LRRB INV 828
Local Road Material Properties and Calibration for MnPAVE

Task 4 Report
Calibration

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Introduction

As originally conceived, model calibration would have made use of pavement management data from cities and counties around the state. Due to incomplete data and difficulty extracting the needed data from various pavement management systems, two alternate sources of data were selected. In 2006 the Minnesota Department of Transportation (Mn/DOT) hired a consulting firm to perform falling-weight deflectometer (FWD) testing on county state aid highways (CSAH) throughout the state. In addiction to the deflection data, structural and traffic data were collected for this project. Mn/DOT also collects pavement distress data on CSAH routes. A spatial query was conducted to select routes that had significant distress as well as deflection, structural, and traffic data.

Figure 1 shows the CSAH pavements that were included in the 2006 data collection project. These pavements have sufficient traffic and structural data to conduct MnPAVE simulations. Figure 2 shows the portions of those pavements that had fatigue or rutting failures reported in 2006. Of the CSAH pavements under consideration, fatigue failures were only reported in Dodge and Mahnomen Counties. A new fatigue calibration based on this data was not feasible for two reasons:

1. The data set is too small.
2. The traffic level on the pavements with fatigue failures was lower than many similar pavements with no fatigue damage reported. This suggests that the failures may have been due to factors other than pavement design (such as material or construction problems). In addition, the 2002 MnPAVE fatigue equation predicted low levels of fatigue damage for these pavements.

As a result the 2006 CSAH data was used to re-validate the existing MnPAVE fatigue transfer function.

There were sufficient rutting failures recorded to re-calibrate the MnPAVE rutting function for local roads. The calibration process is described in the next section.

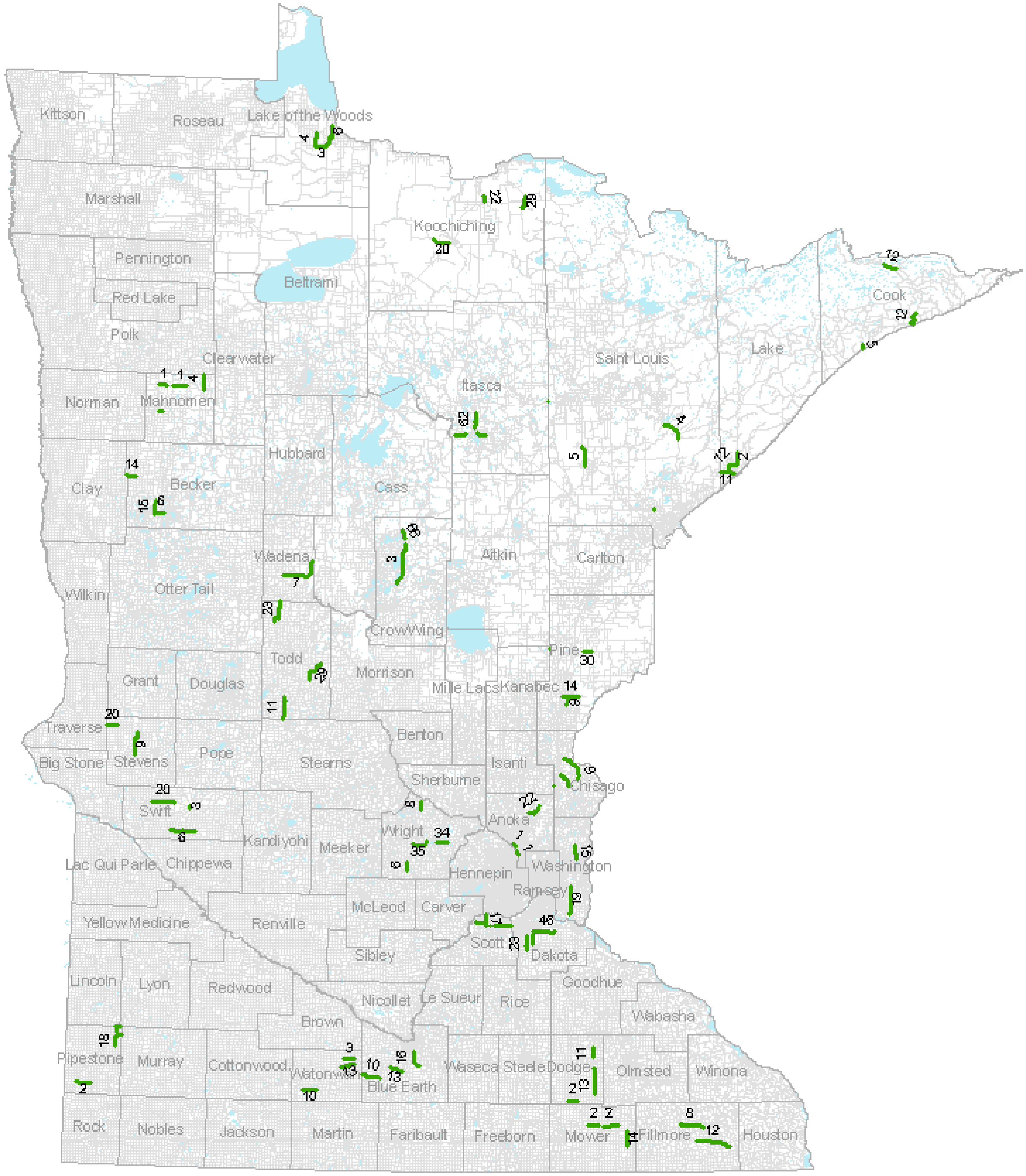

Figure 1: Minnesota CSAH Routes with Traffic and Structural Data from 2006

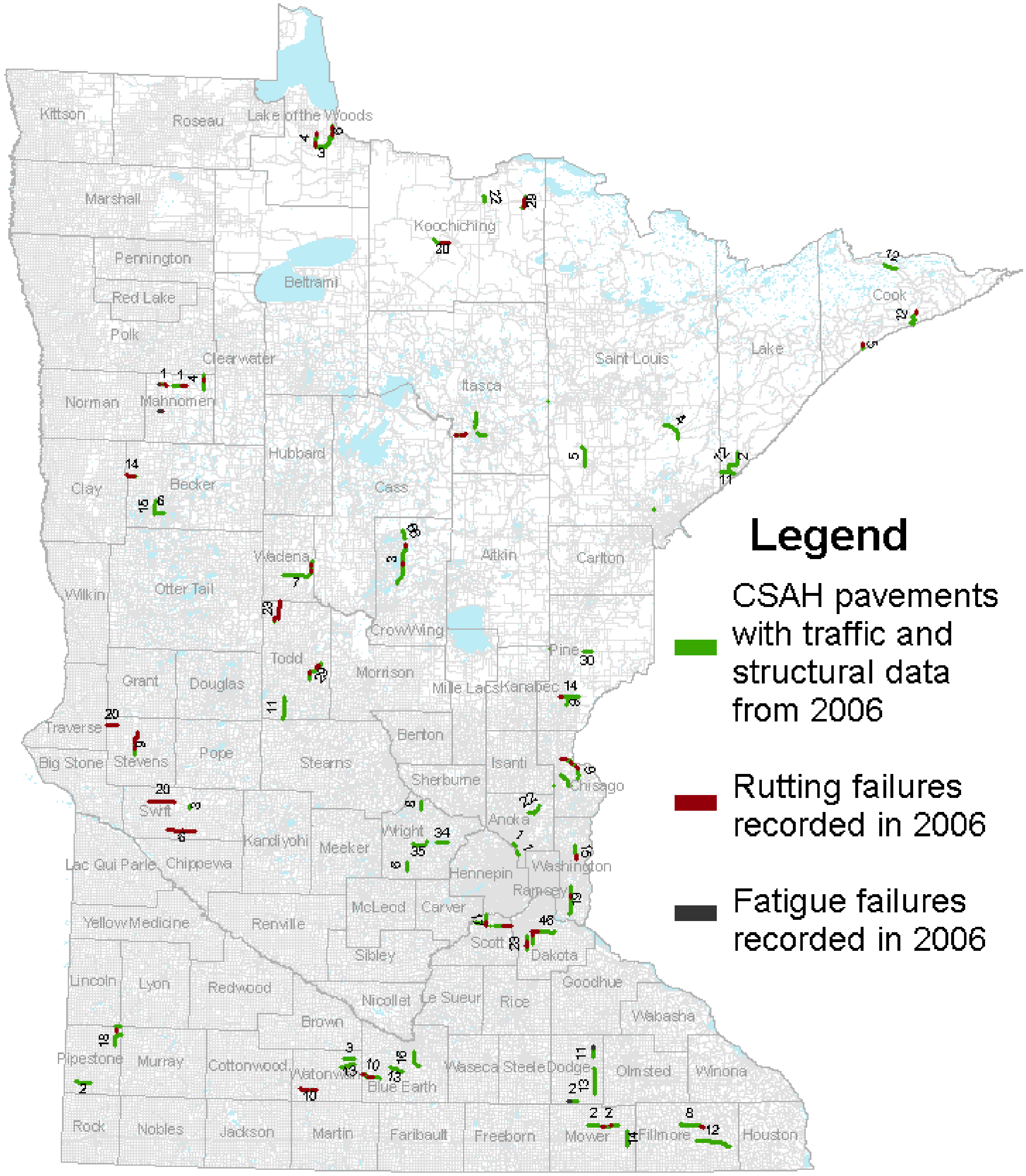

Figure 2: Minnesota CSAH Routes with Traffic and Structural Data, Rutting and Fatigue Failures in 2006

Calibration and Validation of MnPAVE Rutting and Fatigue Models

The two performance measures used in MnPAVE are fatigue cracking and rutting. There is a transfer function for each measure to predict the number of repetitions of a given axle load the structure can withstand before it fails. Equations 1 through 3 make up the MnPAVE fatigue model. Equation 4 describes the MnPAVE rutting model.

Fatigue (based on Asphalt Institute model [1]):

$$N_F = C K_{F1} \varepsilon_h^{K_{F2}} E^{K_{F3}} \qquad (1)$$

where:

- N_F = number of repetitions to fatigue failure ("Allowed Repetitions")
- C = correction factor (See Equation 3)
- S = shift factor (278 for 2002 MnPAVE calibration)
- K_{F1} = SK_{L1} (Design K_1)
- K_{L1} = 4.32 x 10^{-3} (Laboratory K_1)
- K_{F2} = -3.291
- K_{F3} = -0.854
- ε_h = horizontal tensile strain at the bottom of the HMA
- E = HMA dynamic modulus (psi)

Correction Factor:

$$C = 10^M \qquad (2)$$

$$M = C_{F1}\left(\frac{V_b}{V_a + V_b} + C_{F2}\right) \qquad (3)$$

where:

- V_a = volume of air voids (%)
- V_b = volume of asphalt (%)
- C_{F1} = 4.84
- C_{F2} = -0.69

For MnPAVE calibration, V_a = 8.0% at bottom of HMA

Rutting (based on the "Illinois" rutting model [2])

$$N_R = K_{R1} \varepsilon_v^{K_{R2}} \tag{4}$$

where:

N_R = number of repetitions to rutting failure ("Allowed Repetitions")
K_{R1} = 0.0261 (2008 MnPAVE calibration)
K_{R2} = -2.35
ε_v = vertical strain at the top of the subgrade

The "Allowed Repetitions" from Equations 1 and 4 are used to predict the total rutting and fatigue damage over the life of the pavement using a summation known as "Miner's Hypothesis" [3] as shown in Equation 5. For the current calibration the year is divided into 5 seasons to account for differences in material properties due to temperature and moisture conditions. Traffic is defined by applications of an 18,000 lb (80 kN) equivalent single axle load (ESAL). MnPAVE also has the option of defining a load spectrum comprised of different axle types and load levels.

$$Damage = \sum_j \sum_i \frac{n_{season_i, load_j}}{N_{season_i, load_j}} \tag{5}$$

Where:

Damage = a factor indicating relative damage to the pavement where values ≥ 1 indicate failure.
N = Allowed repetitions of $load_j$ during $season_i$ (from equations 1 and 4)
n = Applied repetitions of $load_j$ during $season_i$

To simplify the calibration process, annual composite values for asphalt modulus, horizontal strain at the bottom of the asphalt layer, and vertical strain at the top of the subgrade were calculated using Equation 6.

$$\text{Annual Composite} = F_D \sum_{i=1}^{5} \frac{Value_i Days_i}{365} \tag{6}$$

Where

Value = seasonal strain or modulus value
Days = season length (days)
F_D = Damage Factor (minimizes error between composite and Miner's Hypothesis damage)

Seasonal and composite values for the CSAH Study locations are shown in Figures 3, 4 and 5.

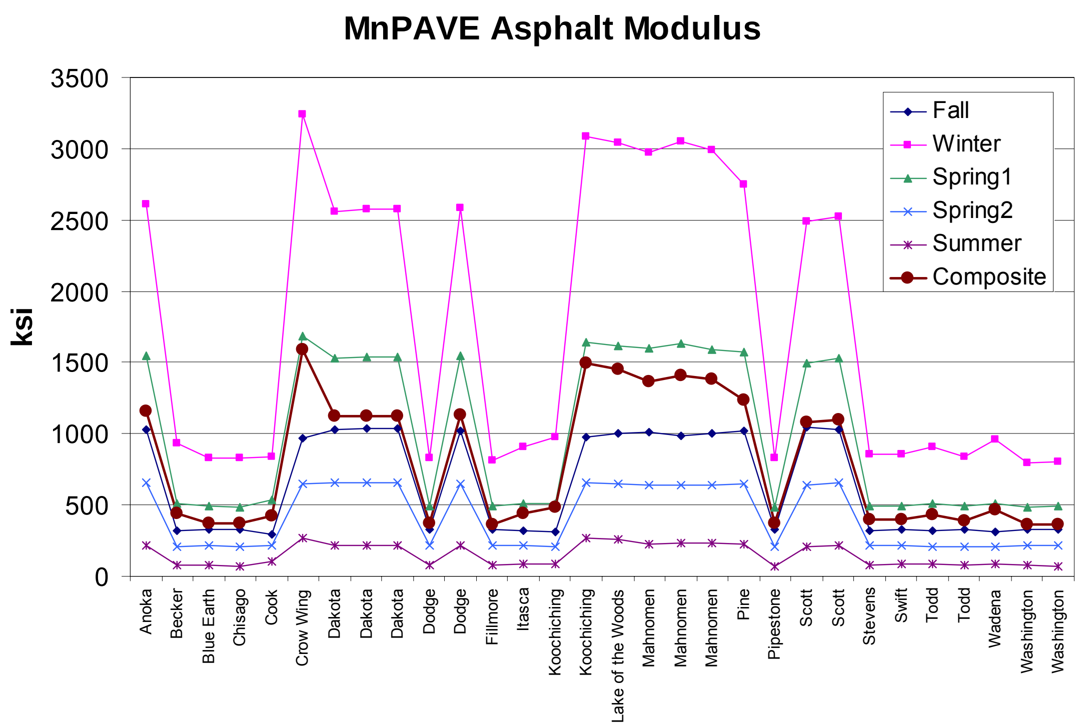

Figure 3: Annual Composite Asphalt Modulus

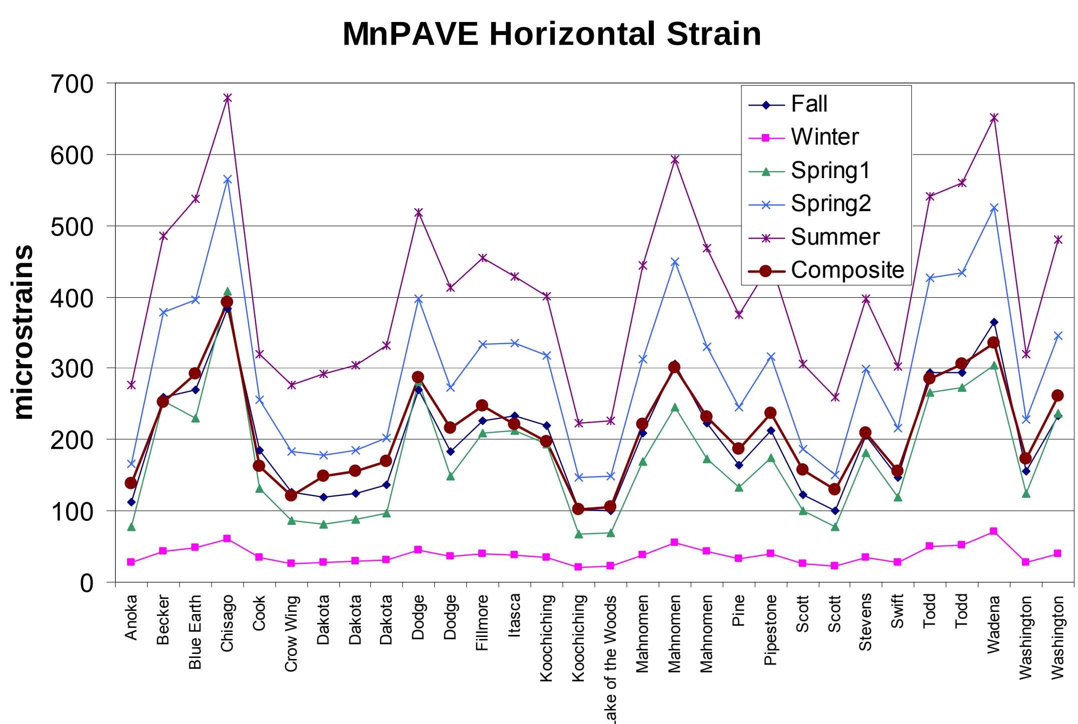

Figure 4: Annual Composite Horizontal Strain

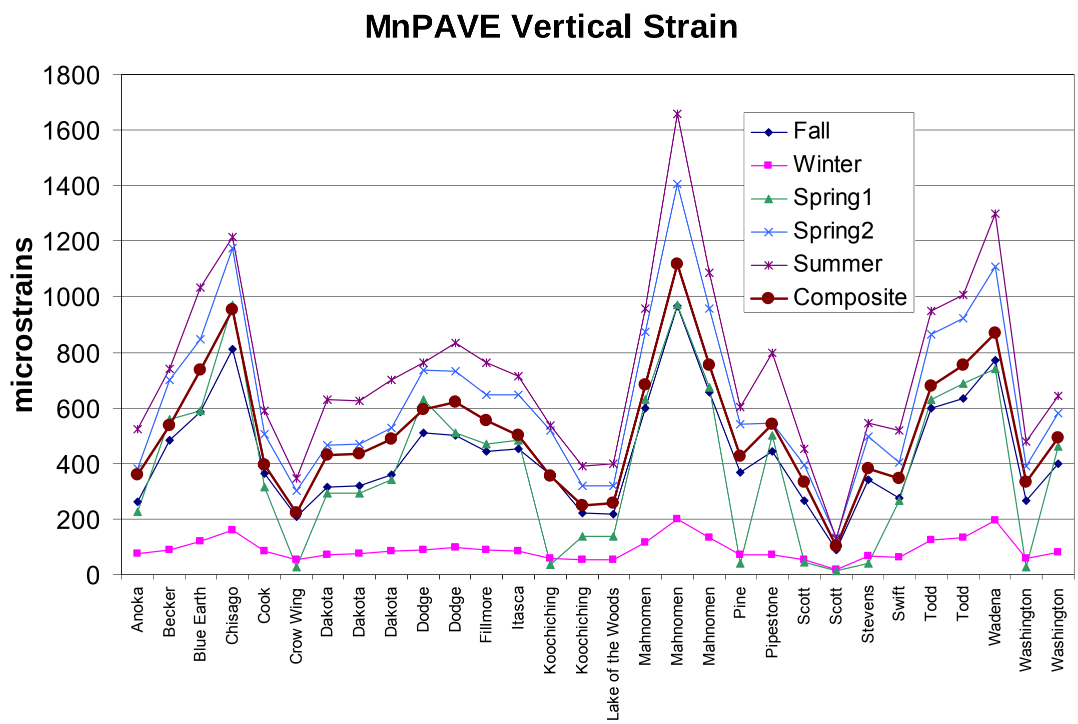

Figure 5: Annual Composite Vertical Strain

To calibrate/validate Equations 1 and 4, they were modified to exclude K_{F1} and K_{R1}, respectively as shown in Equations 7 and 8. This allows the X axis values to be plotted against applied ESALs and the calibration lines have slopes equal to K_{F1} and K_{R1}, respectively.

$$\text{X axis value} = C\varepsilon_h^{K_{F2}} E^{K_{F3}} \tag{7}$$

$$\text{X axis value} = \varepsilon_v^{K_{R2}} \tag{8}$$

Figure 6 shows an updated validation of the 2002 MnPAVE fatigue equation. As noted above, there were insufficient fatigue failures reported in 2006 to update the calibration. The data used includes simulations of the CSAH pavements analyzed in 2006 and selected pavements from Minnesota Department of Transportation Investigation No. 183 (Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota) [4]. Figure 7 shows the test locations used in Investigation 183. The locations used to validate the MnPAVE transfer functions include 1 through 9, 15 through 18, and 101 through 109. Fatigue and rutting data were not available for these pavements, but traffic, structure and present serviceability rating (PSR) are available. PSR is a measure of ride quality. Most of the Investigation 183 data concludes with PSR values between 2.4 and 3.25 (values between 2.0 and 2.5 are commonly assumed to indicate that a pavement is in need of rehabilitation).

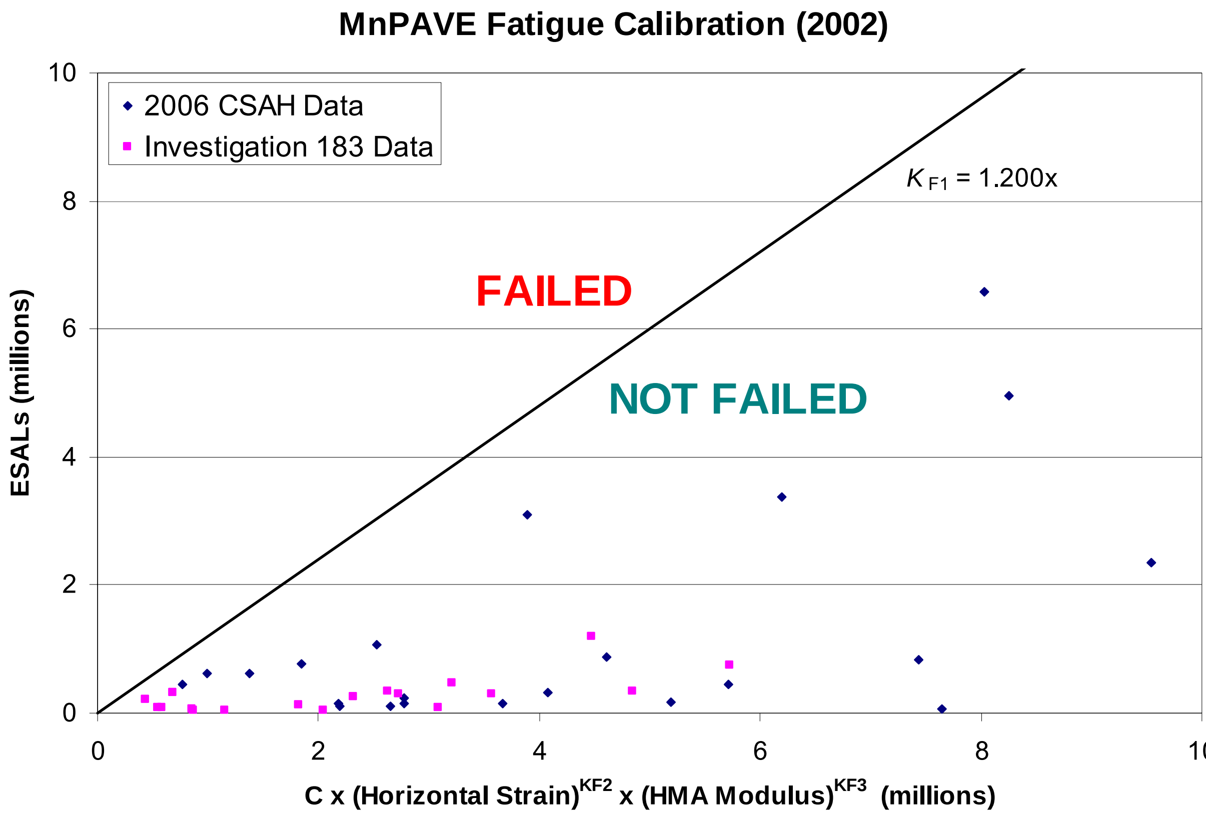

Figure 6: MnPAVE Fatigue Calibration (2002)

Figure 8 shows the 2008 MnPAVE rutting calibration and validation. The new K_{R1} line was fitted to data from CSAH pavements with rutting failures reported in 2006. The same Investigation 183 pavements used to validate the fatigue equation were used to validate the rutting equation.

Conclusions

Given that fatigue failures are rare in Minnesota the fact that all of the pavement data from the 2006 CSAH analysis and Investigation 183 falls below the K_{F1} line is assumed to be a sufficient validation of the 2002 MnPAVE fatigue calibration.

The rutting calibration used data from CSAH pavements with rutting failures reported in 2006. The K_{R1} line was fitted assuming 50% reliability. In MnPAVE pavement the layer thickness and modulus can be adjusted to provide higher reliability for pavement designs. The Investigation 183 data provides a reasonable validation of the 2008 MnPAVE rutting equation.

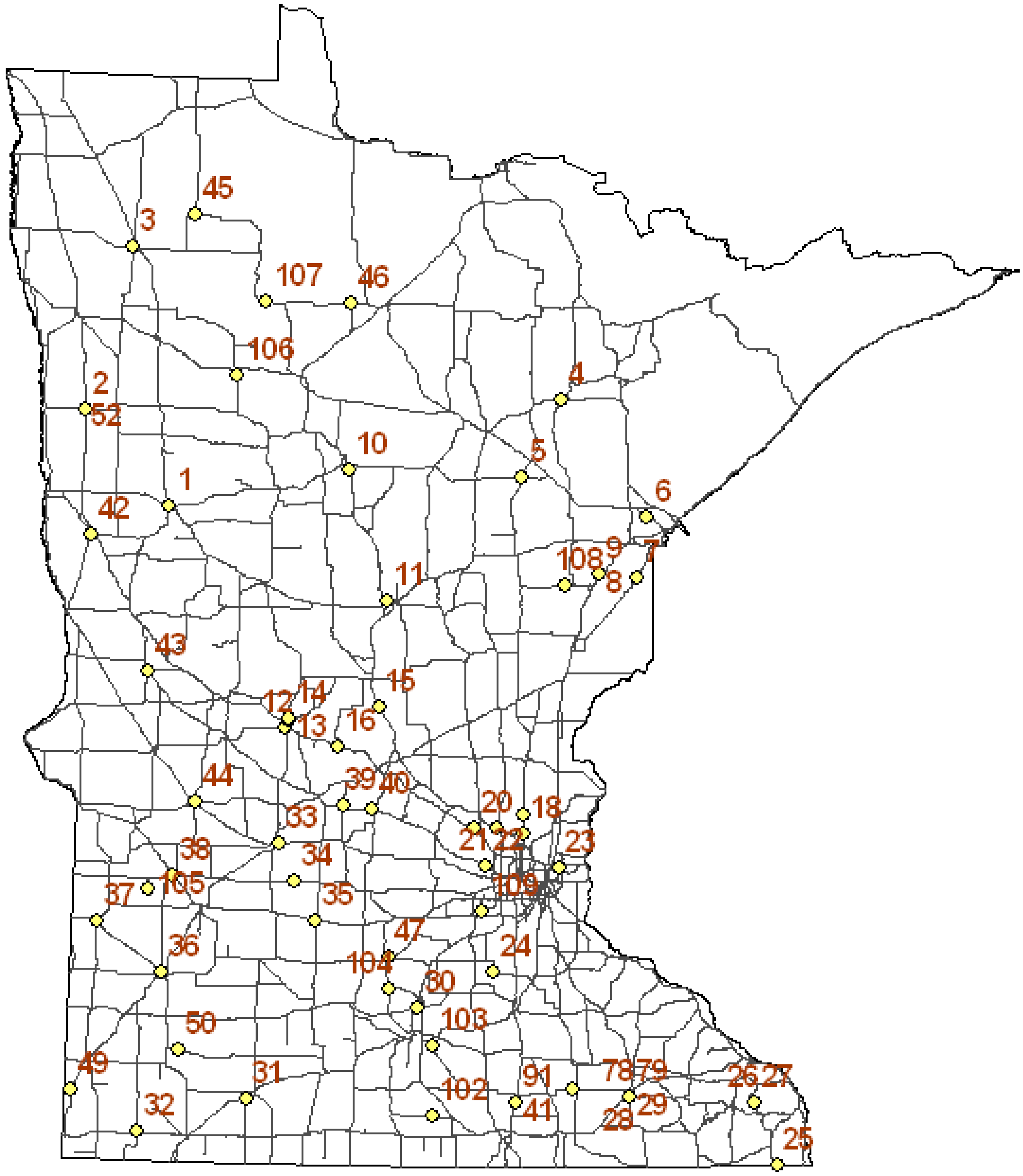

Figure 7: Investigation 183 Locations

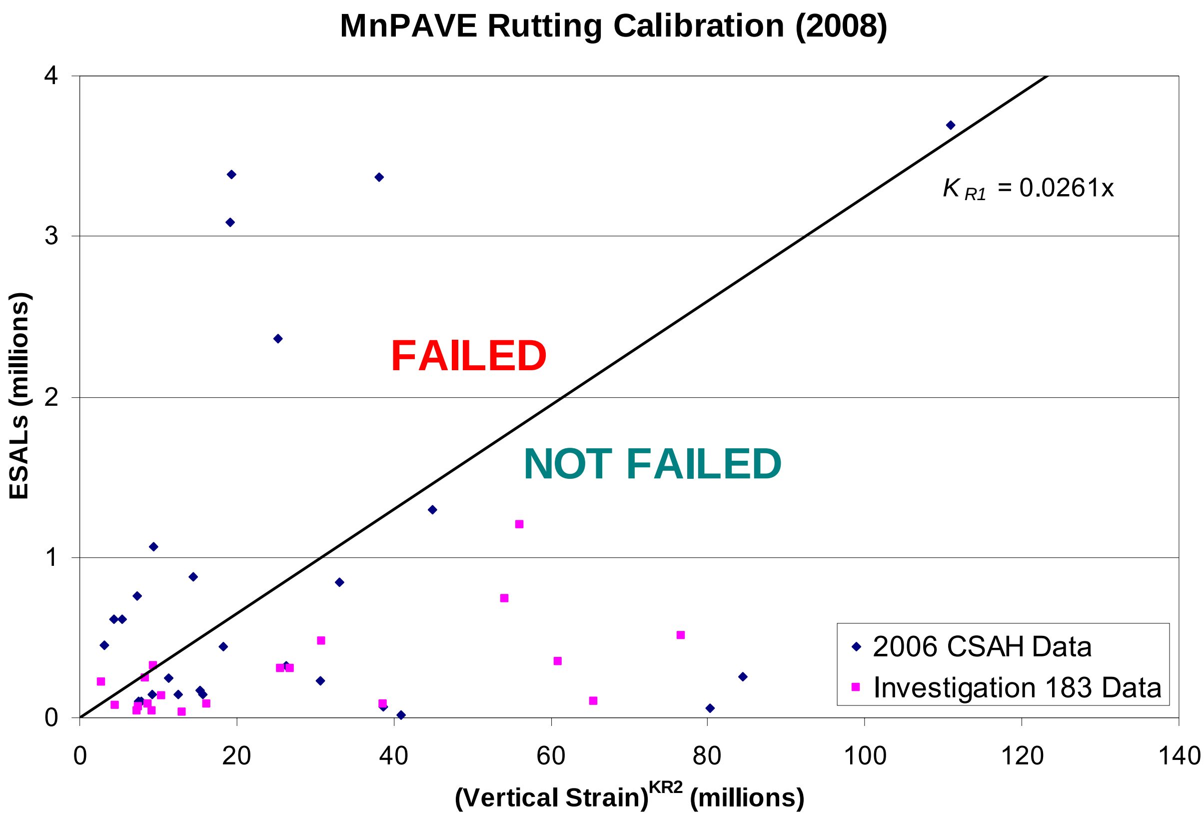

Figure 8: MnPAVE Rutting Calibration (2008)

References

1. "Mechanistic-Empirical Evaluation of Mn/ROAD Mainline Flexible Pavement Sections IHR-535 Cooperative Evaluation of Mn/ROAD Test Results to Illinois Conditions," Illinois Cooperative Highway and Transportation Research Programs Department of Civil Engineering, University of Illinois at Urbana-Champaign and Illinois Department of Transportation with the cooperation of the Minnesota Department of Transportation Mn/ROAD Research Project (Private Communication - Not for Publication) April 1998

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   Finn, F., Saraf, C.L., Kulkarni, R., Nair, K., Smith, W., and Abdullah, A., "Development of Pavement Structural Subsystems," NCHRP Report 291, National Cooperative Highway Research Program, Transportation Research Board, 1986.

2. Thompson, M.R., "ILLI-PAVE Based Full-Depth Asphalt Concrete Pavement Design Procedure," Proceedings, Sixth International Conference on Structural Design of Asphalt Pavements, Ann Arbor, MI, 1987.

3. Miner, Milton A., "Estimation of Fatigue Life with Particular Emphasis on Cumulative Damage," Metal Fatigue, Sines and Waisman, Eds., McGraw Hill, 1959, pp. 278-289.
4. Lukanen, E.O., "Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota," Investigation No. 183 Final Report, Minnesota Department of Transportation, 1980.