3M Science. Applied to Life.™

Reliable wet retroreflectivity, when drivers need it most.

Help drivers get home safely with continuous wet retroreflective pavement markings.

Pavement markings by day, lifelines by night.

Did you know that on average, we only do 25% of our driving at night, yet 50% of traffic deaths happen after dark?[1] Not to mention that when you add rain, the chances of getting into a crash increase?

That's why the kind of pavement markings you choose matter. Non-wet retroreflective markings don't reflect light back to drivers at night when covered with rainfall, making them virtually disappear. But it doesn't have to be that way—there is a solution available today that allows drivers to see markings in dark and rainy conditions.

This eBook will help you understand the benefits of wet continuous retroreflective pavement markings versus sticking with standard markings—and how at the end of the day, the choice is clear and the time to act is now.

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Why wet retroreflective pavement markings matter.

The difference between wet retroreflective and non-wet retroreflective road markings.

It's easy to see pavement markings on a bright, sunny day. Even older, more worn markings can provide drivers enough guidance under ideal circumstances. But what about at night? During a rainstorm when water covers the roads? In these types of conditions, non-wet retroreflective pavement markings disappear, leading to reduced driver visibility, increased driver discomfort[3], less effective CAV lane guidance systems[4,5] and a higher risk of crashes[8]. This is why the type of markings you choose is critical to helping keep drivers safe on sunny days and dark, stormy nights—especially when you factor in changing driver demographics like increased numbers of older drivers with vision limitations.

As recently as 2014 to 2016, the Georgia Department of Transportation observed a startling trend.

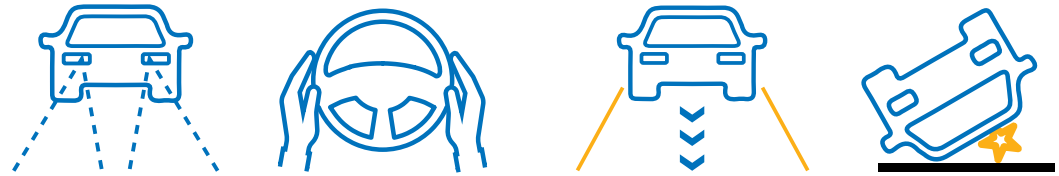
"We saw an upswing in the number of fatalities across the State of Georgia. When we looked at the data, we saw that a tremendous number of those fatalities were happening in wet conditions and in night conditions across the state, so we knew that we needed to get products out there that directly influenced that trend to ultimately try to bring those numbers down," said Andrew Heath, GA DOT State Traffic Engineer.

With many road authorities today adopting a Toward Zero Deaths approach to road safety, understanding the correlation between dark, wet conditions and crashes is of the utmost importance. **At night, during rainy conditions, non-wet retroreflective pavement markings disappear, which leads to:**

TZD Toward Zero Deaths

Learn more in the Georgia case study video.

▶ **Watch video**

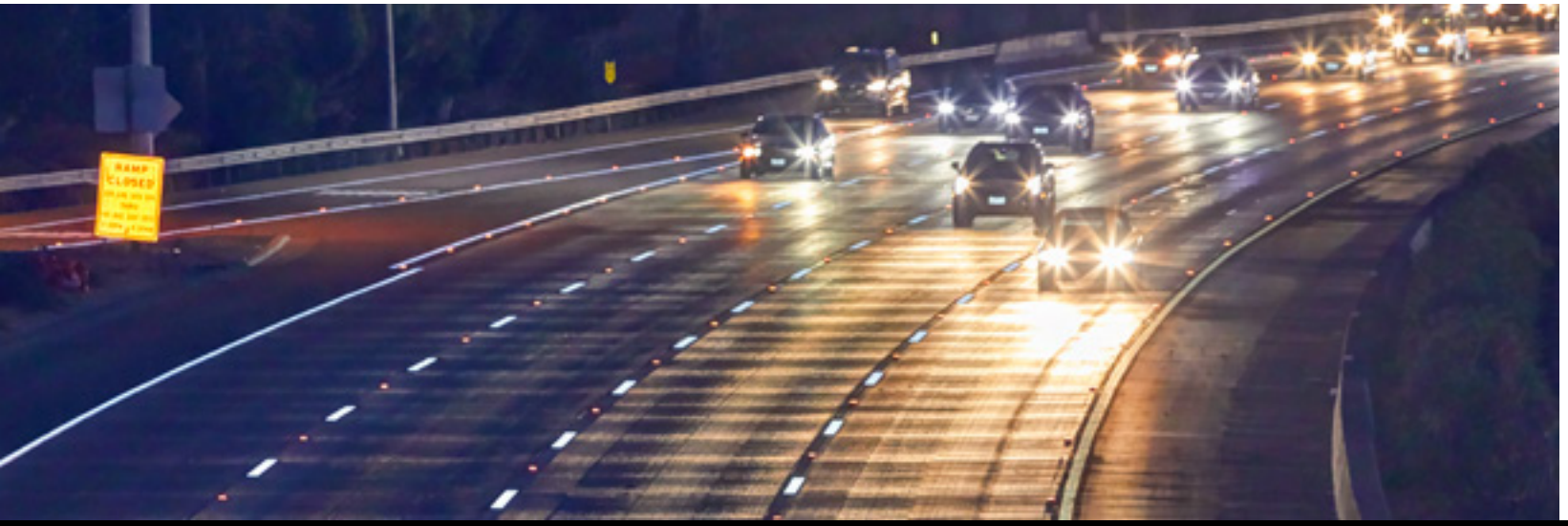


Reduced driver visibility[3]

Increased driver discomfort[3]

Less effective CAV lane guidance systems[4,5]

Crash risk increases[8]



"...a tremendous number of those fatalities were happening in wet conditions and in night conditions..."

Andrew Heath, GA DOT State Traffic Engineer

GDOT

The difference is day and night—and rainy night.

We can tell you how big of a difference the pavement markings you choose makes when it gets dark and rains, but it may be more impactful to just show you.

What drivers see:

Daytime dry
Both the non-wet retroreflective white symbol and center line and the wet retroreflective yellow edge line are visible.

Nighttime dry
Both types of markings are visible in dry night conditions.

Nighttime rain
While the non-wet reflective symbol and center line appear to disappear, the wet retroreflective marking remains visible.

As you can see, parts of the non-wet retroreflective road markings virtually disappear in the dark when they become covered in rain, making the driver unaware the upcoming lane is a left turn lane.

With diverse and aging populations, driver-assisted and automated vehicles and new inexperienced drivers converging on the roads, having pavement markings that are visible to both humans and automotive cameras in a wide range of conditions is more important than ever.

Which section of road would you rather drive on?

See what a difference wet retroreflective pavement markings make.

► Watch video

Statistics tell the story.

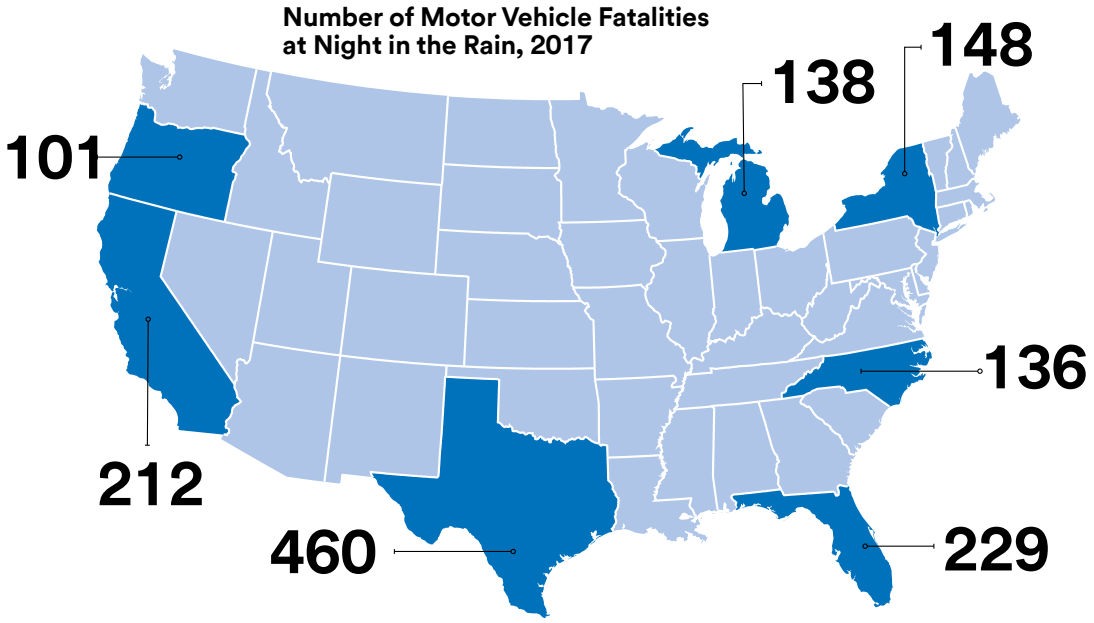
There's a lot on the line—know the numbers.

In 2017, 6,952 people died in crashes on U.S. roads when it was raining. Despite the fact that only 25% of travel occurs at night, a staggering 55% (or 3,811) of those deaths occurred at night or in low-light conditions.[6]

Rain and light conditions are an over-aggregating factor for crash risks. A 2015 study carried out in Texas investigated the temporal and spatial variability of the relative accident risk due to rainy conditions across the state. Researchers found that rainfall increased crash risk across the state by about 57%, and nighttime conditions increased it as high as 80%.[2]

1.25 million
lives lost globally per year due to traffic crashes
Source: WHO. Road Traffic Injuries, Jan., 2018.

49% of fatal crashes
happen at night, even though the majority of traffic is on the road during the day.
Source: Forbes. Most Dangerous Times to Drive, Jan., 2009.



French Crash Studies

In France, similar crash data studies were carried out over the last 12 years. Adjusted for average traffic density in France (90% of traffic occurs during the day), the statistical analysis showed that driving at night increased the risk of an injury-causing crash by 3.5 times, and the risk of a fatal crash by 6 times (compared to driving in the day). At night in the rain, those numbers climb to 7.7 times and 10 times respectively.[7]

Increasing the visibility of pavement markings, especially in dark or rainy and wet conditions, has been proven to reduce crashes.[8] And statistics show that drivers are far more likely to be involved in a crash at night or driving on wet and rainy roads. Improving roads to help drivers better handle these conditions can lead to reduced crashes, injuries, fatalities and costs.

Driving at night in light or heavy rain increases the risk of injury related crashes by

7.7X

and the risk of fatal crashes by

10X

compared to daytime driving

Source: BAAC (French road traffic database, government open data).

Third-party research suggests that wet retroreflective markings will reduce crashes.

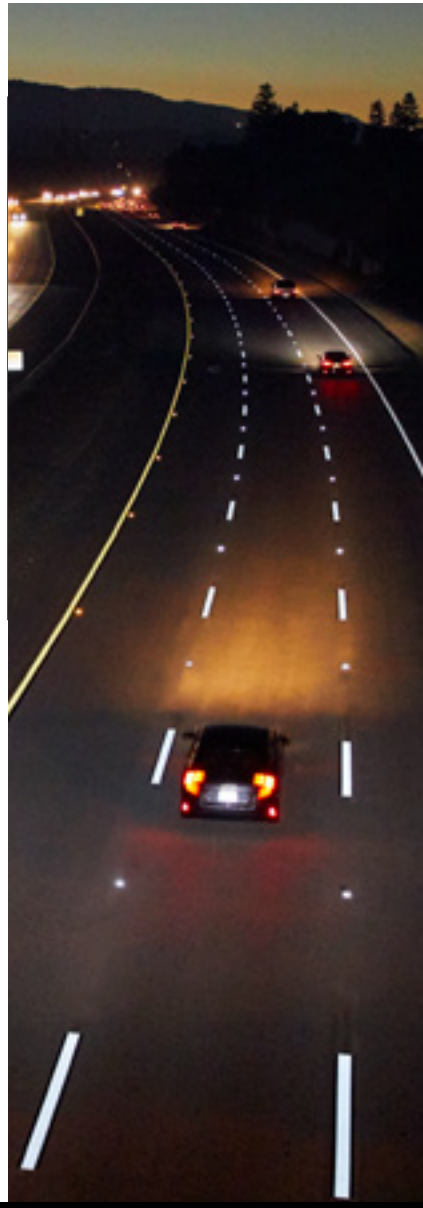
Human drivers rely on effective pavement markings today, and will continue to do so in the future.

Over half of all the cars sold in the U.S. in the past few years were available with automated technologies like lane departure warning systems, but vehicles are still largely operated by human drivers. Any pavement marking solution needs to continue being visible in all weather conditions to help keep these drivers—and others on the roads—safe.

In 2015, the US Federal Highway Authority conducted a rigorous, before-and-after evaluation of wet retroreflective markings used in Minnesota, North Carolina and Wisconsin to develop recommended crash modification factors (CMF). The recommended CMF for crashes with injuries on multilane roads is 0.595 and on expressways is 0.881, suggesting a 40% and 12% reduction respectively in these types of crashes after implementing wet retroreflective pavement markings.[8]

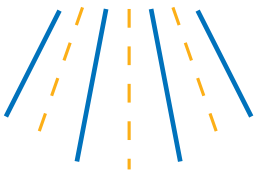
Likewise, a 2018-2019 study by Texas A&M Transportation Institute evaluated the effectiveness of wet-weather pavement markings in TxDOT's Atlanta District. They looked specifically at rainy, night crashes on approximately 630 miles of roadway where wet-weather pavement markings were installed. The study found implementing wet weather pavement markings on those roads reduced wet night crashes by about 30% and wet night fatalities by about 50%.[9]

Finally, according to an EU-sponsored study, *Rainvision: the impact of road markings on driver behavior*, applying retroreflective pavement marking material to the track had a positive effect on the subjective feeling of safety and comfort for drivers, especially in adverse weather conditions. Under nighttime and rainy driving conditions, retrorefeflective markings ensured clear trajectories of the driving path, providing anticipatory stimuli of the road environment and taking substantial workload off the driver. Conversely, errors committed by drivers increased by 70% when road markings were less visible.[3]



Safety Evaluation of Wet Weather Pavement Markings

FHWA Recommended Crash Modification Factors: Crashes with Injuries



Multi-lane Roads
40% reduction

Expressways
12% reduction

Table A: Safety Effects of Wet-Weather Pavement Markings

Percent Crash Reduction Estimates for Wet-Weather Pavement Markings		
Approach	**Wet – Night***	**Wet – Night Fatalities***
Empirical Bayes (EB)	28%	53%
Full Bayes (FB)	32%	49%

*Statistically significant results with 95% confidence

Targeting safety for Connected and Automated Vehicles.

As with human drivers, wet retroreflective pavement markings may enable more robust machine vision too.

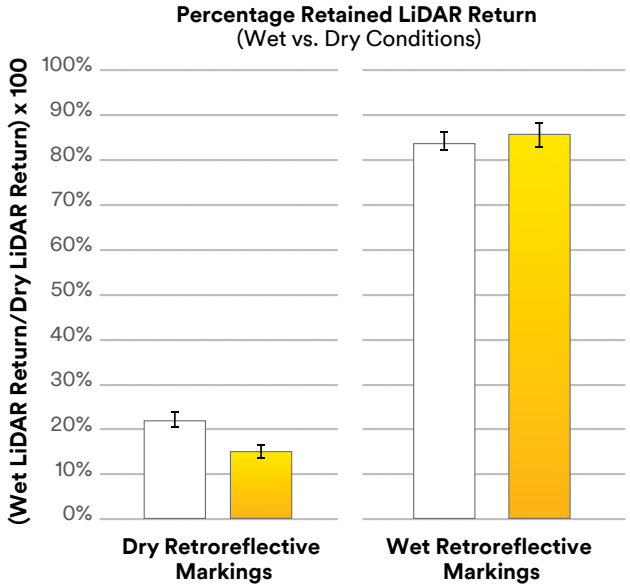
Whether it's optical camera systems in cars on the road today or LiDAR in the cars of tomorrow, recent studies have indicated that wet retroreflective markings also improve visibility for Advanced Driver Assistance Systems (ADAS) and Connected and Automated Vehicles (CAVs).

In the study, Effects of Wet Retroreflectivity and Luminance of Pavement Markings on Lane Departure Warning in Nighttime continuous Rain with and without Glare Sources, published in the Society of Automotive Engineers, 3M researchers explored the effects of wet retroreflectivity and luminance of white and yellow markings on the detection performance of a Mobileye LDW system in continuous nighttime rain conditions.[5]

They found that the percentage of detection at certain confidence levels was found to correlate with a two-factor interaction of the diffuse luminance property and continuous wet retroreflectivity. The researchers propose the possibility that the percentage of detection at certain confidence levels may correlate with a two-factor interaction of the diffuse luminance property and continuous wet retroreflectivity.

Another study specifically analyzed the performance effects of wet retroreflective pavement markings for machine vision feature detection, light detection and LiDAR systems in continuously wet road conditions. Table B plots the % LiDAR return in rainy night time conditions of both dry retroreflective markings and wet retroreflective markings. The preliminary results of this screening study suggested that wet retroreflective pavement markings are likely to be advantageous to both machine vision systems and LiDAR technology.[4]

Table B



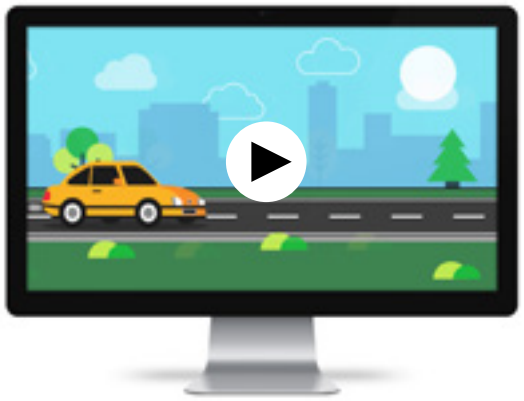
"In nighttime rain conditions, wet retroreflective optics enable detection at longer distances than glass beads on yellow markings."*

*Based on testing jointly conducted with Continental Automotive Systems Inc. in December 2017 in Brimley, Michigan, USA. Materials tested included yellow LPM lines in conventional driving zones and nighttime rain with either glass or 3M elements.

Not all optics are created equal.

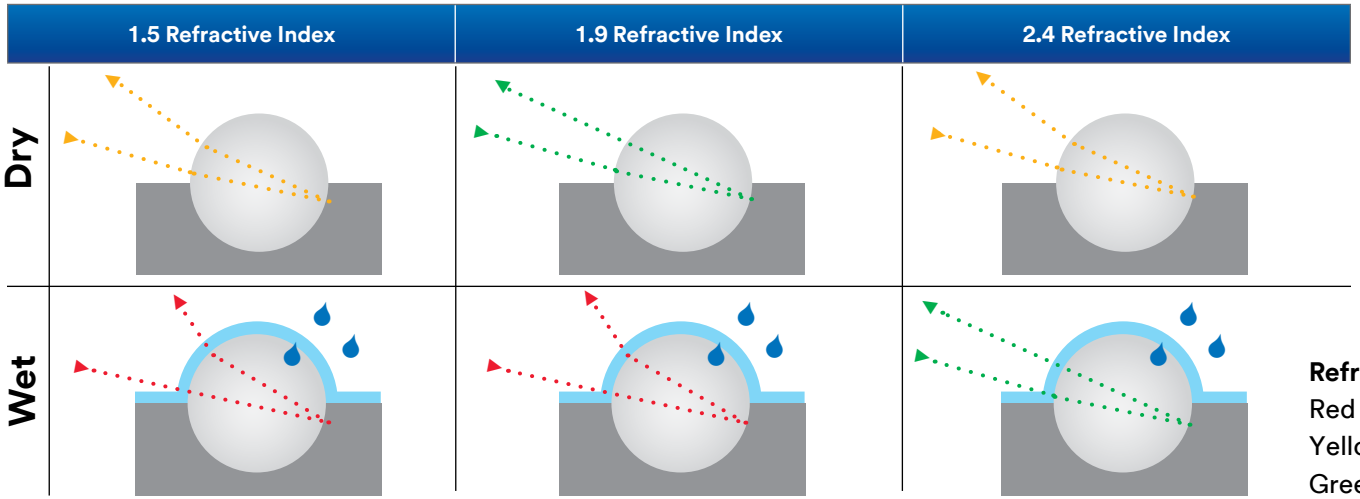
The science beneath the surface of different types of wet-continuous retroreflective markings.

In general, pavement markings are visible at night because of the retroreflective optics on or in the marking returning the light from the headlights of a vehicle back to its driver. However, different optics are better for returning light under different conditions—it's not possible for a single bead to be optimized for both dry and wet conditions.



► **Check out the Video**

Markings with 2.4 index beads can be seen in wet conditions where markings with other beads may not be visible. This is also true for machine vision systems which are based on optical cameras. Watch the video to learn more about the differences in pavement markings.



Refractive Index Key:
Red – least optimal light return
Yellow – sub optimal light return
Green – optimal light return

How to test elements *before* you install them.

The Cup Brightness Test provides an indication of the expected coefficients of retroreflected luminance.

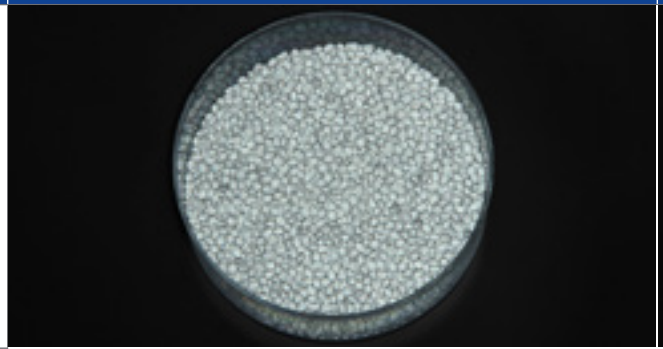
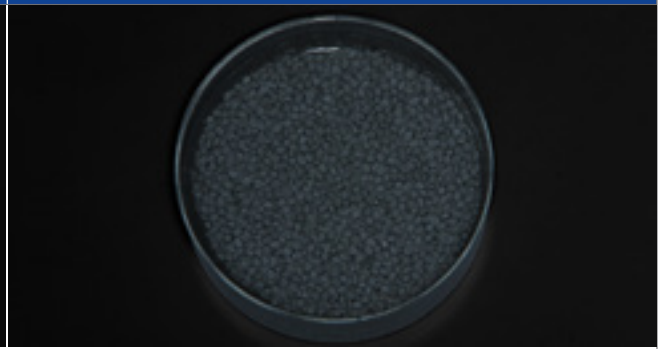
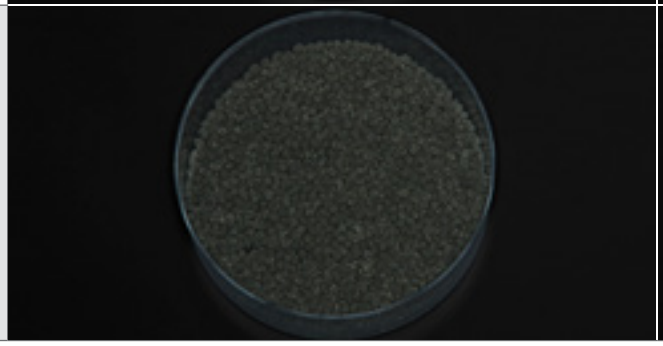
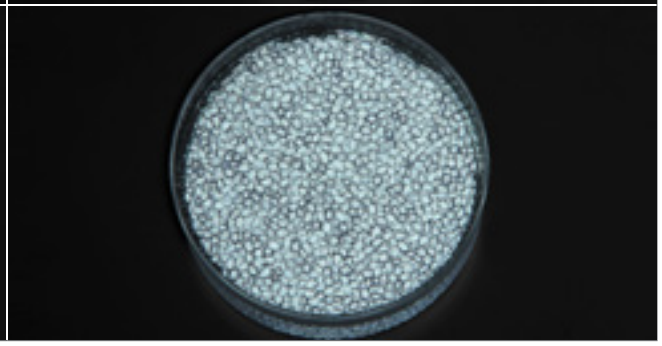
The best time to have an idea of what kind of wet retroreflective performance you can expect from a blend of bead elements or optics is well before you install them on your roadways. That is why it is encouraged to use the Cup Brightness Test prior to specification, especially on wet elements to simulate wet-continuous conditions.

While the ASTM wet continuous test (see next page) is the recommended test methodology for wet retroreflectivity, it can be difficult to conduct readings on every road stripe. Specifying the cup brightness test in addition to the wet continuous test ensures your roadways will meet the desired level of luminance. The cup brightness test can be performed before installing the product and can be done using limited materials in a laboratory setting.

See pg. 2 of the 3M™ Connected Roads All Weather Elements Product Bulletin to learn more on this method.

▸ **Download PDF**

1.9 and 2.4 refractive index bead performance comparison: Dry vs. Fully Submerged in Water

Refractive Index of Beads	Dry	Submerged in Water
1.9 Index Beads		
2.4 Index Beads		

When it comes to test methodologies, wet recovery is not the same as wet continuous.

Side-by-side testing shows there is a big difference in rainy and wet conditions.

Most drivers have experienced a harrowing drive on a dark, unfamiliar highway during a downpour. You may have thought that the pavement markings were old and faded and just needed to be replaced. But the truth is, if they weren't tested and designed to perform under wet continuous conditions, it wouldn't have made much of a difference no matter how old or new they were—wet recovery markings aren't designed to perform like wet-continuous markings can.

Globally, there are two types of test methods used for measuring wet reflectivity of pavement markings: Continuous wetting methods—which simulate wet reflectivity of a pavement marking during rainfall—and Wet Recovery methods—which simulate wet reflectivity of a pavement marking after it's stopped raining and the marking is recovering or draining (see Table A below for an outline of available wet retroreflective test methodologies).

Table A

Type	Continuous Wetting	Wet Recovery
ASTM	E2832	E2177
EN	EN1436 Annex B7	EN1436 Annex B6

Which type of test method is more realistic?

In general, continuous wet methods provide a result more comparable to the actual driver experience in moderate rain events than wet recovery methods. That's because continuous wet methods simulate the level of wet retroreflectivity experienced by a driver in a rain event, while wet recovery methods only simulate it at an instant in time after the rain has stopped.

Wet Recovery vs. Continuous Markings under Dry Conditions

Wet Recovery vs. Continuous Markings under Rainy Conditions

► Read more about testing methods.

What to consider when building a specification.

Here's what Traffic Engineers should think about as they create a pavement marking standard or specification.

Traffic Engineers often ask what the recommended in-service wet continuous retroreflectivity value is to put into a pavement marking specification or standard. Preliminary data from a forthcoming Texas Transportation Institute (TTI) research study shared at a recent regional ATSSA Training and Education Workshop helps answer this question. In coordination with Minnesota Department of Transportation, TTI conducted a human factors study to determine detection distance of pavement markings as a function of different wet retroreflective values. Preliminary findings discussed during a regional ATSSA workshop indicate that 50 mcd/m²/lux wet continuous is an appropriate replacement threshold for in-service pavement markings, but this is a bare minimum and far from optimal.

Why is 50 mcd/m²/lux far from optimal?

50 mcd/m²/lux provides 1.9 seconds of preview time for drivers at 55 miles per hour. Driving simulator studies reported in COST 331, an EU study[11] tasked with recommending optimum pavement marking design, showed that the absolute minimum preview time for safe driving is 1.8 seconds; otherwise, drivers will have trouble maintaining steady lane keeping. The authors emphasized that this was the bare minimum and that a higher value should be used. The COST 331 report established a recommended preview time of 2.2 seconds.

The US FHWA conducted a similar study[12] in 1998 that determined for short-range extreme driving conditions, 2 seconds of preview time was recommended as the safe minimum acceptable limit, allowing enough time for the driver to perceive and react to the pavement marking in hazardous conditions.

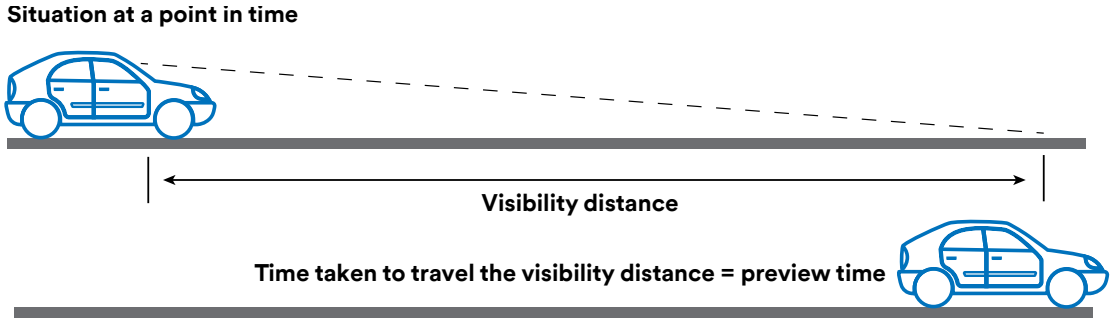
Higher levels of wet continuous retroreflectivity are better.

Table A shows the recommended wet continuous retroreflectivity minimums calculated from the preliminary findings of the forthcoming TTI study at different preview times and speeds.[10] Higher wet continuous retroreflectivity values are needed for different speeds or preview times. While it might be rare that drivers will be traveling 70mph during rain storms at night, this research is important in documenting the relationship between higher wet continuous values and longer preview times.

Table A: Wet continuous retroreflectivity minimums mathematically derived from preliminary findings of the forthcoming TTI study

	1.8-second Preview Time	2.2-second Preview Time
55 mph	50 mcd/m²/lux	130 mcd/m²/lux
70 mph	170 mcd/m²/lux	970 mcd/m²/lux

Figure 1: What is "Preview Time?"



The bottom line: There's a lot on the line.

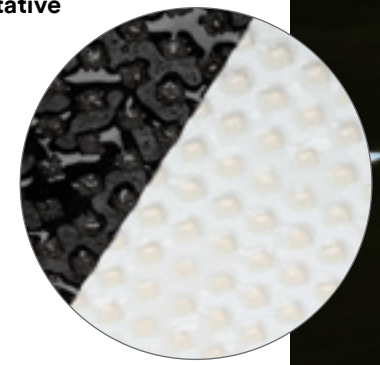
The visibility of road markings is critical day or night, rain or shine.

Applying pavement markings may be one of the last things you do when completing your road project, but they're a first step in helping to improve safety, reduce crashes and save lives. Having the most beautiful road in the world doesn't mean much if it's difficult to navigate in dark and rainy conditions.

As you've read, driving at night and/or in rainy conditions increases crashes, injuries and fatalities—a concern that may grow as more and more vehicles rely on machine vision technology. You've also seen the difference between wet continuous and wet retroreflective pavement markings and learned about the science behind it.

There will always be things you can't control, but you can control which type of road markings you apply—and only wet continuous retroreflective markings are designed to provide reflective brightness in the most crucial circumstances.

Please reach out to your local 3M representative to learn more about wet retroreflective pavement markings and to start an on-road demonstration.



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1.800.553.1380

Sources & Suggested Reading

To learn more about the importance of wet retroreflective pavement markings around the world, we recommend exploring the following studies and documents referenced in this ebook.

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Need help choosing the right road markings?

Contact a 3M expert to help you choose road markings that can minimise traffic disruptions and improve roadway safety.

► **Contact Us**