A New Method to Assess Pavement Marking Retroreflectivity for Compliance with the MUTCD Minimum Pavement Marking Retroreflectivity Levels

July 11, 2025

Authors:

Paul J Carlson, PhD, PE
Automated Roads
Greensboro, North Carolina
paul@automatedroads.com

Sam Miyagawa
Miyagawa Kogyo Co, Ltd
New York, New York

Kevin Goforth
Potters Industries, LLC
Malvern, Pennsylvania

Introduction

Pavement markings are an important element of the roadway infrastructure providing delineation and safety for human drivers as well as machine visions systems used in automated vehicles, making up larger portions of the vehicle fleet in the US each year. The Federal Highway Administration (FHWA) has published minimum retroreflectivity requirements in the Manual on Uniform Traffic Control Devices (MUTCD). Support documents provided by the FHWA describe methods that can be used to manage pavement marking retroreflectivity. This paper describes the requirements set forth by FHWA and also describes a new tool that agencies can use to manage pavement marking retroreflectivity so that they can be in compliance with the National minimum retroreflectivity requirements.

Background

In Edition 3 of the 2009 MUTCD, the FHWA published minimum pavement marking retroreflectivity levels for longitudinal lines. The language remains the same in the 11th Edition

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Section 3A.03 Maintaining Minimum 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. Talk about compliance dates and deadline of August 2026.

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of the MUTCD (the most recent MUTCD). Some of the critical MUTCD language is shown below.

The MUTCD minimum maintained retroreflectivity levels apply to all longitudinal pavement markings (i.e., center lines, lane lines, and edge lines) on roadways with posted speed limits of 35 mph or greater. This includes both temporary and permanent pavement markings. Agencies have the option to exclude markings where ambient illumination assures markings are adequately visible from their method. Also, markings on streets or highways that have an average daily traffic (ADT) of less than 6,000 vehicles per day may be excluded. In addition, dotted extension lines (per MUTCD Section 3B.08), curve markings, parking space markings, and shared-use path markings may be excluded from an agency's method.

Along with Edition 3 of the 2009 MUTCD, the FHWA also published a supporting document that describes acceptable retroreflectivity maintenance methods that, when implemented as intended, provide agencies with flexible means of being in conformance with the standard. These methods were developed specifically for longitudinal pavement markings (i.e., center lines, lane lines, and edge lines) although some of the methods could also be applicable to other types of markings. Agencies are supposed to use the methods that best suit their needs to satisfy compliance of the MUTCD's minimum retroreflectivity levels. The acceptable methods are listed and briefly described below.

Measured Retroreflectivity Method – In this method, pavement marking retroreflectivity is measured and directly compared to the MUTCD minimum levels. The retroreflectivity measurements can be made with either handheld or mobile instruments using the standard 30-meter geometry. Inspectors must follow the instructions provided by the manufacturer to obtain reliable retroreflectivity readings, including periodically calibrating the equipment.

Nighttime Visual Inspection Methods – There are two wo types of nighttime visual inspections that can be implemented to maintain pavement marking retroreflectivity Consistent Parameters Nighttime Visual Inspection and Calibrated Pavement Markings Nighttime Visual Inspection). Both methods are meant to be conducted during dry nighttime conditions. These two methods have common elements such as:

- The use of low-beam headlamp illumination.
- Inspections conducted at prevailing nighttime speeds.
- The use of trained inspectors.
- The dependence on subjective evaluations.

Service Life Based on Historical Data Method – Using this method, an agency documents pavement marking installation dates and, using historical data or research results, establishes a schedule for replacing the markings. The schedule to replace the markings is designed to prevent the pavement marking retroreflectivity from falling below the MUTCD minimum levels.

Pavement marking replacement schedules can be set for similar markings in similar conditions (considering factors such as pavement marking
type, retroreflective optics, pavement type, pavement condition, and traffic volumes).

Service Life Based on Monitored Markings Method – Using this method, an agency documents pavement marking installation dates and periodically monitors the retroreflectivity of a subset of the markings as a way to track their durability (retroreflectivity). The monitored markings represent a larger group of similar markings in similar conditions. When the monitored markings degrade and approach the MUTCD minimum levels, the entire group of markings (both monitored and the larger group they represent) are restriped. This is an alternative method for agencies that want to use a service life type of method but do not have historical data or specific research supporting service life estimates for their region and specific conditions.

Other Methods – An effective approach may be to combine one or more of these methods or to develop other methods based on engineering studies. If an agency develops a different method, however, it is important that the method be based on an engineering study and tied to the MUTCD minimum levels.

Road Marking Assessment Device

A new AI technology tool has been developed that uses a traditional phone (iPhone or Android). The tool is called the Road Marking Assessment Device (or RMAD). With an app installed and the phone mounted in the windshield of a vehicle, the driver turns on the app to record and conducts a daytime drive of the roadway of interest. The app uses AI technology to locate markings on both sides of the road and tracks them. By default, assessments are made at 30-meter intervals but can be customized by the user. The app then uses a 1-meter section of the markings to determine the presence of the markings. The results are mapped using different colors to show the condition of markings using presence. CSV files are available to further analyze the results as well.

Figure 1. RMAD Collecting Data

Figure 2. Assessment of a Worn Marking

Figure 3. Green Boxed on Lane Line and Edge Line Show Area of Assessment

Figure 4. Results Mapped Using Color to Show Categories of Condition

Retroreflectivity Analysis

The RMAD tool was developed and tested in Japan and had shown strong correlations between presence and retroreflectivity. The research described in this paper was conducted to determine if US markings would also produce a strong correlation between presence and retroreflectivity.

The RMAD tool and mobile retroreflectivity were simultaneously used to collect data on 848 miles of roadways in the US. The data were collected in Texas, California, Kansas, North Carolina, and Nebraska in 2024. The roadways included a variety of multilane roadways and two-lane roadways. Statistics of the retroreflectivity data are provided in Table 1.

Table 1. Retroreflectivity Data Summary

Marking Color	Min (mcd)	Avg (mcd)	Max (mcd)
Yellow	28.1	203.7	1174.8
White	51.2	348.3	981.9

Figure 5 shows the mobile retroreflectivity equipment used during the data collection efforts. The marking materials included a variety as well such as paint, thermoplastic, and epoxy. There was no information availability about the age of the markings or the type of beads or their application rates.

Figure 5. LaserLux G7 Mobile Retroreflectivity Equipment

To inspect the data visually, both sets of data were plotted against the distance traveled. Figure 6 shows an example of the measured data plotted against the distance traveled (x-axis).

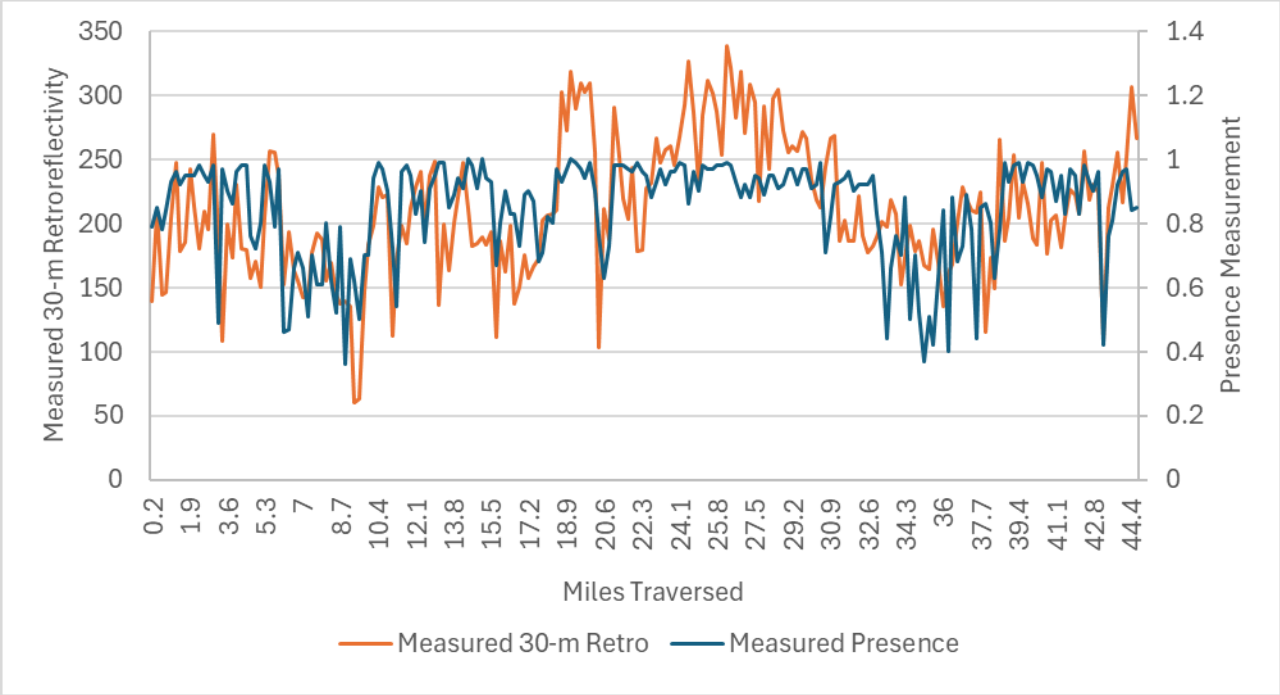

Figure 6. Simple Comparison of Measured Retroreflectivity and Presence

The data were then analyzed by running linear correlations between the measured presence and measured 30-m retroreflectivity readings. The results for the yellow markings are shown in Figure 7 and the results for the white markings are shown in Figure 8.

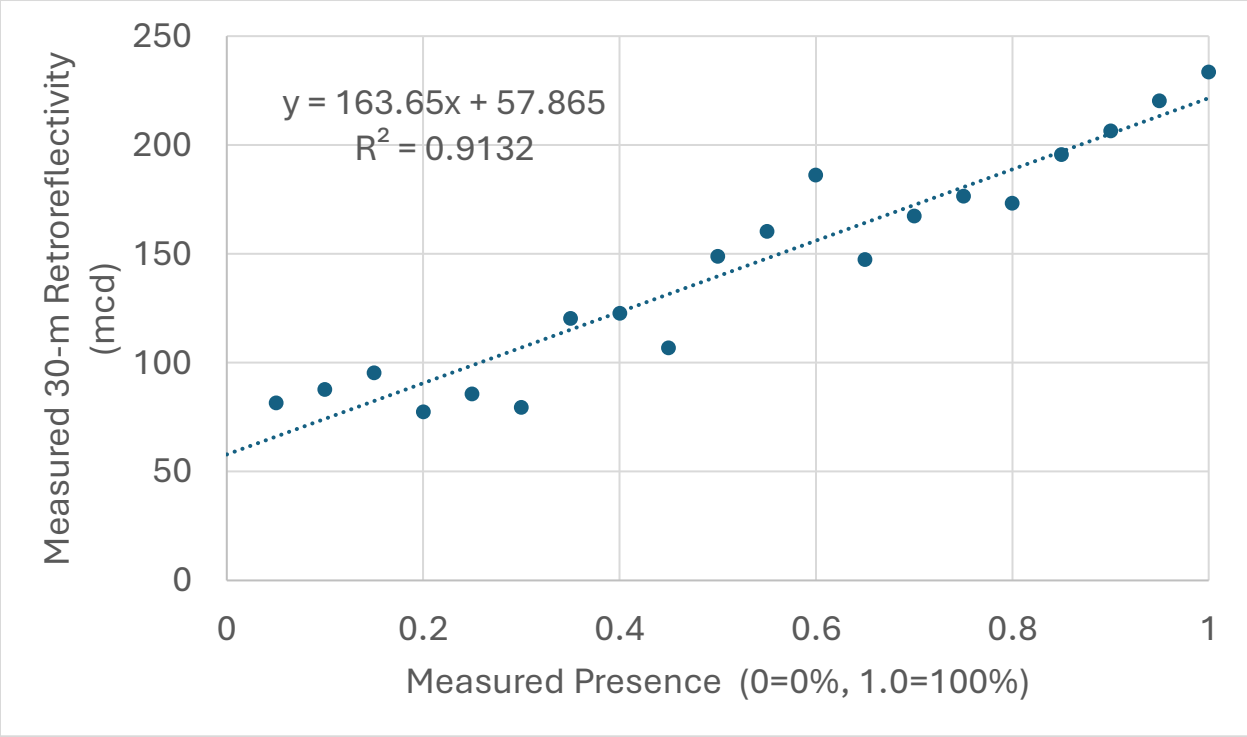

Figure 7. Correlation of Yellow Markings

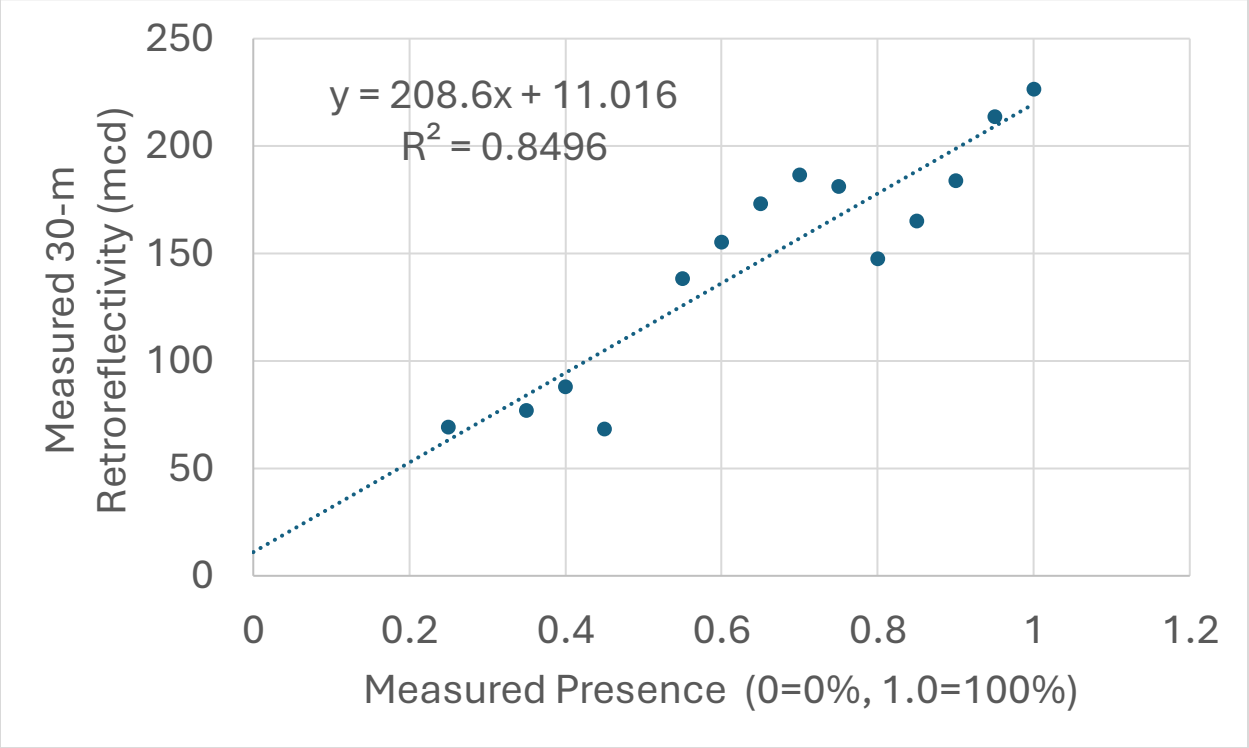

Figure 8. Correlation of White Markings

Both colored markings show a strong correlation that indicate that the results of the RMAD tool can be used to assess not only the presence of the markings, but also the retroreflectivity level. Compared to visual inspection methods, the RMAD device removes the subjectivity from the rating by the human observer. It is also considerably less costly than buying mobile retroreflectivity devices. The RMAD tool could be used on its own by an agency to manage pavement marking retroreflectivity or can be used in combination with methods such as Expected Service Life to help agencies refine their estimated service life based on materials, traffic, etc.

Discussion

It is interesting that the RMAD results correlate well with retroreflectivity given that the RMAD tool collects daytime images. While this work did not have the resources to test different theories, one theory is related to bead loss. As markings wear, they tend to lose the drop on beads that are applied before the marking cures. These drop on beads provide retroreflectivity and nighttime visibility. As the markings wear, the beads can pop out of the markings, leaving small craters. They can also crack or get sheared off by plows. All of these failures tend to leave the marking looking dingy or even dirty, which then cause the RMAD tool to rate the presence lower. See Figure 9 for an example of how bead loss tends to create pockets where road dirt and

grime tends to fill the empty craters leaving the marking dirty and darker looking than it would without the bead loss. Obviously, the retroreflectivity would also be lower in these cases too. Therefore, this might be one way to explain the strong correlation between the RMAD tool results and retroreflectivity.

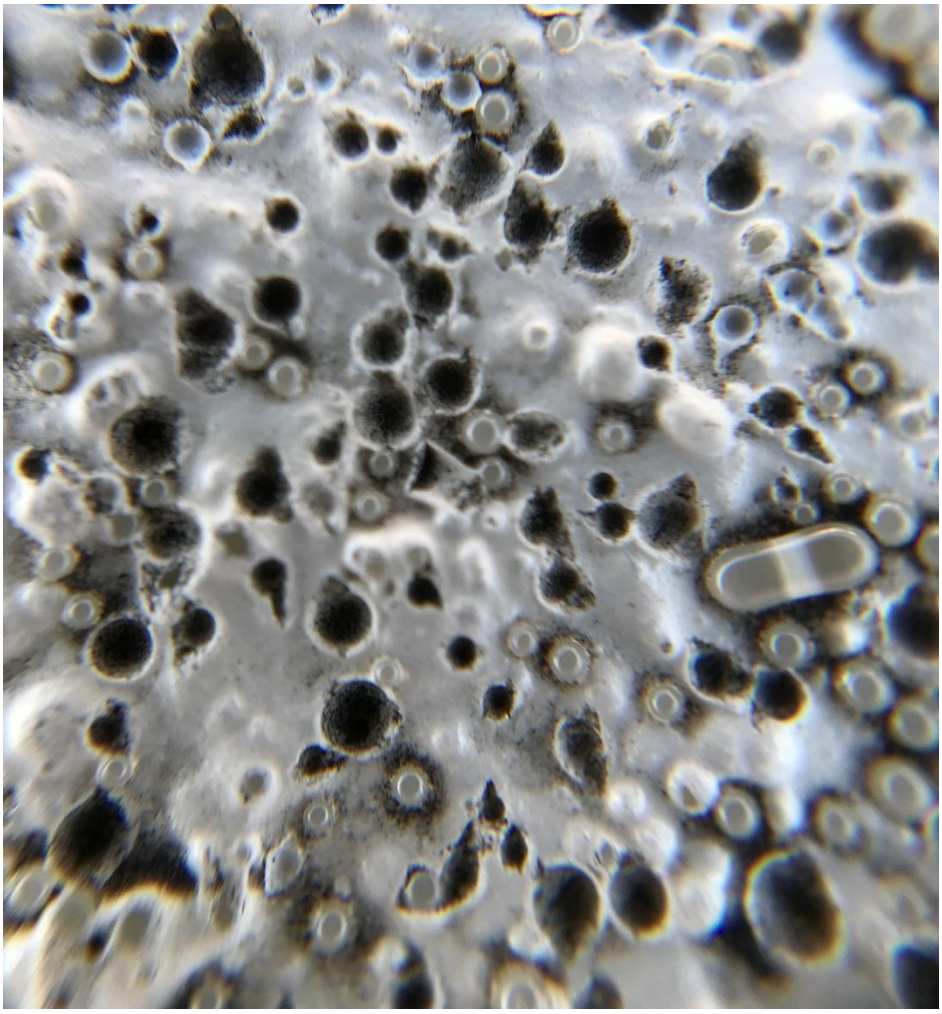

Figure 9. Bead Loss and Dirt Collection

Conclusion

The results of this paper show that the RMAD tool can be used by agencies to complement their existing pavement markings retroreflectivity management program or even be used on its own to meet the MUTCD requirements of maintaining minimum retroreflectivity levels. Technically, this tool would fall under the "Other Methods" as described in the FHWA's report (Methods for Maintaining Pavement Marking Retroreflectivity, FHWA-SA-22-028, July 2022). It can be used on its own or combined with other methods. In many places where measured retroreflectivity is

used, the mobile equipment does not generally measure ramps or frontage roads. In these cases, the RMAD tool would be a good complement. It could also be used for those using the expected service life method. RMAD would most likely be a better method than visual inspections, taking the subjectivity out of the visual inspection method.

Acknowledgement

This paper is based on data collected by Potters Industries. Potters Industries collected both the retroreflectivity data (using a calibrated LaserLux G7 Mobile Retroreflectometer) and smart phone data with the RMAD software loaded and running. We would like to express our sincere gratitude to all those involved for their valuable time and cooperation in collecting and providing the data; and assisting in the analysis and compilation of this paper. Contact Potters Industries for more information about the RMAD, setting up a demonstration, and understanding pricing options.