Perpetual Pavements

Dr. David Timm, P.E.
Tuesday, February 23
SCAPA 2016 Winter Conference
Roadway Infrastructure

- Nearly 40 million miles of roads on Earth (2013)
  - Enough roadways to circle Earth 1,600 times

<table>
<thead>
<tr>
<th>Country</th>
<th>Roadway Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
U.S. Roadway Infrastructure

- 2,674,821 miles paved
- 1,417,901 miles unpaved

Roads

2013 Grade D

Forty-two percent of America's major urban highways remain congested, costing the economy an estimated $101 billion in wasted time and fuel annually. While the conditions have improved in the near term, and Federal, state, and local capital investments increased to $91 billion annually, that level of investment is insufficient and still projected to result in a decline in conditions and performance in the long term. Currently, the Federal Highway Administration estimates that $170 billion in capital investment would be needed on an annual basis to significantly improve conditions and performance.
Economics of Roadbuilding

• Estimates according to ARTBA
  – Construct new 2-lane undivided road
    • $2-$3 million per mile in rural areas
    • $3-$5 million in urban areas
  – Construct a new 4-lane highway
    • $4-$6 million per mile in rural and suburban areas
    • $8-$10 million per mile in urban areas
  – Construct a new 6-lane Interstate highway
    • $7 million per mile in rural areas
    • $11 million or more per mile in urban areas
  – Expand an Interstate Highway from 4 lanes to 6 lanes – about $4 million per mile
  – Mill and resurface a 4-lane road – about $1.25 million per mile

http://www.artba.org/about/transportation-faqs/
Evolution of Pavement Thickness Design

Pre 1950’s Experience
1960’s Development of Empirical Methods
1980’s Initial Mechanistic-Empirical Methods
1990’s NCRHP 1-37A M-E Design
2000’s Implementation of M-E Methods
Empirical Flexible Pavement Design Method

\[ \log W_{18} = Z_R S_0 + 9.36 \log (SN + 1) - 0.20 + \log \left( \frac{\Delta PSI}{4.2 - 1.5} \right) \right] \]

\[ \frac{1094}{0.4 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \log M_R - 8.07 \]
Empirical Method Based on AASHO Road Test

Figure 1. Looking east, Loops 5 and 2 in foreground.

Figure 92. Automatic batch-type plant used to produce binder course mixture; dryers in tandem.
Specific Traffic and Climate

Figure 23. Test vehicles, showing typical axle arrangements and loadings.

Figure 26. During periods of adverse weather traffic operations were governed by safety considerations. Snow and ice conditions usually resulted in operating at reduced speeds.
Mechanistic-Empirical Pavement Design
AASHTO M-E Design Software
Major Limitations of M-E Design

- Pavement performance prediction
  - Evaluation
  - Calibration
  - Verification

- Pavements are still designed to fail
Perpetual Pavements
What is a Perpetual Pavement?

- 35+ years of service
- Minimal structural improvements
- No deep structural distresses
  - Problems at surface easily and quickly remedied
U.S. Perpetual Pavement Award Winners
Goal of Perpetual Pavement Design

- Design so there are no deep structural distresses
  - Bottom up fatigue cracking
  - Structural rutting
- All distresses can be quickly remedied from surface
- Result in a structure with ‘Perpetual’ or ‘Long Life’
No Bottom Up Cracking
No Deep Structural Rutting
Perpetual Pavement Design
Designing Perpetual Pavements

Wheel Loads

Typical Depths
- 1.5 - 3 inches: High Quality HMA/SMA/OGFC
- 4 - 7 inches: High Modulus Rut Resistant HMA
- 3 - 4 inches: Fatigue Resistant HMA

Material

Zone of High Compression

Maximum Tensile Strain

Subgrade
M-E Perpetual Pavement Design

\[ \text{Log } \varepsilon \]

Threshold Strain

No Damage Accumulation

\[ \text{Log } N \]

\[ \varepsilon_t \]

\[ \varepsilon_v \]

\[ D_1 \quad E_1 \]

\[ D_2 \quad E_2 \]

\[ D_3 \quad E_3 \]
Perpetual Pavement Design Software

PerRoad

Press F1 to access full help file. Press Shift+F1 to access context-sensitive pop-up help.

Functional Classification: Urban Collector

Two-Way AADT: 1000 (500 to 5000)

%Trucks: 1 (1 to 20)

%Growth: 1 (0 to 3)

Design Trucks: 63482 (Total Trucks in 30 Years)

Design ESALs: 18917 (Total ESALs in 30 Years)

AASHTO Soil Classification: A-1-a

Soil Modulus: 29500 (10,000 to 30,000 psi)

Aggregate Base Thickness: 4 (0 to 10 in.)

HMA Modulus: 800000 (400,000 to 1,000,000 psi)

Calculated HMA

Design HMA

in. Calculated thickness rounded up to nearest 0.25".
NCAT Test Track – Perpetual Experiments

1.7 mile
46 – 200 ft sections
Test Sections – Experiment 1

N3 (PG 67-22)

- 1.2 Surface Mix
- 1.8 Upper Intermediate Mix
- 2.7 Lower Intermediate Mix
- 2.1 Upper Base Mix
- 1.3 Lower Base Mix
- 6 Aggregate Base

N4 (PG 76-22)

- 1 Surface Mix
- 1.7 Upper Intermediate Mix
- 2.3 Lower Intermediate Mix
- 1.8 Upper Base Mix
- 2 Lower Base Mix
- 6 Aggregate Base

**Designed with 1993 AASHTO Guide to Fail after 10 Million ESALs**

**Survived 30 million ESALs with excellent performance**
FWD Testing

[Diagram showing a vehicle with a device attached for FWD testing, with labeled points and markers.]
Rutting Performance

Failure

Million Equivalent Single Axle Loads

Rut Depth, mm

Date

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0

N3
N4
International Roughness Index

Failure

Million Equivalent Single Axle Loads

Date

International Roughness Index, in/mile

0  2  4  6  8  10  12  14  16  18  20  22  24  26  28  30

170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

10/20/03  01/18/04  04/17/04  07/16/04  10/14/04  01/12/05  04/11/05  07/10/05  10/09/05  01/08/06  04/07/06  07/06/06  10/05/06  01/04/07  04/03/07  07/02/07  10/01/07  01/09/07  04/08/07  07/07/07  10/06/07  01/05/08  04/04/08  07/03/08  10/02/08  01/01/09  04/02/09  07/01/09  10/09/09  01/08/10  04/07/10  07/06/10  10/05/10  01/04/11  04/03/11  07/02/11  10/01/11  01/09/11  04/08/11  07/07/11  10/06/11
Cracking Performance

Crack Map (Trucking Percent Complete via Height of Gray Map Date Box)

Crack Map (Trucking Percent Complete via Height of Gray Map Date Box)

N3

N4

Longitudinal Distance from Far Transverse Joint (feet)
Forensic Trenching
Measured Strain Distributions

Strains at 90\textsuperscript{th} percentile are about 2.18 times the lab endurance limit.
Strain Distributions for Perpetual Design

Percentile vs. Microstrain graph showing differentiation between No Fatigue and Fatigue conditions. The graph includes data points for years 2003 and 2006, with specific markers for N1 to N10 and S11 to S13.
Section Performance - Rutting

2006 Test Track  
2009 Test Track

Rut Depth, mm

ESALs

N8-non perpetual
N9-perpetual

HPM Mill & Inlay
Conventional Mill & Inlay with Fabric
N8 After 1\textsuperscript{st} Rehabilitation @ 3.5 MESAL
N8 After 1st Rehabilitation @ 3.5 MESAL
Cash Flow Diagram

Discount Rate = 2%

Initial Construction

32% Increase

N9

N8

Conventional mill & inlay

N8

HPM mill & inlay

Resurfacing
Net Present Value

26% Savings

Net Present Value (\$/lane/mile)

<table>
<thead>
<tr>
<th>Section</th>
<th>N8 (non-perpetual)</th>
<th>N9 (perpetual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>$600,000</td>
<td>$480,000</td>
</tr>
<tr>
<td>26% Savings</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Future Challenges

SMA


RAP


http://www.hgmeigs.com/images/evotherm_temp.jpg

RAS


GTR


WMA

http://www.calrecycle.ca.gov/Tires/BizAssist/images/CrumbRubber.jpg

Concluding Remarks

• Pavement thickness design in transition
  – From empirical to mechanistic-empirical

• M-E design much more robust
  – Better traffic/climate/materials/performance characterization
  – Capable of adapting to new conditions

• Perpetual pavements are key to sustainable future
  – Incorporation of sustainable materials is critical
Thank you!