ACCOUNTING FOR AGE HARDENING AND CLIMATE VARIABILITY IN FIELD STUDIES OF RUTTING IN HMA PAVEMENTS

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Advanced Asphalt Technologies, LLC

"Engineering Services for the Asphalt Industry"

Problem

Traditionally, it has been difficult to reconcile rutting data from a wide range of field projects into a single, coherent set of data for use in developing or validating rutting models and/or rutting tests.

Purpose

The purpose of this presentation is to describe how to approximately account for a variety of important factors and so help construct coherent sets of data on field rutting.

Scope

- Often neglected but important factors
- How to account for them
- Example data set
  - Without adjustments
  - With adjustments

Often Neglected but Important Factors in Field Rutting Studies

- Age-hardening
- Climate—*the details*
- Extreme rut depth values
- Accuracy of calculating rut rates
- Traffic speed
- Confounding

A Better Title:

Guidelines for the Analysis of Permanent Deformation in HMA Pavements from Multiple Projects

Data Sets for Example

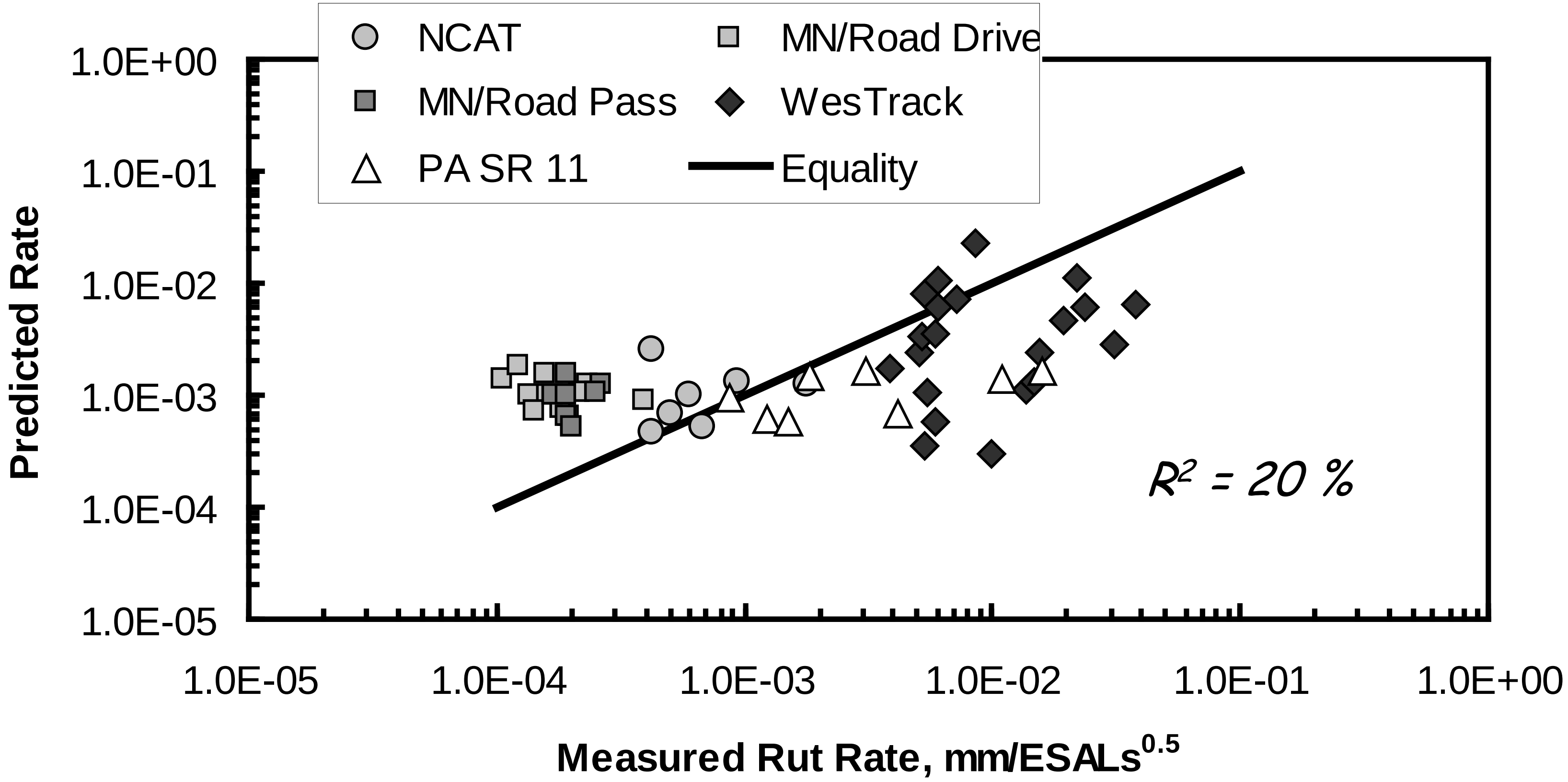
- NCAT first cycle (Brown et al., 2004)
- MNRoad (Mulvaney & Worel, 2002)
- WestTrack (Brown et al., 1998)
- PA SR11 & SR30 (Christensen & Bonaquist, 2002)
- Rutting data from NCHRP 547 (Witczak, 2005)

Resistivity/Rutting Model

$$T = 9.85 \times 10^{-5} \left(\mathrm{P} N_{equivalent} K_s \right)^{1.373} V_{QC}^{1.5185} V_{in-place}^{-1.4727} M$$

$$\mathrm{P} = \frac{\left(\left| G^* \right| / \sin \delta \right) S_a^2 G_a^2}{49 VMA^3}$$

Christensen's crazy!



Age-Hardening in Field Rutting Studies

- Age-hardening can be very significant
- The extent of age-hardening depends on time, temperature, air voids, depth
- The amount of binder age-hardening can vary greatly from study to study
- Must be accounted for

Accounting for Age-Hardening

- Need to estimate binder viscosity at about one-half of project life, 20 mm from surface
- Age-hardening can be accounted for only approximately, using two methods
  - Mirza-Witzak equation
  - Simple empirical approach

Mirza-Witzak Equation

- Mirza-Witczak equation developed on the basis of viscosity data, but can be applied approximately to G*/sin δ data
- Requires knowledge of in-place air voids, viscosity at 25 C

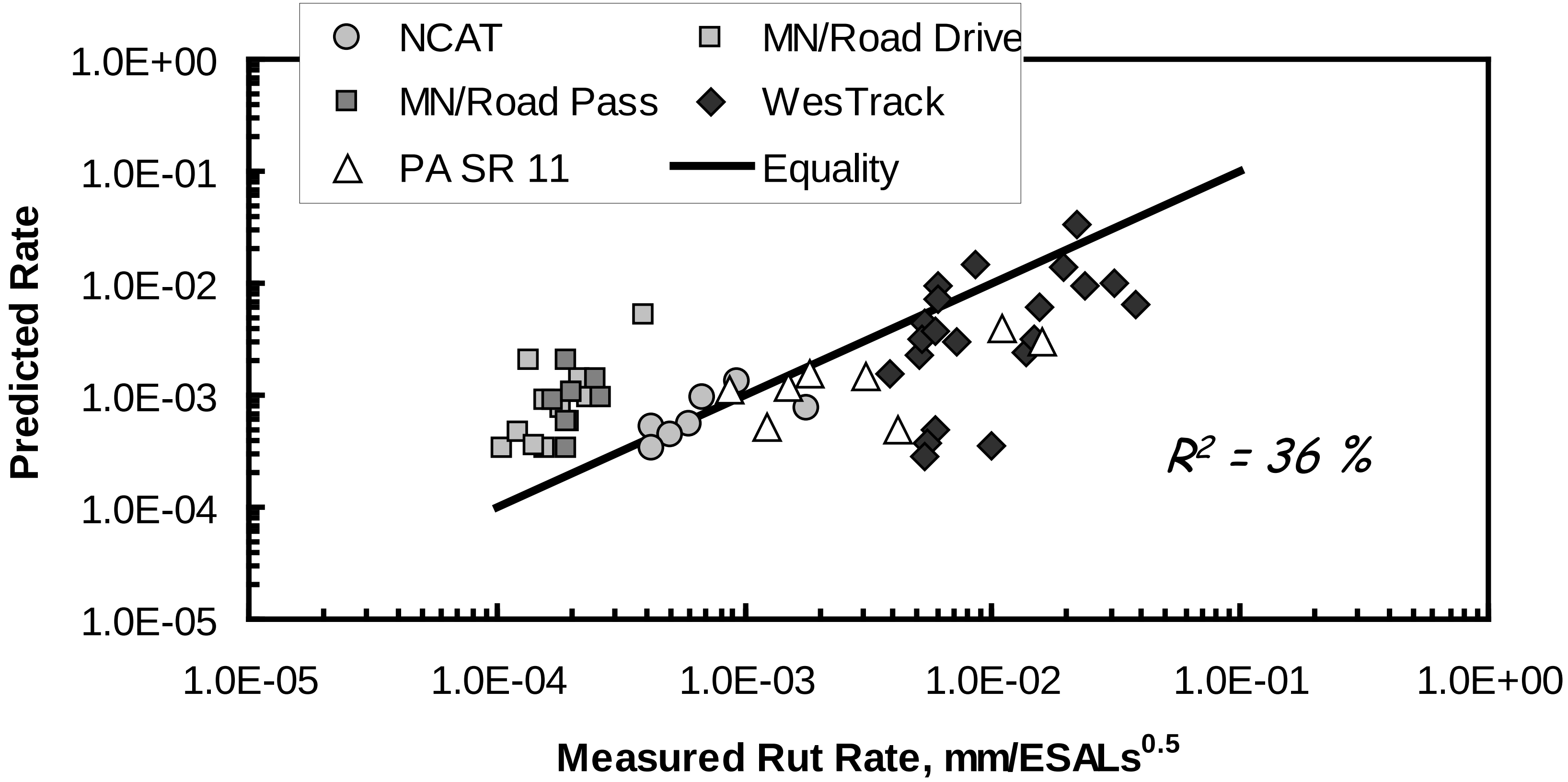
Simple, Empirical Approach

- Use age-hardening factor of 4.0x for long term projects—10 to 20 years
- Use age-hardening factor of 2.5x for short-term projects—1 to 2 years
- For temporary projects or when analyzing catastrophic failures, ignore age-hardening

Example Data

- NCAT: 2.5 x
- MNRoad: 4.0 x
- Westrack: 2.5 x and 3.5 x
- SR11 & SR30: 3.0 x

So what?


NCAT
MN/Road Drive
MN/Road Pass
WesTrack
PA SR 11
Equality
Predicted Rate
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
Measured Rut Rate, mm/ESALs$^{0.5}$
R^2 = 36 %

Climate Details

- Climate in field studies often characterized with long-term averages
- Using long-term averages OK if field study is long—say, 10 years or more
- Climate over the short term can vary significantly from long-term average
- Especially important when study only lasts a few months

Example Data

- Long-term averages OK for all data used in this example
- In earlier analysis, used Westrack replacement sections, which required adjustments because of very short term loading

Estimating Temperatures for Short Term Rutting Studies

- Find pertinent temperature records from NWS
- Calculate average temperature throughout project—use this as average annual temperature (AAT)
- Find site in same region with AAT close to the for study
- Extrapolate to find critical temperature

Extreme Rut Depth Values

- Very low rutting values (less than about 2 mm) can not be measured accurately
- Very high rutting values (greater than about 20 mm) represent non-linear behavior that is both difficult to model and not important from a practical point of view

Difficulties in Calculating Rutting Rates

- Rutting rates often calculated as a function of traffic levels
  - mm/ESALs
  - mm/square root of ESALs
  - mm/cube root of ESALs
- In reality, rut depth as a function of traffic is complex and cannot be expressed so simply

Power-law Exponents for Rutting Eight NCAT Test Sections

$$\text{Rut Depth (in.)} = A \times ESALs^{B}$$

Values of "B":

0.624	0.899
0.704	0.848
0.766	1.057
0.262	0.299

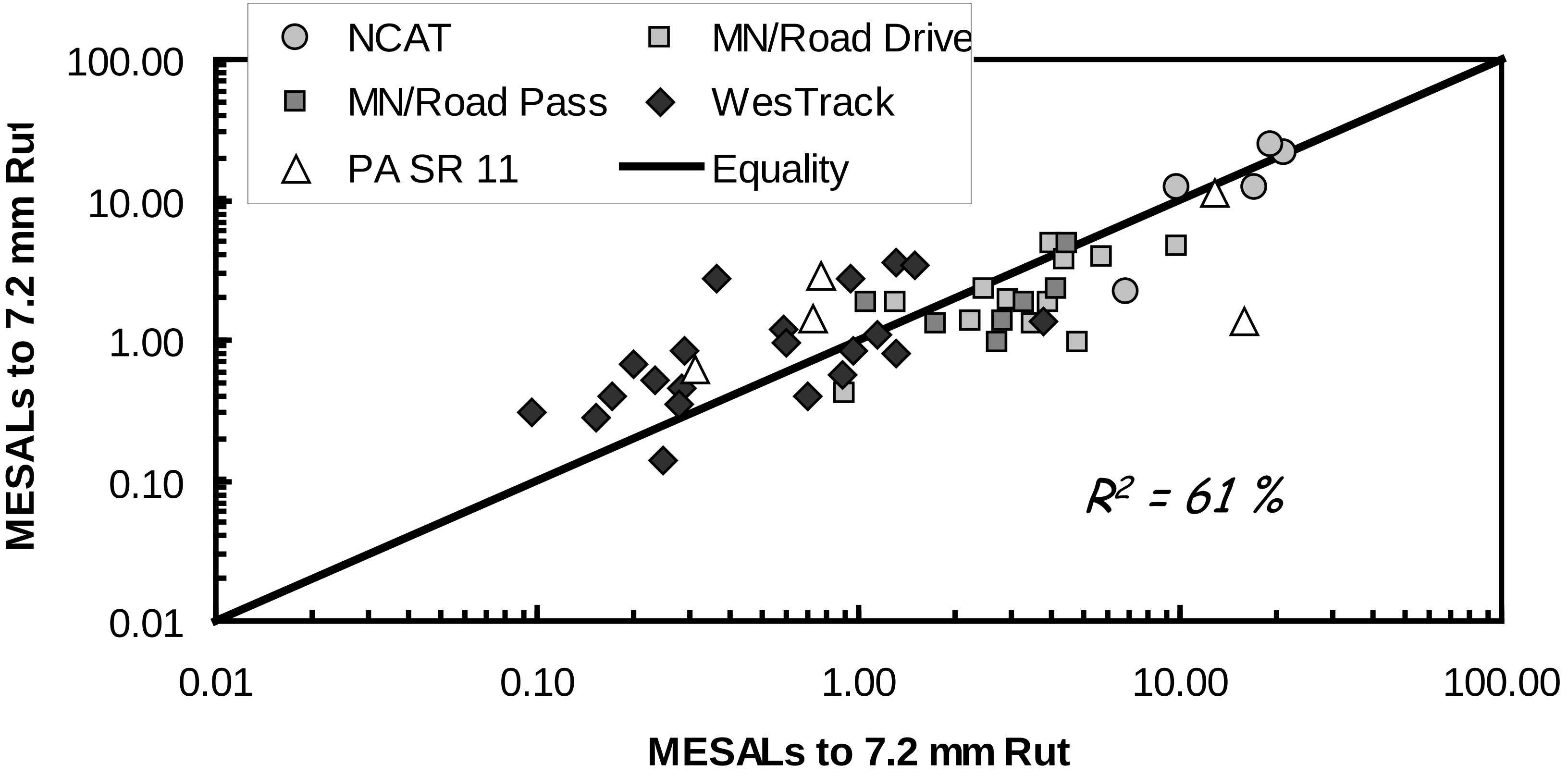
An Improved Approach

- Estimate ESALs to a given allowable rut depth
  - 10 to 12 mm maximum rut depth
  - Include factor of safety: 7.2 mm maximum
- Curve fit observed rutting as function of traffic to determine maximum ESALs

Example Data

- NCHRP 547 Report included measured rut depths as a function of ESALs for NCAT, MNRoad and WesTrack
- Already had SR11/SR30 rutting data
- Calculated ESALs to 7.2 mm rut depth from these data

I'm still not convinced…



Traffic Speed

- Traffic speed can vary significantly among rutting studies
- Differences in traffic speed are equivalent to a difference in binder and mix modulus
- Can estimate the effect of traffic speed

Traffic Speed Adjustment

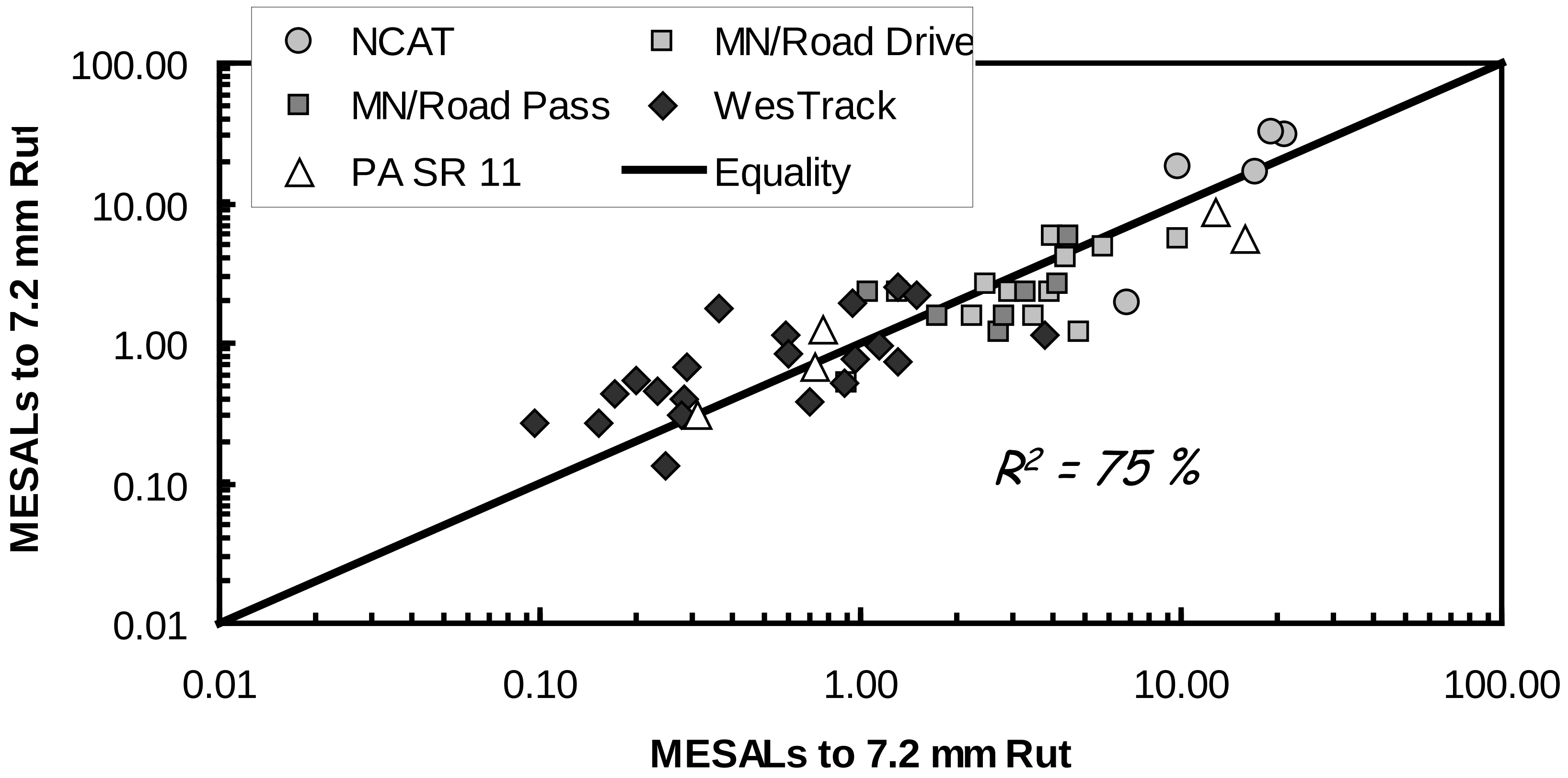
$$G^*/\sin\delta\,(adjusted) = (v/70)^{0.8} \times G^*/\sin\delta$$

- Adjusted $G^*/\sin\delta$ increases with increasing traffic speed
- Correction *Ks* is empirical but accurate, based upon measurements on a wide range of binders close to grading conditions

Traffic speeds and adjustments

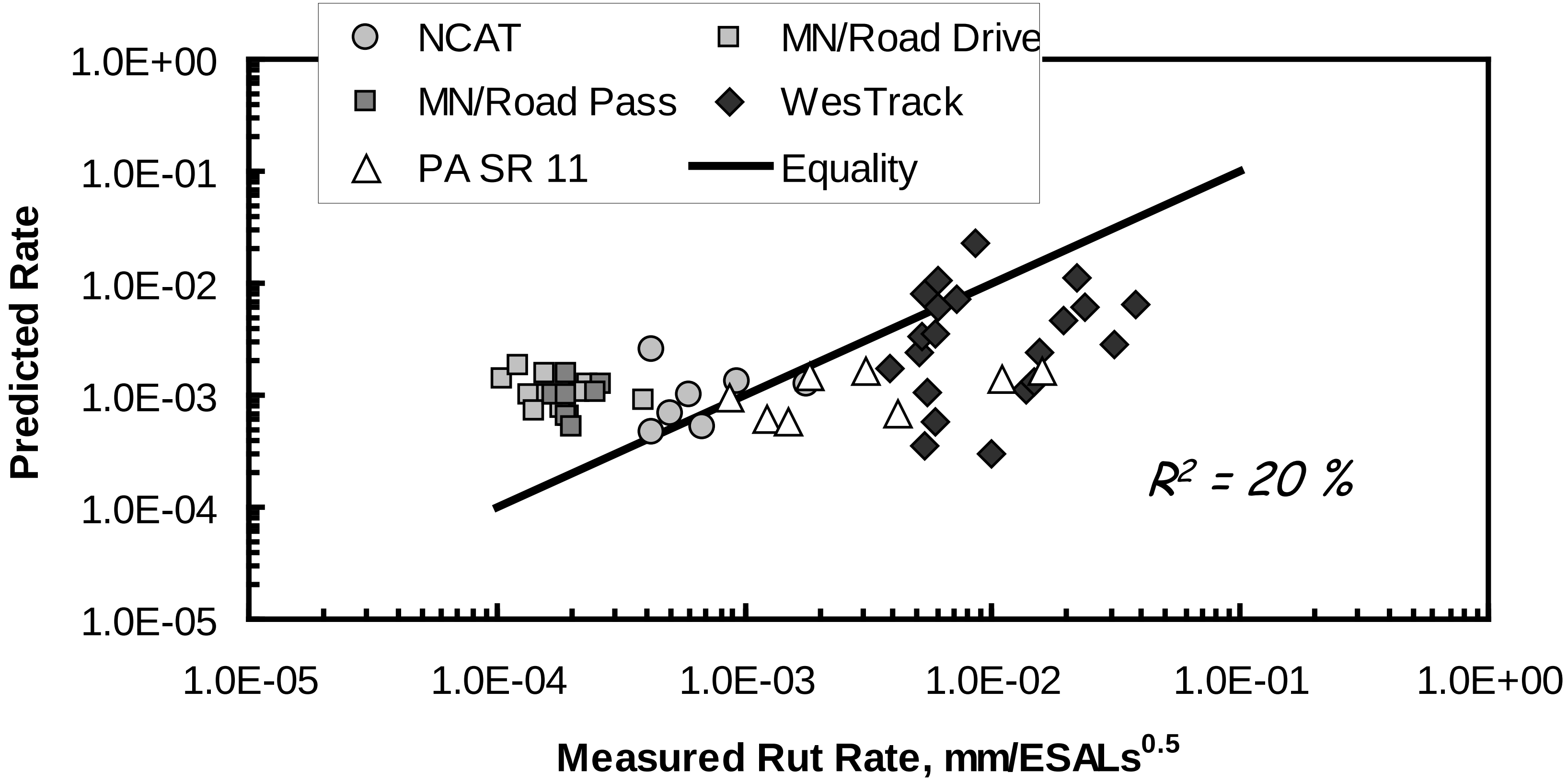
Project	Speed, mph	Ks
NCAT	45	1.02
MNRoad	60	1.29
WesTrack	40	0.93
SR 11/SR 30	25	0.64

Where's Matt?



NCAT
MN/Road Drive
MN/Road Pass
WesTrack
PA SR 11
Equality
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
MESALs to 7.2 mm Rut
MESALs to 7.2 mm Rut
R2 = 75 %

This is where we started:



Confounding

- Confounding occurs when two or more distinct factors cannot be statistically separated
- Example 1: a project in a study contains HMA mixtures with mostly modified binders and exhibiting low in place air voids

Confounding

- Example 2: a project in a study contains HMA mixtures with high VMA, relatively soft binders and high in-place air voids
- Example 3: a project in a study contains HMA mixtures containing fine aggregate with marginal FAA and chemically modified binders

Confounding: How to deal with it

- Plan carefully—consult with statisticians
- In compiling existing studies confounding cannot always be avoided
  - Characterize confounded factors separately
  - Include projects that will help decouple confounded factors

Example Data

- NCAT data consists of HMA with mostly polymer modified data, which also exhibited low in-place voids
- Inclusion of wider range of data helped reduce confounding

Conclusions & Recommendations

Field studies of rutting in HMA pavements can be combined and analyzed successfully if attention is paid to various complicating factors.

Acknowledgments

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- Ray Bonaquist