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EVALUATION OF RAISED PAVEMENT MARKERS (RPMS) (PROJECT NO. 2014-15-11)

Xiang Liu, Ph.D. (Principal Investigator)
Department of Civil and Environmental Engineering
Rutgers, The State University of New Jersey

John Bullough, Ph.D. (Co-Principal Investigator)
Lighting Research Center
Rensselaer Polytechnic Institute

Mohsen Jafari, Ph.D. (Co-Principal Investigator)
Department of Industrial and Systems Engineering
Rutgers, The State University of New Jersey

DEPARTMENT OF TRANSPORTATION THE STATE OF NEW JERSEY

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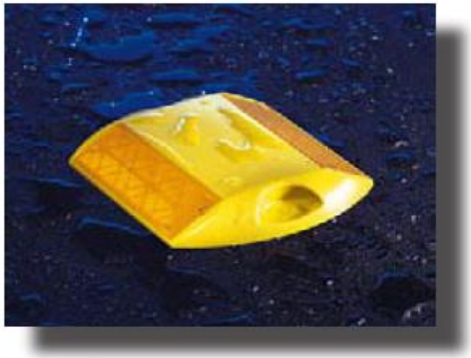
Center for Advanced Infrastructure and Transportation

Background

- Raised pavement markers (PRMs) are delineation devices used to improve preview distances and guidance for drivers in inclement weather and low-light conditions
- RPMs are installed along all centerlines and skip lines, regardless of traffic volume, roadway geometry and roadway classification in New Jersey



Standard Raised Pavement Marker (yellow for centerline).

Snowplowable Raised Pavement Marker.

Research problem

- The extensive use of RPMs requires a considerable safety investment
  - For example, $2,000 per mile for RPM installation at a 40-foot spacing in Indiana (Brennan et al. 2014)

- Therefore, it is important to understand
  - Safety effects of RPMs
  - Promising alternatives or modifications to RPMs
  - Best practices on installation, monitoring and maintenance of RPMs and alternatives

Brennan, T. M., Mitkey, S. R., Bullock, D. M. (2014). Alternatives to raised pavement markers RPMs. FHWA/IN/JTRP-2014/01.

Team organization

NJDOT

Dr. Liu (PI)
Rutgers

Dr. Jafari
Rutgers

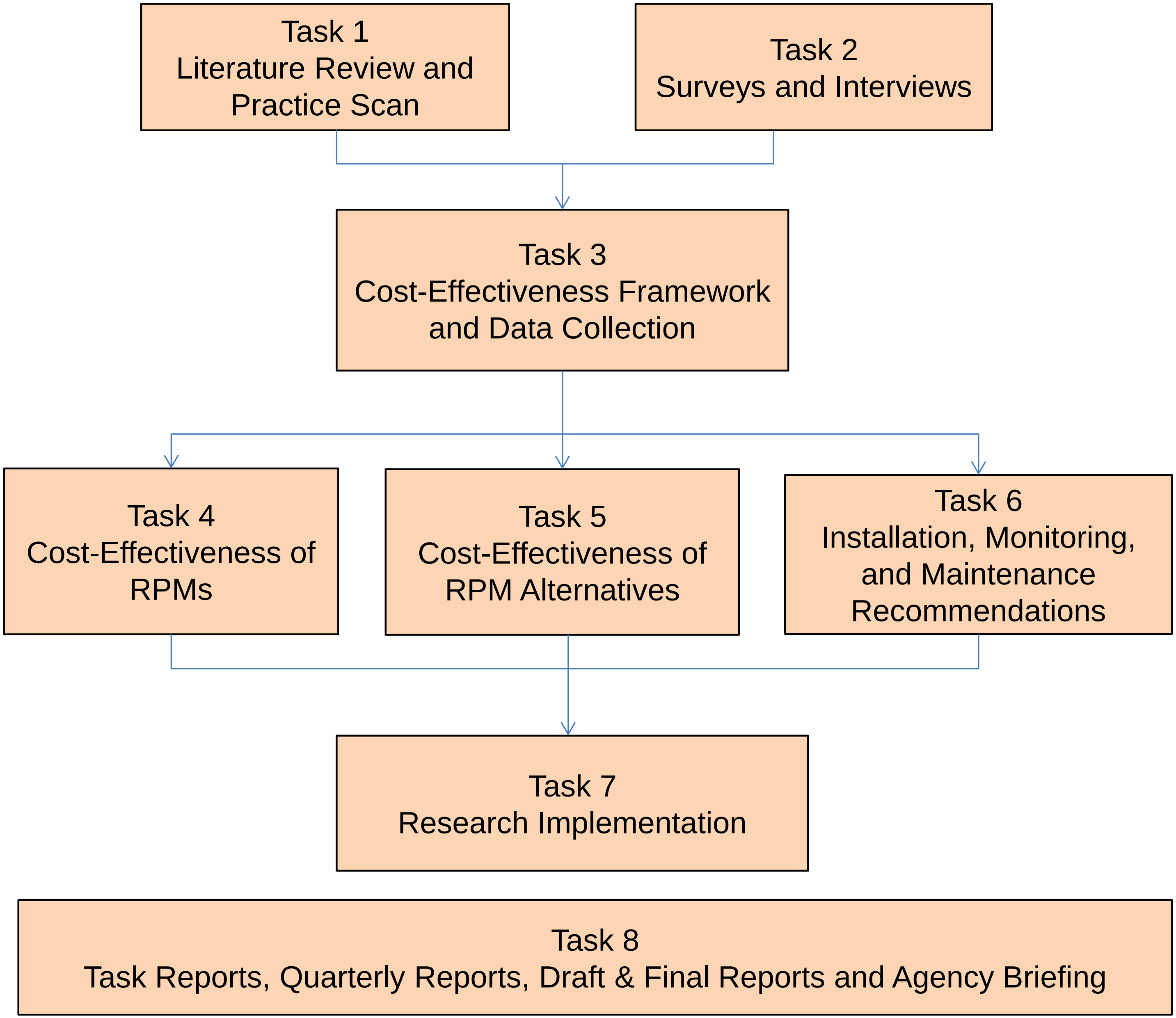
Primary Deliverables
- Statistical safety analysis of RPMs and alternatives
- Decision support tool

Primary Deliverables
- Analytical framework, cost-benefit analysis of RPMs and alternatives
- Development of decision support tool
- Installation and maintenance recommendations

Dr. Bullough
RPI

Primary Deliverables:
- Visual performance analysis of RPMs and alternatives
- Installation and maintenance recommendations

Overview of tasks



Development of a web-based survey tool regarding the installation and maintenance of RPMs

http://www.surveygizmo.com/s3/2508397/Raised-Pavement-Markers-Safety-Evaluation-Long

EVALUATION OF RAISED PAVEMENT MARKERS (RPMs) -- Sponsored by New Jersey Department of Transportation (NJDOT) - (2014-15-11)

Rutgers University and Rensselaer Polytechnic Institute are conducting a research study on the evaluation of raised pavement markers (RPMs), for the New Jersey Department of Transportation (NJDOT). As part of this project, we are seeking input from multiple stakeholders to understand nationwide practices on the installation, monitoring and maintenance of RPMs. The responses provided will remain confidential. Contact information will not be used for any purpose beyond this survey. Only aggregate information, which cannot be tied back to an individual or organization, will be reported. Additionally, survey responses will not be recorded or saved until the respondent selects the "submit" button at the end of the survey.

We greatly appreciate your participation in this survey and/or forwarding this invitation to any individual having an interest in this project. We would be happy to send a copy of the results of this survey to you when the data have been compiled.

Contact Information:
Xiang Liu, Ph.D. (Principal Investigator)
Assistant Professor
Department of Civil and Environmental Engineering
RUTGERS, The State University of New Jersey
E-MAIL: xiang.liu@rutgers.edu

PHONE: 848-445-2868

Next

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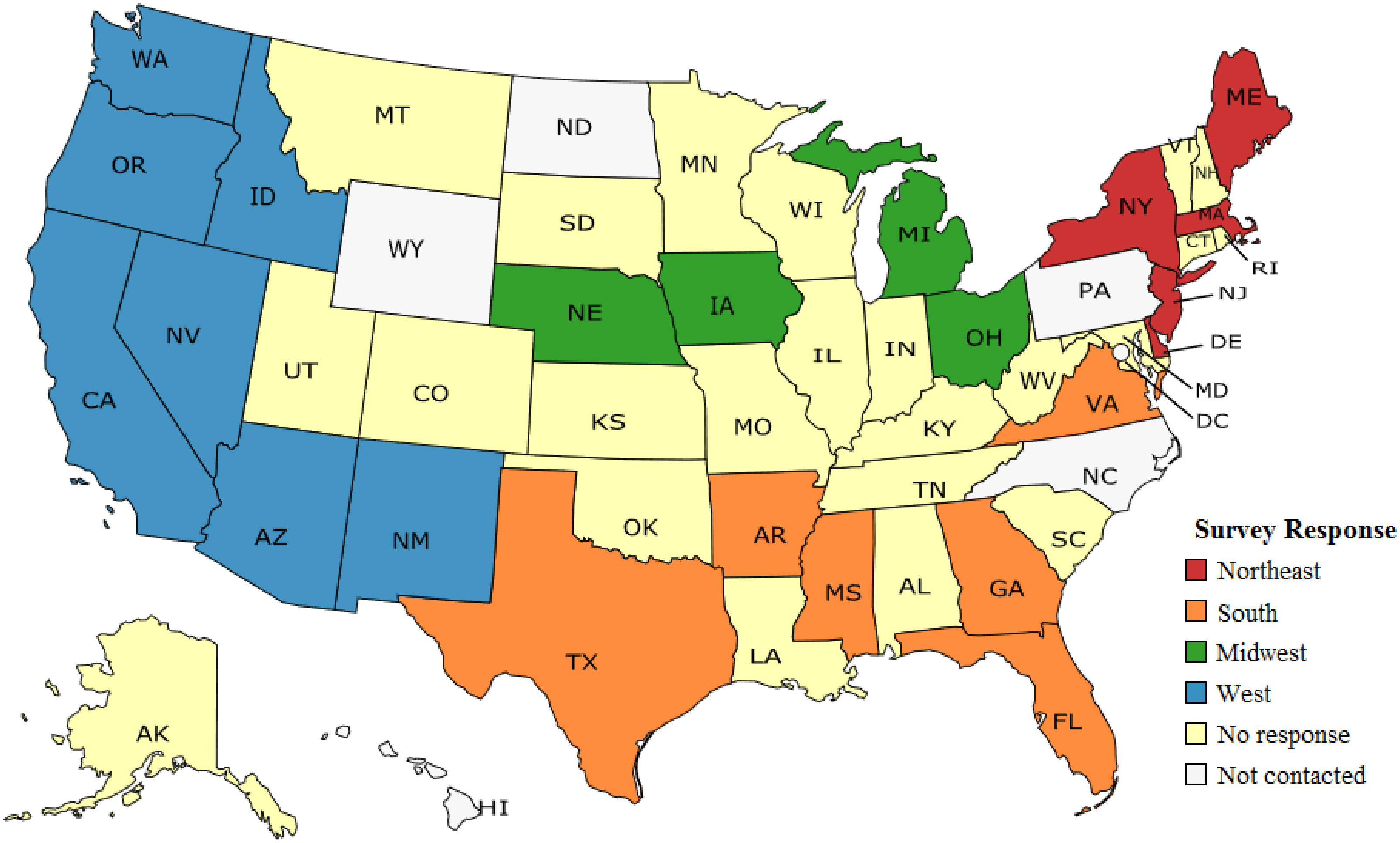
Geographical distribution of surveyed states



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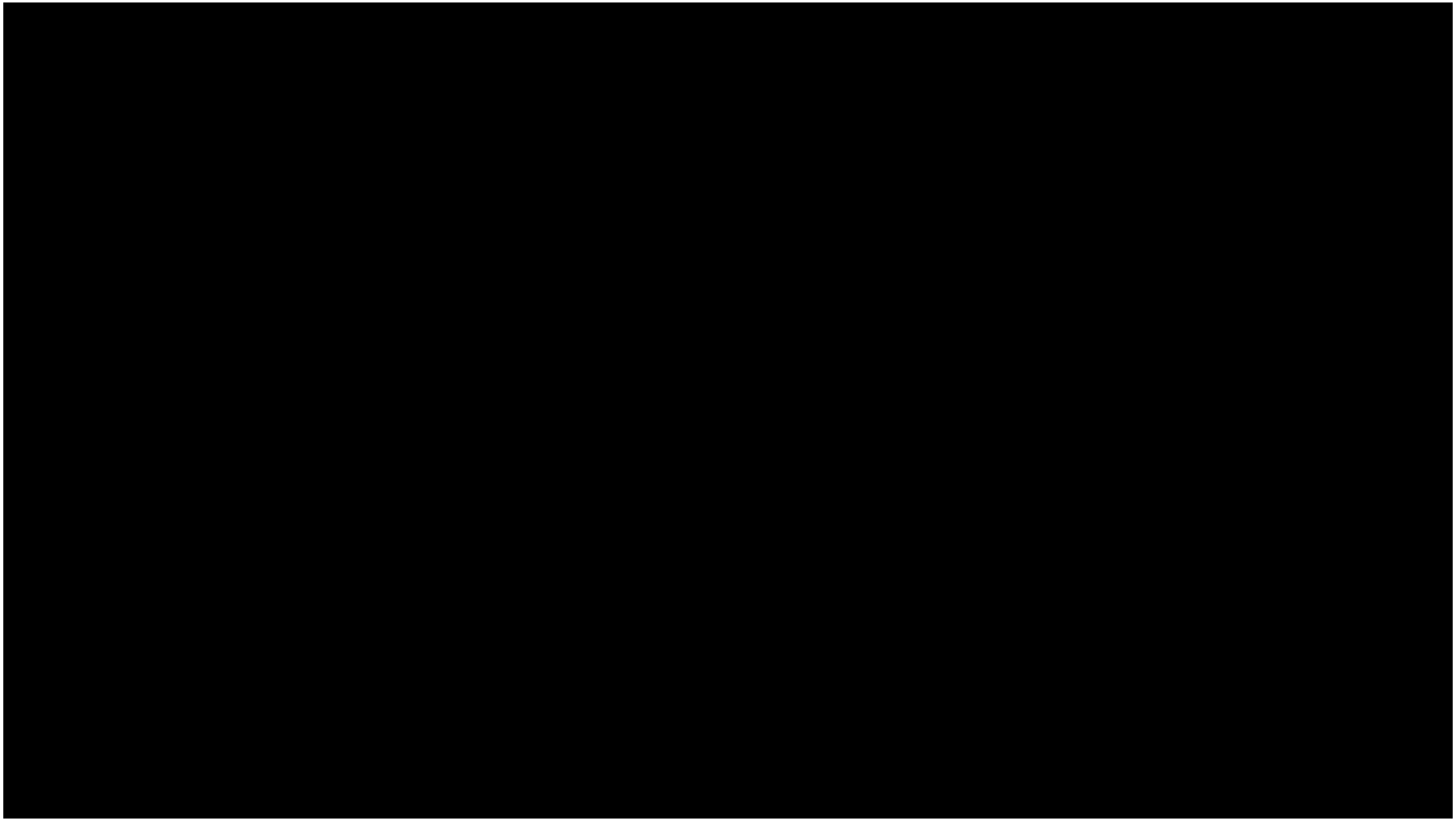
Example survey results

State	Alternative Safety Devices
Ohio	Delineators; Barrier Reflectors; 3M - Linear Delineation System.
Georgia	Reflective materials on guard rails, wet reflective striping materials.
Michigan	Some wet reflective pavement markings.
California	Other pavement marking materials such as tape, thermo etc.
New Mexico	Rumble strip being striped and adding double drop elements.
Arizona	Delineators.
Washington	Striping, RPMS, signing, markings, guideposts, LDS panels, and lighting.
Texas	Buttons, reflective striping.
Oregon	Previously used non-reflective markers; now utilize pavement markers that augment durable markings and perform well in wet weather conditions.
Massachusetts	We are exploring the use of wet reflective tape instead of recessed pavement markers.
Arkansas	Rumble strips

Overview of testing of RPMs and alternatives



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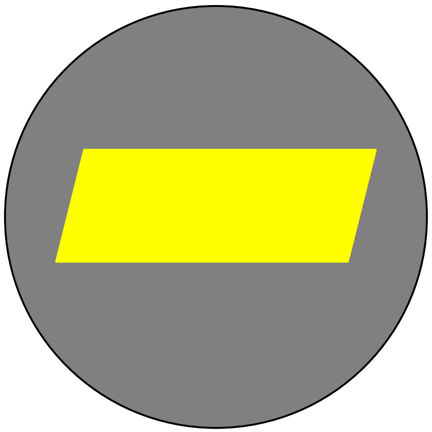
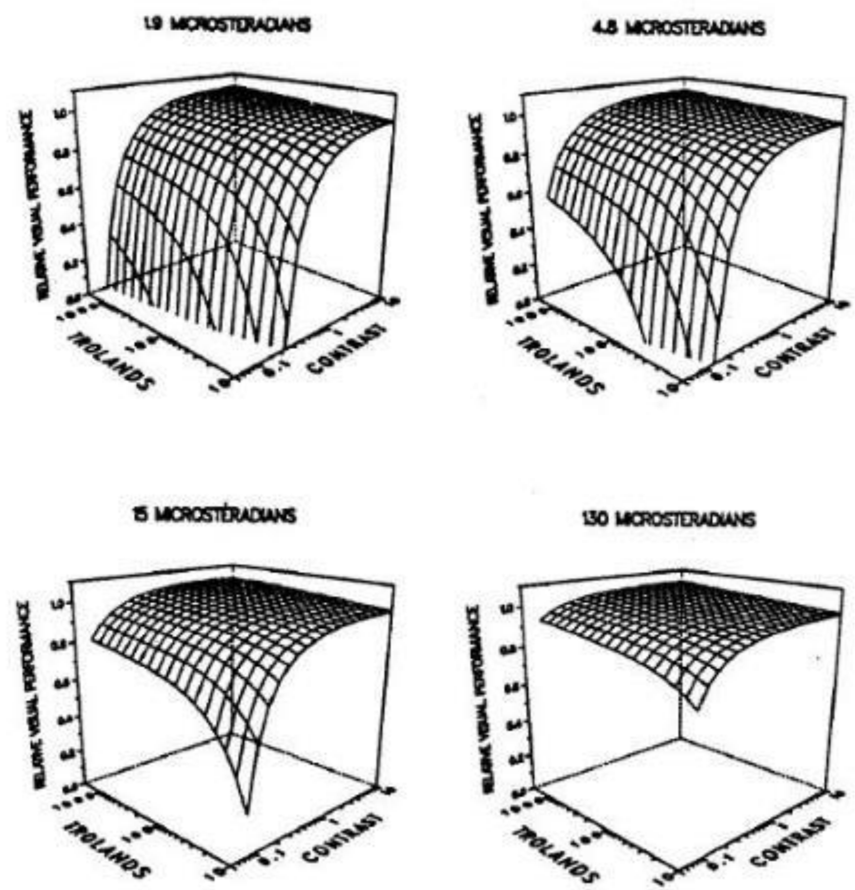
Retroreflectivity calculation

- Luminance meter aperture (1^o) is larger than marker
- Marker luminance (L_m) defined by: $L_m = L_a(0.7854/A_p)$ where A_p is the projected marker area in degrees^2 and L_a is aperture luminance
- Coefficient of retroreflection (R_c, cd/lux/m^2): $R_c = L_m/E$, where E is incident illuminance (lux)



Visual performance analysis

- Relative visual performance (RVP) model (Rea and Ouellette 1991)
- Speed and accuracy as a function of:
  - Light level (luminance)
  - Contrast
  - Size
  - Age (60 years assumed)
- Low-beam headlights



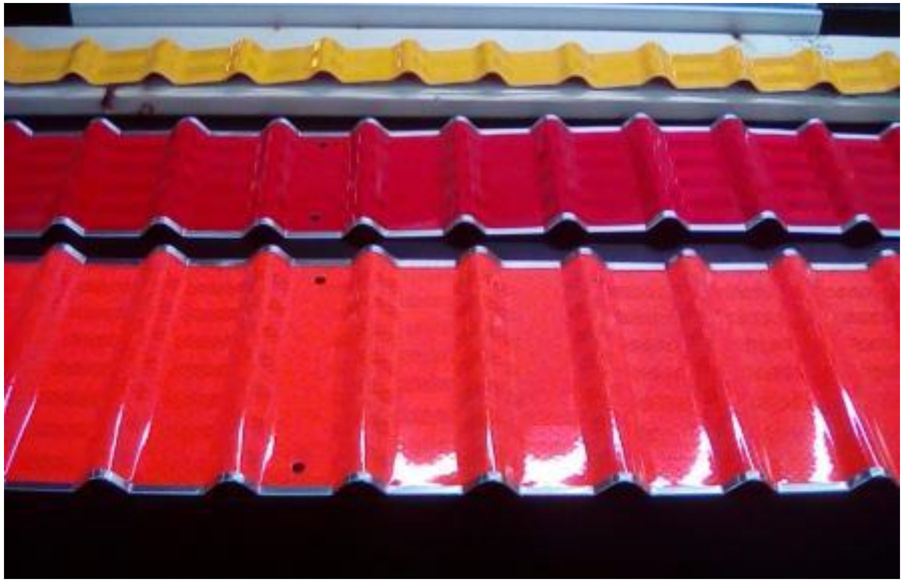
(Rea and Ouellette 1991)

Rea, M. S., & Ouellette, M. J. (1991). Relative visual performance: A basis for application. Lighting Research & Technology, 23(3), 135-144.

Measurement samples - RPMs

Two manufacturers
Steel-casting mounted white and yellow markers
Plastic, white, yellow, red and blue markers

Measurement samples – RPM alternatives



White / yellow wet reflective pavement marking tape

White / yellow / red / orange linear delineation panels

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Example results of RPM measurements

RPM A (yellow)		*Proj. Area (deg²):*	0.068567		
Measured Illuminance (lx)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	0.6	0.7	0.8	0.7	0.6
-1 V	0.6	0.7	0.8	0.7	0.6
Measured Luminance (cd/m²)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	3.577	3.632	4.329	3.574	3.689
-1 V	3.477	3.533	3.847	3.464	3.471
Actual Luminance (cd/m²)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	40.97281	41.60281	49.58661	40.93845	42.25572
-1 V	39.82736	40.46882	44.06553	39.67845	39.75863
Coefficient of Retro. (cd/lx/m²)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	68.28802	59.43259	61.98327	58.4835	70.4262
-1 V	66.37894	57.81259	55.08192	56.6835	66.26439

Headlight Intensity (cd)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	1346	2186	17660	9434	2240
-1 V	6124	10612	37804	19796	5602
Headlight Illuminance (lx)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	0.1346	0.2186	1.766	0.9434	0.224
-1 V	0.6124	1.0612	3.7804	1.9796	0.5602
RPM Luminance (cd/m²)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	**9.19**	**12.99**	**109.46**	**55.17**	**15.78**
-1 V	**40.65**	**61.35**	**208.23**	**112.21**	**37.12**
RVP Value	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	**0.984**	**0.991**	**1.017**	**1.010**	**0.994**
-1 V	**1.006**	**1.011**	**1.023**	**1.017**	**1.005**

In general, all RPMs measured resulted in high levels of visual performance because marker luminance is substantially higher than that of the pavement.

Example results of traffic tape

Tape (yellow)		Proj. Area (deg^2):		0.014247	0.015957
Measured Illuminance (lx)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	0.6	0.7	0.7	0.7	0.6
-1 V	0.6	0.7	0.7	0.7	0.6
Measured Luminance (cd/m^2)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	0.052	0.057	0.047	0.056	0.053
-1 V	0.063	0.06	0.074	0.061	0.061
Actual Luminance (cd/m^2)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	2.86663	3.142268	2.590993	3.08714	2.921758
-1 V	3.100922	2.953259	3.642353	3.00248	3.00248
Coefficient of Retro. ($cd/lx/m^2$)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	4.777717	4.488954	3.701418	4.4102	4.869596
-1 V	5.168203	4.218942	5.203361	4.289257	5.004134
Headlight Intensity (cd)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	1346	2186	17660	9434	2240
-1 V	6124	10612	37804	19796	5602

Headlight Intensity (cd)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	1346	2186	17660	9434	2240
-1 V	6124	10612	37804	19796	5602
Headlight Illuminance (lx)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	0.1346	0.2186	1.766	0.9434	0.224
-1 V	0.6124	1.0612	3.7804	1.9796	0.5602
Device Luminance (cd/m^2)	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	**0.64**	**0.98**	**6.54**	**4.16**	**1.09**
-1 V	**3.17**	**4.48**	**19.67**	**8.49**	**2.80**
RVP Value	Horizontal Angle (degrees)				
Vertical Angle (degrees) ↓	-10 H	-5 H	0 H	5 H	10 H
0 V	**0.799**	**0.897**	**0.985**	**0.977**	**0.911**
-1 V	**0.971**	**0.979**	**1.000**	**0.989**	**0.967**

Issues with RPMs

- Safety
  - RPMs can become loose or damaged from the pavement after longtime exposure to traffic and snowplows, which actually become a danger to drivers.

- Replacement Cost
  - Fixed replacement cycle (e.g. Pennsylvania and Ohio DOTs)
  - Traffic and roadway dependent (e.g. Indiana DOT)

FHWA Guidance to *Shoulder* Rumble Strips Implement (FHWA, 2008)

Guidance Statement	Application
Rumble Strips should be provided on:	• All new rural freeways • All new rural two-lane highways with travel speed ≥ 50 mph
State 3R and 4R policies should consider installing continuous shoulder rumble strips on:	• All rural freeways • All rural two-lane highways with travel speed ≥ 50 mph • All rural two-lane highways with a history of roadway departure crashes, where the remaining shoulder width beyond the rumble strip ≥ 4 feet, paved or unpaved.

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FHWA Guidance to *Centerline* Rumble Strips Implementation (FHWA, 2008)

Guidance Statement	Application
Rumble Strips should be provided on:	• All new rural freeways • All new rural two-lane highways with travel speed ≥ 50 mph
State 3R and 4R policies should consider installing centerline rumble strips on:	• rural 2-lane road projects where the lane plus shoulder width beyond the rumble strip ≥ 13 feet • roadways with higher traffic volumes, poor geometrics, or a history of head-on and opposite-direction sideswipe crashes

Rumble strips issues

- Noise issues
- Pavement deterioration
  - they should not be placed on pavements with inadequate structure, nor should they be placed too close to the pavement edge (WSDOT Design Manual, 2016)

Attributes of preformed tapes (Montebello & Schroeder, 2000)

Estimated Cost ($ per linear foot)	Estimated Life (Months)
$1.50 - $2.65	48 - 96
Advantages	• High retroreflectivity • Longer service life • Useful in high traffic areas • No beads needed • Reduces worker exposure to road hazards
Disadvantages	• Subject to damage from snowplows • High initial expense • Best when used on newly surfaced roads – probably not worth the expense for older road in poor condition

Montebello, D. and Schroeder, J. (2000). Cost of pavement marking materials. Minneapolis: Minnesota Local Road Research Board.

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State wide use of traffic tapes

- **New York State DOT**
  - preformed, wet-reflective tapes are widely used at areas with severe curvilinear alignments, areas prone to flooding, light-deficient, and high-accident locations
  - Wet-reflective tapes are used as an alternative to SRPMs to supplement long-line pavement markings due to the better reflectivity during nighttime, wet weather road conditions.

- **Oregon Department of Transportation**
  - long life span, wet weather retroreflectivity

- **Minnesota Department of Tran**
  - considers using tape and other durable pavement markings due to large volumes of traffic and snowplows during winter months, especially in urban areas

Installation cost of rumble strips and traffic tape

Product	Installation Cost per Linear Foot ($/lf)	Service Life (years)	Cost per Service Life ($/mile/year)
Rumble Strips	0.5	3	880
Traffic Tape	2.75	6	2,420

Carlson, P., Miles, J., Pike, A. and Park, E. Evaluation of Wet-Weather and Contrast Pavement Marking Materials and Applications. College Station: Texas Department of Transportation, 2007.

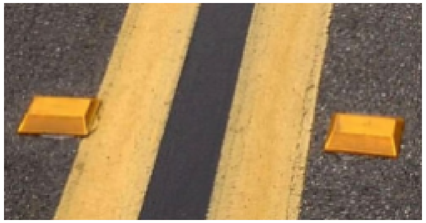
A cost comparison decision support tool

Cost Calculator

Select safety device

- (•) RPM
- ( ) Rumble Strip
- ( ) Traffic Tape
- ( ) Others

RPM



Set cost parameters

Installation cost ($/unit/yr): 30

Traffic control cost ($/unit/yr): 1

Inspection cost ($/unit/yr): 1

Maintenance cost ($/unit/yr): 1.5

Safety risk cost ($/unit/yr): 5

Set road geometry

Number of lanes: 2

Road length (ft): 20000

Install spacing (ft): 40

Other parameters

Annual discount rate: 3 %

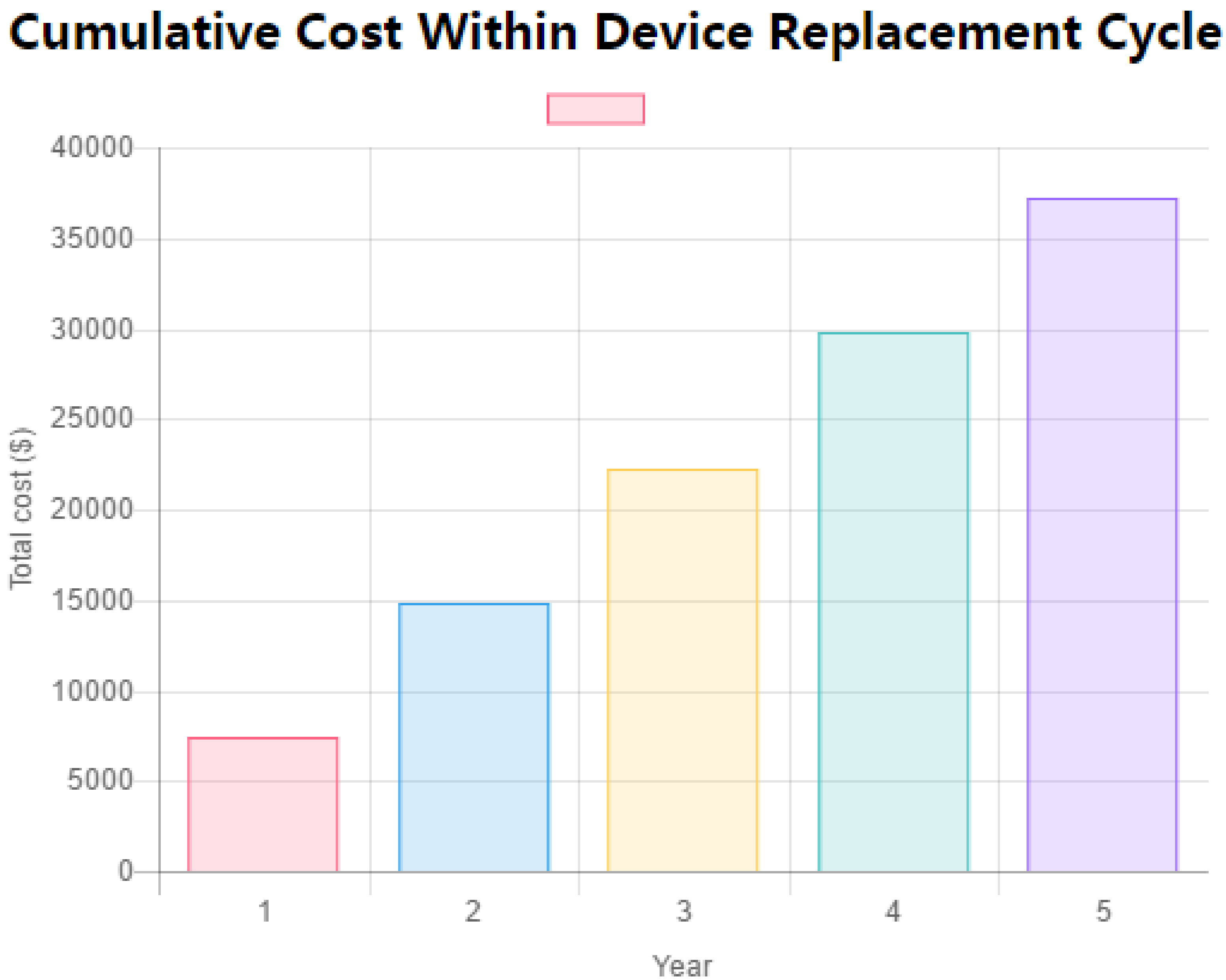
Device replacement cycle (year): 5

Maintenance cycle (year): 3

Annual total cost: $7,434.46

Calculate | Reset

Computer-Aided Capital Planning Tool



Summary of research

- This research studies the safety, cost and maintenance issues related to the use of RPMs and their alternatives
- Lab testing has been conducted to measure the retroreflectivity of RPMs and alternative safety products (e.g., traffic tape)
- A life cycle cost (LCC) based decision support tool is being developed to evaluate and compare alternative safety devices given different traffic and roadway characteristics
- The methodology and tool developed in this study can ultimately assist NJDOT in selecting appropriate safety treatment

Ongoing work

- Finalize the decision support tool for evaluation and comparison of RPMs and alternatives based on comments received in the last user meeting
- Finalize all lab testing and analysis
- Complete a final research report

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Acknowledgements

- NJDOT – Angelo Mendola, Chris Barretts, Vasudevan Ganarajan, Mamun Rashid, Amanda Gendek, Pragna Shah, Camille Crichton-Sumners, Andrew Zeleznock
- 3M – Juan Carlos Ojeda Alcala, Leah Picone, Steven Rhyner, Cristina Thomas, Matt Wilding
- Ennis-Flint – Stephen Bennett, Jerry Britt, Stephen Gainer, Klyne McCarty, Arati Patel, David Villani
- Rutgers & RPI - All the staff and students involved in this project