New Traffic Stripe 968 Times Brighter than Current U.S. Federal Highway Administration Standard

Mark J. O'Neill
Mark O'Neill, LLC
9500 Ray White Road, Suite 200, Fort Worth, Texas 76244 USA
817-380-5930
markoneill@markoneill.com
www.markoneill.com
ORCID: 0000-0001-6234-3517

Abstract

The purpose of developing the new ultra-bright traffic stripe has been to save lives by minimizing lane-departure crashes on dark highways at night. The new stripe has been developed, and early prototypes have been tested for retroreflectivity in a certified laboratory. The measured retroreflectivity of the best new stripe prototype was 968 times higher than the 2023 U.S. Federal Highway Administration minimum standard of 50 mcd/m^2-lux. The reduction in crashes due to brighter road stripes has been empirically quantified by previous researchers. Using published statistics from the U.S. Department of Transportation, a benefit-cost analysis has been conducted for the impact of the new stripes if implemented on all U.S. interstate highways as the white edge stripe to minimize run-off-road fatalities. The results predict very large benefit-to-cost ratios, rapid payback times, and over 1,000 prevented fatalities per year. The new traffic stripe offers substantial retroreflective brightness even when fully submerged underwater, unlike all previous traffic stripes. The new stripe is not only more visible for human drivers, but also for the cameras and sensors used in connected and automated vehicles. The principal conclusion of work to date is that the new traffic stripe should be fully developed and commercialized to save lives and provide substantial economic benefits by reducing the financial impact of vehicle crashes and fatalities.

1.0 Introduction

Traffic stripes on roadways all over the world provide critical guidance information for both human drivers and sensors/cameras on connected and autonomous vehicles (CAVs). Especially at nighttime, these stripes are essential to minimize run-off-road and/or lane departure crashes which are often deadly. Most conventional traffic stripes still use a century-old technology to provide a modest level of retroreflectivity to return headlight illuminance to the driver or sensors on the vehicle to improve visibility. Specifically, conventional stripes utilize glass or ceramic beads of approximately spherical shape dropped onto white paint to refract grazing incidence light from distant headlights onto the white paint thereby retroreflecting a small portion of the incident light along a path approximately the reverse of the incident light back to the vehicle. A practical method of making such glass beads was invented in 1914 by Rudolph Potters (Potters Industries, 2024). Glass/ceramic beads only work well under dry conditions because rainwater disrupts the light refraction process at the exposed bead surface. The amount of retroreflectivity from glass/ceramic beads is modest even under dry conditions. Thus, the latest U.S Federal Highway Administration (FHWA) standard requires a minimum retroreflectivity of only 50 mcd/m^2-lux (FHWA, 2023).

The present work began as a spin-off from previous and ongoing work on prismatic optics for space applications for NASA and other space organizations. A few years ago, a retired NASA executive asked the author of this paper if there was a way to use prismatic optics to overcome the very low nighttime visibility of conventional traffic stripes. The author explored various approaches for several years and finally discovered a promising approach based upon the use of cube corner prisms as the source of the retroreflectivity. Cube corner prisms have been used in traffic signs for decades. The latest cube corner traffic sign sheeting products routinely achieve retroreflectivity values above 100,000 mcd/m^2-lux, which is 2,000 times higher than the FHWA standard for traffic stripes. The basic new idea for the new stripe is to use light-turning prisms on the top surface of the traffic stripe to capture and redirect the grazing rays from distant headlights downward onto retroreflective cube corner prisms on the bottom surface of the stripe, thereby returning most of the rays toward the vehicle. This approach is very simple but very effective. Early prototypes have been fabricated and tested in a certified laboratory with the best retroreflectivity values above 48,400 mcd/m^2-lux, about 1,000 times higher than the new FHWA standard. Benefit-cost analyses have been conducted based on the economic value of lives saved by reducing fatal crashes on high-speed highways, with extremely positive results. The originality of the new traffic stripe approach is evidenced by the awarding of four U.S. patents to date for different configurations of the new traffic stripe technology (O'Neill, 2020-2022). The new traffic stripe technology is described, its measured performance is presented, and its multiple important benefits are discussed in the following sections of this paper.

2.0 Method

The latest preferred version of the new traffic stripe is shown in cross-sectional view in Fig. 1. The stripe is made from a transparent polymer such as thermoplastic polyurethane (TPU), polycarbonate (PC), or polymethyl methacrylate (PMMA). The total thickness of the stripe is less than 1 mm. The approaching vehicle is coming from the right side of the figure with nearly grazing incidence light rays arriving from the distant headlights. Under dry conditions, the higher trapezoidal prisms on the top surface intercept the light and redirect it downward onto smaller cube corner retroreflective prisms by a combination of refraction and total internal reflection (TIR). The cube corner prisms use TIR to retroreflect the light along a path in the opposite direction of the incident rays back toward the vehicle. The incident rays are shown in red and the retroreflected rays are shown in blue (or vice versa since the same physics apply in either direction).

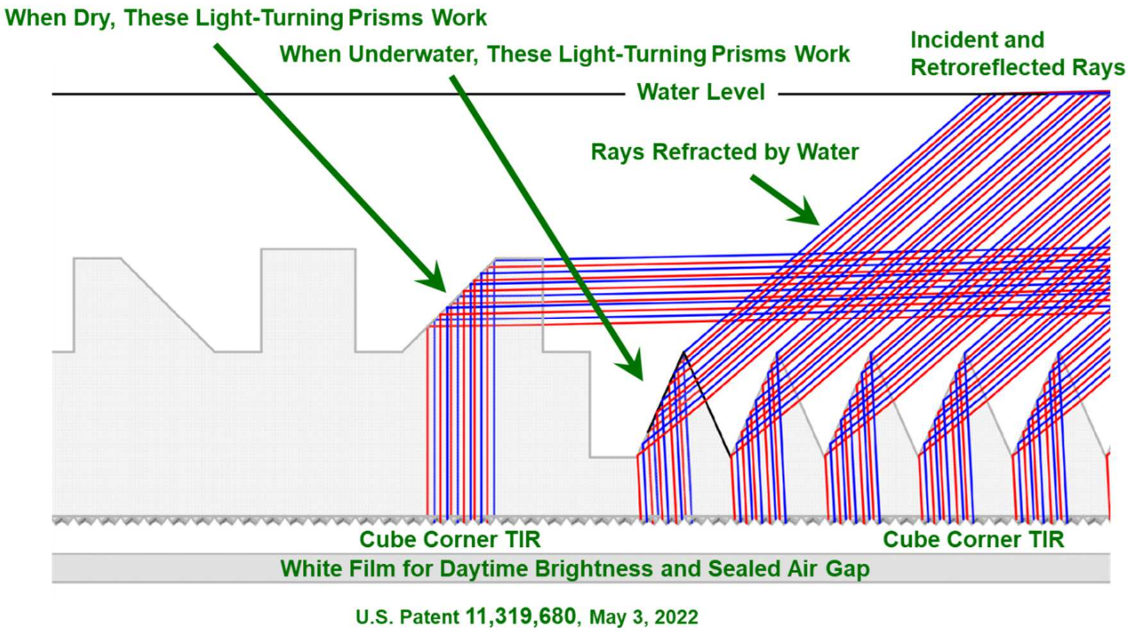


Figure 1 - Latest Configuration of Traffic Stripe for Both Dry and Wet Weather Conditions
(Source: Author)

Under wet conditions, specifically when the traffic stripe is underwater during a heavy rainstorm, the lower set of triangular prisms on the top surface become functional while the trapezoidal prisms no longer function. The water level is shown by the black horizontal line in Fig. 1. The incident rays of light intercept the water surface at nearly grazing incidence and are refracted by the water (refractive index of 1.33) to progress downward at a slanted angle as shown. These rays intercept the triangular prisms which redirect the rays into a more vertical path by employing both refraction and TIR. The rays arrive at the cube corner retroreflective prisms on the bottom surface of the stripe and are redirected along an opposite path back toward the vehicle. Once again, the incident rays are shown in red and the retroreflected rays are shown in blue or vice versa. The wet retroreflectivity will be much lower than the dry retroreflectivity due to the optical losses (about 98-99%) at the water-air interface, but it will still be very visible.

The cube corner prism array on the bottom surface of the new traffic stripe is most efficient if comprised of 100% effective prisms that do not include non-functional portions of conventional cube corner prisms. The 100% effective cube corner prism approach was pioneered by 3M for traffic sign sheeting (Lloyd, 2008). Cube corner prisms do not work if water or dirt contact the surfaces. Sealed air pockets are widely used in traffic sign sheeting to prevent water or dirt from reaching the prismatic surfaces. Small air pockets are created by bonding an opaque white film to the cube corner prismatic sheeting in a matrix arrangement. The white film also provides daytime visibility of the sheeting under solar illumination. The new traffic stripe also uses a white film for these same purposes as shown in Fig. 1.

A symmetrical pattern of both dry and wet light turning prisms is shown in Fig. 1 to provide the same performance for traffic coming from either direction (from the left or from the right). The same stripe can thus be used for bidirectional functionality. The rectangular element between dry light turning prisms facing opposite directions is not optically functional. It is taller than the light turning prisms and is a structural element to absorb tire forces to mitigate damage to the shorter light turning prisms.

The new traffic stripe can be used in two different orientations, one for longitudinal stripes parallel to the highway and the other for lateral stripes perpendicular to the highway, as shown in Fig. 2. The light turning prisms on the top surface need to face the oncoming headlights which requires different orientations for longitudinal stripes like edge lines than for lateral stripes like crosswalk lines. The dry light turning prisms are separated by a significant distance to minimize incident and retroreflected ray shading and blocking by neighboring prisms. The wet light turning prisms on the top surface fill the space between dry light turning prisms.

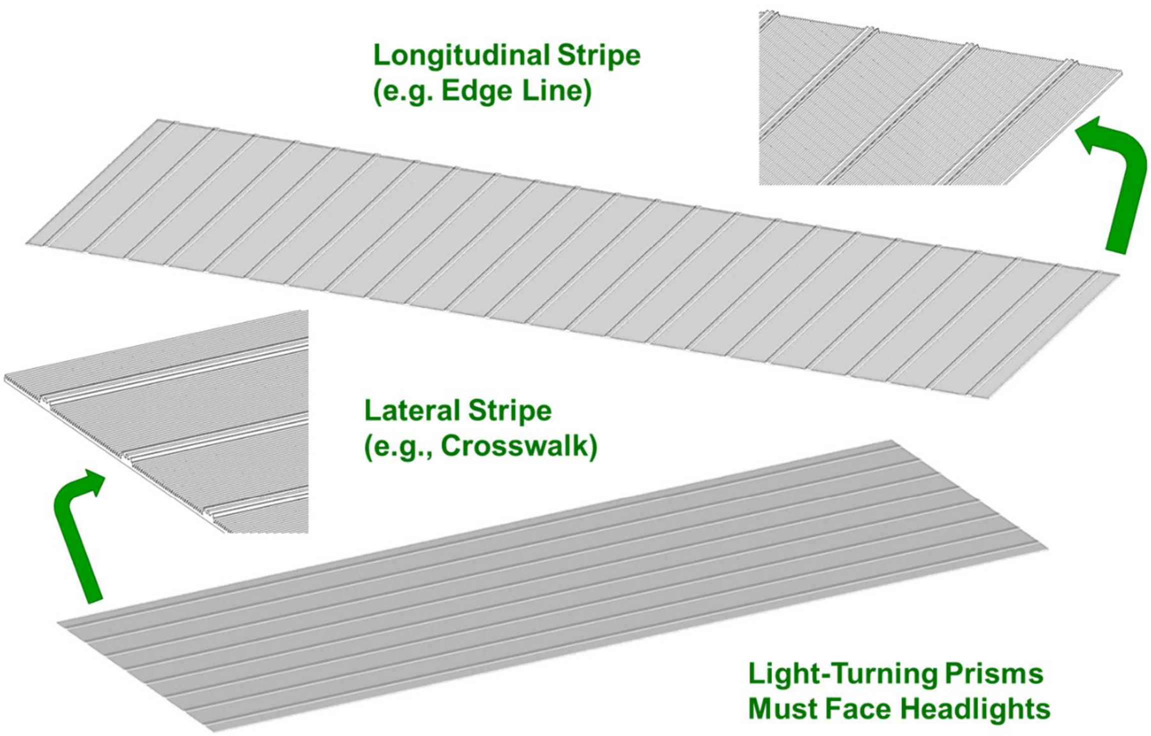


Figure 2 - Longitudinal Versus Lateral Stripe Geometry for Horizontal Applications
(Source: Author)

The new traffic stripe can be used for both horizontal and vertical applications, as shown in Fig. 3. For horizontal applications on the roadway, installation of similar previous stripes in pavement grooves has been shown to mitigate degradation to traffic stripes from traffic damage and snowplow damage on an interstate highway in Chicago, Illinois, U.S. (Hawkins et al., 2019). The installation of the new stripe will use this same technique. For vertical applications, traffic damage and snowplow damage will not be issues.

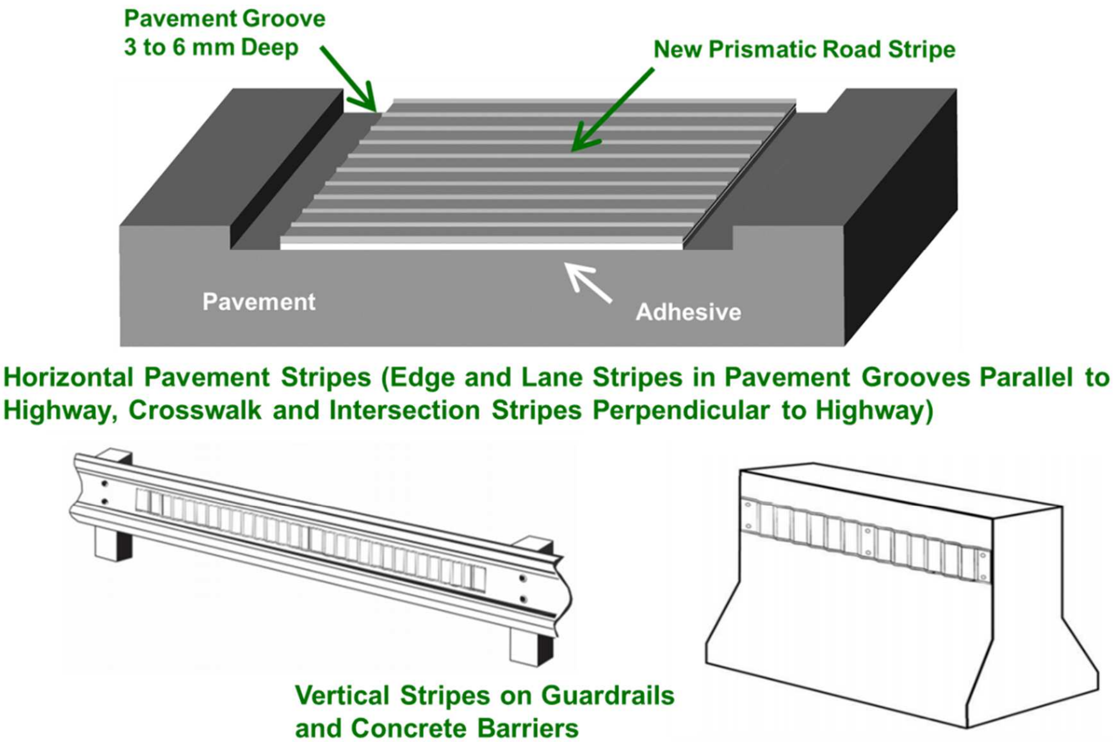


Figure 3 - Horizontal and Vertical Applications of New Traffic Stripe
(Source: Author)

A simple demonstration of the exceptional brightness of the new traffic stripe for both horizontal and vertical applications is shown in Fig. 4. The prototypes of the new traffic stripe shown in Fig. 4 were made by combining six small 10 cm x 15 cm patches of light-turning prisms (made by molding thermoplastic polyurethane) with commercially available retroreflective Type XI traffic sign sheeting (10 cm x 90 cm) using a transparent adhesive. A flash photo in a darkened room from the appropriate glancing viewpoint can simulate the headlights (flash) and the driver's eyes (photo). While not quantitative, such a demonstration is valuable to experience the ultra-bright visibility of the new stripe. A similar demonstration can be done with a small flashlight. Everyone who has seen the new stripe in such demonstrations has been startled by the brightness of the new stripe, often leading to close inspections of the new stripe to ensure that no embedded LEDs are included in the device.

The brightest currently available traffic stripe is 3M™ Stamark™ Pavement Marking Tape Series 380 (3M, 2020), which is promoted for its wet retroreflectivity. A flash photo comparison of the underwater visibility of the 3M product (with the shortened name All-Weather 380 or AW 380) and the new traffic stripe is shown in Fig. 5. The uppermost photo shows the two small samples (10 cm x 15 cm) under about 2 cm of water in a pan in a lighted room with a small wooden stick floating above the samples to show the water level. The lower two photos show flash photos in a darkened room from two different distances to simulate the headlights (flash) and the driver's viewpoint (photo). Note that the new traffic stripe is very visible while the 3M stripe has disappeared.

The 3M stripe relies on glass/ceramic beads of varying refractive indices, but these elements are not effective retroreflectors when fully submerged underwater. The new traffic stripe sample used the same construction as the longer prototype in Fig. 3 as discussed above. It did not contain the triangular wet light-turning prisms shown in Fig. 1, but refraction of the high incidence angle rays by the water surface and retroreflectivity of the cube corner prisms on the bottom surface together provided a stark contrast in brightness compared to the 3M product. When the new stripe is equipped with the triangular wet light-turning prisms in the future, the underwater retroreflective brightness will be greater.

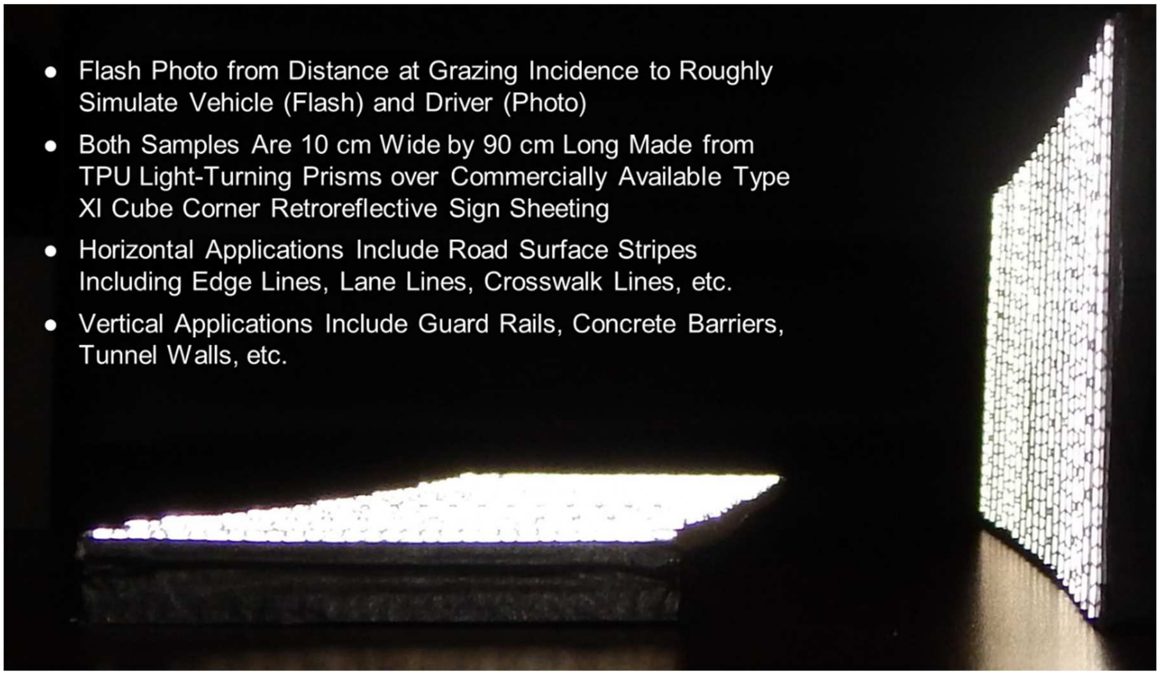


Figure 4 - New Traffic Stripe Will Work for Horizontal and Vertical Applications
(Source: Author)

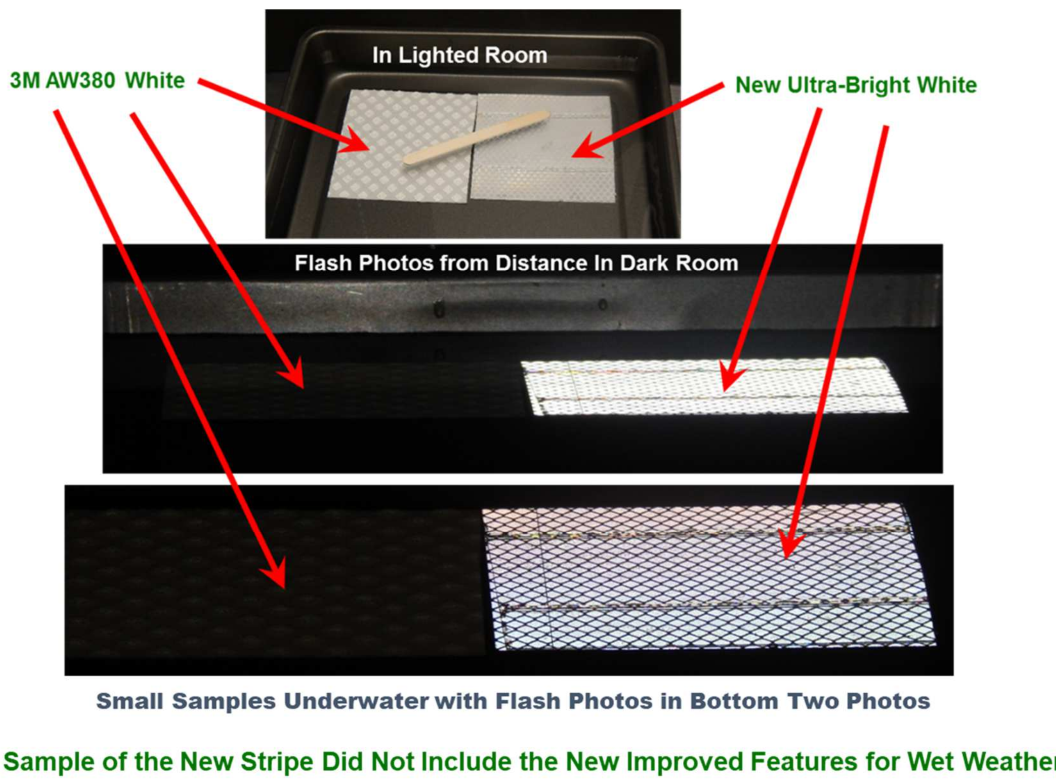


Figure 5 - New Stripe Provides Good Brightness Even Underwater
(Source: Author)

The new traffic stripe also provides excellent daytime visibility as shown in Fig. 6, which compares its brightness with painted stripes in direct sun and in shade. Note that the new stripe is very visible in the daytime. The new stripe can use a tinted polymer to provide a yellow stripe, as shown in one of the stripes, or any other desired color.

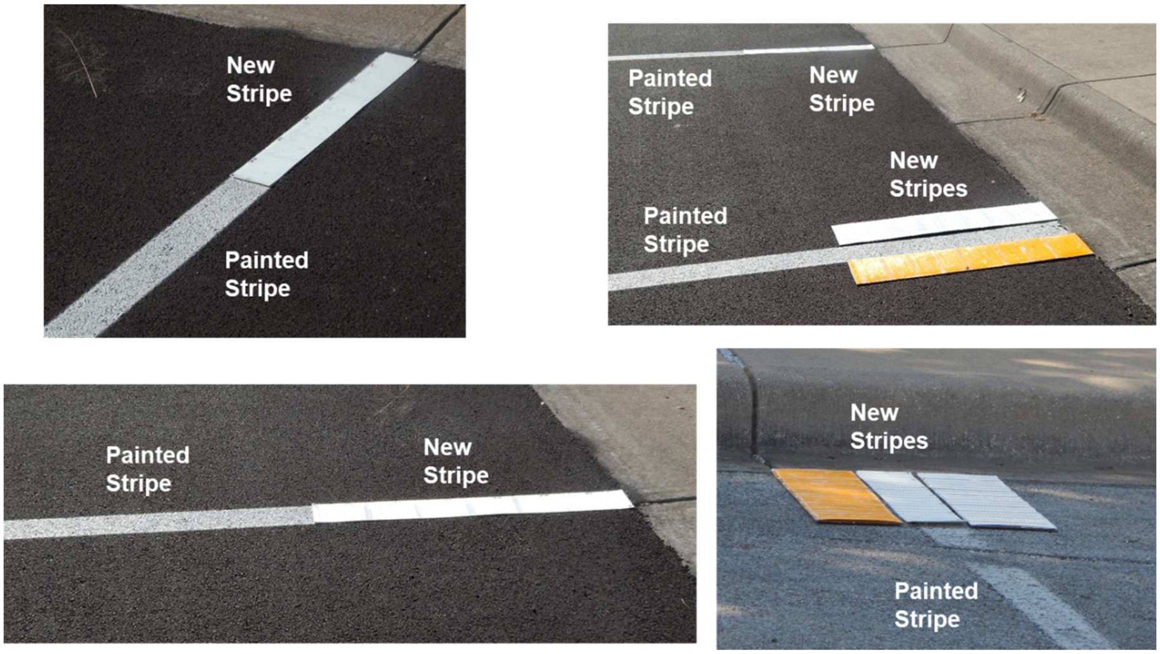


Figure 6 - New Stripe Provides Excellent Visibility During Daytime: Outdoor Photos in Sunlight (First Three) and in Shade (Lower Right Photo

(Source: Author)

3.0 Results

Under limited funding from the U.S. National Academy of Sciences Transportation Research Board (O'Neill, 2022), small (15 cm x 15 cm) molding tools were made for the dry light-turning prismatic pattern shown in Fig. 1, not including the wet light-turning prismatic pattern in Fig. 1. Using these small molding tools, clear polymer parts have been made from a variety of materials, including optical silicones, epoxies, and thermoplastic polyurethanes (TPUs). To make prototypes of the traffic stripe, these small polymer parts were combined with commercially available retroreflective sheeting used for traffic signs. A transparent pressure sensitive adhesive (PSA) was used to laminate the light-turning prismatic parts on the top surface to the retroreflective sheeting on the bottom surface. Several different prototype stripes were assembled of the smallest testable size of 10 cm x 91 cm, and these stripes were tested in a certified laboratory for retroreflectivity according to the test standard ASTM D4061. The best result to date used a top surface of multiple light-turning prismatic parts injection molded from Lubrizol aliphatic TPU laminated to 3M Type XI DG^3 cube corner retroreflective sign sheeting. For comparison, the same laboratory made the same measurements on a sample taken from a new roll of the presently brightest traffic stripe tape, 3M's Stamark AW380 "waffle tape." The results are shown in Fig. 7. The bar charts show the results for the new traffic stripe as the red bar, the 3M tape as the blue bar, and the latest FHWA standard as the green bar. The top chart is linear, and the 3M tape and FHWA standard do not show up. The bottom chart is logarithmic to make these values visible. Note that the new traffic stripe is almost 1,000X brighter than the FHWA standard and more than 60X brighter than the 3M tape.

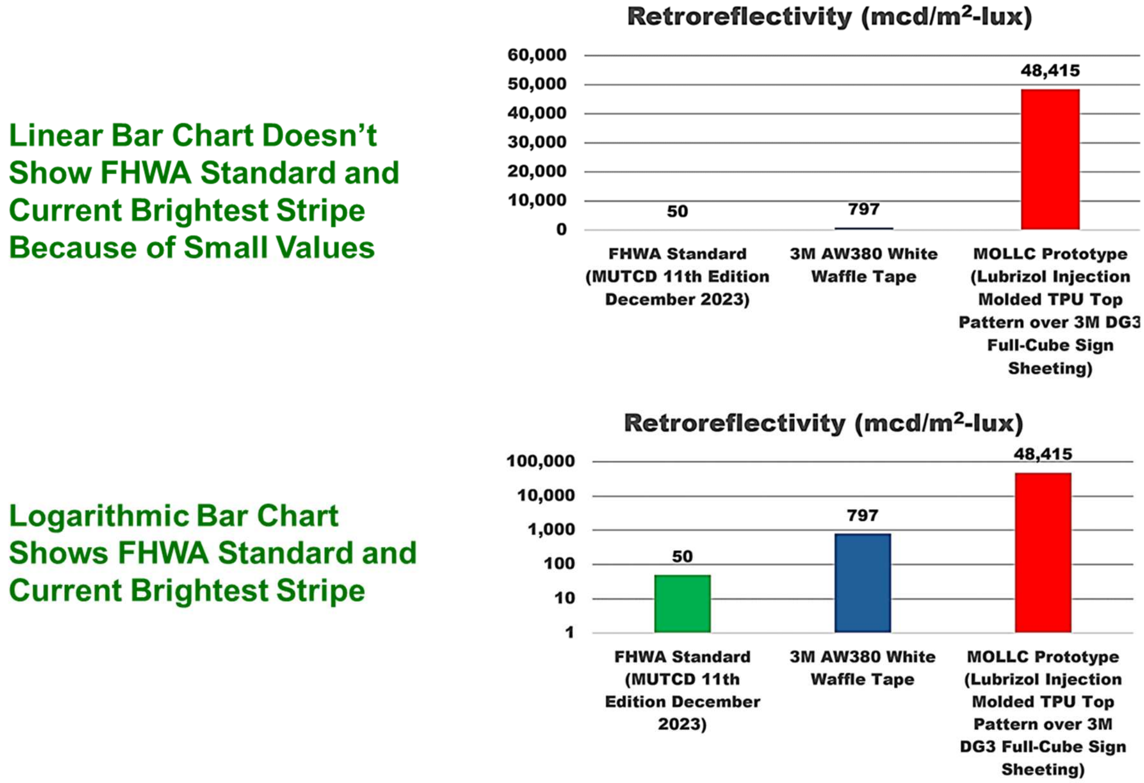


Figure 3 - Certified Lab Measurements of New Traffic Stripe and Currently Brightest Traffic Stripe Versus FHWA Standard
(Source: Author)

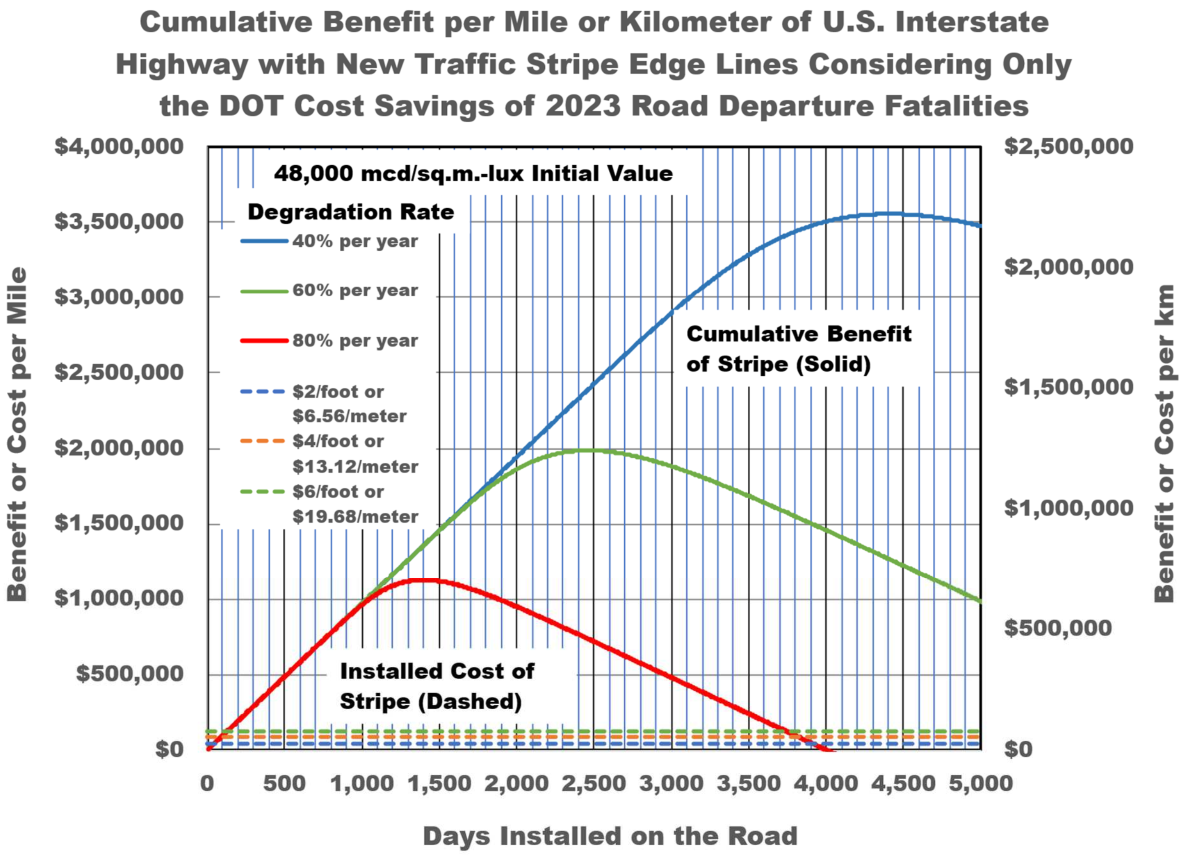
To quantify the benefit of the unprecedented retroreflectivity of the new stripe shown in Fig. 7, a detailed benefit-cost analysis has been performed. The benefit estimate is conservative since it only considers the benefit of reducing fatalities from run-off-road crashes, and not the substantial benefit of reducing non-fatal run-off-road crashes. Using recent, relevant published data from various organizations under the U.S. Department of Transportation, parametric results are shown in Fig. 8.

These results assume that the new stripe is used for the white edge lines on all U.S. interstate highways replacing conventional stripes which have twice the brightness (100 mcd/m^2-lux) of the latest FHWA standard (50 mcd/m^2-lux). Since no data yet exist regarding the degradation rate for the new stripe, three parametric values were assumed (40%, 60%, and 80% per year). Since no data yet exist for the installed price of the new stripe, three parametric values were assumed ($2/foot, $4/foot, and $6/foot, which correspond to $6.56/m, $13.12/m, and $19.68/m). The payback time is represented by the intersection of the benefit curve and the cost curve. Note that for all three values of the degradation rate and all three values of installed cost, the payback times are between 45 days and 130 days. Note also that the peak values of the benefit for all three degradation rates divided by the three assumed values of cost show a benefit to cost ratio between 9X and 84X. The peak benefit value occurs at the time when the traffic stripe should be replaced.

While not shown in Fig. 8, the results also show that if all the edge stripes on U.S interstate highways would adopt the new traffic stripe, over 1,000 lives could be saved per year.

4.0 Discussion

A new traffic stripe technology has been developed and demonstrated in certified testing of relatively crude prototypes to be 968 times brighter than the latest U.S. FHWA standard of 50 mcd/m^2-lux. The new stripe uses prismatic patterns on both the top and bottom surfaces of a thin polymer film to accept light from approaching headlights and retroreflect such light back to the vehicle for the driver or automated sensors to receive.



Data Used for Cost Benefit Analysis				
Item	**Description**	**Value (U.S. Units)**	**Value (Metric)**	**Source**
1	Fatalities on U.S. Interstates in 2023	5,050 deaths	5,050 deaths	NHTSA 2024
2	Fraction of Fatalities at Nighttime in 2023	55%	55%	NHTSA 2024
3	Fraction of Fatalities Due to Roadway Departures in 2023	47%	47%	NHTSA 2024
4	Fatalities on U.S. Interstates in 2023 at Nighttime Due to Roadway Departures	1,305 deaths	1,305 deaths	Item 1 x Item 2 x Item 3
5	Total Miles of U.S. Interstates in 2022	48,605 miles	78,222 km	USDOT 2022
6	U.S. Nighttime Roadway Departure Fatalities per Interstate Mile in 2023	0.0269 deaths/mile	0.0167 deaths/km	Item 4/Item 5
7	Comprehensive Cost of Each Death in 2023 Dollars	$13,200,000 per death	$13,200,000 per death	USDOT 2024
8	Cost of U.S. Nighttime Roadway Departure Deaths per Interstate Mile in 2023	$354,523 per mile	$220,291 per km	Item 6 x Item 7
9	Estimated Cost of Installing 4 New Edge Stripes per Interstate Mile	$42,240 per mile	$26,246 per km	Assuming $2/foot ($6.56/km)
10	Estimated Cost of Installing 4 New Edge Stripes per Interstate Mile	$84,480 per mile	$52,493 per km	Assuming $4/foot ($13.12/m)
11	Estimated Cost of Installing 4 New Edge Stripes per Interstate Mile	$126,720 per mile	$78,739 per km	Assuming $6/foot ($19.68/m)

Figure 4 - Benefit-Cost Analysis of the New Traffic Stripe
(Source: Author)

The new stripe is configured to work equally well for traffic approaching from either direction. The new stripe is the first traffic stripe to provide high retroreflectivity when fully submerged underwater. A quite common complaint among drivers is the disappearance of traffic stripes on dark nights with heavy rain. The new stripe can solve this problem.

The new stripe does not use glass or ceramic beads which are dropped into white paint to form most conventional traffic stripes. The new stripe also requires no paint. The new stripe can be made from green polymers, including bioplastics, offering a much more environmentally friendly approach to traffic stripes.

It has been proven that brighter traffic stripes reduce crashes and the reduction of crashes for brighter stripes has been quantified (Donnel et al., 2009). The U.S. Department of Transportation provides a clearinghouse of crash modification factors (CMFs) and crash reduction factors (CRFs) for different traffic safety countermeasures to enable quantitative analysis of their benefits (CMF Clearinghouse, 2024). (Note that CRF = 1 – CMF.) One of these factors is CMF 2016 which quantifies the reduction in crashes due to brighter traffic stripes (CMF 2016, 2024) which is based on the findings of Donnel et al (Donnel et al., 2009). These data were used to conduct the benefit-cost analysis summarized in Fig. 8. Additional data from the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) were used for the crash statistics in the benefit-cost analysis (NHTSA, 2024) summarized in Fig. 8. Additional data from the U.S. Department of Transportation were used for the total interstate highway miles (DOT, 2022) and the comprehensive cost of a human death (DOT, 2024) in the benefit-cost analysis of Fig. 8. By combining all these statistics, the substantial economic benefits of the new traffic stripe are shown parametrically in Fig. 8. Estimated installed costs of the new traffic stripe are also shown parametrically in Fig. 8. The ratio of benefits to costs is very large for all combinations of parametric values.

The benefit estimates of Fig. 8 are conservative because they only include the economic impact of reduced run-off-road fatalities at nighttime. If the impact of non-fatal crashes were also included, the benefit estimates would be much larger. The shape of the benefit curves in Fig. 8 is interesting. As the new traffic stripe degrades over time, the current benefit becomes smaller. Eventually, when the retroreflectivity falls to the assumed conventional stripe of 100 mcd/m^2-lux, the benefit disappears, and the curve begins to fall. Thus, the peak benefit value occurs at the end of the useful lifetime of the stripe and signals the time for replacement.

The ultra-bright traffic stripe will be beneficial not only for human drivers but also for the cameras and sensors used in connected and automated vehicles (CAVs). A widely reported story about the 2016 Los Angeles Auto Show exemplifies the importance of traffic stripes to CAVs. "Volvo's North American CEO, Lex Kerssemakers, lost his cool as the automaker's semi-autonomous prototype sporadically refused to drive itself during a press event at the Los Angeles Auto Show." "It can't find the lane markings!" Kerssemakers griped to Mayor Eric Garcetti, who was at the wheel. "You need to paint the bloody roads here!" (Sage, 2016). Studies have shown that lane marking is one of the most important infrastructure elements on the existing roadway systems for the safe operation of CAVs (Formosa et al., 2024). Many studies mention that road markings act as rails for CAVs (Correia, 2023). Greg Driskell, Board of Directors member of the American Traffic Safety Services Association (ATSSA) said in 2019 "The most important infrastructure element on our roadway system for automated vehicles (AVs) and for Advanced Driver Assist Systems (ADAS), is pavement markings." (3M, 2019). The unprecedented brightness of the new traffic stripe under both dry and wet nighttime conditions could accelerate the safe advancement of CAVs.

The present study has been based on limited test results for small prototypes of the new traffic stripe and limited data from the U.S. Department of Transportation on the crash reduction benefits of brighter traffic stripes. When the new traffic stripe moves toward production and larger quantities of the stripe are available, on-road performance and durability testing will provide much better information to predict benefits and costs. More studies are needed to quantify the crash reduction benefits of brighter stripes for both human-driven and automated vehicles. Without question, the highways of the future will require better road markings as part of the infrastructure improvements to minimize traffic fatalities.

5.0 Conclusions

- The new traffic stripe was tested with certified retroreflectivity of 48,400 mcd/m^2-lux, 948 times higher than the U.S. Federal Highway Administration standard.
- Crash reduction factor analysis shows that the new stripe could save thousands of lives.
- Benefit-cost analysis shows a rapid payback time and large financial benefits.
- The new brighter stripe improves guidance for connected and automated vehicles.
- The new traffic stripe should be fully developed and qualified by on-the-road testing to move the technology from the laboratory to the highway.

6.0 Acknowledgements

The Transportation Research Board of the U.S. National Academy of Science provided funding for the first prototype molding tools and the first certified testing of the new traffic stripe. Lubrizol Advanced Materials made the top prismatic pattern by compression molding and injection molding of their thermoplastic polyurethane (TPU) material for the prototypes that provided unprecedented retroreflectivity. Road Vista/Gamma Scientific performed the ASTM certified testing of the first prototype traffic stripes, verifying their world-record retroreflectivity.

7.0 Future Plans

Our team is now performing a Phase I Small Business Innovation Research grant for the U.S. National Science Foundation to advance the new traffic stripe technology toward production, qualification, and commercialization. We will report on advancements under this program later in 2025.

8.0 References

Potters Industry (2024). Potters Industries Website "About Us" Page: https://www.pottersindustries.com/about-us/ .

FHWA (2023). U.S. Federal Highway Administration, "Manual on Uniform Traffic Control Devices (MUTCD)" 11th Edition, https://mutcd.fhwa.dot.gov/kno_11th_Edition.htm.

Loyd, John (2008), "A Brief History Of Retroreflective Sign Face Sheet Materials," Retroreflective Equipment Manufacturers' Association, https://www.rema.org.uk/pub/pdf/history-retroreflective-materials.pdf.

O'Neill, Mark (2022), "A Retroreflective Road Lane Marking Tape 1,000X Brighter than Existing Technology," Final Report for NCHRP IDEA Project 228, Submitted to the Transportation Research Board, the National Academies of Sciences, Engineering, and Medicine, https://www.trb.org/Publications/Blurbs/182727.aspx.

O'Neill, Mark (2020-2022), U.S. Patents No. 10,794,021, 11,124,932, 11,319,680, and 11,486,183, https://markoneill.com/patents.html.

3M (2020), "3M Pavement Marking Solutions, https://multimedia.3m.com/mws/media/1833906O/3m-pavement-marking-solutions-stamark-catalogue.pdf.

Donnell, E.T., V. Karwa, and S. Sathyanarayanan (2009). "A Methodology to Explore the Relationship between Pavement Marking Retroreflectivity and Traffic Crash Frequency on Highways in North Carolina: Application of Artificial Neural Networks and the Generalized Estimating Equations." TRB 88th Annual Meeting, Washington, D.C.,

NHTSA (2024), National Highway Traffic Safety Administration, "Early Estimate of Motor Vehicle Traffic Fatalities in 2023," DOT HS 813 561, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813522.

FHWA (2022), "Public Road and Street Length, 1980 – 2022, Miles by Functional System, National Summary, https://www.fhwa.dot.gov/policyinformation/statistics/2022/hm220.cfm.

USDOT (2024), U.S. Department of Transportation, "Departmental Guidance on Valuation of a Statistical Life in Economic Analysis," https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis.

CMF Clearinghouse (2024), https://cmfclearinghouse.fhwa.dot.gov/.

CMF 2016 (2024), "Increase Pavement Marking Retroreflectivity of White Edgelines from X to Y mcd/m^2/lux", https://cmfclearinghouse.fhwa.dot.gov/detail.php?facid=2116.

Sage, Alexandria (2016), "Where's the Lane? Self-Driving Cars Confused by Shabby U.S. Roadways," Reuters, https://www.reuters.com/article/technology/wheres-the-lane-self-driving-cars-confused-by-shabby-us-roadways-idUSKCN0WX131/.

Formosa, Nicolette et al., (2024), "Evaluating the Impact of Lane Marking Quality on the Operation of Autonomous Vehicles," *Journal of Transportation Engineering Part A Systems*, DOI: 10.1061/JTEPBS.TEENG-7688, https://www.researchgate.net/publication/377039933_Evaluating_the_Impact_of_Lane_Marking_Quality_on_the_Operation_of_Autonomous_Vehicles.

Correia, Matheus Gomes and Ferreira, Adelino (2023), "Road Asset Management and the Vehicles of the Future: An Overview, Opportunities, and Challenges," *International Journal of Intelligent Transportation Systems Research*, https://doi.org/10.1007/s13177-023-00366-0.

3M (2019), "Are You Preparing Now for the Roads of the Future?," E-Book, https://multimedia.3m.com/mws/media/1765377O/3mtm-connected-roads-roads-of-the-future-ebook.pdf.