3M Science. Applied to Life.™

Improving road worker safety and reducing carbon emissions

Dr Kim Leong Tan
3M Transportation Safety Division
Asia Regulatory Affairs and NPI Manager

30 March 2023

Introduction of Speaker

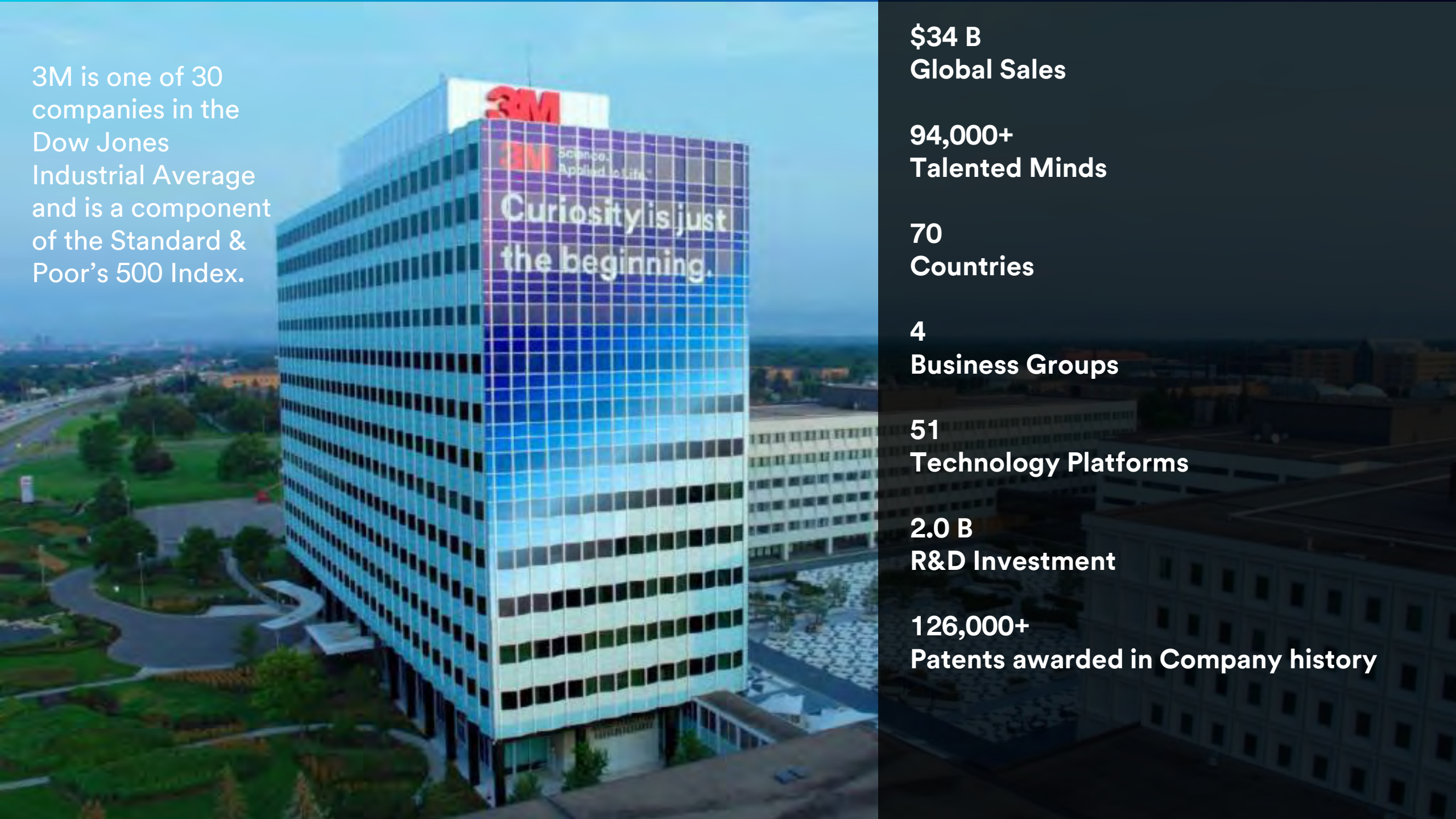
Dr. Kim Leong TAN
Area Regulatory Affairs and NPI Mgr.
Transportation Safety Division, Asia
3M Singapore

Dr. Tan is an optical engineering graduate from the **University of Cambridge.** He had been involved in the optical industry for over 20 years. He first did R&D in optical components in the US, focusing on fiber-optic communications, projectors and LCD displays. He holds more than 20 US and European patents from this research work. He is now based in **Singapore,** having led the application engineering teams for 3M transportation safety business in Asia. His current focus is the regulation development and road safety advocacy through safety standards, webinars and industry outreach. The goal is to help bring families home safely and reduce road traffic crashes in Asia.

Outline

1. 3M and Global Road Safety Leadership
2. Pavement Markings for Assisting Modern Driving
3. Enhanced Pavement Marking and Sustainability
4. Summary

3M and Global Road Safety Leadership



3M is one of 30 companies in the Dow Jones Industrial Average and is a component of the Standard & Poor's 500 Index.

$34 B
Global Sales

94,000+
Talented Minds

70
Countries

4
Business Groups

51
Technology Platforms

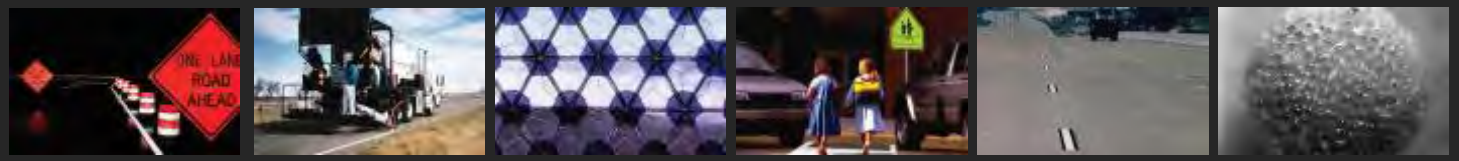
2.0 B
R&D Investment

126,000+
Patents awarded in Company history

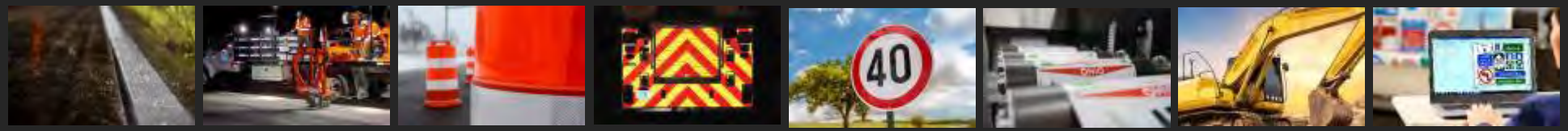
3M Transportation Safety – History Perspective

1930

3M invents reflective sheeting and installs the first fully-reflective traffic sign in 1939; reflective technology expands to road markings and license plates.



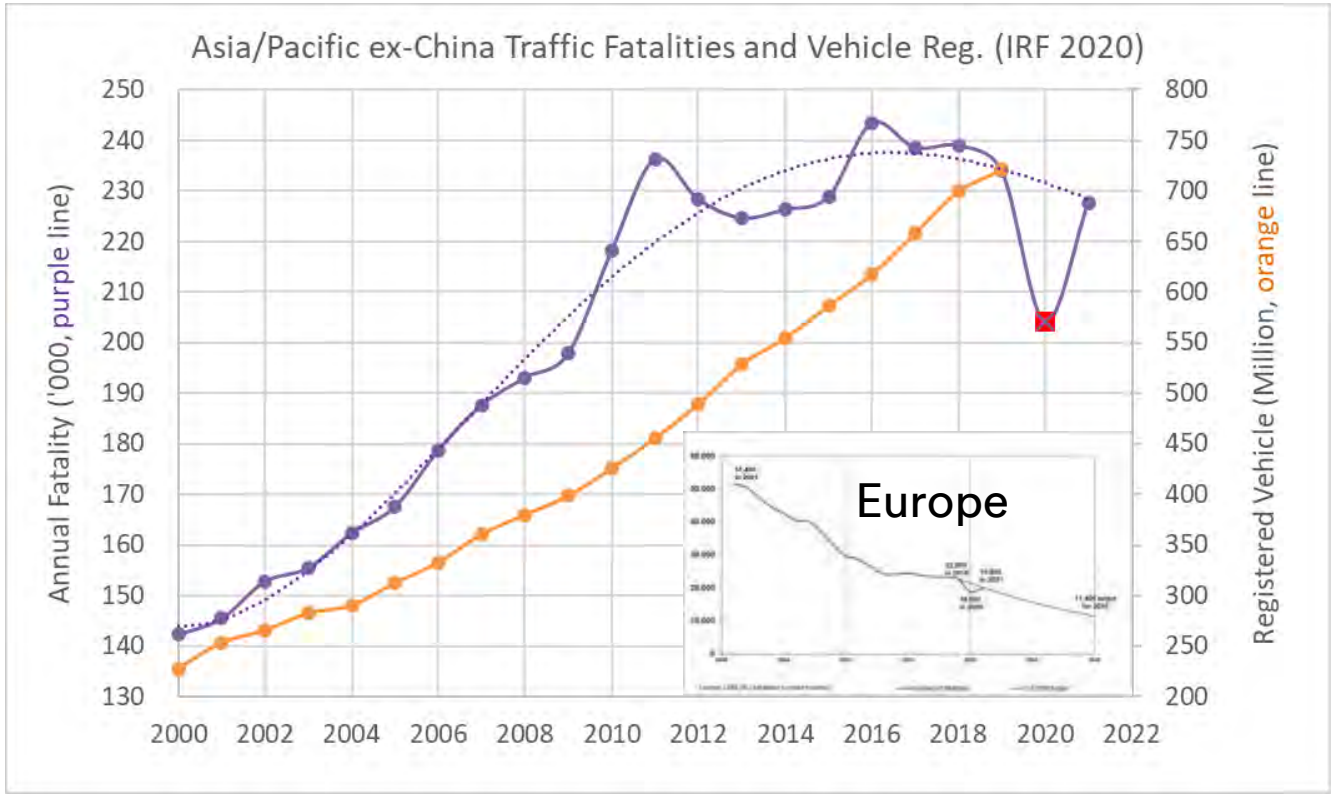
Microreplication technology improves retro reflectivity and increases day and nighttime sign visibility. Fluorescent technology makes work zone signs and devices and pedestrian crossings more visible during dusk, dawn, and inclement weather.



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.

2020

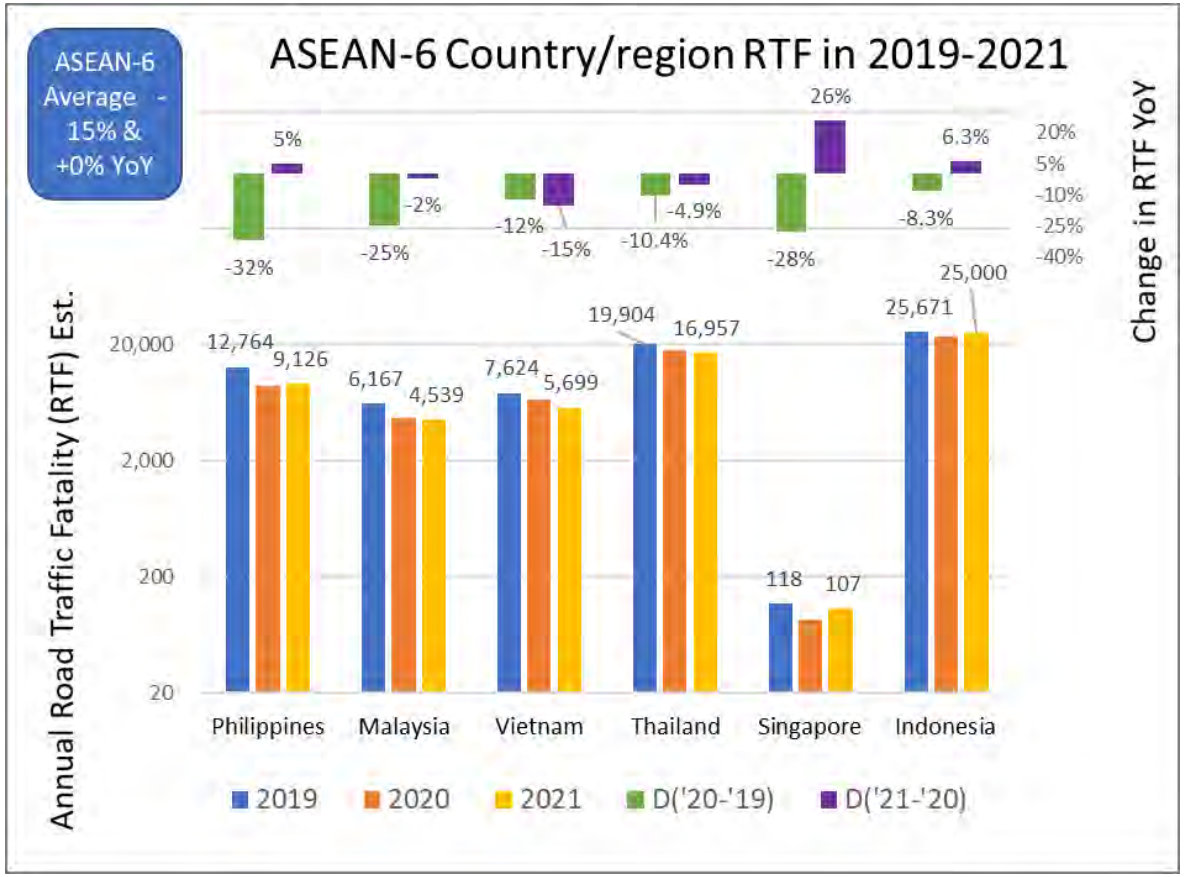
Asia Pacific ex-China Region Road Safety Status

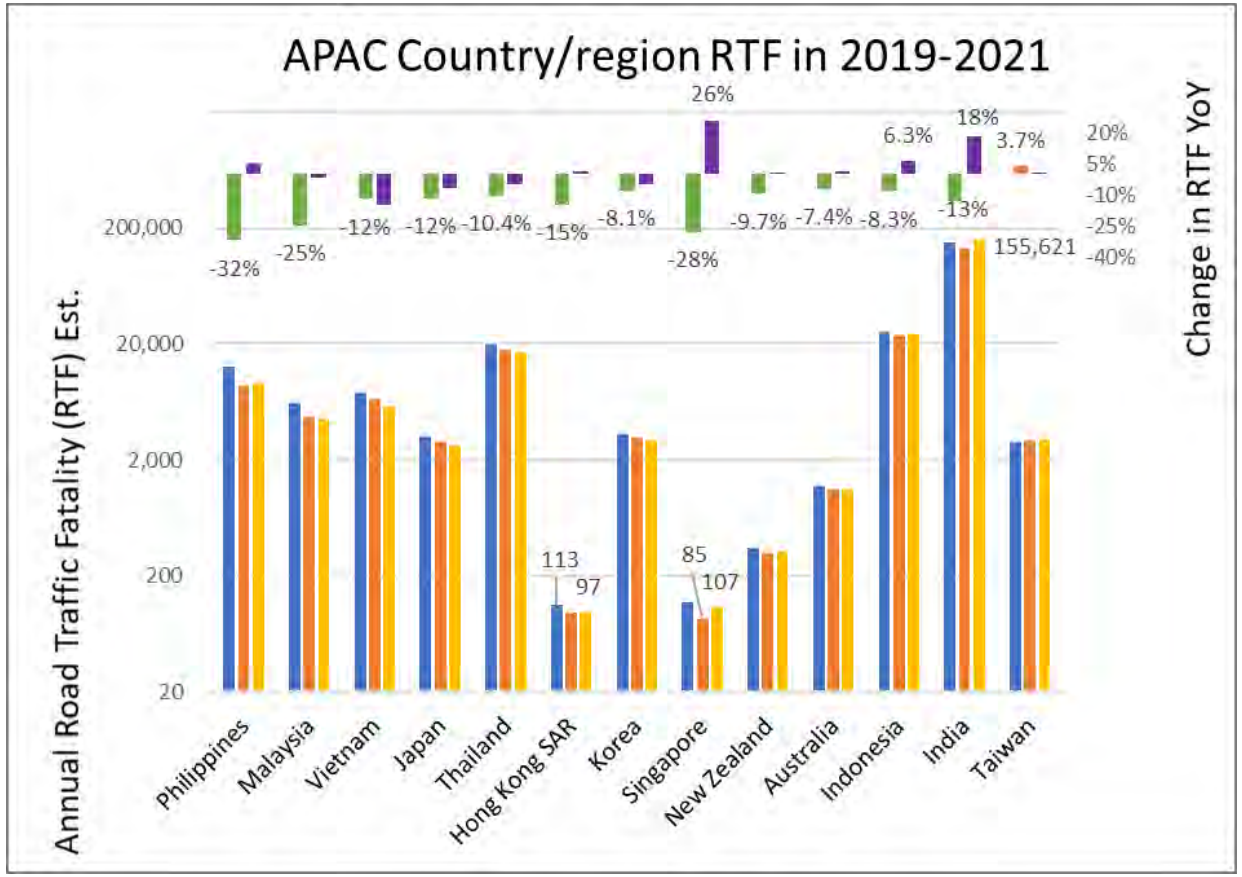


Source: International Road Federation (IRF) Word Road Statistics 2020, https://worldroadstatistics.org/, "2021 road safety statistics: what is behind the figures?" (europa.eu) and public sources online [Last Accessed: 21Sept2022]

Source: https://www.thehindu.com/data/data-in-2021-over-15-lakh-died-in-road-accidents-most-were-young-men-speeding-on-two-wheelers/article65844935.ece [accessed 21Sept2022]

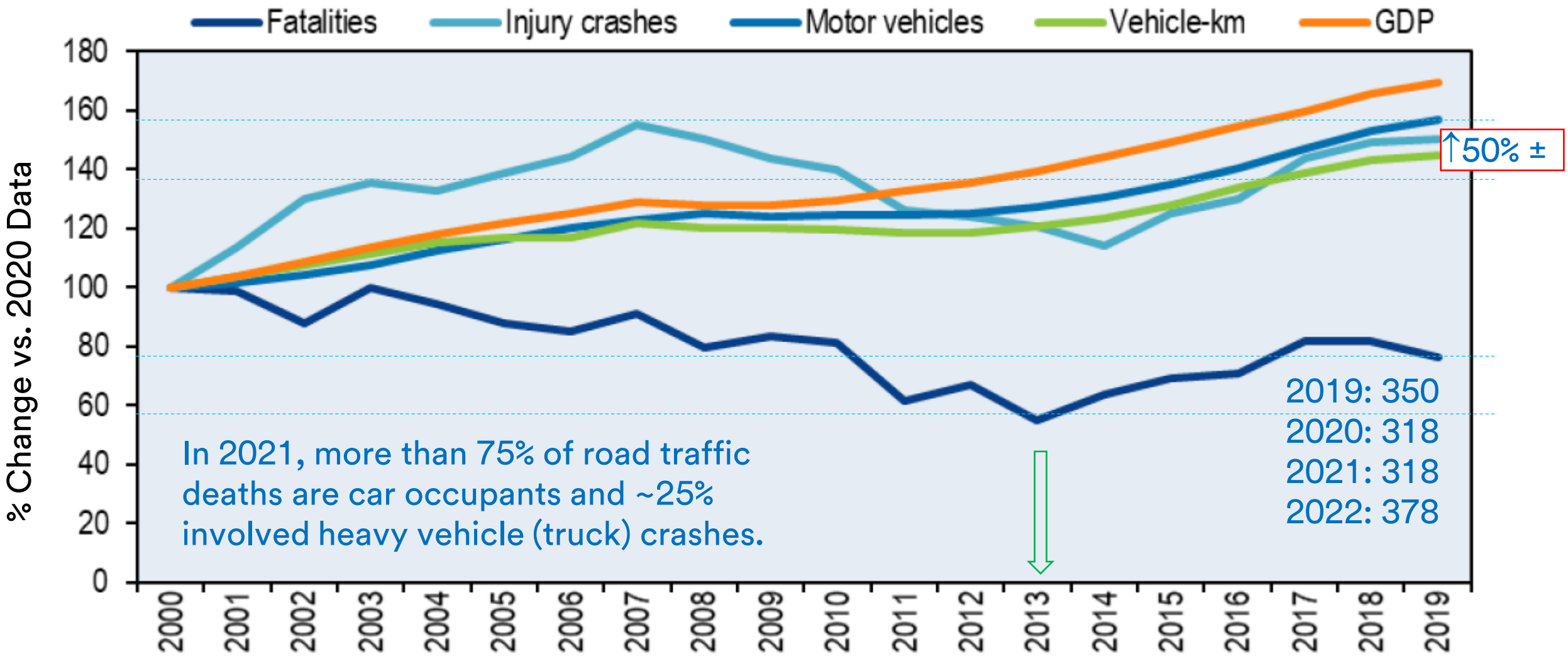
Pre- to Post-Pandemic Year RTF in ASEAN and APAC Countries





Source: various country data sources, please contact 3M Transportation Safety Div. for references.
October 2022 update.

New Zealand Road Traffic Fatality Trends



Reference: ITF Publication on New Zealand Road Safety https://www.itf-oecd.org/sites/default/files/new-zealand-road-safety.pdf

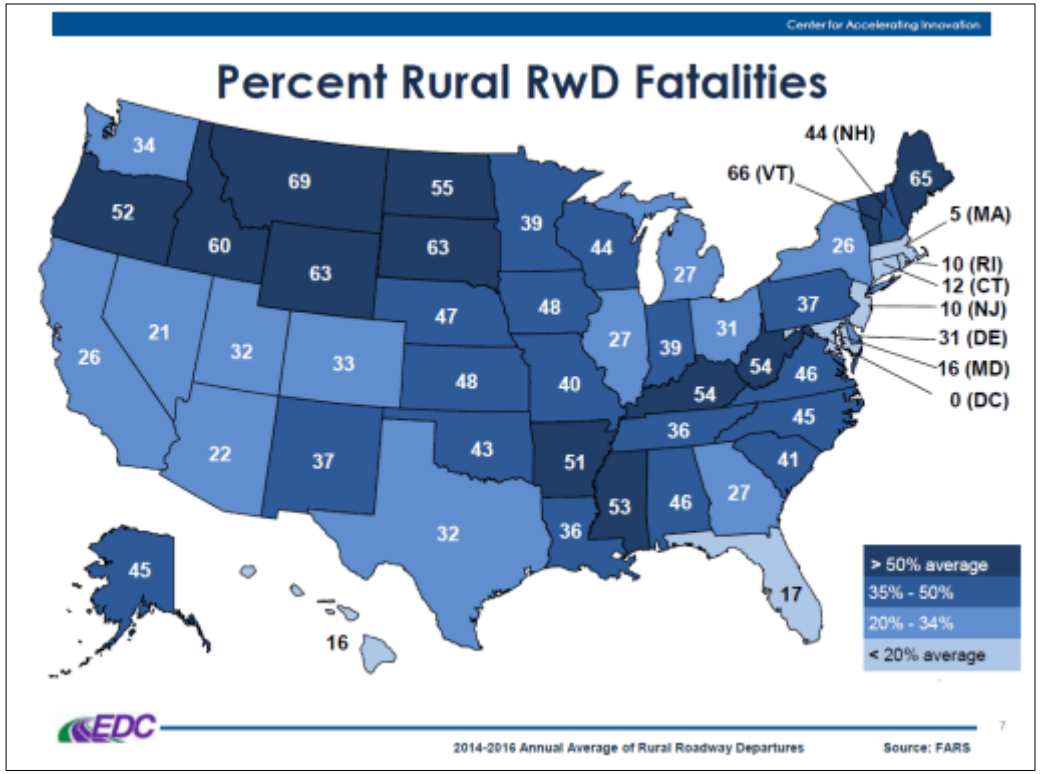
Pavement Markings for Assisting Modern Driving

There’s a lot riding on the line

1) Source: US DOT National Highway Traffic Safety Administration, Fatality Analysis Reporting System (FARS). 2017 – Available from: https://www.nhtsa.gov/researchdata/fatality-analysis-reporting-system-fars

Photo credits – 3M approved stock images

US Roadway Departure (RwD) as % of Crashes 2014-16

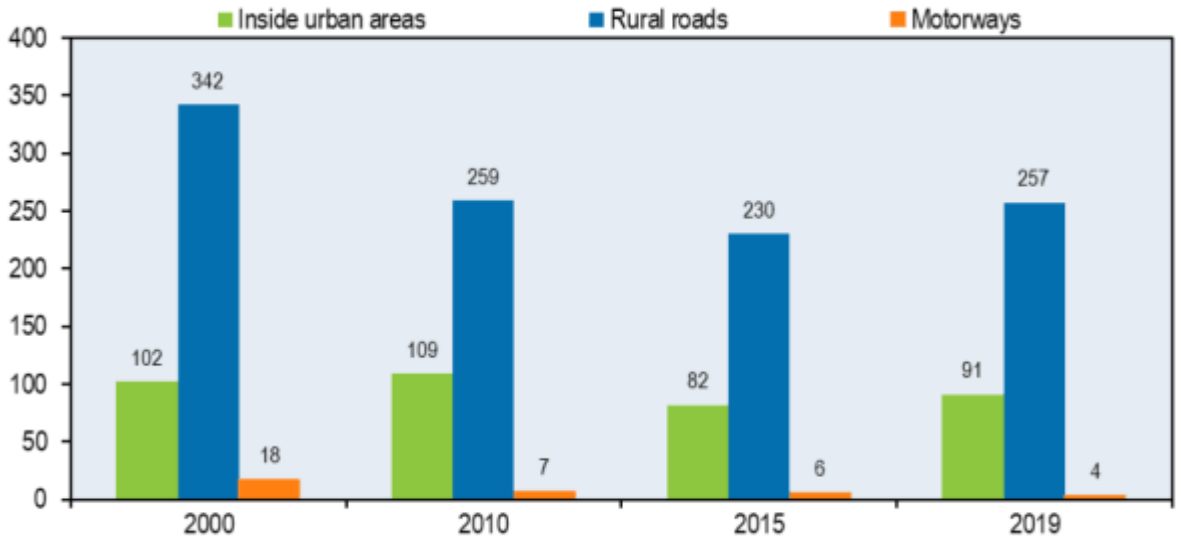


Reference: https://highways.dot.gov/safety/RwD

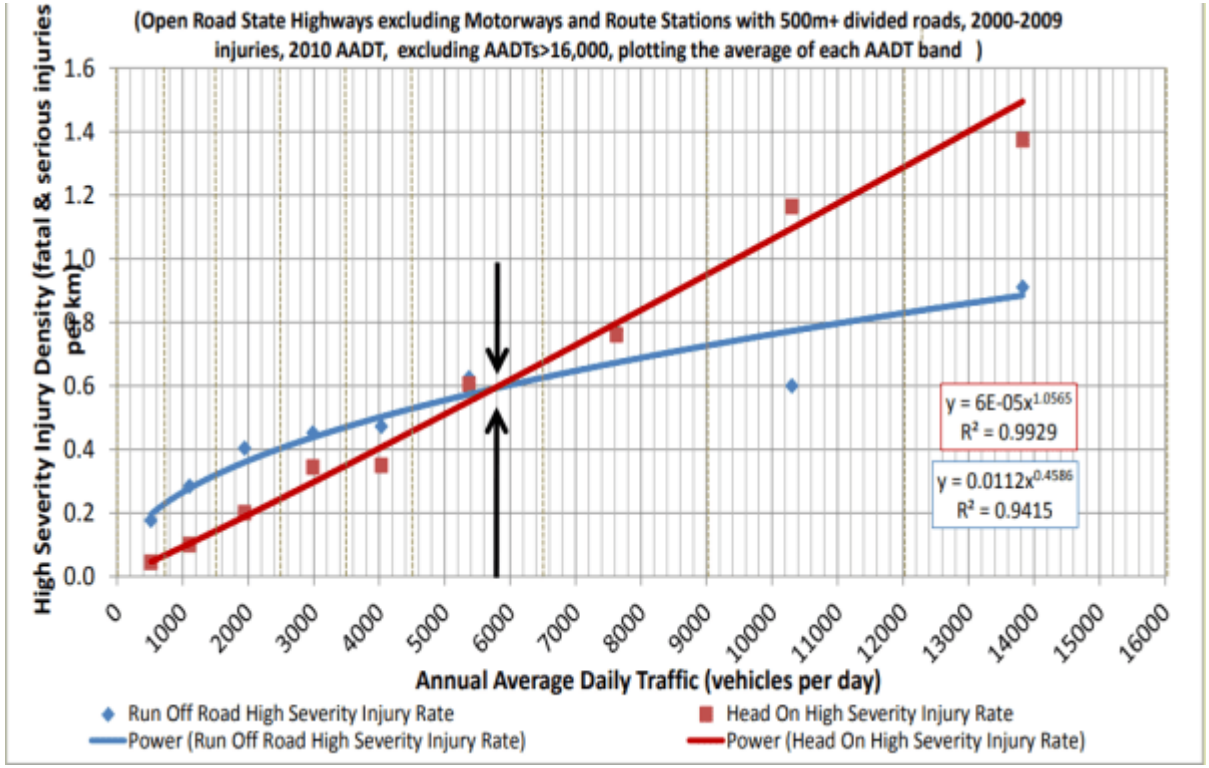
NZ Factors Contributing to Fatal and Injury Crashes 2019

Reference: https://www.transport.govt.nz/statistics-and-insights/safety-annual-statistics/road-deaths-and-injuries/

NZ Analysis of Road Traffic Fatalities by Road Types



Over 70% of fatalities occur in rural areas on both state highways and local roads

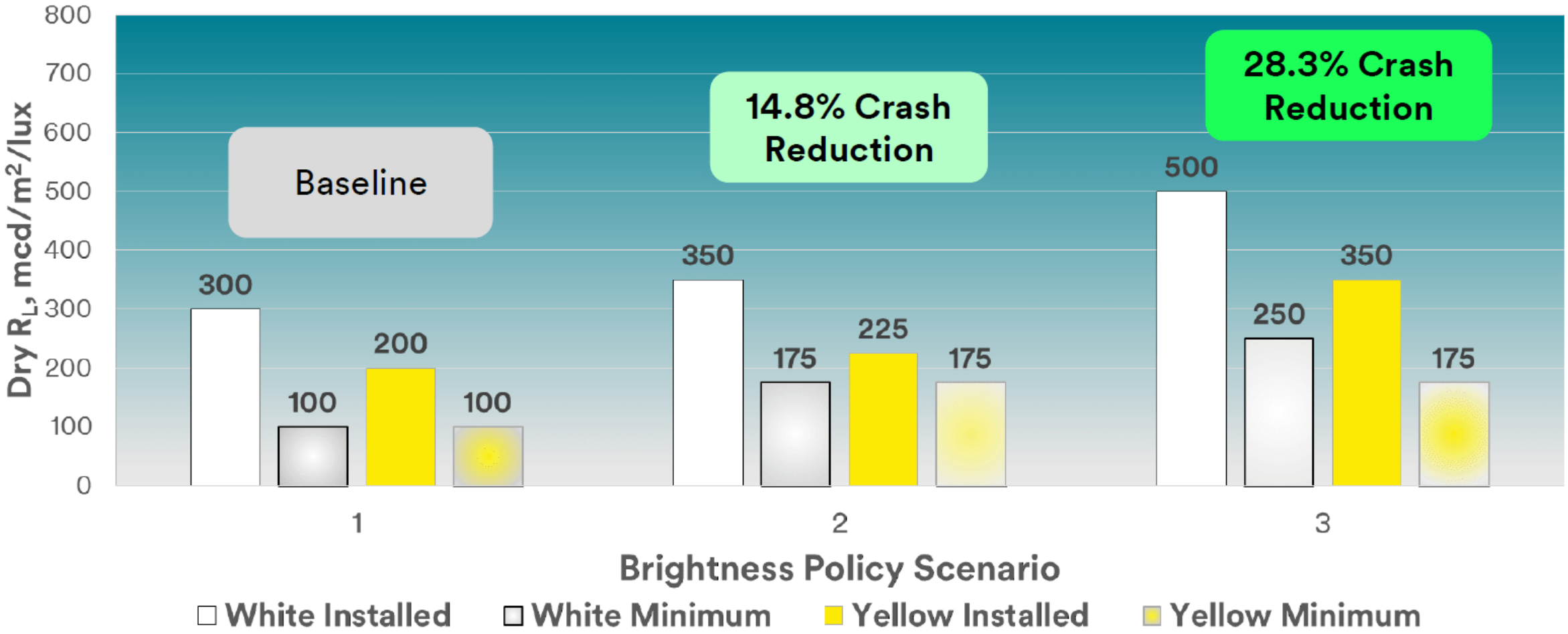


In rural State Highways with low traffic density (AADT < 6k), Run Offs contributing to fatalities and serious injuries may be 2X more frequent than head on collisions.

References: 1. ITF Publication on New Zealand Road Safety https://www.itf-oecd.org/sites/default/files/new-zealand-road-safety.pdf; 2. NZTA Publication “High Risk Rural Roads 2011” https://www.nzta.govt.nz/assets/Uploads/High-risk-rural-roads-guide-September-2011.pdf

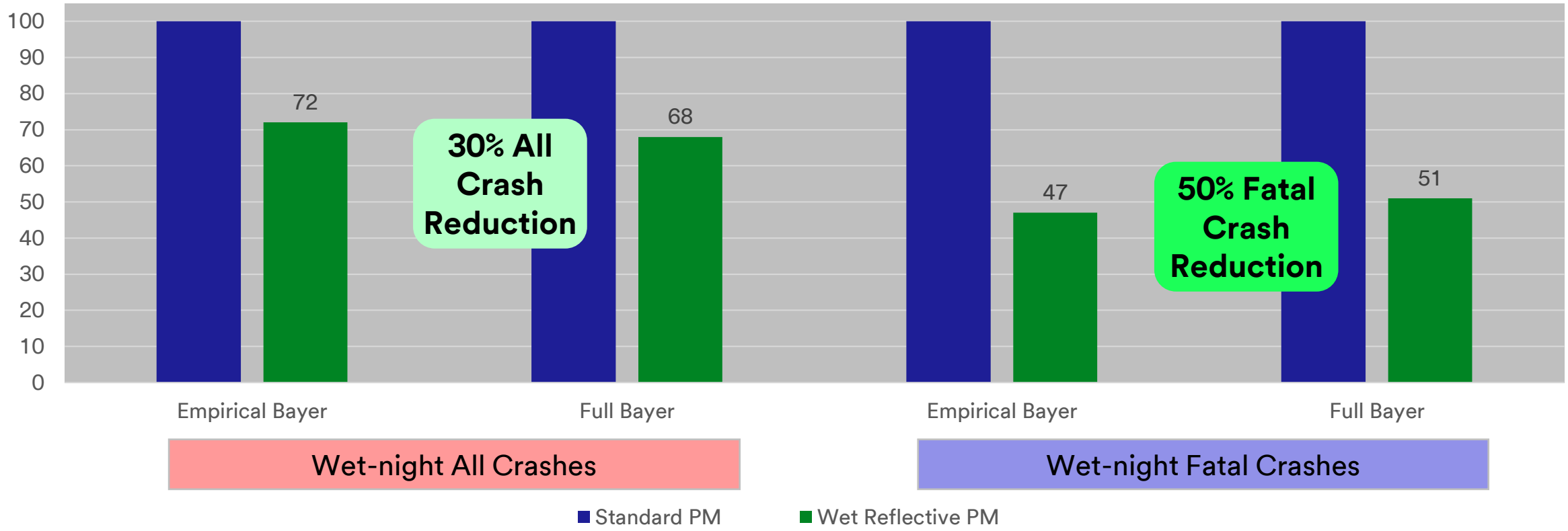
Brighter pavement markings helps save lives

Nighttime Safety and Pavement Marking Retro reflectivity on Two-Lane Highways: Revisited with North Carolina Data
Paul J. Carlson, Raul E. Avelar, Eun Sug Park, Dong Hun Kang. Texas A&M Transportation Institute.



Wet Reflective Pavement Markings Save Lives

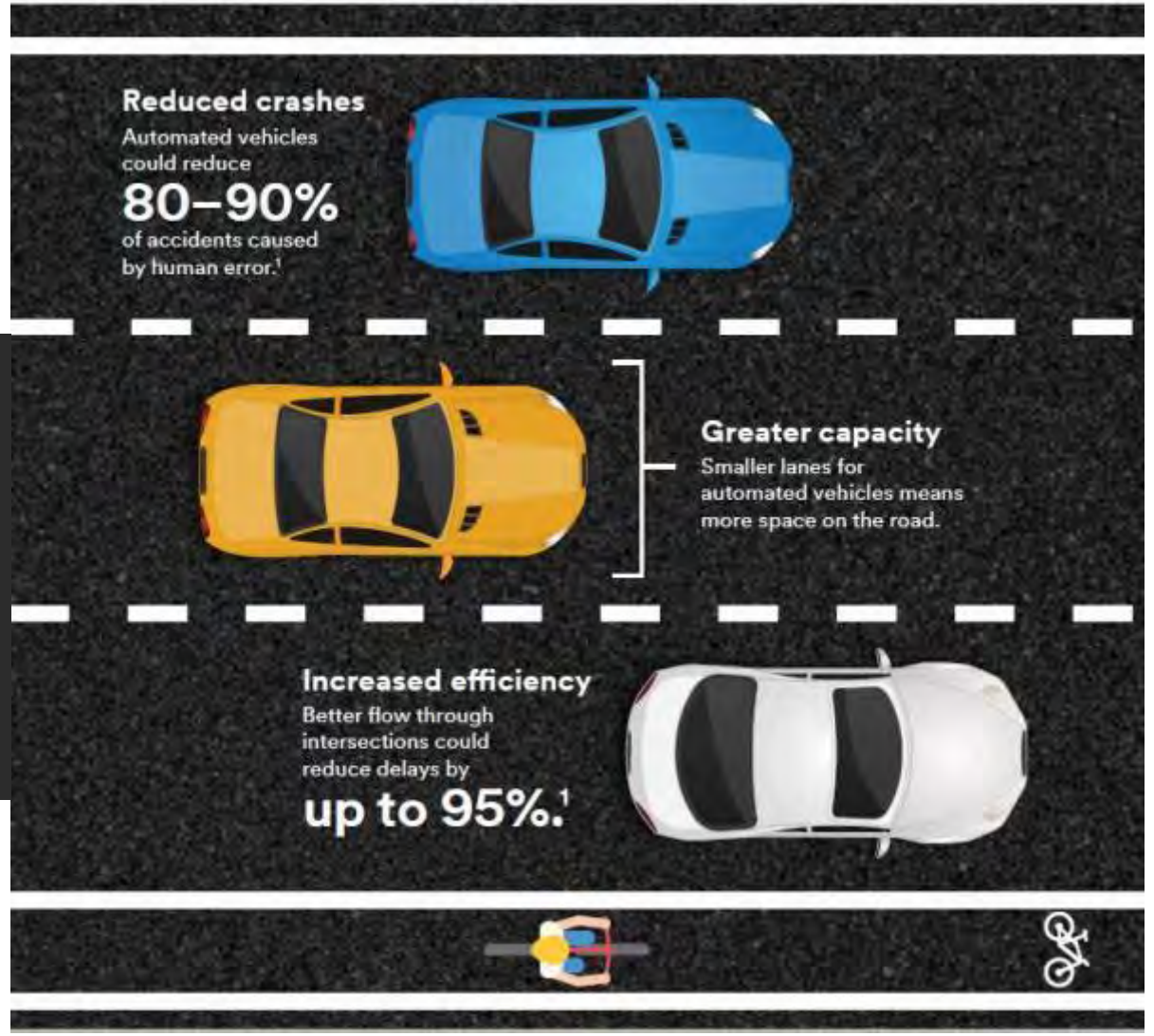
Crash Reductions with Wet Reflective Pavement Markings (E.S. Park, TRB 2019 Annual Meeting, Paper 19-04199)



E.S. Park, et al., "Safety Effects of Wet-Weather Pavement Markings." Transportation Research Board 2019 Annual Meeting, Paper 19-04199, https://trid.trb.org/view/1572259.

Autonomous Vehicles Require High Visibility PMs

Automated vehicle cameras depend on visible markings to support functions like lane departure warning (LDW) and lane keep assist (LKA), part of SAE Level 1 Advanced Driver Assistance Systems (ADAS).



SOURCE[1]: Center for Transportation Research, The University of Texas at Austin, http://library.ctr.utexas.edu/ctr-publications/0-6847-1.pdf.

There's a Lot Riding on the Line

Roadway Infrastructure optimized for human and machine vision help enable safer navigation

Better road marking systems can further improve Lane Departure Warning systems.

An optimally working LDW system can:

Prevent 7,500 fatal crashes annually (US)[1]

Reduce injuries by 8.9% per annum in EU[2]

Provide a socio-economic benefit-cost ratio of greater than **20:1**[3]

1. Crash Avoidance Potential of Four Passenger Vehicle Technologies, Jermakian, 2011, Accident Analysis & Prevention
2. Effects of Lane Departure Warning on Police-Reported Crash Rates, Cicchino, 2018, Journal of Safety Research
3. Economics of Lane-Departure prevention technologies: benefits resulting from reduced traffic-accident losses*, Miyoshi, 2017, ITEC

Dr Hashimoto – 3M TSD Webinar 15-Oct-2020

Findings – standard pavement markings are not recognized by the AV sensor systems in the night with light rain to heavy rain. Even without full AVs, the safety features of LKA and LDW could not be activated in light rain during the night.

Research on Automated Vehicles

Infrastructure – Collaboration with 3M

Background

Impossible: Availability of sensor for all condition

For safety priority place or highspeed area
Improvement of Infrastructure may be necessary

Experiments

Can vision system recognize lane marker?

Experiments with vision system under several conditions(rainy, dark) with high reflection lane marker

- 3M Stamark High Performance Contrast Tape 380AW
- 3M Stamark High Performance 380AW

Result

Time	Weather	Velocity	Trial	Lane Marker No.1	Lane Marker No.2	Lane Marker No.3
				Recognition Rate		
Daytime	Sunny	30km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
		65km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
	Light Rainy	30km/h	1st	100%	100%	11%
			2nd	100%	100%	26%
		65km/h	1st	100%	100%	8%
			2nd	100%	100%	23%
	Rainy	30km/h	1st	100%	100%	93%
			2nd	93%	100%	94%
		65km/h	1st	100%	100%	62%
			2nd	62%	100%	100%
Twilight	Sunny	30km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
		65km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
	Rainy	30km/h	1st	92%	100%	57%
		65km/h	1st	98%	100%	82%
Nighttime	Sunny	30km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
		65km/h	1st	100%	100%	100%
			2nd	100%	100%	100%
	Light Rainy	30km/h	1st	100%	100%	0%
			2nd	100%	100%	0%
		65km/h	1st	100%	100%	0%
			2nd	100%	100%	0%
	Rainy	30km/h	1st	100%	100%	0%
			2nd	100%	100%	0%
		65km/h	1st	100%	100%	0%
			2nd	100%	100%	0%

- Usual Paint: (No.3)
  → Low recognition rate under rain/dark condition

- All weather lane markers (No.1,2)
  - 3M Stamark High Performance Contrast Tape 380AW
  - 3M Stamark High Performance 380AW

  → More than 90% recognition rate under rain/ dark condition

Possibility of increasing area in which use of image processing is available by using all-weather lane markers

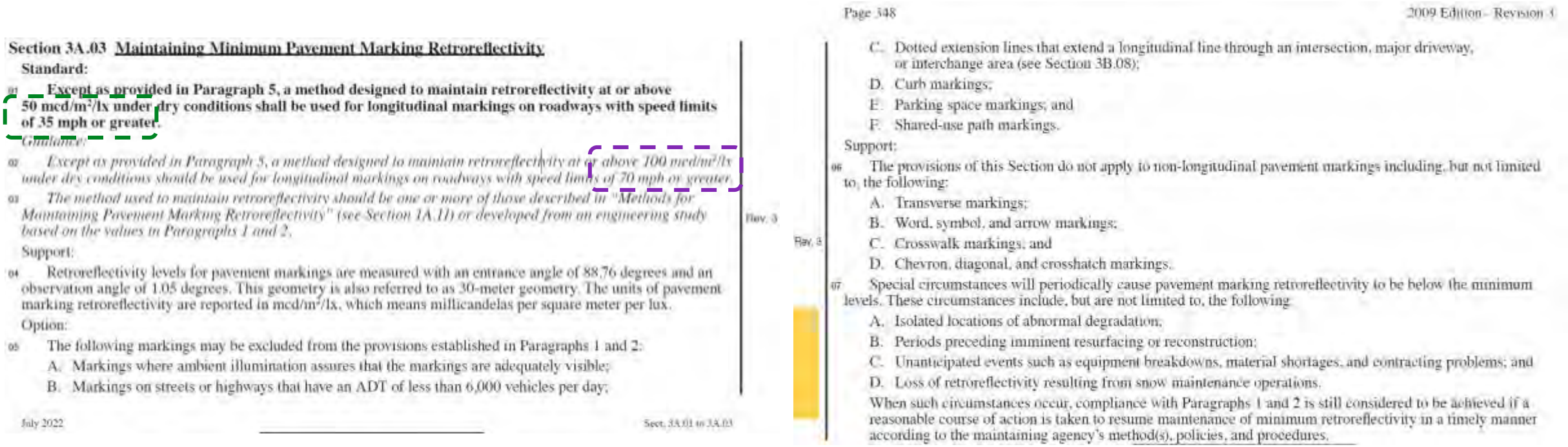
Depending on Case (Automated vehicle's road, accident-prone points, high speed courses...

N.Hashimoto

53

Ref: 3M Transportation Safety Webinar
by Dr Hashimoto, Oct. 2020

Mandating Minimum Pavement Marking Performance Intervention Levels (FHWA from 6 Sept 2022)



Section 3A.03 Maintaining Minimum Pavement Marking Retroreflectivity

Standard:

01 **Except as provided in Paragraph 5, a method designed to maintain retroreflectivity at or above 50 mcd/m²/lx under dry conditions shall be used for longitudinal markings on roadways with speed limits of 35 mph or greater.**

Guidance:

02 *Except as provided in Paragraph 5, a method designed to maintain retroreflectivity at or above 100 mcd/m²/lx under dry conditions should be used for longitudinal markings on roadways with speed limits of 70 mph or greater.*

03 *The method used to maintain retroreflectivity should be one or more of those described in "Methods for Maintaining Pavement Marking Retroreflectivity" (see Section 1A.11) or developed from an engineering study based on the values in Paragraphs 1 and 2.*

Support:

04 Retroreflectivity levels for pavement markings are measured with an entrance angle of 88.76 degrees and an observation angle of 1.05 degrees. This geometry is also referred to as 30-meter geometry. The units of pavement marking retroreflectivity are reported in mcd/m²/lx, which means millicandelas per square meter per lux.

Option:

05 The following markings may be excluded from the provisions established in Paragraphs 1 and 2:

A. Markings where ambient illumination assures that the markings are adequately visible;

B. Markings on streets or highways that have an ADT of less than 6,000 vehicles per day;

Rev. 3

July 2022

Sect. 3A.01 to 3A.03

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C. Dotted extension lines that extend a longitudinal line through an intersection, major driveway, or interchange area (see Section 3B.08);

D. Curb markings;

E. Parking space markings; and

F. Shared-use path markings.

Support:

06 The provisions of this Section do not apply to non-longitudinal pavement markings including, but not limited to, the following:

A. Transverse markings;

B. Word, symbol, and arrow markings;

C. Crosswalk markings; and

D. Chevron, diagonal, and crosshatch markings.

07 Special circumstances will periodically cause pavement marking retroreflectivity to be below the minimum levels. These circumstances include, but are not limited to, the following:

A. Isolated locations of abnormal degradation;

B. Periods preceding imminent resurfacing or reconstruction;

C. Unanticipated events such as equipment breakdowns, material shortages, and contracting problems; and

D. Loss of retroreflectivity resulting from snow maintenance operations.

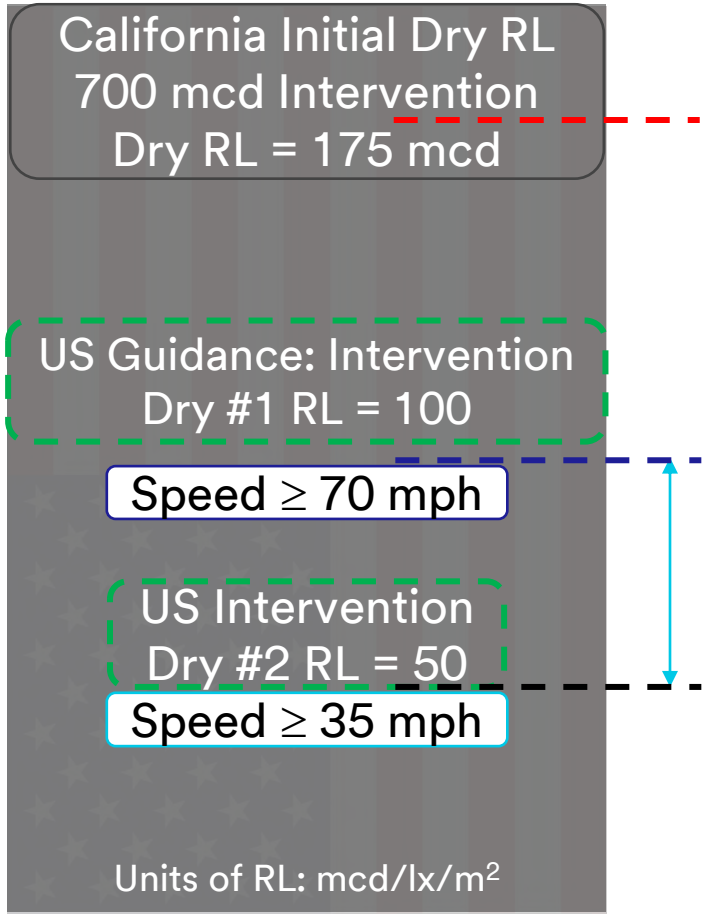
When such circumstances occur, compliance with Paragraphs 1 and 2 is still considered to be achieved if a reasonable course of action is taken to resume maintenance of minimum retroreflectivity in a timely manner according to the maintaining agency's method(s), policies, and procedures.

Rev. 3

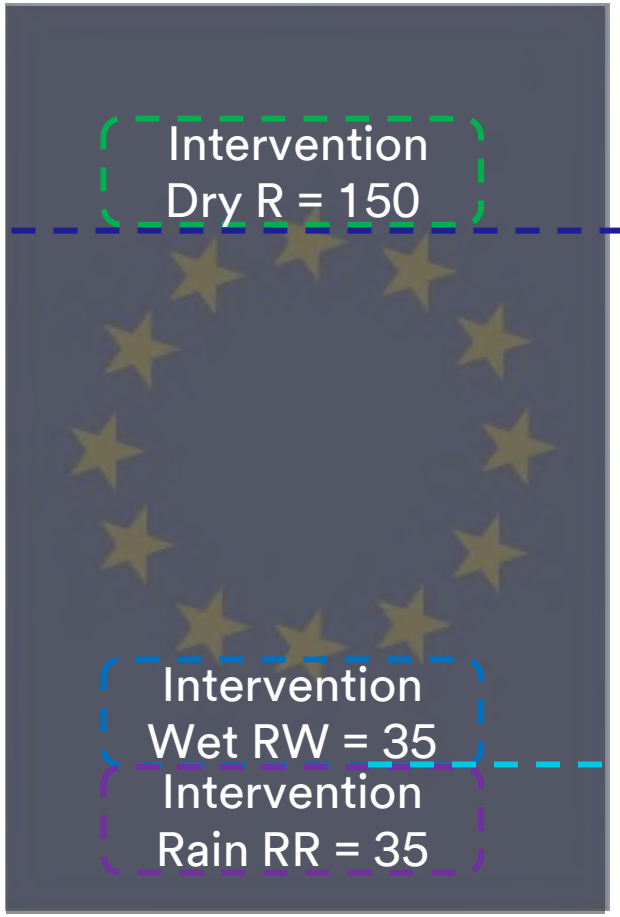
References:

1. FHWA Announces Final Rule to Reduce Roadway Fatalities in Dark Conditions by Improving Visibility with Retroreflective Pavement Markings | FHWA (dot.gov)
2. Federal Register :: National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Maintaining Pavement Marking Retroreflectivity
3. Methods for Maintaining Pavement Marking Retroreflectivity (dot.gov)

Global Standards for PM Intervention Levels to Enhance Driving Safety and "Assist" ADAS/CAV Vehicles



US FHWA (effective 6/Sep/2022); Metrology Standard ASTM E1710



EU Road Fed. Recomm. 2019; Metrology Standard EN 1436

NZTA P30:2009 Standard; Metrology Standard TNZ M/20 for R and RW; EN 1436 for RR

Enhanced Pavement Marking and Sustainability

Importance of fully compliant pavement markings

Providing critical driver direction during daytime and nighttime, dry and wet conditions

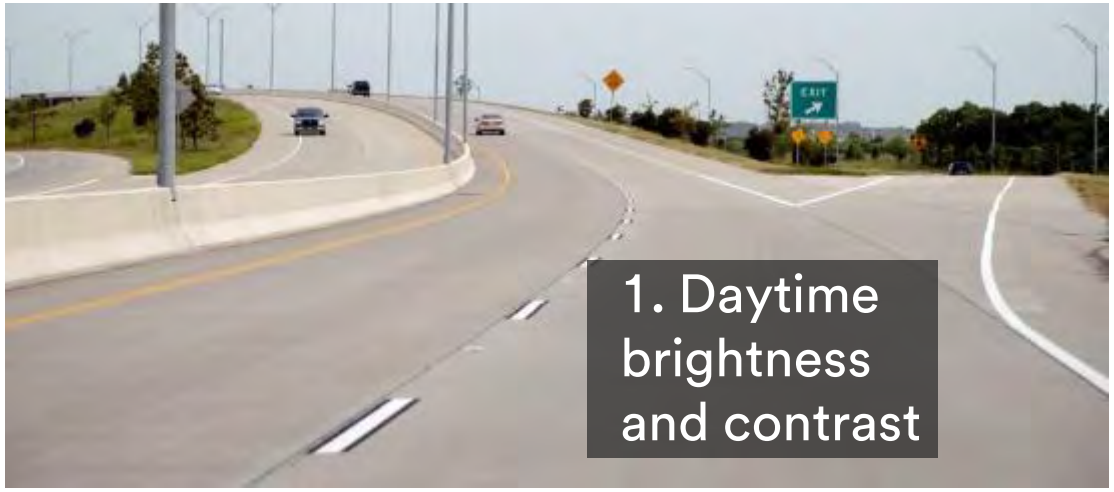
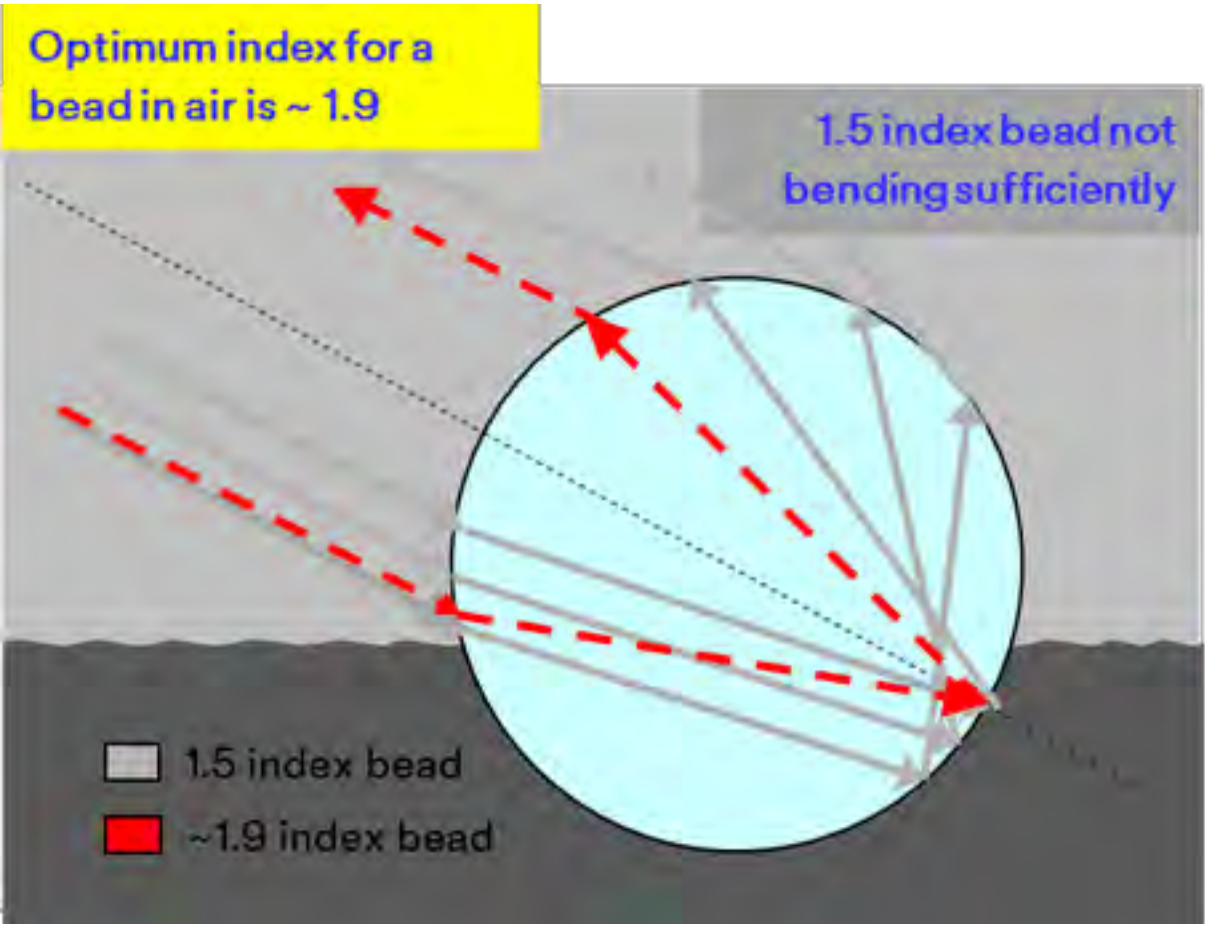
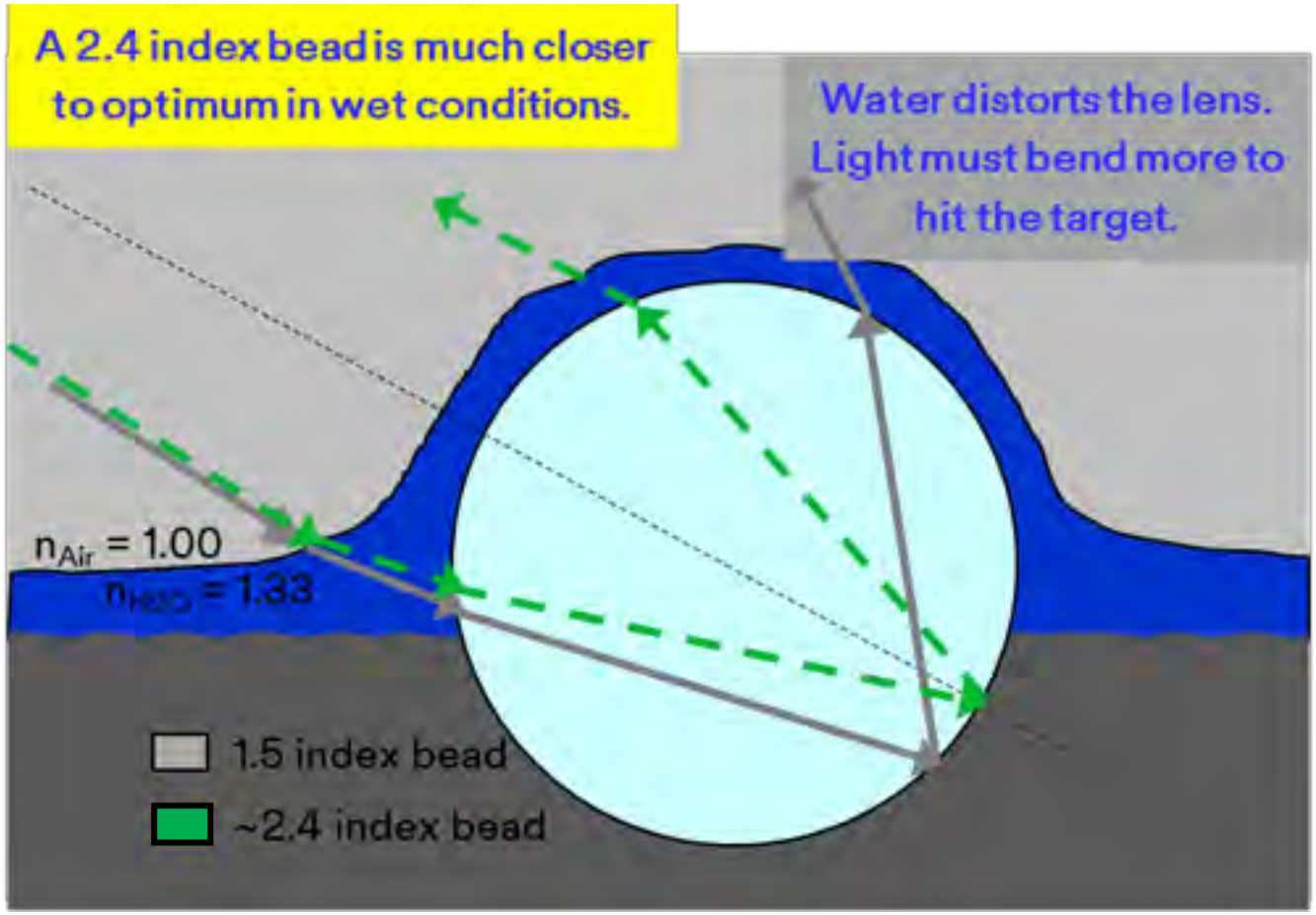


Photo credits – 3M approved stock images

Solutions for Visibility in All Weather Conditions

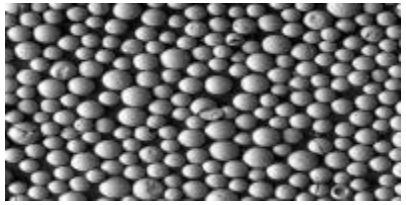
High Performance Pavement Marking for Day/Night and Dry/Wet Conditions





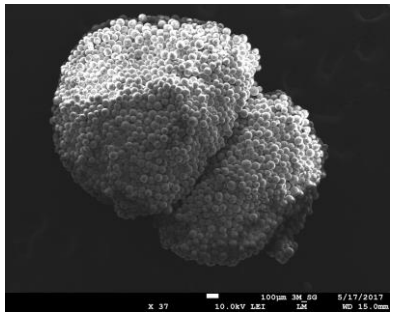
3M Reflective Optics based Portfolio of Products

3M Ultra High Refractive Index Micro-crystalline Beads (MCB)



1.7x Index
1.9 Index
2.4 Index
Blend 1.9/2.4

3M Clustered Reflective Optical Elements

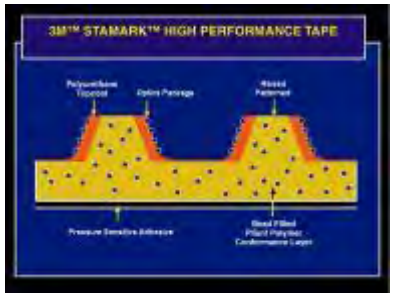


AW Liquid Marking

AW: All Weather

- AW Paint
- AW Thermoplastic
- AW Polyurea
- AW Epoxy
- AW MMA

3M Structured Reflective Optical Tapes



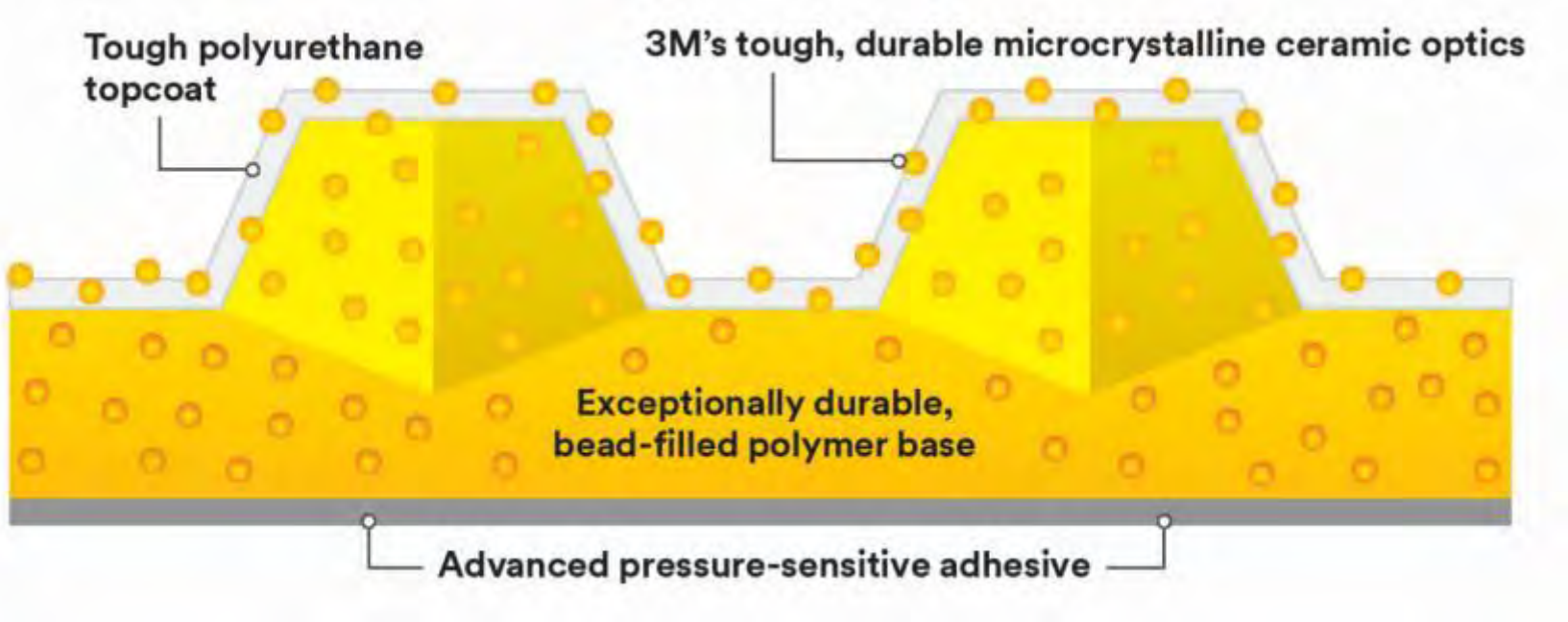
Stamark™ PM Tapes

- 380AW
- 380i ES
- 380ESD
- 380 Contrast
- 710 Temp Tape

Stamark technical features and benefits

Advanced technologies in every aspect of Stamark construction, inside and out

Construction



Supply Format

Technical Benefits of Stamark Construction vs. Thermoplastic

- Polyurethane topcoat → better durability on the wearing surface and greater bead adhesion
- Profiled Pattern → Higher initial and retained dry and wet retroreflectivity
- Advanced pressure sensitive adhesive → Reliable adhesion to asphalt and concrete surfaces, colder weather applications
- Reinforced netting → durability
- Ceramic skid particles → skid resistance

 Sources: See Notes

3M™ Stamark™ 380 Series Tapes – Applied Images

380ESD Germany + Day time

380AW France + Flash

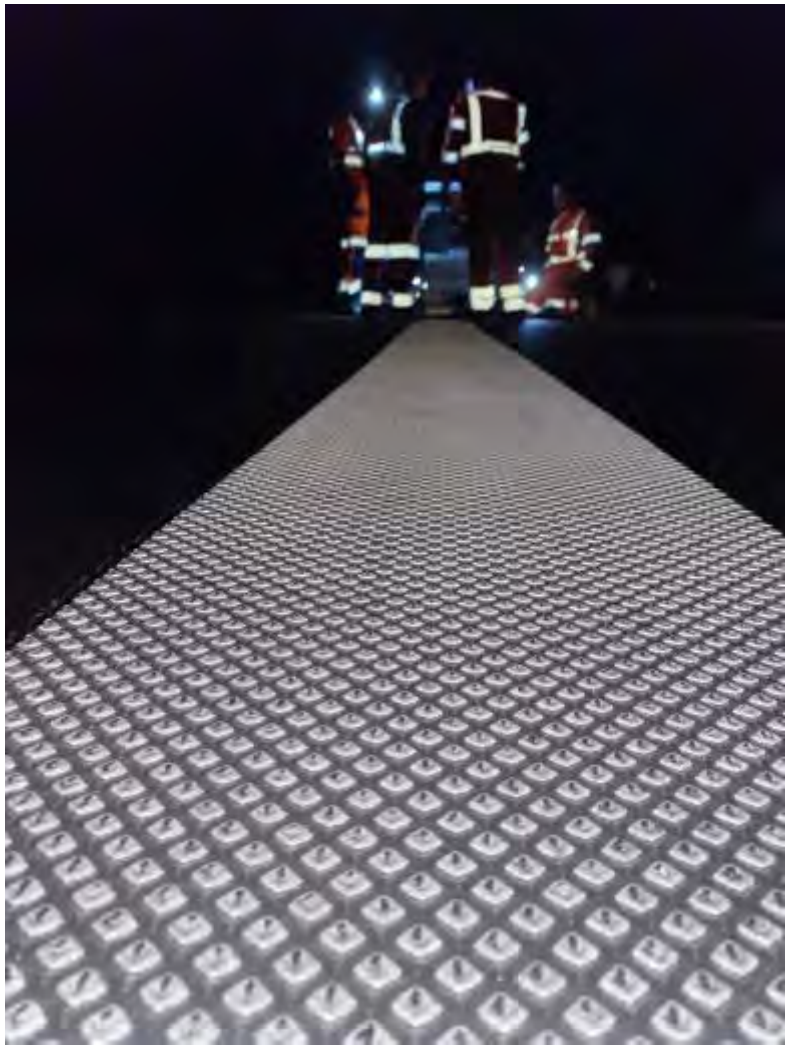


Photo credits – 3M employee with consent

Stamark 380ESD field performance data – Germany

Large 3rd party data set helps substantiate Stamark durability value proposition

25 Different Sites in East Germany

Study Information

Materials: 380ESD

Measurement Methodology: Internal data collected by3M Germany with Zehntner ZRM 1013 Reflectometer following EN 1436.

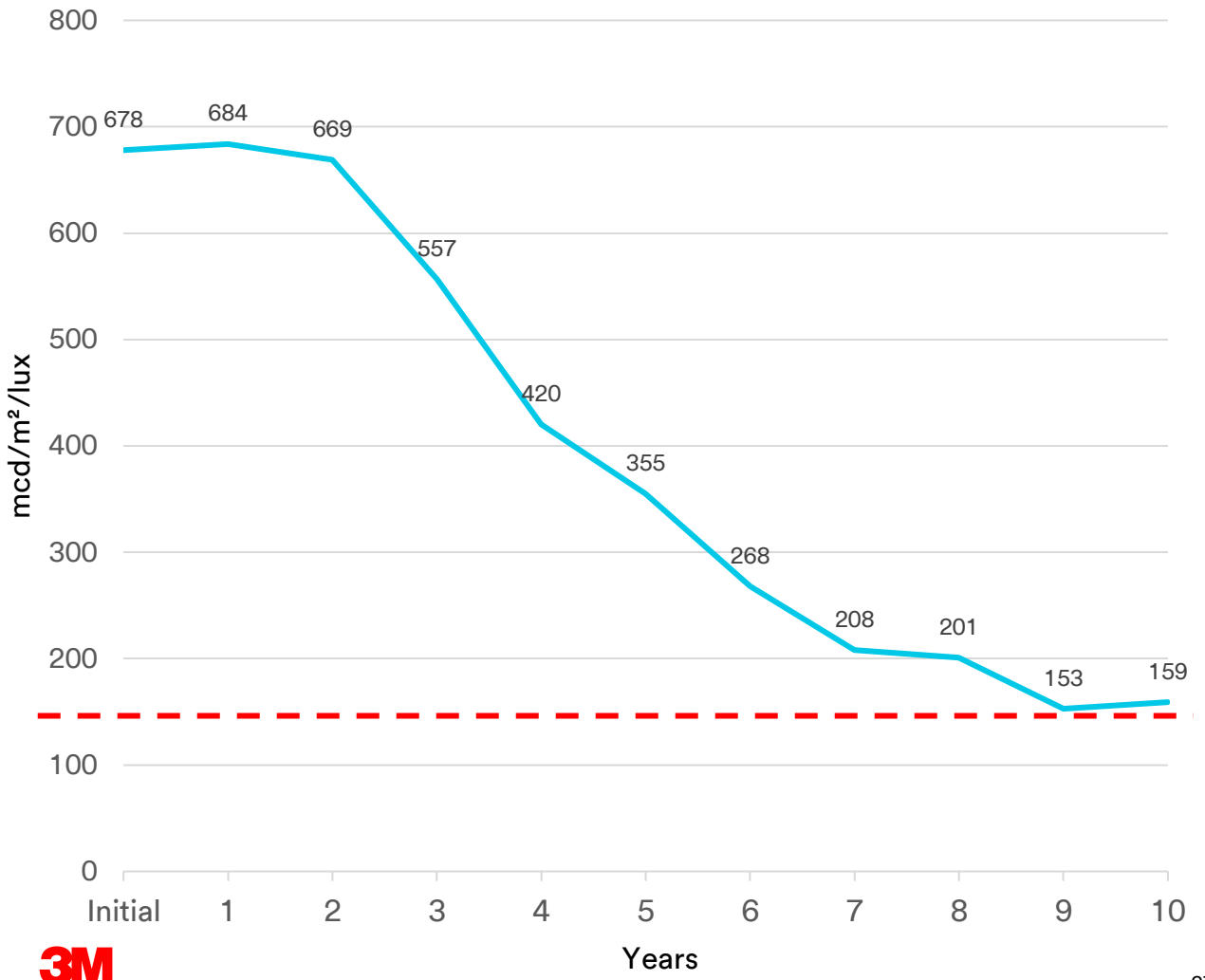
Installation Date: Every year from 2009 to 2019

Measurement Date: 2017 – Measurements were taken on markings of different ages, then consolidated. Added 2019 data updates.

Site Information

- Expressway, road ADTs ranging from 19,000 to ~94,500
- Surface Applied Skip Line and Right Edge Lines

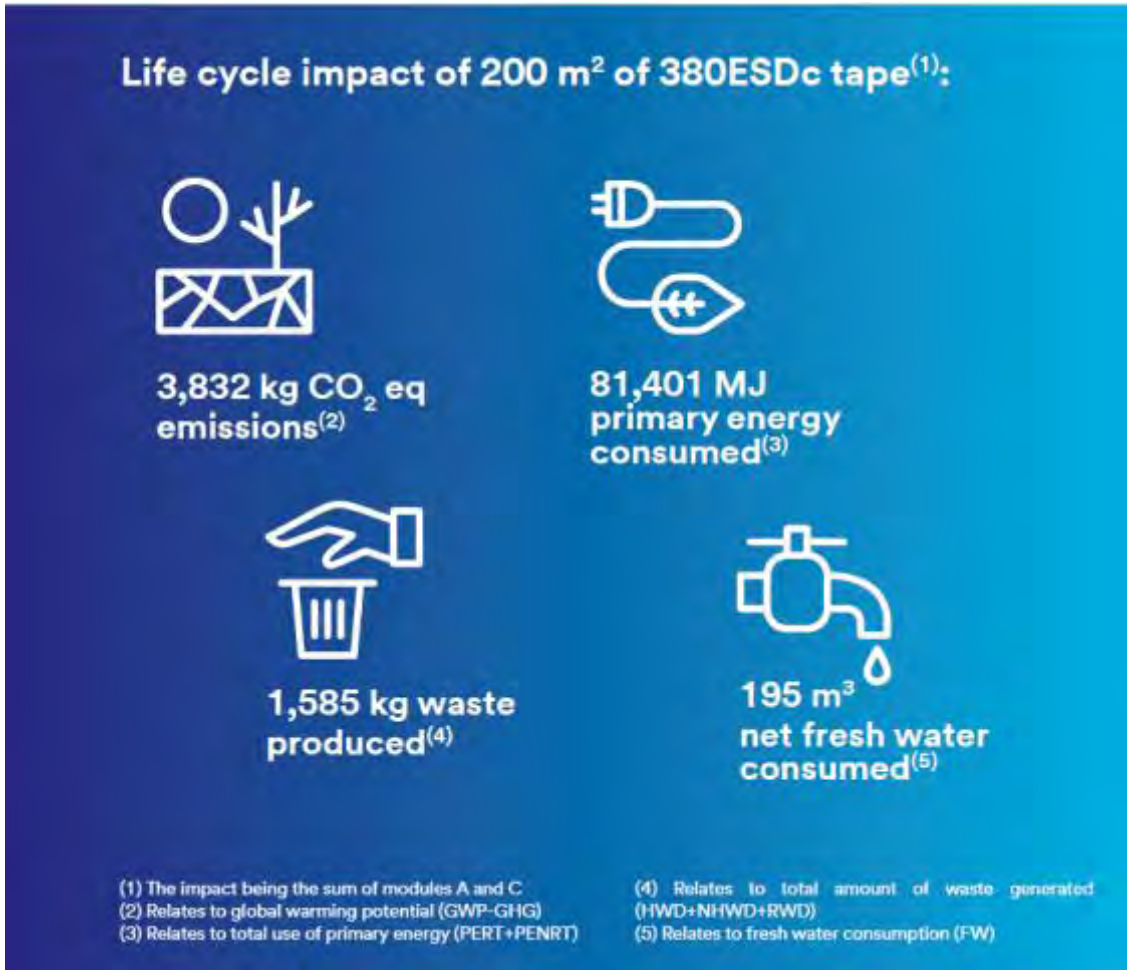
Average Dry Retroreflectivity After 10 Years



Note: many factors influence field performance, always consult AE team for guidance

Ref: 3M Germany Technical Report

Carbon Emission Estimates of Road and PM Constructions



3M Tape CO_2e 3,832 kg/200 sqm + CO2e from 15,000 km ocean freight = 3,981 kg CO_2e / 660 kg.

Thermoplastic CO_2e 3,822 kg/ton mass, yields 200 sqm PM. Local production + local truck freight + application carbon 302 kg = 4,122 kg CO_2e / ton + 120 kg glass beads.

- Tapes reduces carbon emission using thermoplastic PM by 65-70% because its service life is 8-10 years whereas thermoplastic is about 3 years.
- Tape CO2e of ~4 ton is negligible (~5%) compared to ~75 ton of CO_2e from 1,060 ton of asphalt concrete to build 2" of overlay for 435 m x 21 m wide 4-lane road.

Data sourced from Environmental Product Declaration (EPD) for 3M™ Stamark™ High Performance PM Tape Series 380ESD issued Nov. 2022.

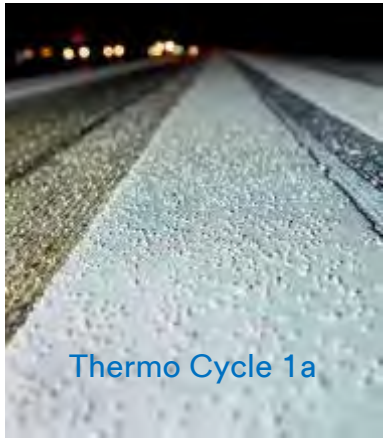
Thermoplastic CO_2e is estimated based on published data on solvent borne paint because both are similar in compositions. https://www.carbonfootprint.com/factors.aspx

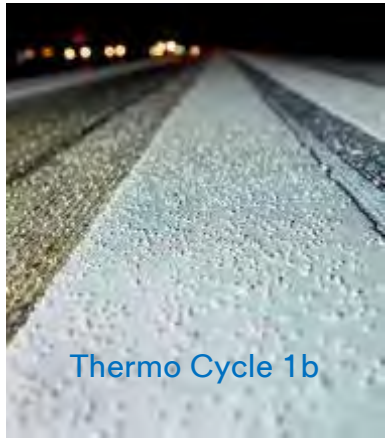
Congestion Carbon @ PM Maintenance - Tape:Thermoplastic 1:3.5

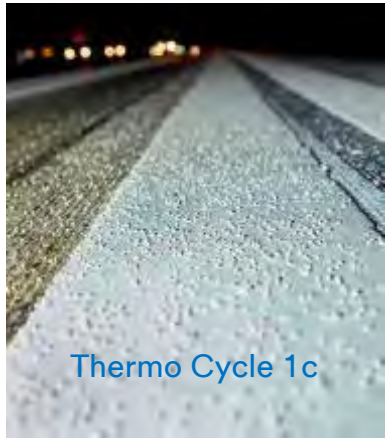
Thermoplastic 1200 kg including 120 kg of glass beads, packaging bags and pallets

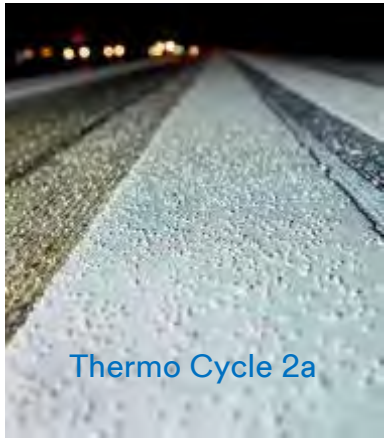
Tape 660 kg includ. packaging cartons and pallets

Assume thermoplastic application 4 tons / 12 hour shift; 2X more productive for tape application.









4.1t CO_2e PM + Traffic 228 kg/hr/lane/ km x 2 lanes x 0.87 km x 3 hr = 5.3t CO_2e

Renew #1 Thermoplastic: 5.3t CO_2e

Renew #2 Thermoplastic: 5.3t CO_2e

Total in 3 cycles = 15.9t CO_2e

4t CO_2e PM + Traffic 228 kg/hr/lane/km x 2 lanes x 0.87 km x 1.5 hr = 4.6t

Total in 1 cycle = 4.6t CO_2e

Free Flow Traffic 5 kg/hr/lane/ km x 2 lanes x 0.87 km x 3 hr x 2 skipped renewal = 52 kg CO2e

Thermo. vs. Tape ~ 3.5X vs. Tape

Both PM solutions yield 200 sqm of PM: 435 m 4-lane highway @ 100 m line width, 3 m marking + 7 m gap skips

Ref: J. Anthonissen, et al., Journal of Cleaner Production 102 (2015) 96-102

Construction Work Zone Studies

UK HW Agency (2006)

- Vehicles : 5x higher risk in CWZ
- CWZ workers
  - 1 on 5 has been involved in accident
  - 1 on 2 experienced dangerous situation.

USA (2005)

- 43,000 fatal road accidents
- 1,704 in a CWZ (4% of total)
- CWZ workers : 32 fatal accidents / 100,000 employees

  (3x higher that general building & construction)

Netherlands

Cobouw study (2005) : CWZ worker safety

- 75% experienced “near misses”
- 91% does not feel safe due to
  - Speeding of traffic
  - No discipline and understanding by passing traffic

SWOV (2005) :

- 16% of fatalities on Dutch motorways
  - 39% in a CWZ

Summary

- New Zealand road traffic fatalities in 2022 exceed pre-pandemic year 2019.
- Amongst OECD countries, NZ lies in the bottom 1/3 in key road safety metrics.
- NZ is unique in that **rural roads** contribute more than **70% of the road fatalities** and they make up more than 70% of total road networks.
- It means the rural road network to make safety improvement is very large and can be daunting.
- Research data show **boosting reflectivity** values of pavement markings and **adding wet reflective** requirements can reduce road crashes and fatalities by double digit percentages.
- 3M's **Connected Roads optical elements** and **Stamark High Performance Pavement Marking tapes** could deliver these requirements.

- The super **high index ceramic beads at 1.9 and 2.4** are innovations that deliver high retroreflectivity, visibility in the rain and are durable against heavy traffic.
- Our field data from Germany and the US demonstrate that Stamark High Performance Pavement Marking tapes are good for **service lives between 7 to 10 years.**
- Because of the long durability, the carbon emission of pavement marking tape, though similar to thermoplastic per square area, works out to be **2/3 lower annualized** for life cycle.
- With less frequent restriping while keeping minimum PM interventional levels, the **congestion related carbon emission** is also reduced by 45X (from about 228 kg to 5 kg / hour).
- Roads are safer for the crew and motorists without workzones, with road construction workers being **exposed to 3X the risks** relative to building construction workers.
- "Doing Things Differently", we hope Pavement Marking is an infrastructure area to improve upon in the **New Zealand's Road to Zero Strategy 2020-2030** and an interim target **of 40% fatality reduction** from 2018 levels.

Thank you!
Ngā mihi

Questions – Dr. Tan

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