Impact of Variation of Materials & Construction Factors on Performance

Preliminary Study: Task Order 10
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Pavements = Variation
How much does variation of Materials & Construction affect performance?
Layer Thickness Variation: Impact?

HMA

PCC
PCC Strength & HMA Smoothness Variation: Impact?

- Mean (μ) = 677 psi
- Standard Deviation (σ) = 65 psi
- Sample Size (n) = 270 tests*
- Coefficient of Variation (COV) = 9.6%

*Note: The asterisk indicates the sample size.
HMA OL Field Performance Variability!

Mixture types "D" and "E" (Districts 2 to 9)

Percent Sections Failed

Cumulative ESALs, millions

"D" mix OL 1
"E" mix OL 1
"D" mix OL 2
CRCP Field Performance Variability!
Overview

- **Simulated construction** of 6-mile highway projects of JPCP & HMA.

- **M&C variations** “along the project” included (thickness, material properties, initial IRI)

- **M&C variations NOT considered:**
  - Between “as-design” and “as-built” (design & as-built thickness).
  - Associated with testing.
Overview

- This study included only “variations along the project”.
- The impact of these variations on performance was demonstrated using simulation techniques using models from the new AASHTO MEPDG.
JPCP Performance MEPDG Models

IRI (smoothness)

Joint Faulting

Transverse Cracking
HMA Performance MEPDG Models

IRI (smoothness)

Rutting

Fatigue Alligator Cracking
Calibrated using National LTPP database + other data.

Calibrations being repeated by SHAs show good prediction. (WI and Utah)

Sections are 500 ft long, a “unit” of prediction.

MEPDG models for fatigue HMA & PCC cracking, rutting, joint faulting, and IRI are actually predicting performance of “units” of pavement.
Illustration: Variation Along Project

Note right lane, no repairs yet

Note right lane less than a mile away, many repairs
JPCP Example

Using Actual Wisconsin Project & Extensive Variation Data Collected from 8 Wisconsin projects
JPCP Project

- Wisconsin US 18 (17 miles from Lone Rock, WI)
- Constructed 1989
- 10-in JPCP, (dowels included)
- Aggregate base (low fines, 2.3%)
- Subgrade A-1-b
- Joint spacing random (uniform 15-ft. used)
M&C Factors Included JPCP

- Slab thickness
- PCC mixture: strength (correlated with modulus of elasticity)
- Initial smoothness (IRI)
WI M&C Initial Smoothness Example

An estimate of the variance of initial smoothness was calculated from Wisconsin QA data based on eight projects.

- 8 projects ranging in total length from 1.5 to 10 miles.
- “Units” for measurement of IRI were 0.1-mile long by one traffic lane. There were a total of 1104 “units” of profile measurement.
- Inside and outside traffic lane were measured.
- Inner and outer wheel paths were measured.
## Analysis of Variance IRI Units

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Statistic</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Projects</td>
<td>7</td>
<td>36917</td>
<td>5274</td>
<td>83.71</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Units</td>
<td>544</td>
<td>88470</td>
<td>163</td>
<td>2.58</td>
<td>Highly Significant</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
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</tr>
<tr>
<td>Lane</td>
<td>1</td>
<td>25</td>
<td>25</td>
<td>0.40</td>
<td>Not Significant</td>
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<td></td>
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<td>Error</td>
<td>551</td>
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<td>Corrected Total</td>
<td>1103</td>
<td>160129</td>
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<td></td>
</tr>
</tbody>
</table>

\[ \text{Std Dev} = \sqrt{163} = 13 \text{ in/mile} \]
Simulated Initial IRI – 60 Units

Mean = 70 in/mile
Std Dev. = 13 in/mile

Mean = 70 in/mile
Std Dev. = 13 in/mile

Frequency

IRI, in/mi

35 50 65 80 95 110 125 140

0 2 4 6 8 10 12 14 16
An estimate of the variance of slab thickness was calculated from Wisconsin QA data based on 6 projects.

- 6 projects ranging in total length from 1.5 to 10 miles.
- “Units” for measurement of slab thickness were 500-ft long by one traffic lane. There were a total of 388 “units” of thickness measurement.
- Inside and outside traffic lane were measured.
- 4 replicates within each lane were measured.
Simulated Slab Thickness – 60 Units

Mean = 10-in
Std Dev. = 0.33-in
An estimate of the variance of concrete strength (28-days) was calculated from Wisconsin QA data based on 4 projects.

- 4 projects ranging in length from 1.5 to 10 miles.
- 43 lots (essentially daily production)
- 297 “Units” or sublots for measurement of concrete strength were 500-ft long.
- 2 replicate cylinders within each batch were tested and the mean determined.
Simulated Strength – 60 Units

Mean = 5000 psi
Std. Dev. = 175 psi
# Simulation of 60 “Units”
Along US 18 Project

<table>
<thead>
<tr>
<th>Unit (528-ft)</th>
<th>Comp Strength, psi</th>
<th>Initial IRI, in/mi</th>
<th>Slab Thickness, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4289</td>
<td>56.9</td>
<td>9.63</td>
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<td>2</td>
<td>4048</td>
<td>50.2</td>
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<td>3</td>
<td>4514</td>
<td>75.1</td>
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<td>4</td>
<td>5343</td>
<td>91.2</td>
<td>9.89</td>
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<tr>
<td>5</td>
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<td>99.0</td>
<td>9.83</td>
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<td>6</td>
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<td>69.7</td>
<td>9.93</td>
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<td>12</td>
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<td>77.2</td>
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<td>13</td>
<td>5874</td>
<td>104.5</td>
<td>9.07</td>
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<tr>
<td>14</td>
<td>5114</td>
<td>61.1</td>
<td>10.30</td>
</tr>
<tr>
<td>Etc</td>
<td>Etc.</td>
<td>Etc.</td>
<td>Etc.</td>
</tr>
</tbody>
</table>
JPCP Performance Prediction Models

IRI (smoothness)

Joint Faulting

Transverse Cracking
Distribution of Cracking of Units Along Project @ Age 20 Years

Cracking at Age = 20 years

- Frequency
- Cumulative %
Distribution of IRI of Units Along Project @ Age 20 Years

IRI at Age = 20 years

- Frequency
- Cumulative %

Expanding the Realm of Possibility
Distribution of Age of 60 Units Along Project @ 15 % Cracking

- Frequency
- Cumulative %

- Age, years
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90

- Frequency

- Cumulative %

- Expanding the Realm of Possibility
Trucks to Reach 15% Cracking of Units Along Project

![Graph showing the frequency and cumulative percentage of trucks reaching 15% cracking of units along a project. The graph displays the number of trucks in millions on the x-axis and frequency and cumulative percentage on the y-axis. The data points indicate that as the number of trucks increases, the frequency and cumulative percentage of units cracking also increase.]
Cumulative “Failure” of 60 JPCP Units Along US 18
Summary JPCP Variation

- **Variation of M&C** strength, thickness, and initial IRI factors have significant effect on service life along a typical JPCP project resulting in early failures.

- **Early failures** impacts maintenance cost and results in early rehabilitation, both increasing life-cycle costs of pavement.

- **Reduction in variation** of M&C factors would reduce early maintenance and prolong rehabilitation, both decreasing life-cycle costs of pavement.
HMA Example

Using Actual Utah Project With Variation Data From Literature & Historical QA Projects
HMA Project

- Location: SR 71, Salt Lake County, Utah
- Constructed 2003
- Initial AADTT: 2653 two-way, growth 4%, 30 million trucks
- Design
  - 6-in HMA
  - 6-in UTBC
  - 18-in Granular Borrow
  - Subgrade A-2-4
UT M&C Factors Included HMA

- HMA Thickness
- HMA Mix: Density, Air Voids, and Binder Content
  - Binder Content was simulated & Air Voids & Density were computed through correlation
- Initial smoothness (IRI)
HMA Performance Prediction Models

IRI (smoothness)

Rutting

Fatigue Alligator Cracking
UT Simulated HMA Thickness

Mean = 6.0 in
Std Dev = 0.67 in
Expanding the Realm of Possibility

UT Simulated HMA Initial IRI

Mean = 63.4 in/mi
Std Dev. = 13 in/mi
UT Simulated HMA Binder Content
(by volume, not weight)

Mean = 10.5 percent
Std Dev. = 0.3 percent
UT Simulated Variation HMA Density (from correlation)

Mean = 145 lbs/ft³
Std Dev. = 1.2 lbs/ft³
UT Simulated Field Air Voids (from correlation)

Mean = 7.2 percent
Std Dev. = 0.6 percent
Variation Fatigue Cracking @ 20-Years

Cracking, percent @ Age = 20 years

Frequency

0 2 4 6 8 10 12 14 16 18

Cracking @ 20 Years

0.00% 20.00% 40.00% 60.00% 80.00% 100.00% 120.00%

5 10 15 20 25 30 35
Variation IRI @ 20 Years

IRI, in/mi @ Age = 20 years
Variation Age @ 15% Cracking

Age, years @ 15 percent cracking
Variation Age @ 0.5-in Rutting

Age, years @ 0.5 in Rutting

Frequency
Variation Age @ IRI 150-in/mile
“Unit” Failure in Fatigue Cracking Along Project

Alligator Cracking

Percent

Age, years
Summary HMA Variation

- **Variation** of thickness, initial IRI, & HMA mixture properties have significant effect on service life along a HMA project.

- **Early failures** impacts maintenance cost and results in early rehabilitation, both increasing life-cycle costs of pavement.

- **Reduction in variation** of M&C factors would reduce early maintenance and prolong rehabilitation, both decreasing life-cycle costs of pavement.
Next Step, Understanding Variability

- **Obtain additional knowledge** about M&C factor variability.
  - State databases for projects.
  - Research studies (LTPP, others).
  - UW web site QC cleaning house
  - GPR for layer thickness & other factors.
  - NCAT sections.

- **Conduct additional simulation studies.**
Next Step, Understanding Variability

- Demonstrate how **reduced variability** leads to increased pavement life.
- Demonstrate **how reduced variability** leads to lower construction, maintenance, rehabilitation, and life cycle costs.
- Demonstrate how **incentive/disincentive pay factors** can be derived from this knowledge to encourage lower construction variability.