Webinar
Marking the Road: Infrastructure to Improve Safety

October 2, 2019

#WeTheStates
Dan T. Chen, PhD & PE, Vice President and General Manager, 3M Transportation Safety Division

Ethan Peterson, PE, State Pavement Marking & Traffic Device Crashworthy Engineer, MnDOT Office of Traffic Engineering

Adam M. Pike, PE, Associate Research Engineer Program Manager, Texas A&M Transportation Institute

Moderator:
Jake Varn, Policy Analyst, National Governors Association
Improving Pavement Marking Visibility at Night in the Rain

Dan Chen, Division Vice President

Transportation Safety Division
A Global and Local Crisis

In the United States:

• Crashes are the leading cause of death in first three decades of life
• Each year motor-vehicle related injuries send about 3 million people to an emergency department
• 37,800+ deaths on US roads in 2017

Motor vehicle crash deaths in 10 comparison high-income countries, 2013

- United States: 10.3
- New Zealand: 5.6
- Canada: 5.4
- France: 5.1
- Japan: 4.5
- Germany: 4.0
- Spain: 3.6
- Switzerland: 3.3
- United Kingdom: 2.8
- Sweden: 2.7

Deaths per 100,000 people

https://www.cdc.gov/vitalsigns/motor-vehicle-safety
3M invents reflective sheeting and installs the first fully-reflective traffic sign in 1939; reflective technology expands to road markings and license plates.

Microreplication technology improves retro reflectivity and increases day and nighttime sign visibility. Fluorescent technology makes work zone signs and devices and pedestrian crossings more visible during dusk, dawn, and inclement weather.

Wet reflective technology makes road markings visible in the rain; conspicuity markings make trucks and vehicles more visible; digital printing innovations enable enhanced graphics and more efficient traffic sign and license plate production.
3M Technology improves the visibility of roadway infrastructure

Signing

Pavement Markings

Temporary Traffic Control
Pavement markings must be visible both day and night.
Driving at night in the rain is a big problem
In 2017, 6,952 people died in crashes on U.S. roads when it was raining.
55% (or 3,811) of those deaths occurred at night or in low light conditions.
Only 25% of travel occurs at night.
Why Pavement Marking Visibility Matters
What do drivers see?

Daytime Dry

Night-time Dry

Night-time Rainy
What happens when pavement markings are hard to see?

- Reduced Visibility
- Increased Discomfort
- Less Effective Lane Guidance
- Increased Crash Risk
<table>
<thead>
<tr>
<th></th>
<th>Reduction in</th>
<th>Reduction in</th>
<th>Reduction in</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Run-off-road crashes on multi-lane roads</td>
<td>crashes with injury on multi-lane roads</td>
<td>crashes with injury on freeways</td>
</tr>
<tr>
<td><strong>46%</strong></td>
<td></td>
<td><strong>41%</strong></td>
<td><strong>12%</strong></td>
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</table>
All weather pavement marking activity

- GDOT specifies all weather tape to counteract wet night crashes
- MassDot RPM and other markings to all weather solutions
- MnDOT/TTI Wet Visibility Research

- 2014-2016: 30% increase in fatalities, many happening at night in rain
- Move to all weather tape on concrete expressway centerline, skip line, and edge line
- Replacement of raised pavement markers with all weather tape and elements
- Move to 4”x2ft tape skips and all weather elements for edge lines
- Initial cost increase while life cycle cost of markings decreasing
- Currently no minimum wet visibility wet retroreflectivity standards
- Research project to determine driver needs, recommended visibility requirements
Pavement Markings in Minnesota

Ethan Peterson | State Pavement Marking and Traffic Device Crashworthy Engineer
Office of Traffic Engineering
10/2/19

mndot.gov
Importance

• Single vehicle road departures are nearly 30% of all Minnesota fatalities

  • These crashes were widely distributed across the entire state and local network, with horizontal curves making up a disproportionate amount.

  • When looking at how low the crash density (~0.01 severe road departure/mile/year) is, pavement markings are extremely cost effective to cover an entire system.

  • Road departures are especially prevalent on rural county highways, which is why MnDOT has been an advocate for local safety planning and providing HSIP money for locals.

  • It’s not the road departure that’s the main concern, it’s what happens afterwards!

<table>
<thead>
<tr>
<th>Fatal and serious injury crashes</th>
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<tbody>
<tr>
<td>3,199 severe crashes</td>
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<tr>
<td>640 severe crashes per year</td>
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<tr>
<td>45.5% of all severe crashes</td>
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</table>

<table>
<thead>
<tr>
<th>Crashes of all severities</th>
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<tbody>
<tr>
<td>86,902 crashes</td>
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<tr>
<td>17,380 crashes per year</td>
</tr>
<tr>
<td>24.0% of all crashes</td>
</tr>
</tbody>
</table>

On Minnesota roadways, there were 3,199 severe lane departure crashes (including run-off-road, head-on, and sideswipe opposing crashes) between 2008 and 2012. This is an average of 640 severe crashes per year and accounted for 45.5% of all severe crashes during the five-year period.
• “Provide an appropriate pavement marking on all highways, 365 days per year.”

• An appropriate pavement marking is one that meets or exceeds the standards defined in the MN MUTCD. During winter weather events, pavement markings should provide presence after pavement is clear of snow and ice.
## MnDOT Provisions for Pavement Marking Operations

### Expected Life of Surface Applied Markings

<table>
<thead>
<tr>
<th>Material</th>
<th>ADT</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1,500</td>
</tr>
<tr>
<td>Latex Paint</td>
<td>&gt;1 yr.</td>
</tr>
<tr>
<td>Multi-Component Liquid</td>
<td>&gt;5 yr.</td>
</tr>
<tr>
<td>Preformed Polymer Tape or Thermoplastic</td>
<td>&gt;5 yr</td>
</tr>
</tbody>
</table>

### Expected Life of Recessed Markings

<table>
<thead>
<tr>
<th>Material</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1,500</td>
</tr>
<tr>
<td>Latex Paint</td>
<td>&gt;3 yr.</td>
</tr>
<tr>
<td>Multi-Component Liquid</td>
<td>&gt;6 yr.</td>
</tr>
<tr>
<td>Preformed Polymer Tape or Thermoplastic</td>
<td>&gt;7 yr</td>
</tr>
</tbody>
</table>
MnDOT Provisions for Pavement Marking Operations

Longitudinal Striping

New Bituminous (mill & overlay or reconstruct)
- Preservation planned within 3 years
- <1500 ADT – Surface Applied Latex until Preservation
- ≥1500 ADT – Surface Applied Multi Component Liquid/Recessed WR Latex until Preservation
- <1500 ADT – Recessed WR Latex
- ≥1500 ADT – Recessed WR Multi-Component Liquid

Bituminous Preservation Projects (micro-surface, ultra-thin bonded wear course, chip seal, fog seal)
- <1500 ADT – Recessed WR Latex
- ≥1500 ADT – Recessed WR Multi-Component Liquid

New Concrete (restoration or reconstruction)
- 2 Lane 2 way

Recessed Contrast WR Tape/Multi-Component Liquid (CL, LL) Recessed WR Multi-component Liquid (EL)

Pavement Messages
(Transverse, gore markings, cat tracks, and roundabouts)

New Bituminous (mill & overlay or reconstruct)
- Preservation planned within 1-2 years
- <1500 ADT – Latex
- ≥1500 ADT – Multi-Component Liquid

Bituminous Preservation Projects (micro-surface, ultra-thin bonded wear course, chip seal, fog seal)
- <1500 ADT – Multi-Component Liquid
- ≥1500 ADT

New Concrete (restoration or reconstruction)
- Contrast Recessed Thermoplastic or Tape

1. Based on life of material and suggested optimum time to initial preservation project.
2. Methods for recessing markings on chip seals are still being developed.
3. Enhanced skid resistant materials are recommended for roundabouts and crosswalk blocks.
Research has shown that the threshold between an acceptable and an unacceptable pavement marking based on nighttime driver visibility needs is between 80 and 120 MCD/m²/lux.

MnDOT is adopting a minimum performance of 100 MCD/m²/lux for both white and yellow. As markings approach this threshold they will be replaced.

Minimum initials have been set to get the desired longevity of the pavement markings. These are tested via mobile retroreflectometer.

<table>
<thead>
<tr>
<th>PREF TAPE</th>
<th>600 mcd/ m²/lux</th>
<th>500 mcd/m²/lux</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREF THERMO</td>
<td>300 mcd/ m²/lux</td>
<td>200 mcd/ m²/lux</td>
</tr>
<tr>
<td>PREF THERMO, ESR (Enhanced Skid Resistance)</td>
<td>250 mcd/ m²/lux</td>
<td>150 mcd/ m²/lux</td>
</tr>
<tr>
<td>MULTI COMP</td>
<td>300 mcd/ m²/lux</td>
<td>200 mcd/ m²/lux</td>
</tr>
<tr>
<td>PAINT</td>
<td>275 mcd/ m²/lux</td>
<td>180 mcd/ m²/lux</td>
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</table>
Wet Retroreflectivity Benefits

Safety Evaluation of Wet Reflective Pavement Markings
Craig Lyon, Bhagwant Persaud, and Kimberly Eccles. Vanasse Hangen Brustlin, Inc. (VHB) and Persaud Lyon, Inc. 2015
U.S. DoT, FHWA Sponsored Study

![Chart showing reduction in wet road crashes due to wet reflective markings compared to standard markings on freeways and multilane roads.](chart.png)
A Technical Advisory Panel with Texas A&M Transportation Institute has been ongoing to establish minimums (initial and maintained) of measured wet retroreflectivity (wet continuous) for MnDOT.

The study has included a comprehensive review of past research, analysis of available data sources, and a human factors study at the 3M test facility.

There have been discussions with manufacturers of wet retroreflective media and they believe our desired initial install of 200 MCD/m²/lux for yellow and white is attainable.

A small amount of 2020 projects will include the initial wet retroreflectivity special provision.

Adam Pike with Texas A&M Transportation Institute will present study specifics.
Other PM Topics

- 6” edgelines
- Rumble and Mumble Strips
- Connected and Autonomous Vehicles asks for pavement markings
- Enhanced Skid Resistance for pavement marking messages
Thank you again!

Ethan Peterson

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651-234-7380
Driver Needs: Wet-Night Pavement Marking Visibility

Adam Pike, Manager
Signs and Markings Program
Global Presence

TTI has conducted research in all 50 states and 51 countries.
MnDOT Study – Wet Retroreflectivity Standards

• What retroreflectivity levels are needed by drivers in wet-night conditions?
• Utilized rain tunnel at 3M Test Track in Cottage Grove, MN to simulate active rain conditions
• Evaluated participant detection distance of marking samples
  • 43 participants
  • Average age 58.5 (over half were 65 or older)
• Over 1200 total observations
Luminance Images of Markings

Values indicate continuous wet retroreflectivity (mcd/m²/lux)
## Retroreflectivity Requirements by Preview Time and Speed

<table>
<thead>
<tr>
<th>Retroreflectivity (mcd/m²/lx)</th>
<th>45 mph</th>
<th>50 mph</th>
<th>55 mph</th>
<th>60 mph</th>
<th>65 mph</th>
<th>70 mph</th>
<th>75 mph</th>
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<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
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<tr>
<td>2.5</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>10</td>
<td><strong>1.8</strong></td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>12.5</td>
<td><strong>1.9</strong></td>
<td>1.7</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
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<tr>
<td>15</td>
<td><strong>2.0</strong></td>
<td><strong>1.8</strong></td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
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<tr>
<td>20</td>
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<td>2.0</td>
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<td>1.7</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
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<tr>
<td>25</td>
<td>2.1</td>
<td>2.1</td>
<td><strong>1.8</strong></td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
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<td>30</td>
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<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>50</td>
<td>2.4</td>
<td>2.1</td>
<td>1.9</td>
<td><strong>1.8</strong></td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
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<tr>
<td>60</td>
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<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
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<tr>
<td>90</td>
<td>2.6</td>
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<td>1.9</td>
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<td><strong>1.8</strong></td>
<td>1.6</td>
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<tr>
<td>110</td>
<td>2.6</td>
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<td><strong>2.0</strong></td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
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<tr>
<td>150</td>
<td>2.7</td>
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<td>2.1</td>
<td>1.9</td>
<td><strong>1.8</strong></td>
<td>1.6</td>
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<tr>
<td>200</td>
<td>2.8</td>
<td>2.6</td>
<td>2.3</td>
<td>2.1</td>
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<td><strong>1.8</strong></td>
<td>1.7</td>
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<tr>
<td>250</td>
<td>2.9</td>
<td>2.6</td>
<td>2.4</td>
<td>2.2</td>
<td>2.0</td>
<td>1.9</td>
<td><strong>1.7</strong></td>
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<tr>
<td>400</td>
<td>3.1</td>
<td>2.8</td>
<td>2.5</td>
<td>2.3</td>
<td>2.1</td>
<td>2.0</td>
<td><strong>1.8</strong></td>
</tr>
<tr>
<td>425</td>
<td>3.1</td>
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<td>2.5</td>
<td>2.3</td>
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<td>2.0</td>
<td><strong>1.9</strong></td>
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<tr>
<td>800</td>
<td>3.3</td>
<td>3.0</td>
<td>2.7</td>
<td>2.5</td>
<td>2.3</td>
<td>2.1</td>
<td><strong>2.0</strong></td>
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Recommendations

- Minimum maintained continuous wet retroreflectivity level (ASTM E2832), **50 mcd/m²/lux**
  - Minimum driver needs at 60 mph
  - Considers older driver population
  - Heavy rain conditions

- Initial continuous wet retroreflectivity, **200 mcd/m²/lux**
  - Based on expected service life of 4 years
  - Considered actual MnDOT continuous wet retroreflectivity degradation
  - Achievable initial level
Safety Evaluation of Wet-Weather Pavement Markings

• Study location: TxDOT Atlanta District
• Considered specific crash types
• Considered time of day
• Included wet weather exposure levels
• Evaluated segments with wet-weather marking implementation

Safety Evaluation of Wet-Weather Pavement Markings

- 196 total segments evaluated
- 1052 center line miles
- 2011 to 2017 crash period
- Empirical Bayes Before-After and Full Bayes Before-After

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<tbody>
<tr>
<td>EB</td>
<td>33% (10%)</td>
<td>10% (7%)</td>
<td>58% (10%)</td>
<td>21% (9%)</td>
<td>25% (13%)</td>
<td>5% (9%)</td>
</tr>
<tr>
<td>FB</td>
<td>47% (10%)</td>
<td>4% (10%)</td>
<td>60% (9%)</td>
<td>7% (14%)</td>
<td>35% (11%)</td>
<td>-6% (12%)</td>
</tr>
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On-going Pavement Marking Projects

• Pavement Marking Patterns and Widths – Human Factors Study
• Reference Machine Vision for ADAS Functions
• A Sensor Fusion and Localization System for Improving Vehicle Safety In Challenging Weather Conditions

Thank You!