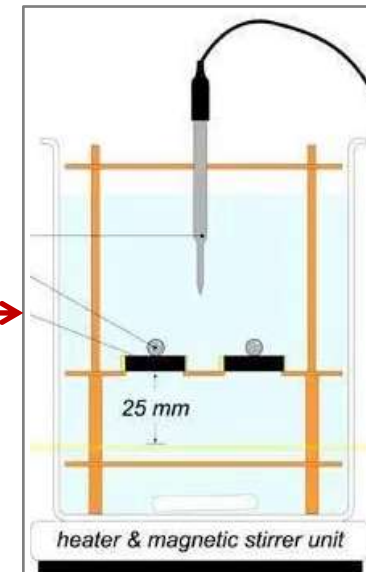
❑ Penetration at 77 °F



❑ Brookfield Viscosity  
at 212, 250, 275, 300,  
and 351 °F

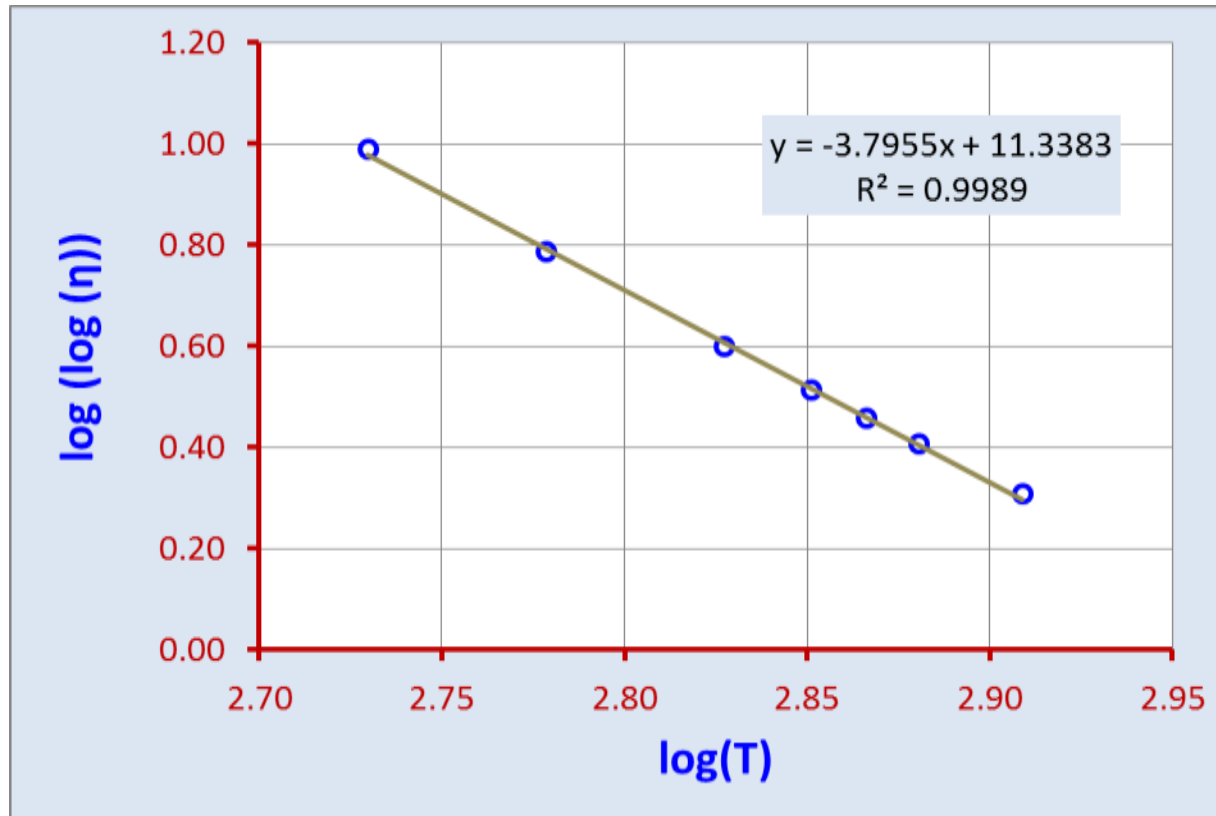


❑ Softening Point





# Viscosity-Temperature Susceptibility (VTS)



Regression parameters **Ai** (intercept) & **VTSi** (slope) describe the Viscosity-Temperature relationship

For the plot shown:

**Ai = 11.3383**

**VTSi = -3.7955**



# Dynamic Modulus Test

## Control:

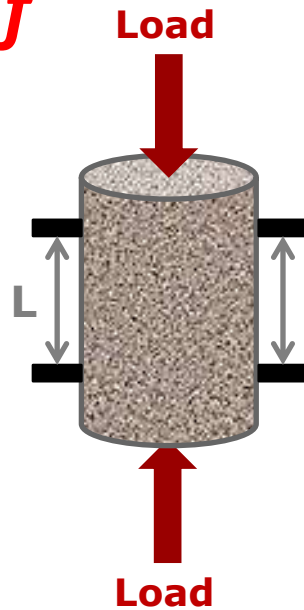
Temperature  $T$

Load Frequency  $f$

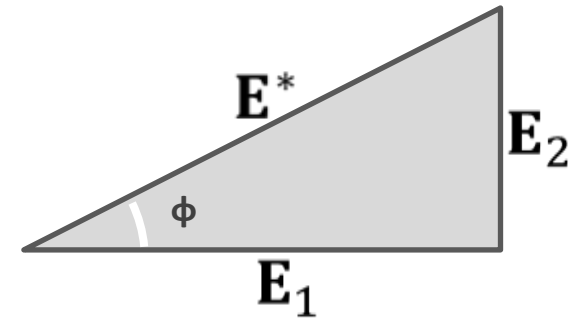
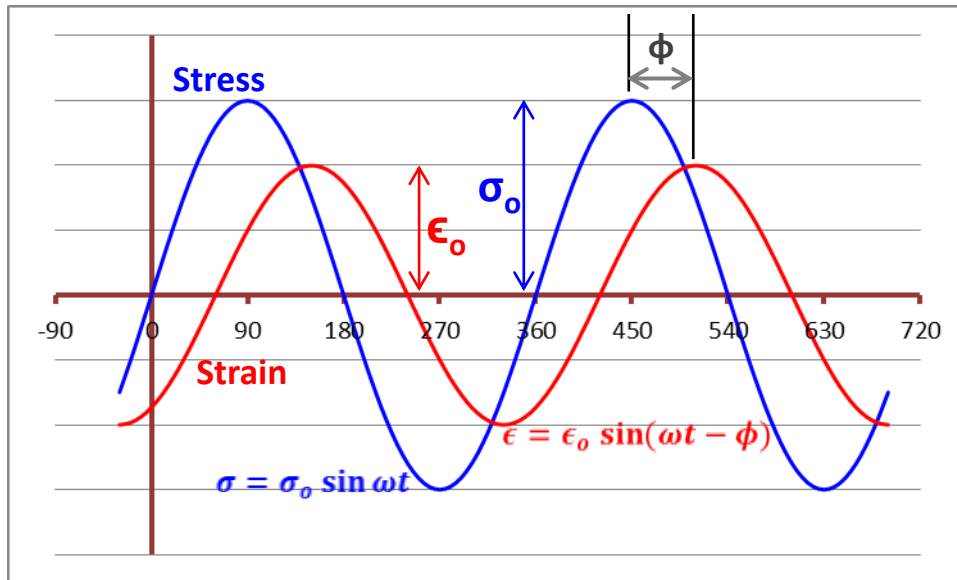
## Measure:

Stress  $\sigma$

Strain  $\epsilon$



# Dynamic Modulus, $E^*$ of Visco-Elastic Material



$$|E^*| = \frac{\sigma_o}{\epsilon_o}$$

Pavement ME Design  
in Maricopa County

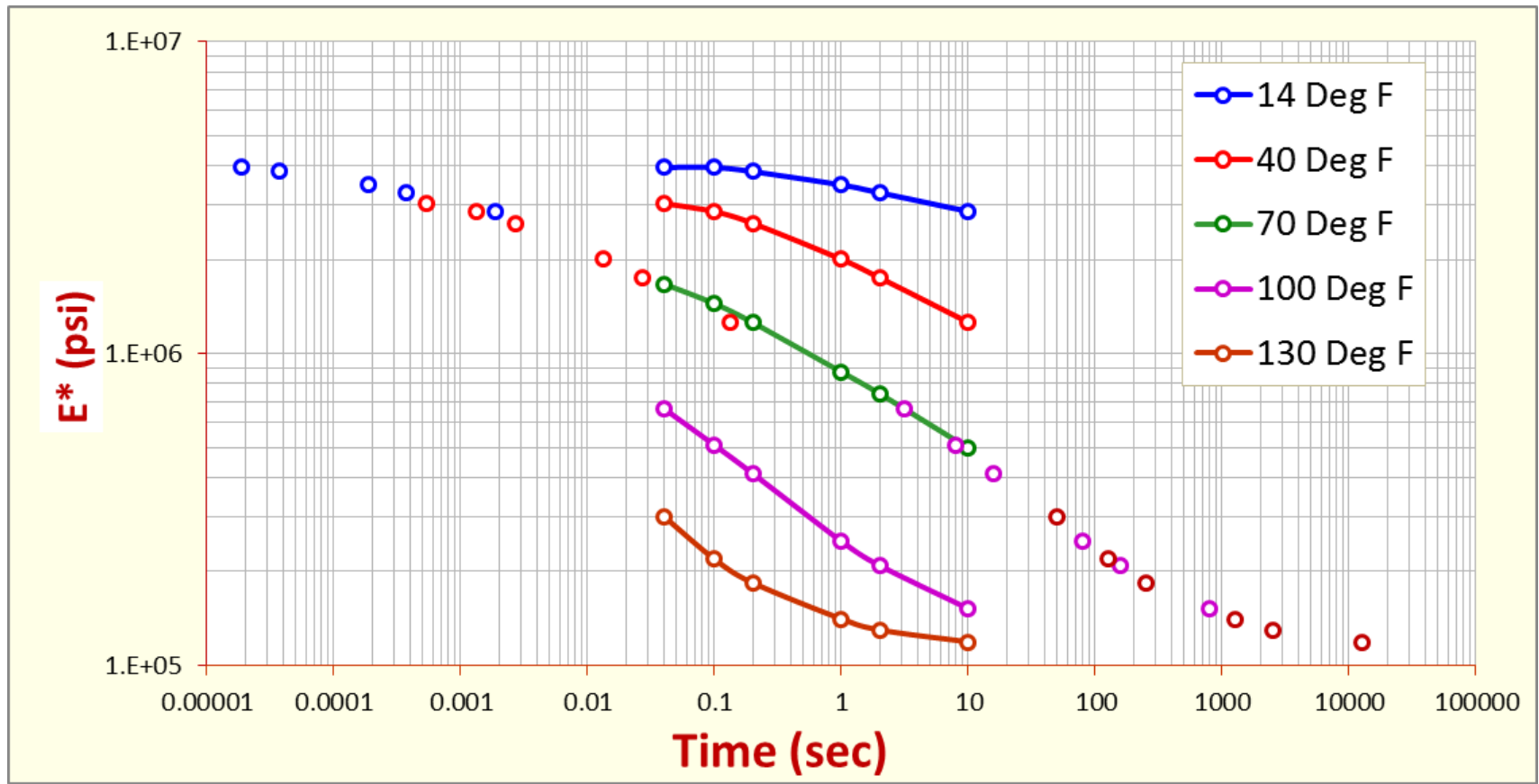
# $E^*$ in kips/in<sup>2</sup> Obtained after Testing

<b>EG</b>	Frequency (Hz)					
	Time (sec)					
Temp (°F)	0.1	0.5	1	5	10	25
	10	2	1	0.2	0.1	0.04
14	2,854	3,276	3,470	3,829	3,947	3,952 Max
40	1,258	1,749	2,004	2,614	2,850	3,030
70	497	743	872	1,256	1,445	1,670
100	152	209	250	412	508	665
130	119 Min	130	141	184	219	300

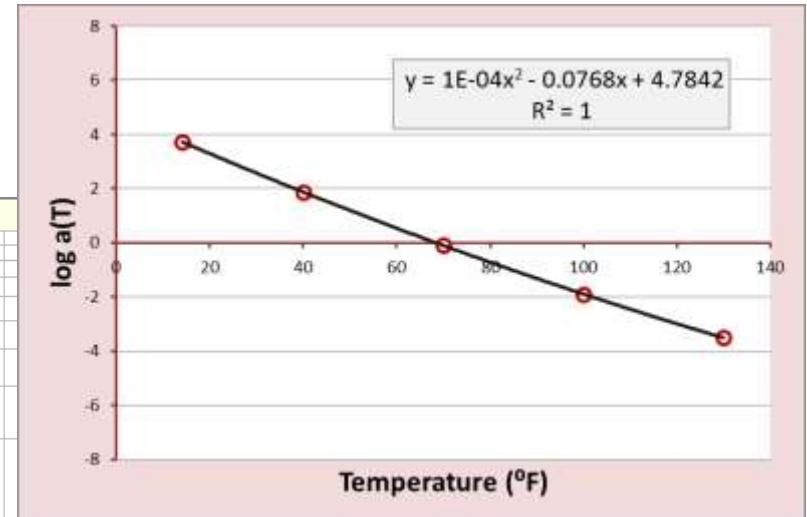
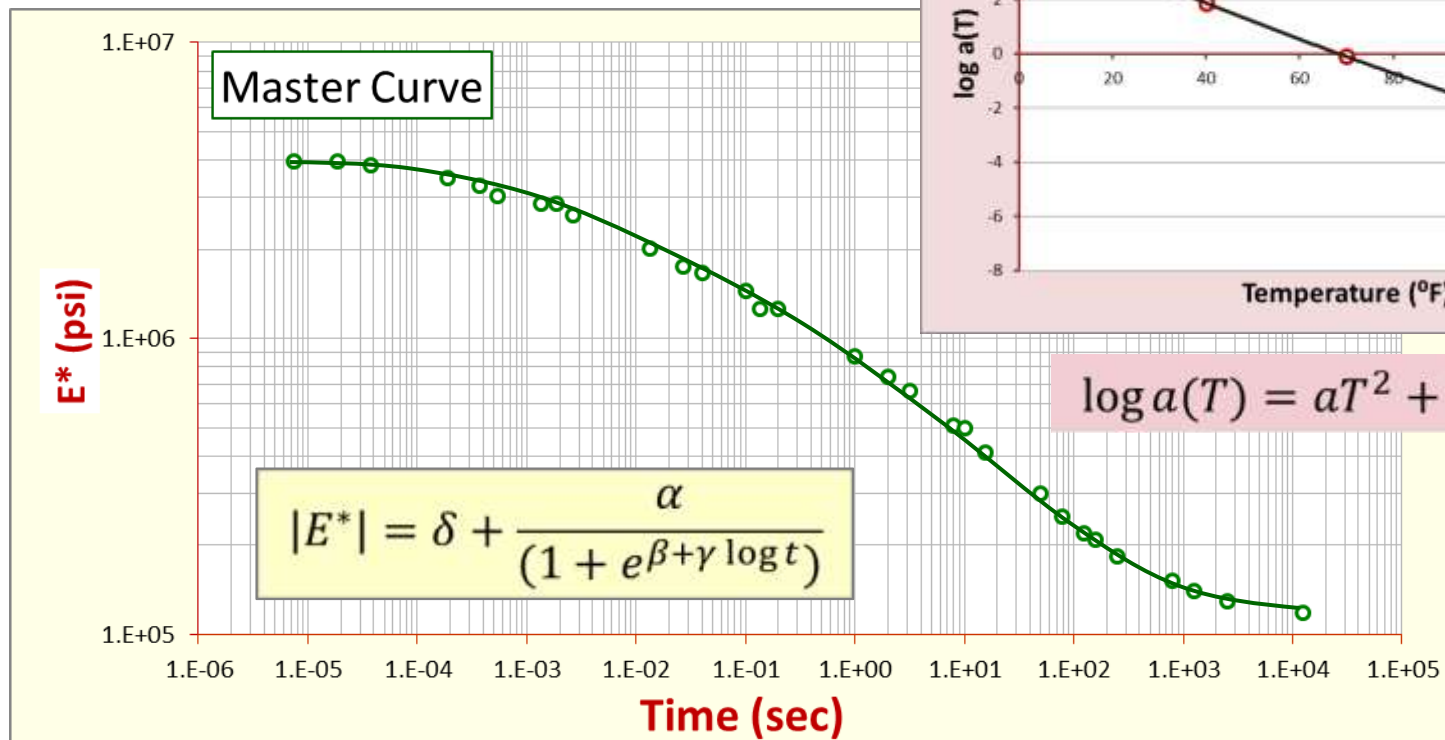


# Plotting $E^*$ and Master Curve

## Principal of Time-Temperature Superposition



# Master Curve Function & Shift Factor Function



$$\log a(T) = aT^2 + bT + c$$

# Maricopa County Research 2006 to 2009

- ❑ ASU conducted a research program for Maricopa County from 2006 to 2009
- ❑ All pavements were flexible pavements
- ❑ Binder, AC mix, AB, and soil samples from 15 road construction projects were collected for testing



# Material Characterization under The Research Program

<b>AC/AR Surface Course</b>	}	Viscosity tests on asphalt binder
<b>AC Base Course</b>		Dynamic modulus on mixes Ignition tests on mixes
<b>AB Aggregate Base</b>	}	Sieve, PI, Proctor Resilient Modulus
<b>Subgrade Compacted/Treated</b>	}	Sieve, Hydrometer, PI Specific Gravity, Proctor
<b>Subgrade</b>		Resilient Modulus Soil-Water Characteristic Curve (SWCC)





# MCDOT Test Roads

No.	Site ID	Project Name	Project Termini		Road Align.	Traffic On Date
			Start	End		
1	EG	Ellsworth Road	Germann Rd	Pecos Rd	NS	Jan-07
2	HH	Hawes Road	Hunt Hwy	Stacey Rd	NS	Mar-07
3	TQ	Tuthill Road	Queen Creek Rd	Pecos Rd	NS	Aug-07
4	IO	Indian School Road	Old Litchfield Rd	Dysart Rd	EW	May-08
5	CM	Cotton Lane	Cotton Ln Bridge	MC 85	NS	Nov-07
6	CS	Chandler Heights	Sossaman Rd	Hawes Rd	EW	Mar-08
7	MT	MC 85	Turner Rd	SR 85	EW	May-08
8	ED	El Mirage Road	Deer Valley Rd	Loop 303	NS	Mar-09
9	GC	Gavilan Peak Parkway	Cloud Rd	Daisy Mtn Rd	NS	May-09



# MCDOT Test Road Locations with 2016 Photos

El Mirage Rd



Gavilan Peak Pkwy



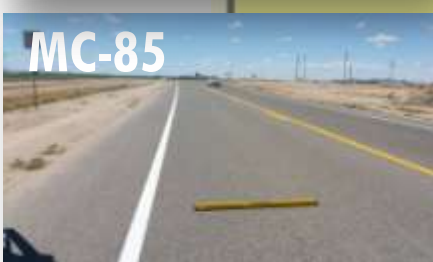
Indian School Rd



Ellsworth Rd



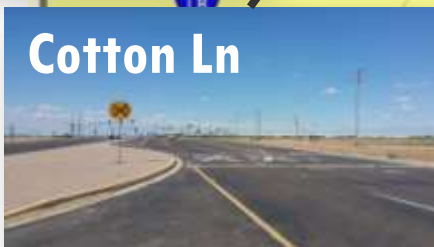
MC-85



Hawes Rd



Cotton Ln



Tuthill Rd



Chandler Hts. Rd



# Field Measurements Distresses on Flexible Pavements

Transverse  
Cracking

IRI

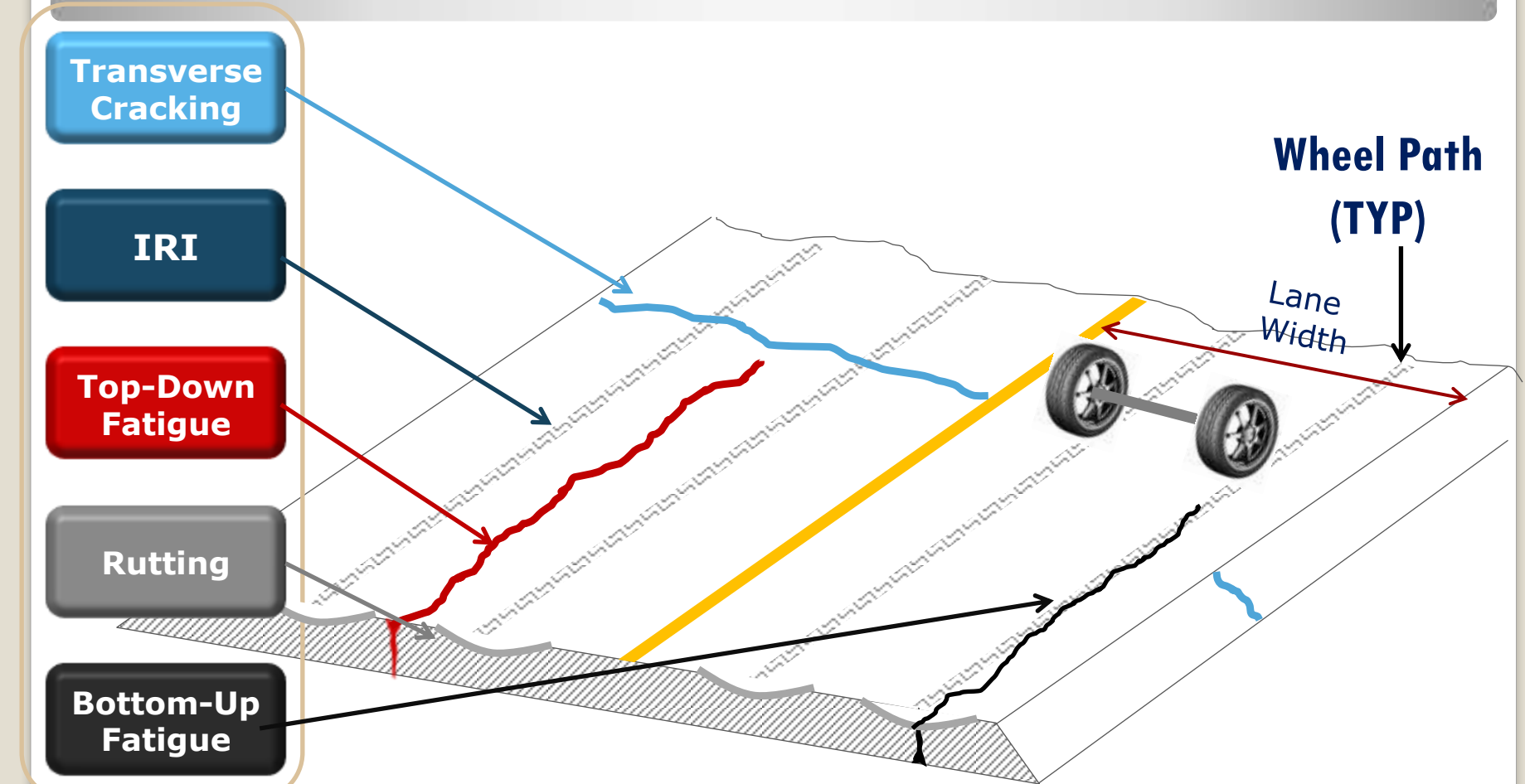
Top-Down  
Fatigue

Rutting

Bottom-Up  
Fatigue

Wheel Path  
(TYP)

Lane  
Width

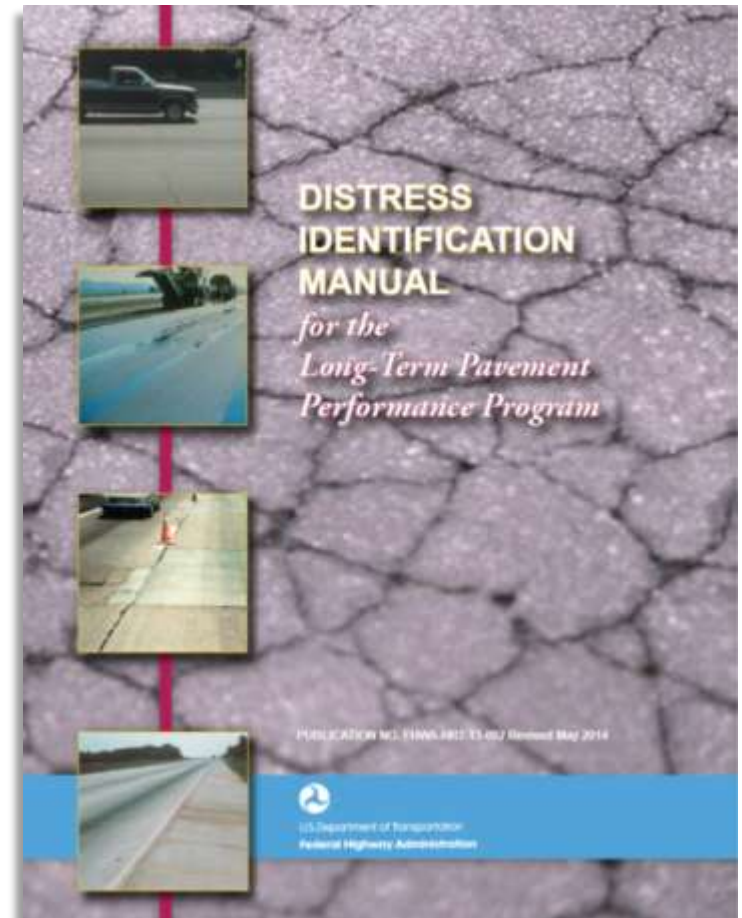


# MCDOT Distress Evaluation & Database

- ❑ MCDOT distress evaluations based on LTPP Distress Identification Manual
- ❑ MCDOT Roadway Management System (RMS) Database

The screenshot shows a web-based application window titled "RMS Query Road Inventory". The interface includes a search bar with "On Road" selected and a checkbox for "Include other criteria". Below the search bar are tabs for "Search Results", "PCR, IRI, SUFF Ratings", "Inventory", "Total Miles", "Lane Miles", and "Sq Yds". A table with columns "Hwy", "On Road", "From Road", "Other", "To Road", "Offset", "Dist", "Clear", and "Subdivision" is visible. A large grey box is overlaid on the bottom half of the window, containing a list of data points.

- IRI (International Roughness Index)
- Pavement Condition Rating (PCR)
- Sufficiency Rating
- Traffic Data
- Pavement Structure
- Work History



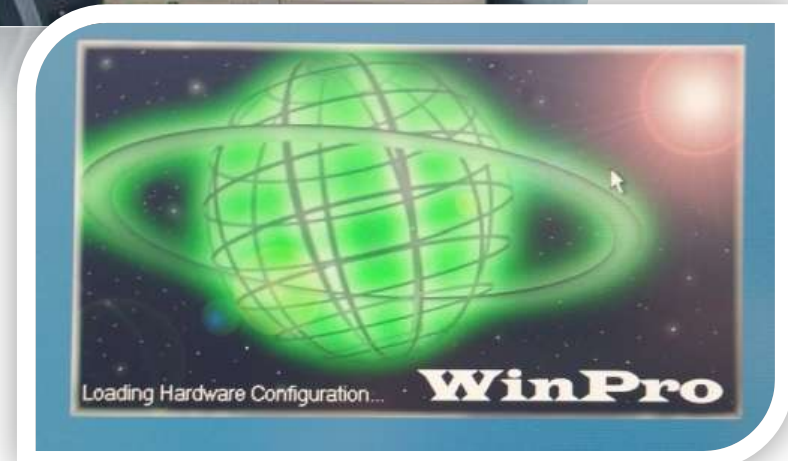
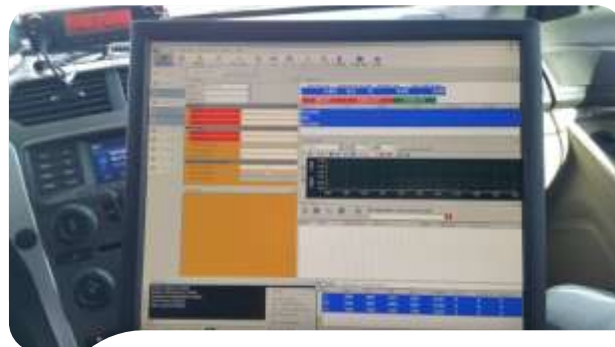


# IRI Field Measurements

## Laser Truck



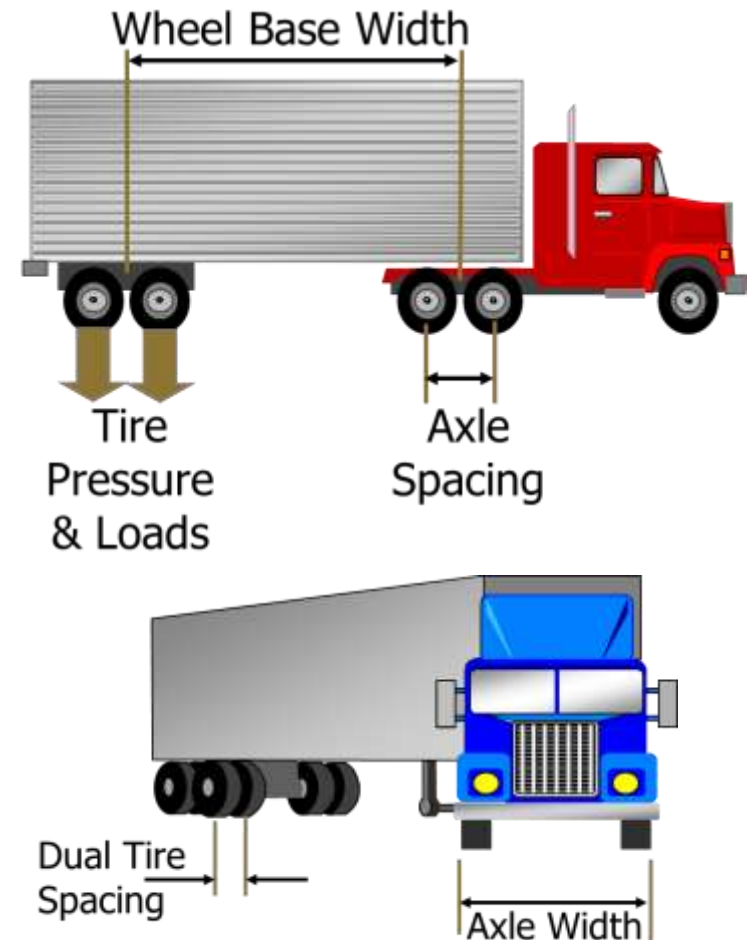
## IRI Software Program

















# MCDOT Traffic Data & Axle Configuration Inputs

Traffic data from MCDOT Traffic Management group:

1. ADT counts over the past years
2. Vehicle class distribution
3. Operational speed



FHWA Vehicle Classifications			
<b>1. Motorcycles</b> 2 axles, 2 or 3 tires 	<b>2. Passenger Cars</b> 2 axles, can have 1- or 2- axle trailers 	<b>3. Pickups, Panels, Vans</b> 2 axles, 4- tire single units Can have 1 or 2 axle trailers 	<b>4. Buses</b> 2 or 3 axles, full length 
<b>5. Single Unit 2-Axle Trucks</b> 2 axles, 6 tires (can have 1 or 2 axle trailers) 	<b>6. Single Unit 3-Axle Trucks</b> 3 axles, single unit 	<b>7. Single Unit 4 or More-Axle Trucks</b> 4 or more axles, single unit 	<b>8. Single Trailer 3- or 4-Axle Trucks</b> 3 or 4 axles, single trailer 
<b>9. Single Trailer 5-Axle Trucks</b> 5 axles, single trailer 	<b>10. Single Trailer 6 or More-Axle Trucks</b> 6 or more axles, single trailer 		
<b>11. Multi-Trailer 5 or Less-Axle Trucks</b> 5 or less axles, multiple trailers 		<b>12. Multi-Trailer 6-Axle Trucks</b> 6 axles, multiple trailers 	
<b>13. Multi-Trailer 7 or More-Axle Trucks</b> 7 or more axles, multiple trailers 			

# Data Entry for Pavement ME Design Program

## Climate



- Weather data over 20 year period
- Latitude, Longitude, and Elevation
- Depth to Groundwater Table

## Traffic



- AADTT (Average Annual Daily Truck Traffic)
- Class Distribution (Class 4 thru 13)
- Axle Distribution (Single, Tandem, Tridem, & Quad)

## Materials



- Binder Viscosity
- Asphalt Mix ( $E^*$ , binder content, air voids)
- Base material (Gradation, PI)
- Subgrade (Gradation, PI, R-Value, Resilient Modulus, SWCC)



## Pavement ME Design in Maricopa County

# New Pavement ME Design Material Data

The screenshot shows the AASHTOWare Pavement ME Design 2.3.0 software interface. On the left, a vertical stack of red boxes with arrows points to specific parts of the software: 'Climate' points to the 'Design type' dropdown, 'Traffic' points to the 'Design life (years)' dropdown, 'AC Layers' points to the 'Base construction' dropdown, 'AB Layer' points to the 'Pavement construction' dropdown, and 'Subgrade' points to the 'Traffic opening' dropdown. On the right, a red box labeled 'Performance Criteria' has an arrow pointing to a table of performance criteria. The table has two columns: 'Level' and 'Reliability'. The data rows are:

Level	Reliability
63	90
112	90
2000	90
25	90
1000	90
0.75	90
0.25	90

The software interface also displays a cross-section diagram of a pavement structure with layers labeled 'AC', 'AB', and 'Subgrade'. The 'Performance Criteria' table is located in the top right corner of the software window.



## Pavement ME Design in Maricopa County

# New Pavement ME Design Climate Data

AASHTOWare Pavement ME Design 2.3.0

Menu

Recent Files ▾

New Open SaveAs Save SaveAll Close Exit Run Batch Import Export Undo Redo Help

Explorer

- Projects
  - 1 EG-E2
  - Multiple Project Summary
  - Batch Run
- Tools
  - ME Design Calibration Factors
    - New Flexible
    - Rehabilitation Flexible
    - New Rigid
    - Restored Rigid

1 EG-E2:Project FlexibleNew 1 EG-E2:Climate 1 EG-E2:Traffic

Climate Station

Elevation (ft)	1105
Climate station	PHOENIX,AZ (23183)
Latitude (decimals degrees)	33.443
Longitude (decimal degrees)	-111.99
Depth of water table (ft)	Annual(150)

Identifiers

8/15/2016
Gant Y.
8/15/2016
Maricopa
Climate
NB
Climate
2
Germann Rd
False
Ellsworth Road
0
AZ
Pecos Rd

User defined field 3

Summary Hourly climate data

Climate Summary

- Mean annual air temperature (deg F)
- Mean annual precipitation (in)
- Freezing index (deg F - days)
- Average annual number of freeze/thaw cycles
- Number of wet days

Monthly Temperatures

- Average temperature in January (deg F)
- Average temperature in February (deg F)
- Average temperature in March (deg F)
- Average temperature in April (deg F)
- Average temperature in May (deg F)
- Average temperature in June (deg F)
- Average temperature in July (deg F)
- Average temperature in August (deg F)
- Average temperature in September (deg F)
- Average temperature in October (deg F)
- Average temperature in November (deg F)
- Average temperature in December (deg F)

- Elevation
- Climate Station
- Latitude
- Longitude
- Depth to Groundwater



## Pavement ME Design in Maricopa County

# New Pavement ME Design Traffic Data

- AADTT
- Number of Lanes
- Operational Speed
- Class Distribution
- Growth Rate
- Axle Configuration
- Axles per Truck

The screenshot displays the '1 EG-E2-Traffic' window in the Pavement ME Design software. The left sidebar shows project parameters: AADTT (1626), Number of lanes (4), Percent trucks in design dir (50), Percent trucks in design lane (90), Operational speed (mph) (54.5), Traffic Capacity (Not enforced), and Axle Configuration (8.5). The main area is titled 'Vehicle Class Distribution and Growth' and contains a table with columns for Vehicle Class, Distribution (%), Growth Rate (%), and Growth Function. Below this is a table for 'Import Monthly Adjustment' with columns for Class 5 through Class 13. At the bottom, there is a table for 'Single', 'Tandem', 'Tridem', and 'Quad' axle configurations with columns for Single, Tandem, Tridem, and Quad.

Vehicle Class	Distribution (%)	Growth Rate (%)	Growth Function
Class 4	2.7	6.6	Compound
Class 5	7.4	6.6	Compound
Class 6	25.4	6.6	Compound
Class 7	13.4	6.6	Compound
Class 8	4.2	6.6	Compound
Class 9	19.3	6.6	Compound
Class 10	2.4	6.6	Compound
Class 11	7.1	6.6	Compound
Class 12	6.5	6.6	Compound

Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

Single	Tandem	Tridem	Quad
1.62	0.39	0	0
2	0	0	0
1.02	0.99	0	0
1	0.26	0.89	0
2.98	0.67	0	0
1.12	1.33	0	0
1.19	1.89	0.89	0
4.29	0.26	0.06	0
3.52	1.14	0.06	0



## Pavement ME Design in Maricopa County

# New Pavement ME Design Calibration Screen

AC  
Cracking

AC  
Fatigue

AC  
Rutting

AB &  
Subgrade  
Rutting

IRI

Thermal  
Fracture

The screenshot shows the '1.66-E2Project - HwableNew' window in the AASHTO Pavement ME Design 2.3.0 software. The left sidebar lists project files and tools. The main area displays calibration parameters for three categories: AC Cracking, AC Fatigue, and AC Rutting. Each category has a list of parameters with checkboxes and numerical values. A large orange box highlights the '82 Calibration Parameters'.

Category	Parameter	Value
AC Cracking	AC Cracking C1 Bottom	1
	AC Cracking C1 Top	7
	AC Cracking C2 Bottom	2
	AC Cracking C2 Top	3.5
	AC Cracking C3 Bottom	6000
	AC Cracking C3 Top	0
	AC Cracking C4 Top	1000
	AC Cracking Top Standard Deviation	$200 + 2300/(1 + \exp(1.072 - 2.1624 \cdot \log(10(TOP - 0.0001))))$
	AC Fatigue	1
	AC Fatigue BF1	1
AC Fatigue BF2	1	
AC Fatigue BF3	0.007560	
AC Fatigue K1	3.3452	
AC Fatigue K2	1.281	
AC Rutting	AC Rutting Standard Deviation	$0.00001 \cdot \text{Pow}(\text{RUT.D.176}) + 0.001$
	AC Rutting - Layer 1	0.69
	AC Rutting BR1 (1)	1
	AC Rutting BR2 (1)	1
	AC Rutting BR3 (1)	1
	AC Rutting K1 (1)	-3.35412
	AC Rutting K2 (1)	1.5606
	AC Rutting K3 (1)	0.4791
	AC Rutting - Layer 2	0.69
	AC Rutting BR1 (2)	1
	AC Rutting BR2 (2)	1
	AC Rutting BR3 (2)	1
AC Rutting K1 (2)	-3.35412	
AC Rutting K2 (2)	1.5606	
AC Rutting K3 (2)	0.4791	
AC Rutting - Layer 3	AC Rutting BR1 (3)	0.69
	AC Rutting BR2 (3)	1
	AC Rutting BR3 (3)	1
	AC Rutting K1 (3)	-3.35412
AC Rutting K2 (3)	1.5606	
AC Rutting K3 (3)	0.4791	

82 Calibration  
Parameters



# Pavement ME Design Computation Process

Integrated Climatic Model

Thermal Cracking

Asphalt Damage

Asphalt Rutting & Fatigue

Asphalt IRI





# Pavement ME Design Input & Output



1 EG-E2

File Name: C:\Users\yasanyakeg\Desktop\1 EG-E2.dgpx



## Design Inputs

Design Life: 20 years  
Design Type: FLEXIBLE

Base construction: September, 2006  
Pavement construction: December, 2006  
Traffic opening: January, 2007

Climate Data 33.443, -111.99  
Sources (Lat/Lon)

## Design Structure

Layer type	Material Type	Thickness (in)
Flexible	AC 3/4-inch Arterial EVAC	2.5
Flexible	AC 3/4-inch Arterial EVAC	3.0
NonStabilized	AB MAG Specs	10.0
Subgrade	Silty Sand (SM)	Semi-infinite

### Volumetric at Construction:

Effective binder content (%)	14.3
Air voids (%)	5.8

## Traffic

Age (year)	Heavy Trucks (cumulative)
2007 (initial)	1,626
2017 (10 years)	3,623,480
2027 (20 years)	10,489,300

## Design Outputs

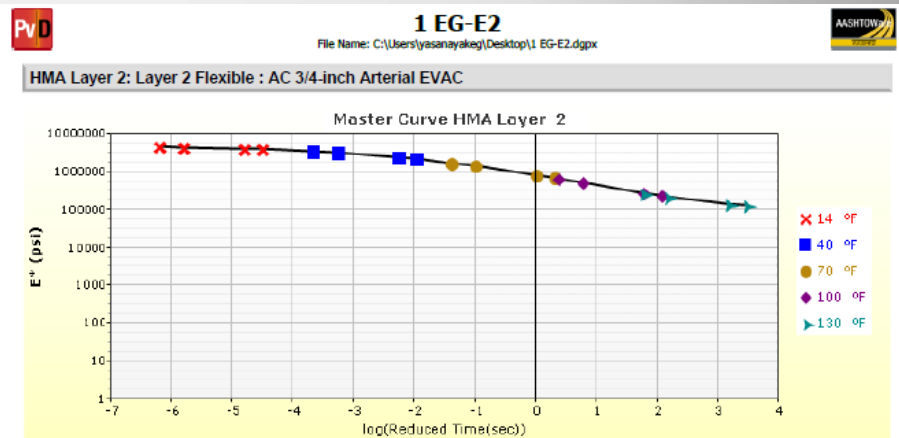
### Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	172.00	168.82	90.00	91.54	Pass
Permanent deformation - total pavement (in)	0.75	0.82	90.00	72.67	Fail
AC bottom-up fatigue cracking (% lane area)	25.00	22.47	90.00	92.49	Pass
AC thermal cracking (ft/mile)	1000.00	27.17	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	3406.60	90.00	73.15	Fail
Permanent deformation - AC only (in)	0.25	0.52	90.00	3.29	Fail

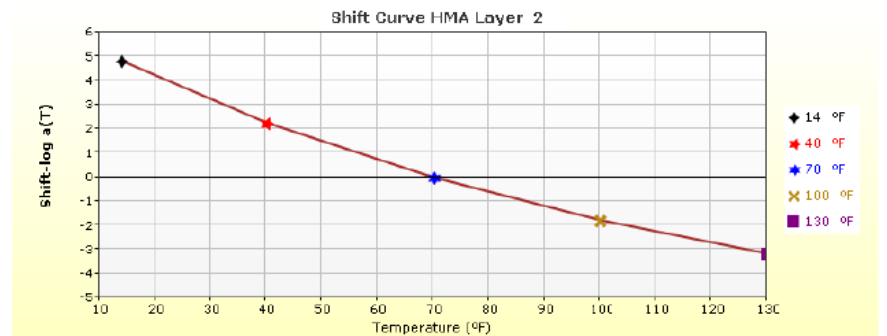


# Pavement ME Design Input: Master Curve & VTS

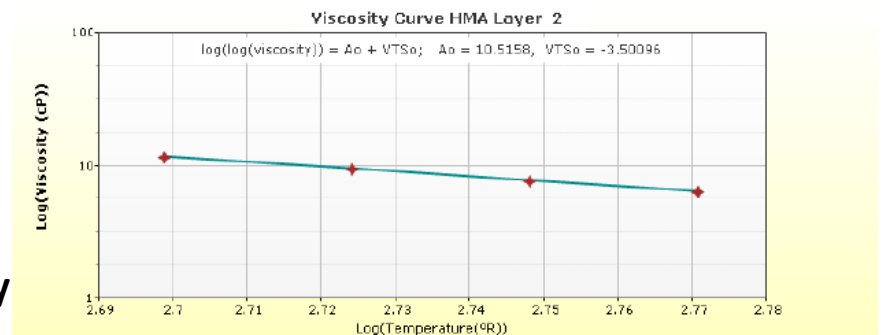
Master Curve



Shift Curve



Viscosity Curve



VTS = Viscosity-Temperature Susceptibility



Maricopa County  
Department of Transportation



# Pavement ME Design Output: Distress Charts

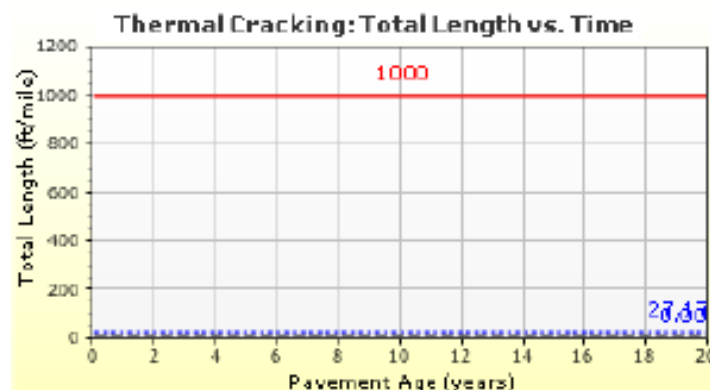
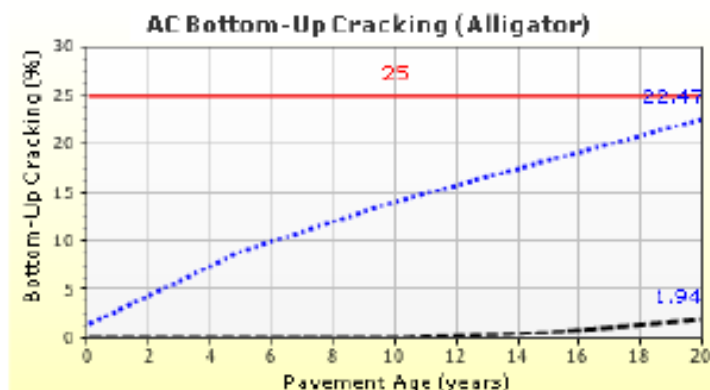
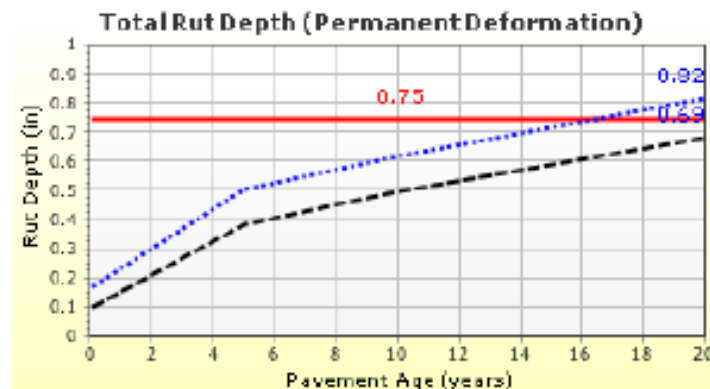
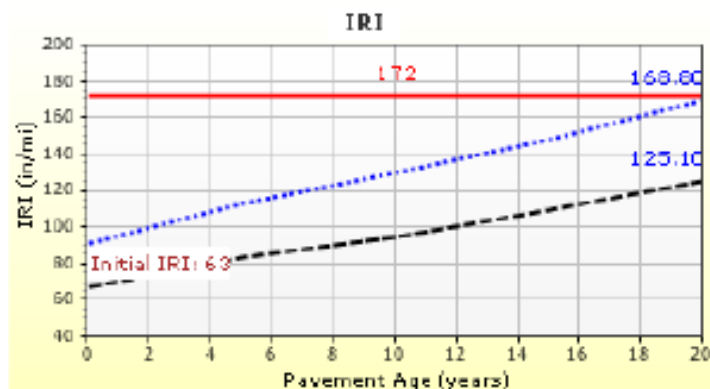


1 EG-E2

File Name: C:\Users\yanayakeg\Desktop\1 EG-E2.dgpx



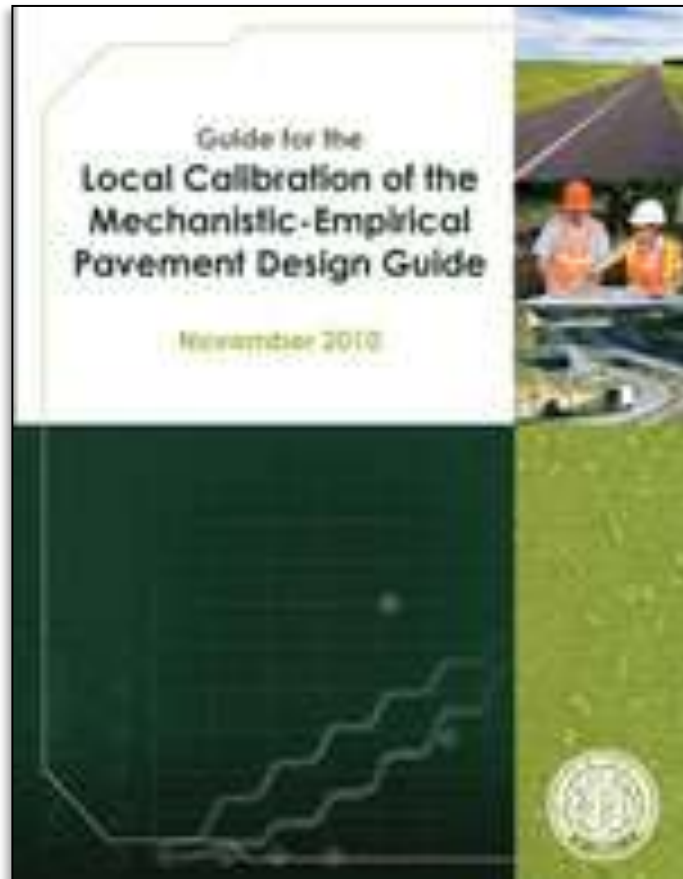
## Distress Charts



— Threshold Value    ..... @ Specified Reliability    --- @ 50% Reliability



# Local Calibration & Validation Procedure



Material  
Characterization



Prediction of  
Distresses



Field Monitoring



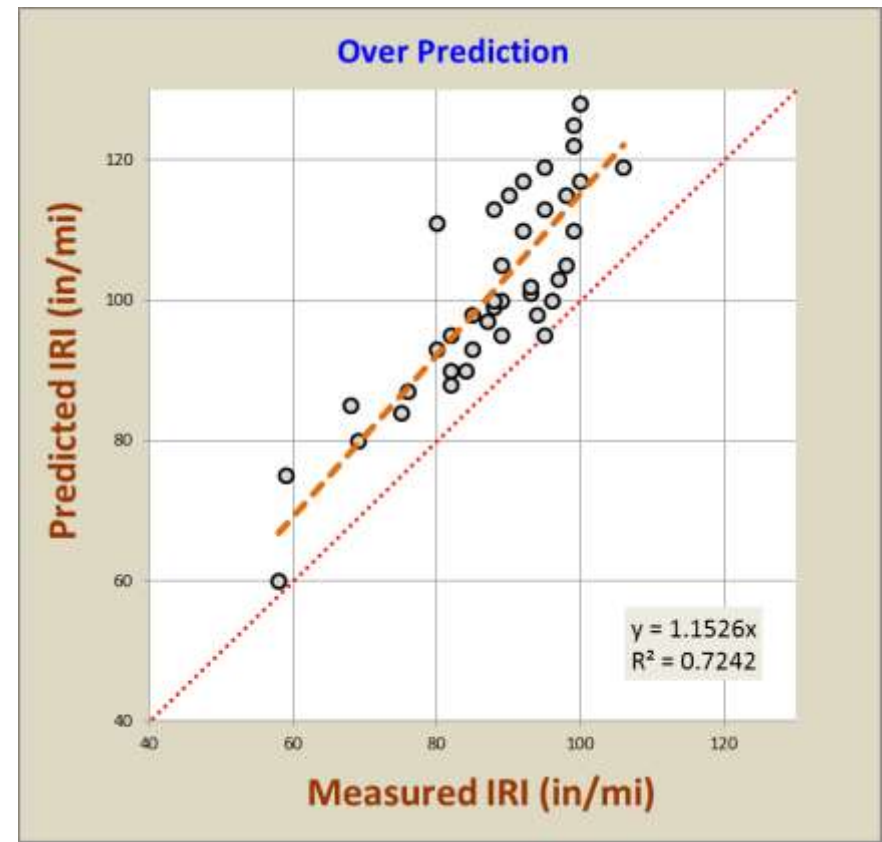
Predicted vs  
Measured



Modify parameters to  
eliminate any bias

## Local Calibration: Bias and Goodness of Fit

- ❑ Reduce bias (avoid over-designed and under-designed pavements)
- ❑ Goodness-of-fit criteria is used to find the best set of calibration parameters
- ❑ Method of least squares using linear regression analysis is adopted



## Approach to Local Calibration and Validation

Traditional  
Split-Sample

Use split-sample  
approach if the  
sample size is **large**

Jack-Knifing

Use jack-knife  
approach if the  
sample size is **small**



# Model Validation Jack-Knife Method

- ☐ For “n-1 Jack-Knife” validation, remove one set of data and calibrate the model with remaining n-1 data sets
- ☐ n = 9 for this study
- ☐ The 9 sites were grouped into nine 1 | 8 groups as shown on the table
- ☐ The final calibration was checked with each data set

Site>	EG	HH	TQ	IO	CM	CS	MT	ED	GC
1	C	C	C	C	C	C	C	C	V
2	C	C	C	C	C	C	C	V	C
3	C	C	C	C	C	C	V	C	C
4	C	C	C	C	C	V	C	C	C
5	C	C	C	C	V	C	C	C	C
6	C	C	C	V	C	C	C	C	C
7	C	C	V	C	C	C	C	C	C
8	C	V	C	C	C	C	C	C	C
9	V	C	C	C	C	C	C	C	C



# Field Measurements and Calibration and Validation

Trivial Data to  
Analyze

❑ **Rutting**—no or little rutting

Trivial Data to  
Analyze

❑ **Fatigue Cracking**—no or little fatigue

Currently no  
predictions  
available

❑ **Transverse Cracking**—light to  
moderate thermal cracking

Main distress used  
in the calibration

❑ **IRI**—measured data available for all  
the test sites



# Statistical Parameters

**$b \rightarrow 0$**

When  $b = 0$   
and  $m = 1$ :  
Predicted  
= Measured

**$m \rightarrow 1$**

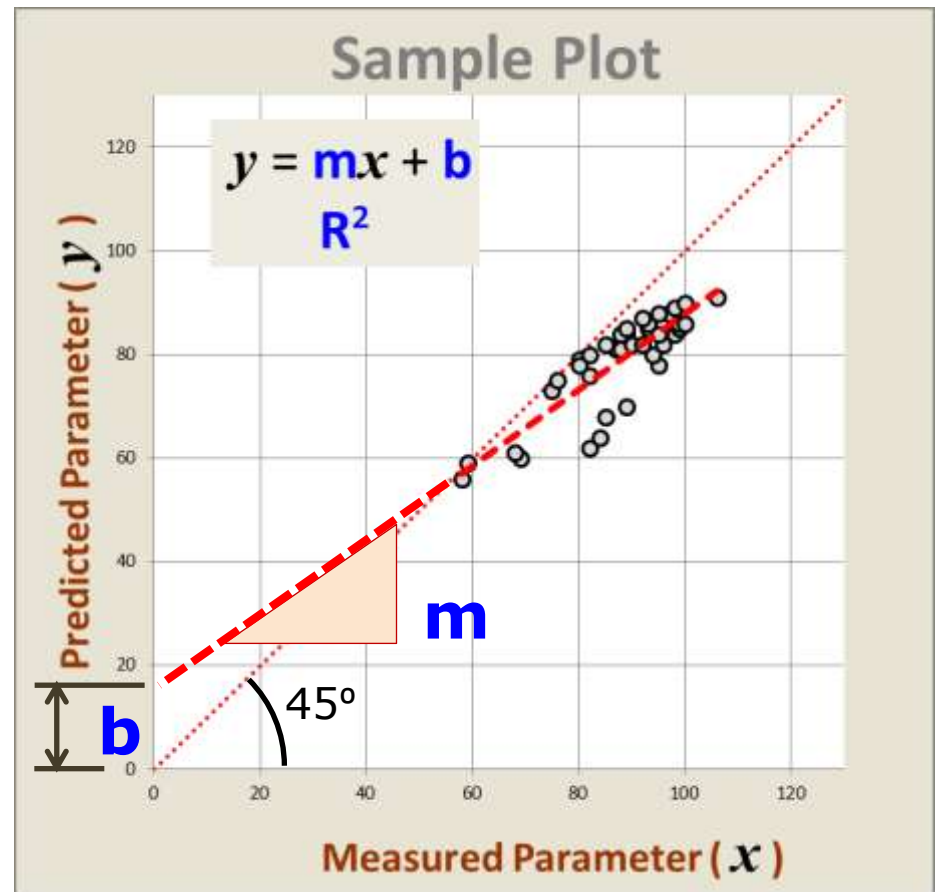
**$R^2 \rightarrow 1$**

$R^2 = 1$  gives  
best goodness  
of fit

**$S_e \rightarrow \text{Min}$**

$S_e$  = Standard Error

$$S_e = \sqrt{\frac{\sum_{i=1}^n (e - \bar{e})^2}{n - 1}}$$



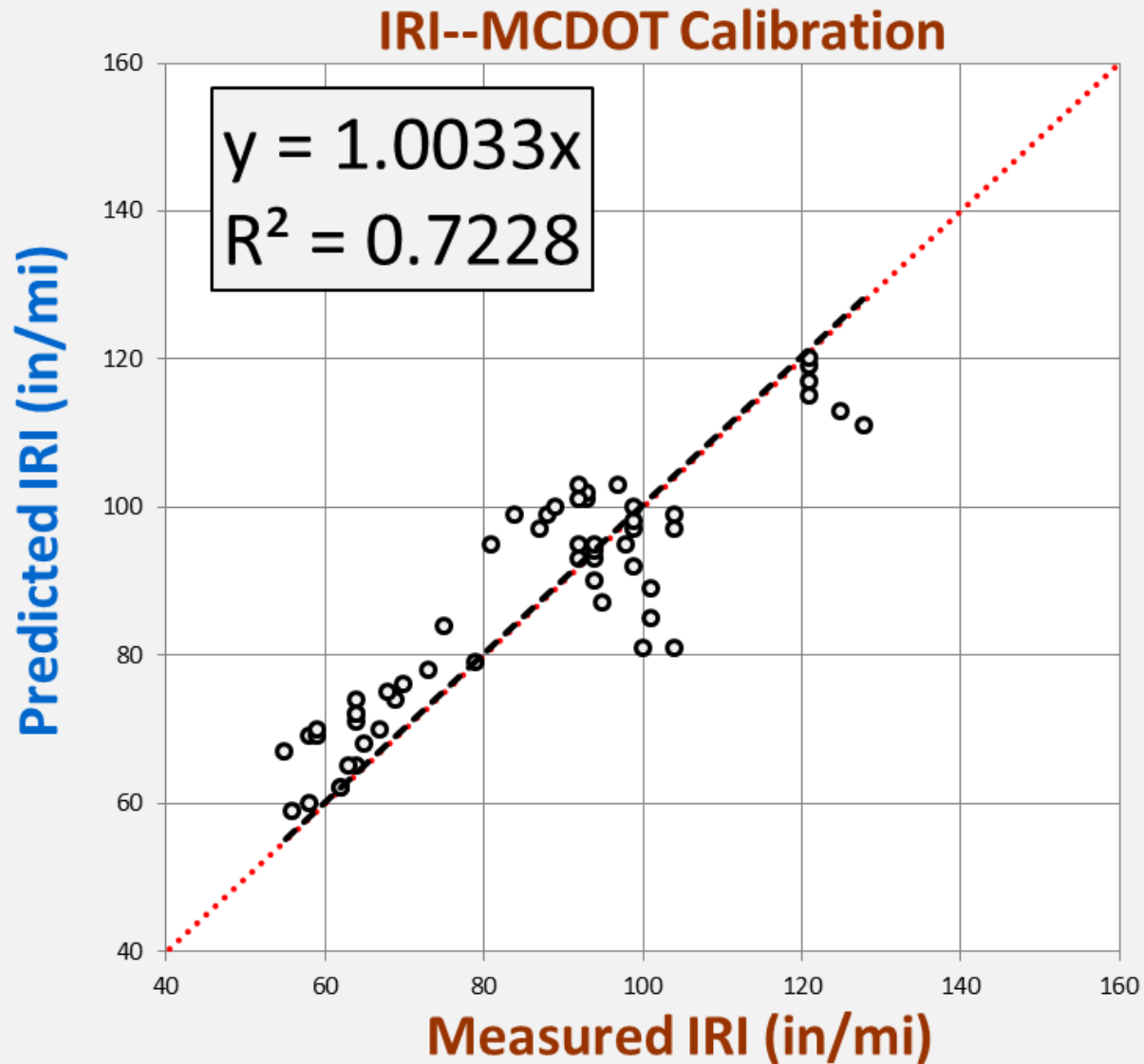


# Calibrated Parameters

	Parameter				
	C2	C4	BR1	BS1	BS1
	Bottom Up Cracking	IRI	Asphalt Rutting	Base Rutting	Subgrade Rutting
NAT'L	1.0	0.015	1.00	1.00	1.00
ADOT	4.5	0.028	0.69	0.14	0.37
MCDOT	2.0	0.033	0.69	1.00	1.00



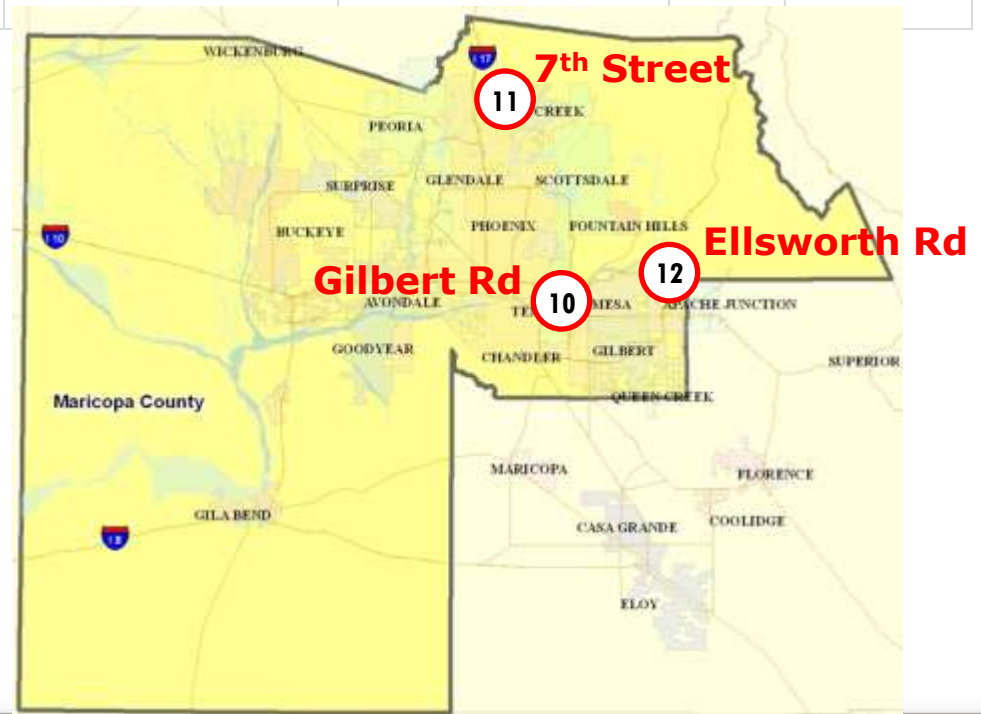
# IRI Data Plot Three Calibrations



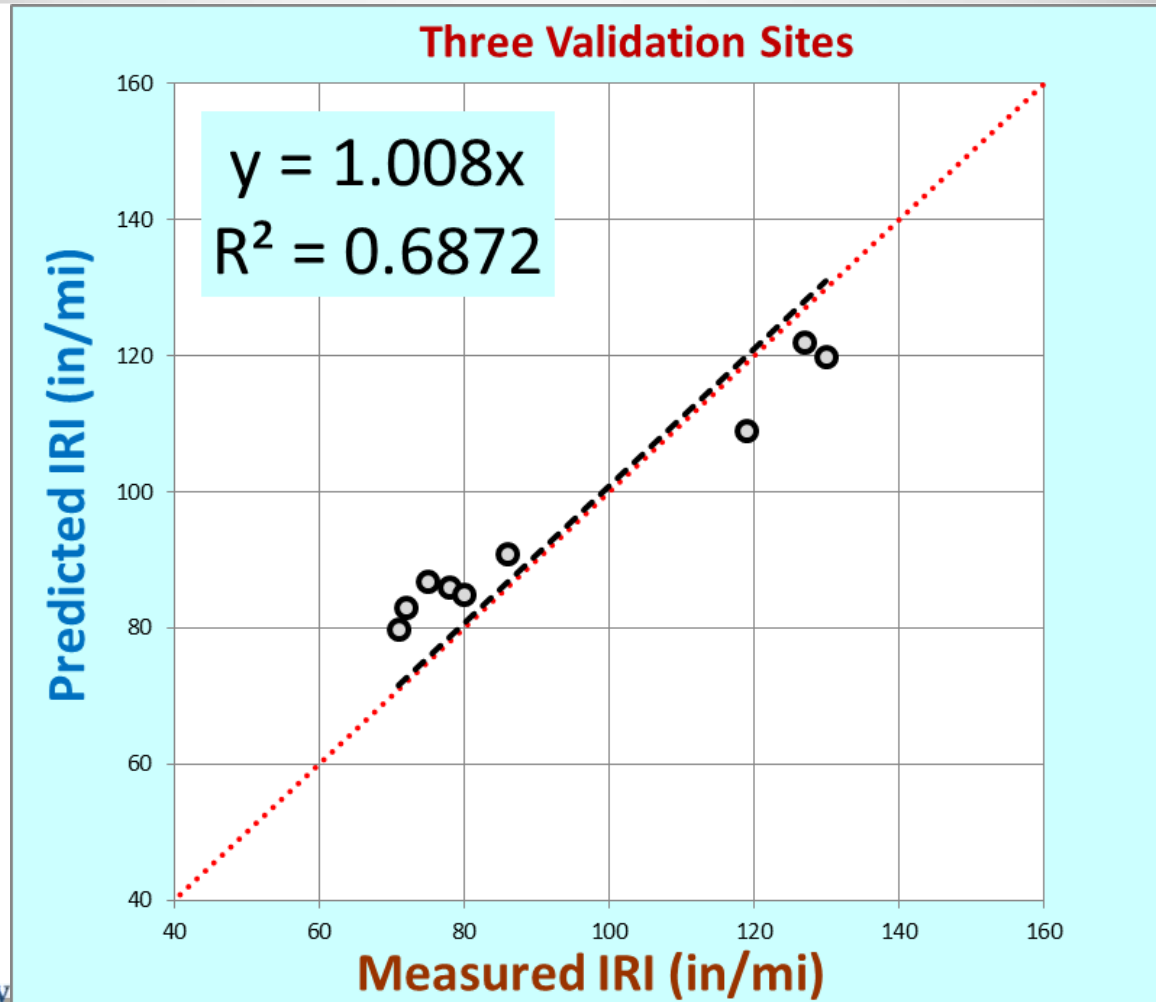
# Model Validation: Three Independent Sites

Other Sites	10	GS	Gilbert Road	South of Salt River	North of Salt River	NS	Jul-11
	11	ST	7th Street	Tanya Road	Desert Hills Dr	NS	May-11
	12	EU	Ellsworth Road	University Dr	Adobe Road	NS	Feb-06

- ❑ Data from 3 additional roadway projects were used for validation
- ❑ These three sites were never used in the calibration process







# Validation: IRI Data Plot with MCDOT Calibrations

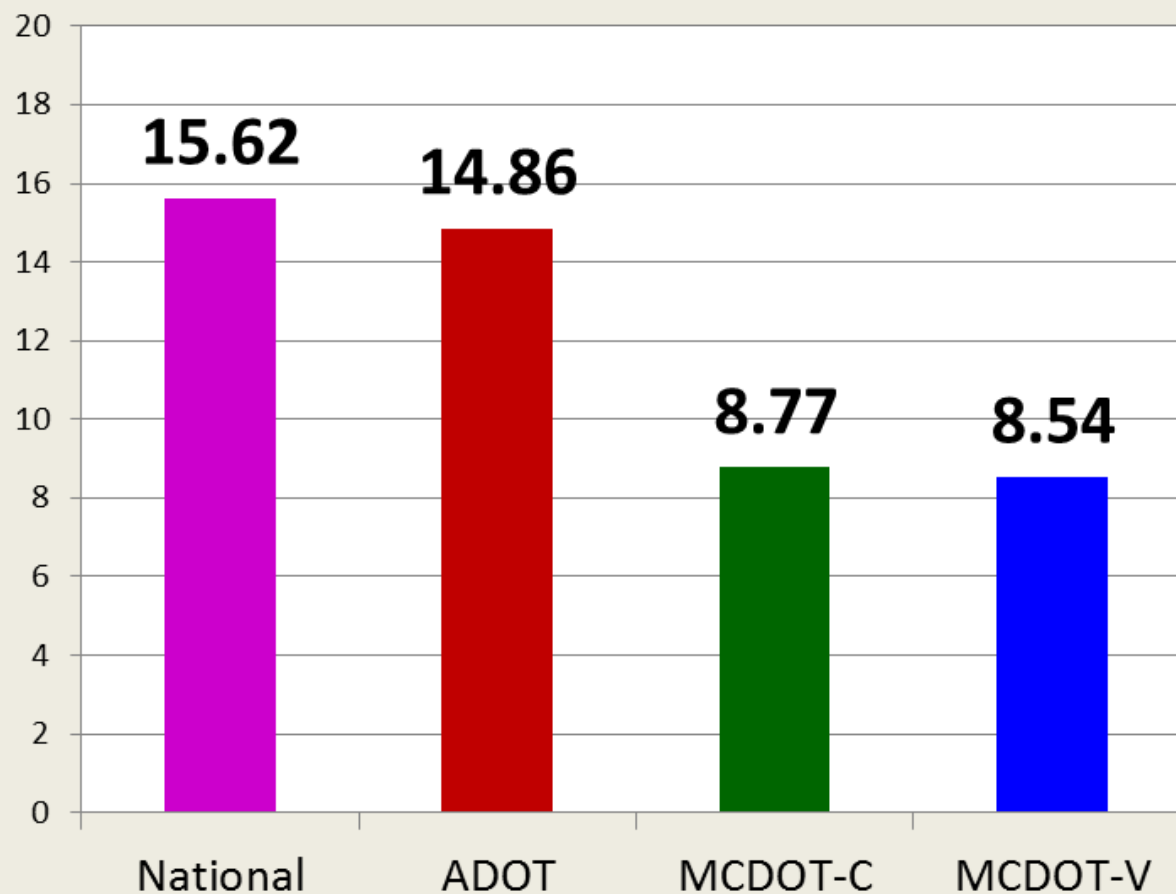


# Calibration and Validation — Summary


Legend:

-  National
-  ADOT
-  MCDOT-Calibration
-  MCDOT-Validation

$S_e \rightarrow \text{minimize}$



# Future Work

- 
- Continue monitoring the test sites and the implementation process of Pavement ME Design
  - Prepare an interim MCDOT Pavement Design Guide and start designing MCDOT pavements using it
  - Investigate the possibilities of modeling transverse cracking
  - Provide useful suggestions to AASHTO and ARA to solve the problems encountered while using the software



# Acknowledgements

- ASU
- ADOT
- ARA
- AASHTO
- Terracon
- MCDOT Traffic Group
- MCDOT Materials Lab
- MCDOT Pavement Management Group







# **Thank You!**

