MINNESOTA PERPETUAL PAVEMENT ANALYSIS AND REVIEW

Minnesota Transportation Conference

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Outline

- Introduction
- Objectives
- Perpetual Pavement Background
- Minnesota Award Winner Projects
- Metro Projects In-depth Analysis and Evaluation
- rePave Analysis
- Conclusions
Perpetual Pavements

“an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement”
Perpetual Pavements Award Program: Asphalt Pavement Alliance (APA)

- Having served for 35 years with no structural failure.
- Must have hot-mix or warm-mix asphalt binder and surface layers.
- Has not received more than 4 inches of new asphalt over the preceding 35 years.
- Resurfacing intervals of no less than 13 years on the average.
- Minimum project length is two miles.
Perpetual Pavements Award Program

<table>
<thead>
<tr>
<th>Year of award</th>
<th>District</th>
<th>Highway</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1</td>
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<td>2005</td>
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<td>TH 18</td>
<td>1959</td>
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<tr>
<td>2006</td>
<td>6</td>
<td>USTH 61</td>
<td>1969</td>
</tr>
<tr>
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<td>USTH 71</td>
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<tr>
<td>2008</td>
<td>Metro</td>
<td>TH 36</td>
<td>1960</td>
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<td>2009</td>
<td>4</td>
<td>USTH 10</td>
<td>1973</td>
</tr>
<tr>
<td>2010</td>
<td>1</td>
<td>USTH 61</td>
<td>1969</td>
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<td>2011</td>
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</table>
Objectives

- One of the objectives of this study is to review all the award winning roadways in Minnesota to determine common material, design factors, and considerations which may have contributed to the roadways extended life, often exceeding 50 years despite the harsh Minnesota climate
  - MnDOT Highway Pavement Management Application (HPMA) data and performance histories
  - The construction histories and plans
Fatigue Theory

High Strain = Short Life
Low Strain = Long Life
Fatigue Cracking

Repeated Bending Leads to Fatigue Cracking
Fatigue Cracking (Contd.)

Repeated Bending Leads to Fatigue Cracking
The fatigue endurance limit (EL) concept assumes a specific strain level, below which the damage in hot mix asphalt (HMA) is not cumulative → Unlimited Fatigue Life!
Fatigue Endurance Limit

- Varying FEL levels have been reported:
  - 70 µε – Monismith and McClean, 1972
  - 150-200 µε – Mishizawa et al., 1996
  - 70-100 µε – Willis, 2009
  - 75-200 µε – Prowell et al., 2010
  - 100-250 µε – MEPDG

- What about:
  - Weather?
  - Traffic Speed?
Goal of Perpetual Pavement Design

- Design the structure such that 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’.
Perpetual Pavement Distresses

Top-Down Cracking

Non-Structural Rutting
Perpetual Pavement Responses

Layer 1
HMA
$E_1$

Layer 2
Granular Base
$E_2$

Layer 3
Subgrade Soil
$E_3$

Deflection ($\delta$)
Tensile Strain ($\varepsilon_t$)
Compressive Strain ($\varepsilon_c$)

$h_1$
$h_2$

No bottom boundary, assume soil goes on infinitely.
Perpetual Pavement Design
Perpetual Pavement Three Layer System

Each layer designed to resist specific distresses:

- **HMA Surface/Wearing** – designed to resist surface initiated distresses (top-down cracking, rutting, etc.)
- **HMA Intermediate** – designed for durability and stability (rut resistance)
- **HMA Base** – designed to resist fatigue and moisture damage, to be durable
Perpetual Pavement Three Layer System

Newcomb et al, 2000
Perpetual Pavement: HMA Surface

- High quality HMA, SMA or OGFC/BWC
- Rut resistance
  - Aggregate Interlock
  - PG grade
- Crack resistance
  - PG grade
  - Polymer, fibers
- High friction
Perpetual Pavement: HMA Intermediate

- **Stability**
  - Stone-on-stone contact
  - Angular aggregate
  - High temperature PG-grade

- **Durability**
  - Proper air void content
  - Moisture resistant
Perpetual Pavement: HMA Base

- Resistant to fatigue cracking
  - Higher binder content $\rightarrow$ lower air voids (designed at 2-3%) $\rightarrow$ higher density $\rightarrow$ durability and fatigue resistance
- Binder grade – soft/flexible
- Fine gradation
- Moisture resistant
Perpetual Pavements Benefits

- **Economics**
  - Lower life cycle cost
  - Reduced user delays and costs
  - No structural repairs means lower cost rehab
  - Little to no added thickness preserves curb and gutter elevations, overhead clearance

- **Sustainability/Environmental benefits**
  - Better use of resources
  - Reduced CO2 emissions
  - Reduced energy consumption
Design Software: rePave

- An interactive web-based pavement design.
- Includes approaches for employing existing pavements in-place.
- Identifies new alternatives to renewal approaches.

Benefits:
- Decreased use of new pavements.
- Shorter construction time.
- A better return on investment based on longer pavement service life.
rePave Inputs

- Project Info: name, route, and location
- Existing section: pavement type, number of through lanes, thicknesses, and year of construction of each layer
- Proposed section: design period, Subgrade resilient modulus ($M_R$), ESALs, growth rate, current ADT, number of through lanes, and height restrictions
- Exiting pavement conditions
### rePave Output

<table>
<thead>
<tr>
<th>Existing</th>
<th>Proposed</th>
<th>Recommended Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot; HMA</td>
<td>9.5&quot; New Pavement</td>
<td>Renewal Type: Flexible</td>
</tr>
<tr>
<td>12&quot; Granular Base</td>
<td>12&quot; Pulverized HMA</td>
<td>Design Period: 50 years</td>
</tr>
<tr>
<td>Subgrade</td>
<td>12&quot; Granular Base</td>
<td>Design ESALs: 47 million</td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>Subgrade MR: 10,000 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-existing Pavement or Base Modulus: 50,000 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Actions</strong>: Pulverize existing flexible pavement to eliminate all cracking or materials related damage and treat pulverized material to produce treated base and overlay with HMA.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pavement Removed: 0&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Existing Pavement: 24&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimated Design Thickness: 9.5&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New Pavement: 9.5&quot;</td>
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<tr>
<td></td>
<td></td>
<td>Added Elevation: 9.5&quot;</td>
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</table>
Minnesota Perpetual Pavements

- The location of the roadway
- The construction history
- The mainline typical section at the time of the construction
- Maintenance activities performed
- Available ADT data
- Available HCAADT data
- Calculated percentage of HCAADT for the available data
- Fitted compound growth function
- Calculated traffic at the time of construction \((\text{ADT}_0)\) and the growth rate \((r)\)
- Pavement performance data
## Perpetual Pavements Award Program

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Observations

- Rate of construction in 1960’s was low → better compactions
- Subgrade corrections → increase in the uniformity of compacted materials
- A select granular backfill material was used in subgrade correction areas → strong construction platform to pave against
- Use of non-frost susceptible base and subbase materials in underlying layers → drainage improvements
In some cases the upper portion of the granular subbase or aggregate base was treated with bituminous to increase in the foundation strength.

In some cases a layer of prime coat was placed over the aggregate base to increase in the integrity of the granular base and reduce dust during construction.

Staged construction allowed the foundation to go through seasonal cycles and thus enhanced the overall pavement structural stability.
Observations (Contd.)

- Several projects had a road-mixed bituminous base material → provides a flexible fatigue resistant base layer
- Road-mixed base could provide similar characteristics as current emulsion base stabilization materials used at MnRoad Cells 2, 3, and 4.
- Base stabilization creates a bound layer → the maximum tensile strains transfers deeper into the pavement structure → reduction in the strain levels at the bottom of the HMA layers
MnRoad Cells 2, 3, and 4*

*Johanneck and Dai, 2013

Cell 2

Cell 3

Cell 4

40 mph

5 mph
Fatigue Cracking Origins: Material Factors

- **Initiation**
  - Microscopic defects and incompatibilities amplify applied stress and microcracks form

- **Coalescence**
  - Microcracks grow and coalesce into macrocracks

- **Propagation**
  - Macrocracks move through the asphalt concrete ultimately showing up as visible flaws on pavement surface
Metro District Projects

- Metro Projects: **TH 10, TH 36, TH 95, and TH 47**
- Field testing: coring, hand auger borings, and Dynamic Cone Penetrometer (DCP) test in the selected core holes
- Laboratory testing:
  - Thickness and density
  - Asphalt content
  - Extracted gradation
  - Resilient Modulus (ASTM D 7369)
Coring

Uncracked wheelpath (UWP)

Uncracked non-wheelpath (UNWP)

Cracked wheelpath (CWP)
### Thicknesses and Densities

<table>
<thead>
<tr>
<th>Roadway</th>
<th># Cores</th>
<th>Avg. Thickness (in.)</th>
<th>Avg. Density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 10</td>
<td>12</td>
<td>9.9</td>
<td>93.3</td>
</tr>
<tr>
<td>(2004 winner)</td>
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<td></td>
<td></td>
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<tr>
<td>TH 36</td>
<td>9</td>
<td>6.5</td>
<td>93.4</td>
</tr>
<tr>
<td>(2008 winner)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 95</td>
<td>12</td>
<td>5.4</td>
<td>93.9</td>
</tr>
<tr>
<td>(2013 winner)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 47</td>
<td>12</td>
<td>7.9</td>
<td>94.0</td>
</tr>
<tr>
<td>(2014 winner)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- No CWP core for TH 36 as it was reconstructed in 2015
- Thicknesses were verified with the thicknesses from the construction plans
- Individual densities generally ranged from 92 to 95%
Penetration (inch) vs. DPI (inch/blow) for different TH values:

- TH 10 (2004)
- TH 36 (2008)
- TH 95 (2013)
- TH 47 (2014)
Extracted Gradations

NMAS = ½ inch

Max Agg. Size = ¾ inches (Type B)
Resilient Modulus

- RM was done on the pucks obtained from the bottom of un-cracked cores (UWP and UNWP)
- At -5°C and 25°C
# Resilient Modulus

<table>
<thead>
<tr>
<th>Roadway</th>
<th>Avg. RM at 25°C (ksi)</th>
<th>Avg. RM at -5°C (ksi)</th>
<th>RM ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 10 (2004 winner)</td>
<td>707</td>
<td>2,415</td>
<td>3.4</td>
</tr>
<tr>
<td>TH 36 (2008 winner)</td>
<td>260</td>
<td>2,316</td>
<td>8.9</td>
</tr>
<tr>
<td>TH 95 (2013 winner)</td>
<td>488</td>
<td>2,755</td>
<td>5.6</td>
</tr>
<tr>
<td>TH 47 (2014 winner)</td>
<td>362</td>
<td>2,490</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Max and Min difference = 172%

Max and Min difference = 19%

- Similar performance at low temperatures!
rePave Analysis

- rePave analysis was ran twice; in the current year (2016) and in the year which the first overlay was performed.
- Existing section: core thicknesses (for 2016) construction plans for others
- Design period: 30 years
- Subgrade soil $M_R$: 20,000 psi (CBR 13%) due to performed subgrade corrections
- Existing base modulus of 50,000 due to high CBR values reported from field DCP
**rePave Analysis**

- **Existing pavement conditions**

<table>
<thead>
<tr>
<th>rePave Input</th>
<th>MnDOT Distress Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue cracking (%)</td>
<td>Sum of the longitudinal cracking (%) and the longitudinal joint deterioration (%) and block cracking (%)</td>
</tr>
<tr>
<td>Patching (%)</td>
<td>Sum of patching (%) and alligator cracking (%)</td>
</tr>
<tr>
<td>Rutting (in)</td>
<td>Average rut depth (in)</td>
</tr>
<tr>
<td>Transverse cracking (per 100 feet)</td>
<td>Transverse cracking (%) was converted to the number of cracks</td>
</tr>
<tr>
<td>Stripping</td>
<td>Assumed to be present where raveling was reported</td>
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### rePave Analysis: ESALs

#### 2016

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>ADT in 2016</td>
<td>73,000</td>
<td>31,000</td>
<td>14,000</td>
<td>39,000</td>
</tr>
<tr>
<td>Truck (%)</td>
<td>4.7</td>
<td>3.7</td>
<td>5.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Growth rate (%)</td>
<td>0.66</td>
<td>0.41</td>
<td>0.66</td>
<td>0.31</td>
</tr>
<tr>
<td>20-year forecast</td>
<td>8,196,000</td>
<td>2,941,000</td>
<td>2,087,000</td>
<td>3,079,000</td>
</tr>
<tr>
<td>ESAL (per year)</td>
<td>410,000</td>
<td>147,000</td>
<td>104,000</td>
<td>154,000</td>
</tr>
</tbody>
</table>

#### First Overlay

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>ADT in the year of first overlay</td>
<td>57,000</td>
<td>27,000</td>
<td>12,000</td>
<td>36,000</td>
</tr>
<tr>
<td>Truck (%)</td>
<td>4.7</td>
<td>3.7</td>
<td>5.6</td>
<td>3.4</td>
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<td>0.41</td>
<td>0.66</td>
<td>0.31</td>
</tr>
<tr>
<td>20-year forecast</td>
<td>6,410,000</td>
<td>2,620,000</td>
<td>1,739,000</td>
<td>2,851,000</td>
</tr>
<tr>
<td>ESAL (per year)</td>
<td>321,000</td>
<td>131,000</td>
<td>87,000</td>
<td>143,000</td>
</tr>
</tbody>
</table>

\[
ADT = ADT_0 \times \left( 1 - \frac{r}{100} \right)^{n-1}
\]

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rePave Renewal Options

- Full Depth Reclamation (FDR) and overlay
- Stabilized Full Depth Reclamation (SFDR) and overlay
- Full Depth Mill and overlay

When transverse cracking is not present, the renewal options can also include:
- Patch and overlay (less than 10% patch)
- Mill and overlay
### rePave Results

<table>
<thead>
<tr>
<th>Roadway</th>
<th>rePave recommended new pavement thickness</th>
<th>HMA Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2016</td>
<td>Year of first overlay</td>
</tr>
<tr>
<td>TH 10</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>(2004 winner)</td>
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</tr>
<tr>
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<td>3</td>
<td>7.5</td>
</tr>
<tr>
<td>(2008 winner)</td>
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</tr>
<tr>
<td>TH 95</td>
<td>7.5</td>
<td>7.5</td>
</tr>
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<tr>
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<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>(2014 winner)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- TH 36 (2016): mill and overlay, the rest: remove and replace (FDR, SFDR, full depth mill)
- rePave results fit well with MnDOT’s perpetual award winners in the Metro District
**rePave Sensitivity Analysis**

**Diagram (a):**
- **TH 10**
- **Base Modulus (psi)**: 0 to 125,000
- **Thickness (in.)**: 0 to 12
- **Subgrade Modulus**:
  - 5,000 psi
  - 10,000 psi
  - 20,000 psi

**Diagram (b):**
- **TH 36, TH 95, TH 47**
- **Base Modulus (psi)**: 0 to 125,000
- **Thickness (in.)**: 0 to 12
- **Subgrade Modulus**:
  - 5,000 psi
  - 10,000 psi
  - 20,000 psi

**Remarks:**
- 0.3 inches decrease per each 5,000 psi increase in the base modulus
- 0.2 to 0.5 inches decrease per each 5,000 psi increase in the subgrade modulus
Conclusions

- Most of the test results were similar among all the Metro projects → comparing “good” pavements
- HMA thicknesses from the cores were similar to the expected thicknesses from the construction plans.
- DCP test results indicated that the in-situ materials were strong with high CBR values in all the tested sections.
- The extracted aggregate gradations satisfied the Supepave (½ inches) and MnDOT Type B mixtures control points → stability and durability
Conclusions (Contd.)

- Resilient Modulus testing showed that the asphalt mixtures from different Metro sections perform different at medium temperatures, but this difference is much less pronounced at low temperatures → low temperature condition in a substantial portion of a year

- rePave renewal recommendations:
  - Full Depth Reclamation (FDR) and overlay
  - Stabilized Full Depth Reclamation (SFDR) and overlay
  - Mill and overlay (either full depth or in the top few inches)
The required pavement thicknesses from the remove and replace rePave runs were fairly close to the actual pavement thicknesses → award winner projects in Metro District compare to the rePave program results fairly well.

The rePave sensitivity analysis:

- Fixed subgrade modulus: thickness decreases approximately 0.3 inches for every 5000 psi increase in the base modulus
- Fixed base modulus: thickness decreases approximately between 0.2 to 0.5 inches for every 5000 psi increase in the subgrade modulus.
Innovations – D2 Geo grid placement
Questions?