Evaluation of Non-Nuclear Density Gauges for Measuring In-Place Density of Hot Mix Asphalt

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Outline

- Background
- Objectives
- Research Approach
- Results
- Cost Analysis
- Findings
- Recommended further studies
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The density of in-place may be the single factor that most affects the performance of a properly designed pavement.

- Hot mix asphalt
Background

- Hot mix asphalt (HMA)
  - Lab - Maximum theoretical specific gravity
  - Field acceptance
    - Nuclear Gauge
    - Cores (true)
Background

- Core for HMA
  - Accurate
  - Destructive
  - Time consuming

- Nuclear gauge
  - Fast
  - Less accurate
  - Radiation
  - Strict regulation
Outline

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Objectives

- Evaluate non-nuclear density gauges
- Compare performance of non-nuclear density gauges with nuclear gauges
  - Determine potential factors influencing gauge measurements
- Make recommendations
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Research Approach

- HMA Devices
  - Trans Tech Pavement Quality Indicator (PQI) 301
  - Troxler PaveTracker (PT) Plus
Research Approach

- Theory
- Measures bulk dielectric constant of pavement/soil
  - Aggregates
  - Air
  - Asphalt Binder or Moisture

From Romero, 2002
Research Approach

Potential Factors Influencing Accuracy

- Global factors – different paving operations
  - HMA Classes
  - Nominal Maximum Aggregate Size
  - Aggregate Source
  - Percent Aggregate Absorption
  - Mat Thickness
Research Approach

- Potential Factors Influencing Accuracy
  - Local factors – one paving operation
    - Temperature
    - Moisture (high dielectric constant)
    - Presence of Fines/Debris: with and without fines
    - Presence of Paint/Marking: with and without spray
    - Change of density with Roller Passes
    - Gauge movement
  - Accuracy at the paving joints
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Map of Projects
HMA

Testing

- 16 Test Strips
  - HMA Classes (SP 2 to SP 6)
  - Nominal Maximum Aggregate Size (1/2” and 3/4”)
  - Aggregate Source (Alluvial, Basalt, Quartz)
  - Percent Aggregate Absorption
  - Mat thickness: thin and thick (1.8” to 3.12”)

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HMA

Testing

- Nuclear Gauge, PQI and PaveTracker
- Continuous reading for roller pattern
- 5 shot average for each device at core locations
- Moisture, fines, paint, and temperature study
- Five 4” or 6” cores in test strip for ITD correction
- Up to seven additional locations for tests and cores for validation
- Nuclear, non-nuclear shots, and/or cores at additional locations on joints.
HMA Field Work

- Testing
  - Local Factors
    - Plain HMA
    - Roller pattern
    - Fines
    - Moisture
    - Temperature
    - Paint
Results

- **Analysis Procedure**
  - Obtain correction factors from first 5 cores
  - Verify accuracy with additional cores
PQI Correlation: Average Correction

**PQI, NDG vs Core Density: Average**

- **PQI No Fines**
  - $y = 1.00x$
  - $R^2 = 0.88$

- **PQI Fines**
  - $y = 1.00x$
  - $R^2 = 0.89$

- **NDG**
  - $y = 1.00x$
  - $R^2 = 0.89$

- PQI no fines
- PQI with fines
- NDG

Linear (PQI no fines)
PT Correlation: Avg. Correction

PT, NDG Density vs Core Density: Average

- **PT No Fines**
  - \( y = 1.00x \)
  - \( R^2 = 0.83 \)

- **PT Fines**
  - \( y = 1.00x \)
  - \( R^2 = 0.84 \)

- **NDG**
  - \( y = 1.00x \)
  - \( R^2 = 0.89 \)
Slope Correction: PQI

- Offset not constant

**Core Density vs PQI Density: US 95 Athol**

\[ y = 2.54x - 155.61 \]
\[ R^2 = 0.87 \]
Slope Correction

- Develop best-fit trendline for each project using calibration cores from test strip
  - Both PQI and PT

- NDG results
  - NDG also has this slope
  - Continued to use average method in accordance with ITD specifications,
NDG Slope

Core Density vs NDG Density: SH 55

\[ y = 1.10x - 14.38 \]

\[ R^2 = 0.84 \]
PQI Correlation: Slope Correction

**PQI, NDG vs Core Density: Slope**

- **PQI No Fines**
  - $y = 1.00x$
  - $R^2 = 0.89$

- **PQI Fines**
  - $y = 1.00x$
  - $R^2 = 0.90$

- **NDG**
  - $y = 1.00x$
  - $R^2 = 0.89$

- **Graph Elements**
  - PQI no fines
  - PQI with fines
  - NDG
  - Linear (PQI no fines)
  - Linear (PQI with fines)
  - Linear (NDG)
PT Correlation: Slope Correction

**PT, NDG vs Core Density: Slope**

- **PT No Fines**
  - $y = 1.00x$
  - $R^2 = 0.70$

- **PT Fines**
  - $y = 1.00x$
  - $R^2 = 0.92$

- **NDG**
  - $y = 1.00x$
  - $R^2 = 0.89$
Slope Correction Method

- Good slopes not always possible

![Graph showing Core Density vs. PQI Density: SH 37](image)

- Linear equation: $y = 0.25x + 111.45$
- $R^2 = 0.02$
Hybrid Method

- Use slope correction if $R^2 > 0.5$
Hybrid Method

- If $R^2 < 0.5$, use average correction method
PQI Correlation: Hybrid Method

![Graph showing PQI, NDG vs Core Density: Hybrid](image)

- **PQI No Fines**
  - $y = 1.00x$
  - $R^2 = 0.90$

- **PQI Fines**
  - $y = 1.00x$
  - $R^2 = 0.90$

- **NDG**
  - $y = 1.00x$
  - $R^2 = 0.89$

Legend:
- ![PQI no fines](image)
- ![PQI with fines](image)
- ![NDG](image)
- ![Linear (PQI no fines)](image)
- ![Linear (PQI with fines)](image)
- ![Linear (NDG)](image)
PT Correlation: Hybrid Method

**PT, NDG vs Core Density**

- **PT No Fines**
  - $y = 1.00x$
  - $R^2 = 0.84$

- **PT Fines**
  - $y = 1.00x$
  - $R^2 = 0.92$

- **NDG**
  - $y = 1.00x$
  - $R^2 = 0.89$
Potential Factors

- **Global Factors**
  - HMA Classes
  - Nominal Maximum Aggregate Size
  - Aggregate Source
  - Percent Aggregate Absorption
  - Mat Thickness

- **Local Factors**
  - Moisture
  - Temperature
  - Paint
  - Fines
Potential Factors

- Global Factors
  - HMA Classes
  - Nominal Maximum Aggregate Size
  - Aggregate Source
  - Percent Aggregate Absorption
  - Mat Thickness

- Local Factors
  - Moisture
  - Temperature
  - Paint
  - Fines
Moisture Field Data: PQI

PQI 301 Water Effect: Field

\[ y = -0.16x - 1.15 \]

\[ R^2 = 0.84 \]
Moisture Field Data: PT

PaveTracker Water Effect: Field

\[
y = 0.049x + 4.47 \\
R^2 = 0.05
\]
2013 Moisture Lab Data: PQI 380

PQI 380 Water Effect: Lab

\[ y = 0.58x + 1.02 \]

\[ R^2 = 0.66 \]
Moisture Study: Solution

- Towel drying works reasonably well

![Graph](PQI 380: Slab 12)

- Uncorrected Gauge Density (pcf)
- H₂O Index
- Dry
- Light Water
- Medium Water
- Heavy Water
- Towel Dried
Moisture Investigation

- All electromagnetic gauges affected by surface moisture
  - PQI 301, PT, PQI 380
- Used PQI 301 \( \text{H}_2\text{O} \) Index to quantify moisture for all gauges
  - Otherwise difficult to quantify
- Dry the surface with towel if moisture is present
Roller Pattern Use

- How do NNDGs compare to NDGs on a roller pattern setup
  - 3 case studies
Roller Pattern: Example 1

US 95 Wilder Phase 2 Roller Pattern

Corrected Gauge Density (pcf)

Roller Pass

PQI Corrected
PT Corrected
NDG Uncorrected
Roller Pattern: Example 2

US 95 Wilder Phase 3 Roller Pattern

Corrected Gauge Density (pcf)

Roller Pass

- PQI Corrected
- PT Corrected
- NDG Uncorrected
Roller Pattern: Example 3

SH 162 Four Corners Roller Pattern

Corrected Gauge Density (pcf)

Roller Pass

PQI Corrected
PT Corrected
NDG Corrected
Asphalt NNDGs Findings

- PQI and PT have similar core correlations compared to NDGs.
  - PQI generally has a better correlation to cores than PT
- Slope correction recommended unless the correlation coefficient is low ($R^2 < 0.5$)
  - Average method recommended if $R^2 < 0.5$
- No global factors causing error with statistical significance
Asphalt NNDGs Findings

- Paint and fines do not cause error with statistical significance
  - Clean surface recommended
- Moisture effect gauge readings
  - Keep surface dry, use towel if necessary
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# Life Cycle Cost

<table>
<thead>
<tr>
<th>Device</th>
<th>Initial Cost</th>
<th>Annual Cost</th>
<th>Lifetime (10 years) Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDG (Troxler 3430)</td>
<td>$8,000</td>
<td>$1,652.30</td>
<td>$24,523</td>
</tr>
<tr>
<td>PQI 301</td>
<td>$9,150</td>
<td>$475</td>
<td>$13,900</td>
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<td>PQI 380</td>
<td>$8,900</td>
<td>$525</td>
<td>$14,150</td>
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<tr>
<td>PT</td>
<td>$8,800</td>
<td>$500</td>
<td>$13,800</td>
</tr>
<tr>
<td>EDG</td>
<td>$9,060</td>
<td>$315</td>
<td>$12,210</td>
</tr>
<tr>
<td>SDG</td>
<td>$8,900</td>
<td>$525</td>
<td>$14,150</td>
</tr>
</tbody>
</table>
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Asphalt NNDG Implementation

- NNDGs can be used to replace NDG for QA/QC
- Use hybrid correction method
  - Slope correction when $R^2 > 0.5$
  - Average correction when $R^2 < 0.5$
- Surface shall be dry or dried with towel
- Use 6” cores for calibration
- Revised ITD FOP for AASHTO 343
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Further Studies

- Temperature effects in the field
- NNDG production paving repeatability
  - This study only examined data from test strips, not production paving
- Longitudinal joints
  - Both NNDGs and NDGs
Acknowledgements

- Project Committee: Clint Hoops, Mike Santi, Ned Parrish, Jake Legler, Garth Newman, Jayme Coonce, Kyle Holman
- ITD District Engineers, Technicians, Consultants, and Contractors
- External Reviewers: Dr. Bob Holtz (University of Washington) and Dr. Pedro Romero (University of Utah).
Thank You

QUESTIONS?