Preliminary Investigation

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Commercial Pavement Marking Management Systems

Requested by Steve Takigawa, Deputy Director, Caltrans Maintenance and Operations
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Key Word Search: PMMS, pavement markings management system, pavement markings, retroreflectivity, striping

Background

The current Caltrans practice on pavement marking maintenance consists of district maintenance crews performing mostly visual inspections of the pavement markings. These visual inspections become the impetus for pavement markings replacement activities. Visual inspections are subjective evaluations where different individuals can come up with different values even when inspecting the same pavement marking. Instead of visual inspections, Caltrans can potentially change to a different practice that is more objective and systematic.

One inspection system is to gather retroreflectivity levels of the pavement marking throughout the state periodically. This preliminary investigation (PI) surveyed and interviewed other state department of transportations (DOTs) to discover their pavement marking maintenance practices. The PI also attained information about the various companies that can take retroreflectivity readings with their mobile reflectometer unit (MRU). Information regarding pavement marking presence and other indicators of pavement marking effectiveness is scarce; as a result, most of the information this PI found is focused on retroreflectivity levels and their indications on the performances of the pavement markings.

Summary of Findings

State DOT's Use of Pavement Marking Management System

Indiana DOT repaints their highway center lines annually, but it takes readings of edgelines to evaluate if the edgelines need repainting. The edgelines' reflectivity must be below 130 mcd/m^2/lux. Indiana DOT uses this value because their internal research found that 130 mcd/m^2/lux will retain 100 mcd/m^2/lux after the winter. The 100 mcd/m^2/lux is based on the proposed minimum retroreflectivity in the MUTCD, a proposal which currently has not been adopted by Federal Highway Administration. Indiana DOT saved about 30% on their pavement marking budget after implementing this practice.

North Carolina DOT (NCDOT) uses paint, thermoplastic, cold applied plastic, and polyurea pavement marking materials. NCDOT has been taking pavement marking retroreflectivity readings since 2000. This data became the basis for a North Carolina University research in 2009 which developed a degradation model for the different types of pavement marking. This research also recommended the minimums of 150 mcd/m^2/lux thermoplastic white markings and 100 mcd/m^2/lux for thermoplastic yellow markings.

NCDOT performed a cost analysis using this set of pavement marking retroreflective reading data and the degradation models in April 2015. It compared the costs and performances of the different pavement marking materials in a projected 20 year time period in different average daily traffic (ADT) and road conditions. It showed that moving to thermoplastic and polyurea materials would save NCDOT about $16 million a year. This cost savings information led to NCDOT's central office developing a guidance to encourage the divisions to make the change to use thermoplastic and polyurea materials. It is estimated that 50% of their divisions have adopted the practice.

Missouri DOT's practice before 2015 was to restripe every minor route and replace the pavement markings in major routes two to three times a year. Because of a reduced budget in 2015, Missouri DOT changed their practice to evaluating the pavement markings before making a decision to perform a replacement. Missouri DOT's minimum retroreflectivity is 150 mcd/m^2/lux for white markings and 125 mcd/m^2/lux for yellow markings. If the readings are below those levels, then the decision is to restripe the route. Missouri DOT is able to skip restriping 50% of their 28,000 miles of minor routes each year.

Minimum Retroreflectivity Levels

Numerous research has been performed on minimum reflectivity levels. This minimum reflectivity levels research established the basis of the analysis on how well average motorist can perceive the presence and visibility of the pavement markings. One study shows that a minimum of 3.65 seconds preview time is needed to allow motorist to react to pavement markings.

There is also a standard geometry for how to measure the reflectivity of the markings. Most research uses 30 meter geometry for retroreflectivity measurement described in the ASTM 1710 – 11. The geometry is shown below.

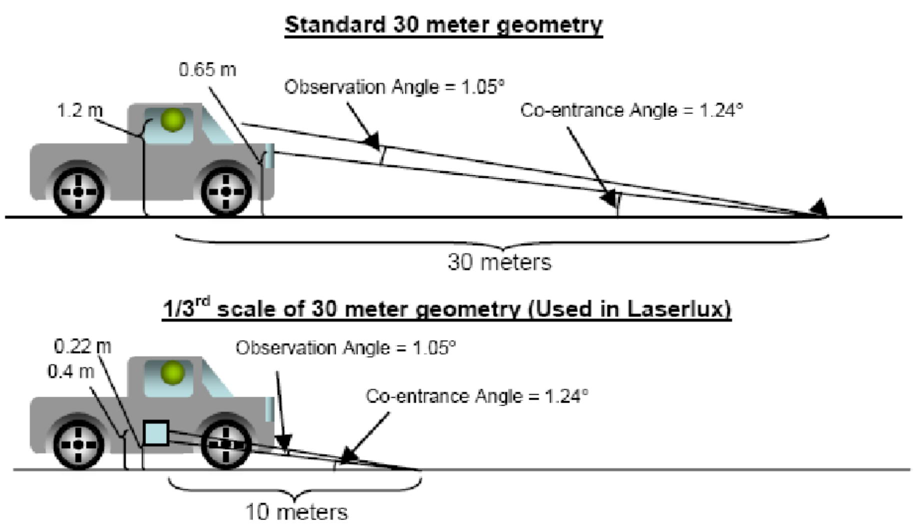

Figure 1. Standard 30 meter geometry described in ASTM 1710 – 11. The figure is taken from page 18 of *Serviceable Pavement Marking Retroreflectivity Levels: Technical Report.* (See page 8 of this report for full reference).

Based on the 3.65 seconds preview time and the 30 meter geometry, a minimum retroreflectivity levels can be determined. There are different minimum retroreflectivity for white and yellow lane markings. The white ranges from 90-150 mcd/m^2/lux and the yellow ranges from 90-100 mcd/m^2/lux.

A minimum reflectivity level was proposed for federal requirement, but it was never adopted. The proposed federal minimum is 100 mcd/m^2/lux for all pavement markings for most highways.

Individual states can set up their own minimum levels. Most states interviewed and surveyed seem to place their minimums at or above the proposed minimum levels.

Summary of State DOT Survey and Interview Responses

Indiana DOT

Indiana DOT crews run their own MRU. They repaint the centerline every year. For the white edgelines, repainting depends on retained retroreflectivity levels. The minimum edgeline retroreflective values Indiana DOT will accept is 130 mcd/m^2/lux or above.

This minimum level is based on an Indiana DOT internal research. Their research found that when the edgelines are above 130 mcd/m^2/lux, they will retain 100 mcd/m^2/lux after the winter season. The internal research is not in this preliminary investigation, because it is not conducive for public disclosure.

Indiana DOT measures the retroreflective values in the white edgelines with MRU during spring to gather the data. This data is used to plan for restriping program for the year. After Indiana DOT implemented this marking management system, it saved about 30% by not having to repaint their white edgelines every year.

North Carolina DOT

North Carolina DOT use paint, thermoplastic, cold applied plastic, and polyurea pavement marking materials. NCDOT took pavement marking retroreflectivity readings since the year 2000, and this large data set allowed NCDOT to do analysis on their different pavement marking materials. The data allowed them to build a degradation model for their pavement marking materials and to perform a cost analysis of different pavement marking materials. The result is that NCDOT can save roughly $16 million a year by using thermoplastic and polyuria. NCDOT central office then establish this guidance for the divisions. An estimated 50% of the divisions adopted the practice.

Missouri DOT

Missouri DOT's practice before 2015 was to annually restripe every route. It would replace the pavement markings in major route two to three times a year. Due to budget constraints in 2015, Missouri DOT changed their practice to evaluating the pavement markings before making a decision to replace them. Missouri DOT employees gather the retroreflectivity readings by performing visual inspections and using handheld reflectometer. Missouri DOT uses *BC Engineering, Inc.* to take readings of its divided highway with an MRU.

Missouri has a minimum of 150 mcd/m^2/lux for white markings and 125 mcd/m^2/lux for yellow marking. If the reading are below those two levels, then the decision is to restripe the route. This allowed Missouri DOT to skip restriping 50% of their 28,000 miles of minor routes each year.

Pavement Marking Acceptance Table, mcd/m^2/lux		
	White	Yellow
New Pavement Markings	300	225
Existing Pavement Markings Expected to Last Through Winter (measured in the fall)	200	175
Pavement Marking Failure Point	150	125

Figure 2: Missouri DOT pavement marking acceptance table. Figure taken from Missouri DOT's engineering Policy Guide website.
http://epg.modot.org/index.php?title=620.13_Measurement_of_Retroreflectivity_by_Handheld_Retroreflectometers#620.13.5_Acceptance

Kansas DOT

Currently, Kansas DOT has district maintenance crews perform the evaluations of the pavement markings. Each district has a different way to collecting information about which route needs to be restriped. The minimum retroreflectivity levels for Kansas are 150 mcd/m^2/lux for white and 100 mcd/m^2/lux for yellow. Kansas DOT is considering whether to have a company use an MRU to record the entire state's highway system in the future. The data collected will allow Kansas DOT to better plan on restriping activities. Another benefit that Kansas DOT anticipate is that the information on pavement marking materials will allow it to analyze the pavement marking materials to determine which pavement markings perform better in different conditions.

Michigan DOT

Michigan DOT replaces most of their paint pavement markings annually. However, it has durable pavement markings installed during a construction project. Michigan DOT takes retroreflectivity readings of the durable markings to determine if it should replace the pavement markings. Michigan DOT uses *Millennium Data Management, Inc.* and *Precision Scan, LLC* contractors for retroreflectivity readings. One of its challenges is maintaining an accurate log of the quantities and locations of the durable pavement markings.

Florida DOT

Florida DOT use mobile reflectivity reading to decide when to restripe. It utilizes *BC Engineering, Inc.* The challenges that Florida DOT faces is the difficulty in having the consultants around throughout the year. Another challenge is having in-house database experts to support and maintain the data for the pavement marking.

Iowa DOT

Iowa DOT currently uses a Lazerlux Van, handheld LTL-X reflectometer, and contractors for taking pavement marking readings. Iowa DOT built a system to track the durable marking locations and use the retroreflectivity data to decide when to repaint the pavement marking.

Pavement Marking Management Vendors

BC Engineering, Inc. of So. St. Paul, MN

Out of the seven state DOTs that were successfully contacted, four DOTs used *BC Engineering, Inc. BC Engineering* received an overall favorable rating. Out of the five ratings (very poor, poor, average, above average, and exceptional), *BC Engineering* obtained one average, two above average, and one exceptional rating.

The positive comments about *BC Engineering* include their ability to give feedback on observations in the fields, and they have several MRUs to complete the pavement marking retroreflectivity readings in a short amount of time. The positive comments are accompanied by negative comments. In one state, *BC Engineering* uses a single MRU to take reading of the entire state, which may not be enough. Another negative comment is that *BC Engineering* is considering making a change to their charging practice. They may begin charging for the mapping tools instead of offering it as an included service. One state had a concern that *BC Engineering* was not familiar with its specification, so it was hard for *BC Engineering* to perform a pass or fail test on pavement markings.

Precision Scan, LLC of Thomasville, NC

Three of the state DOTs surveyed use the services of *Precision Scan, LLC*. *Precision Scan* receives two above average and one exceptional rating, making its rating great. *Precision Scan* has multiple positive comments. It is detailed in its data gathering, has good pricing, delivers on time, requires minimum oversight, is flexible, and answers questions about data quickly. In the survey, one state mentioned that *Precision Scan* reportedly had incorrectly summarized data and had inaccuracies in a report. Overall, *Precision Scan* provides a great service to their state DOT customers.

Millennium Data Management, Inc. of East Bethel, MN

There was one state DOT that used *Millennium Data Management, Inc.* services. *Millennium* got an above average rating. The positive comments said that Millennium has good contract pricing, delivers on time, and requires minimum oversight. However, the same state in the survey reported that *Millennium* had inaccuracies in its reports.

Gaps in Findings

This preliminary investigations mainly investigated retroreflectivity as a measurement for pavement markings. There is a gap in other systematic ways of evaluating the performance of the pavement markings. This report also focused on the companies that are currently providing state DOTs' pavement marking retroreflectivity readings. Companies servicing cities, counties, and other organizations were not included.

Next Steps

Indiana DOT, North Carolina DOT, and Missouri DOT were able to reduce the cost of their pavement marking activities after implementing a pavement marking management system. Indiana DOT saved 30% by repainting their white edgelines only if it falls below 130 mcd/m^2/lux. North Carolina DOT was able to complete a study to find the most cost effective pavement marking materials, potentially saving up to $16 million a year. Missouri DOT was able to skip replacing 50% of their 28,000 miles of minor routes pavement marking. These reductions in the pavement marking replacement cost provide a good incentive for Caltrans to adopt a pavement marking management system (PMMS). All of the state DOTs surveyed recommended that Caltrans use a PMMS. It is recommended that Caltrans perform a pilot project PMMS in order to test it.

Detailed Findings

North Carolina

"Pavement Marking Performance Analysis" 2009. Willion J. Rasdorf. North Carolina State University, 2009.
http://repository.lib.ncsu.edu/publications/bitstream/1840.2/2351/1/212

This report analyzed pavement marking materials using North Carolina DOT's large data set of pavement marking retroreflective readings and developed a degradation models for thermoplastic and paint pavement markings. It found that thermoplastic pavement marking materials degraded to a level in between 150 and 300 mcd/m^2/lux after five years of being applied. The models can be used to determine the cost effectiveness of the different pavement marking materials, which NCDOT completed in 2015. This research found that edgelines degrade at a slower rate than skip lines and midlines, so there can be the potential to save costs by replacing edgelines less frequently than midlines and skip lines.

"Pavement Marking Life Cycle Cost Analysis." North Carolina DOT, 2015.
https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Pavement_Marking_Cost_Analysis.pdf

In April 2015, NCDOT performed an analysis using a set of pavement marking retroreflective reading data and the pavement marking degradation models. It compared the costs and performances of the different pavement marking materials in a projected 20 year time period in different average daily traffic (ADT) and road conditions. It showed that moving to thermoplastic and polyurea materials would save NCDOT about $16 million a year.

Iowa

"Pavement Markings Integrated Approach to Pavement Marking Management" Neal Hawkins, Omar Smadi, Zach Hans, and Thomas H. Maze. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1948 pp. 99-107, 2005
http://trrjournalonline.trb.org/doi/abs/10.3141/1948-11

Abstract: Providing good pavement marking performance is an essential component of the transportation system. According to Tom Welch, state safety engineer for the Iowa Department of Transportation (DOT), "Every older driver forum has included a consistent demand for brighter and more durable pavement markings." This paper summarizes some management tools developed for Iowa DOT as part of a pavement marking management system (PMMS). A summary of how retroreflectivity data are used statewide in managing pavement marking performance is provided as well as a discussion of how the PMMS was integrated with other infrastructure management resources for Iowa DOT.

Planning Developing Implementing Iowa Pavement Marking Phases (IPMMS): Phases I and II, U. S. DOT, 2006.
http://publications.iowa.gov/21035/1/IADOT_Planning_Developing_Implementing_Iowa_Pavement_Marking_Phases_I_II_2006.pdf

Abstract: With an annual pavement marking program of approximately $2 million and another $750 thousand invested in maintenance of durable markings each year, the Iowa DOT is seeking every opportunity to provide all-year markings staying in acceptable condition under all weather conditions. The goal of this study is to analyze existing pavement marking practices and to develop a prototype Pavement Marking Management System (PMMS).

This report documents the first two phases of a three-phase research project. Phase I includes an overview of the Iowa DOT's existing practices and a literature review regarding pavement marking practices in other states. Based on this information, a work plan was developed for Phases II and III of this study.

Phase II organized the key components necessary to develop a prototype PMMS for the Iowa DOT. The two primary components are (1) performance/life cycle curves for pavement marking products, and (2) an application matrix tailored to the pavement marking products and roadway and environmental conditions faced by the Iowa DOT. Both components will continue to be refined and tailored to Iowa materials and conditions as more performance data becomes available.

Texas

"Serviceable Pavement Marking Retroreflectivity Levels: Technical Report" Texas DOT, Project 0-5656, March 2009
http://www.wsdot.wa.gov/NR/rdonlyres/123C0047-7DD7-4C44-8F78-22ABFD039D52/68897/056561.pdf

This paper summarized the history of minimum retroreflectivity levels researches. Most of these researches were based on how well the public perceived pavement marking materials. There were different conclusions from the researches with different minimum recommendations. Some researches distinguished between white and yellow while some did not. However, all of the minimum recommendations were in excess of 80 $mcd/m^2/lux$ for both colors.

This research also developed best practices for Pavement Marking Management System. It recommended that a PMMS uses a color coded map to show a priority of which pavement marking areas that need to be addressed. It suggested that the green color be used to indicate that the pavement retroreflectivity levels are above 150 mcd/m^2/lux, signifying that it is adequate. A yellow color would show that the retroreflectivity levels are in between 100 and 150 mcd/m^2/lux. The yellow would indicate that this pavement marking area would need attention in the near future. The red color would indicate that the pavement marking retroreflectivity levels are below 100 mcd/m^2/lux, a level at which the pavement marking will need to be replaced.

"Mobile Retroreflectivity Best Practices Handbook" Texas DOT, July 2009
http://tti.tamu.edu/documents/0-5656-P1.pdf

Abstract: This handbook documents best practices related to proper use of the mobile retroreflectometer, sampling of sites for data collection, and handling of mobile retroreflectivity data. The best practices described in this handbook are derived from the results of Texas Department of Transportation (TxDOT) Project 0-5656 and the author's observation in using the mobile retroreflectometer. The first part of the handbook provides information on sampling of pavement markings, periodic data quality checks, and data file naming conventions. The sampling procedure described here provides a systematic way of reducing the number of samples under a constrained budget. File naming conventions suggested in this handbook will be helpful in automating mobile retroreflectivity data handling and analysis.

The second section of the handbook provides information on equipment required to calibrate the mobile retroreflectometer and collect the data. This handbook also describes the best practices for initial setup and calibration of the mobile retroreflectometer and calibration checks. Since several factors change as data are being collected, best practices for accounting for changes in variables, such as variations in vehicle speed and operating temperature, etc., are described.

The final section pertains to best practices in data handling and suggested analysis of mobile data. This handbook elaborates on the consistency of data file headers and quality checking of data. A prototype of automation for data analysis is demonstrated that will prove handy in dealing with large amounts of mobile data.

Minimum Retroreflectivity Levels

National Guidance

"Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs," Debaillon C., P.J. Carlson, Y. He, T. Schnell, and F. Aktan. Federal Highway Authority Report, FHWA-HRT-07-059, October 2007.
http://www.fhwa.dot.gov/publications/research/safety/07059/07059.pdf

This research is an update on the minimum levels of retroreflectivity study done in the early 1990s in an FHWA sponsored research done by using Ohio University's Computer-Aided Road-Marking Visibility Evaluator (CARVE) model. This study uses University of Iowa's Target Visibility

Predictor (TARVIP) model which takes into account changes in pavement marking materials, headlamps, and types of roadway surfaces. TARVIP did various simulations with different pavement surfaces, pavement marking configurations, vehicle types, and vehicle speeds. The recommended reflectivity levels for highways without retroreflective raised pavement markers (RRPMs) end up being 150 mcd/m^2/lux for white and 100 mcd/m^2/lux for yellow. This report's table 1 summarizes the recommendations. The yellow 100 mcd/m^2/lux levels helped the proposed minimum retroreflectivity levels in the MUTCD. The report's table 1 on page 5 shows the recommendations on minimum retroreflectivity levels under different conditions.

Table 1. FWHA research recommendations for minimum pavement marking retroreflectivity.[7]

Option 1		**Non-Freeway, ≤ 40 mi/h**	**Non-Freeway, ≥ 45 mi/h**	**Freeway, ≥ 55 mi/h**
Option 2		**≤ 40 mi/h**	**≥ 45 mi/h**	**≥ 60 mi/h, >10K ADT**
Option 3		**≤ 40 mi/h**	**45–55 mi/h**	**≥ 60 mi/h**
With RRPMs	**White**	30, per Zwahlen	35, per Zwahlen	70, per Zwahlen
	Yellow	30, per Zwahlen	35, per Zwahlen	70, per Zwahlen
Without RRPMs	**White**	85, per Zwahlen	100, subjectively chosen to accommodate many drivers while minimizing impact.	150, increased from lower speed category to accommodate increase in required preview time. Recommended that such roads be outfitted with RRPMs since older drivers may have difficulty with this retro value.
	Yellow	55, lowered by 35% from White value since drivers primarily use white edge line, reflecting field data.	65, lowered by 35% from White value since drivers primarily use white edge line, reflecting field data.	100, lowered by 35% from White value since drivers primarily use white edge line, reflecting field data.

Note: Retroreflectivity values are in mcd/m^2/lux
1 mi/h = 1.61 km/h

Summary of the MUTCD Pavement Marking Retroreflectivity Standard. Federal Highway Administration, FHWA-SA-10-015, 2010.
http://safety.fhwa.dot.gov/roadway_dept/night_visib/fhwasa10015/

There are discussion about adding minimum retroreflectivity to longitudinal pavement markings. The proposed minimum levels are summarized in Table 3A-1 taken from the FHWA website listed above. The relevant minimum retroreflectivity for highway speeds that are not two lane roads with a centerline marking only is 100 mcd/m^2/lux. This proposal has not been adopted yet.

Table 3A-1. Minimum Maintained Retroreflectivity Levels[1] for Longitudinal Pavement Markings			
	Posted Speed (mph)		
	≤30	**35–50**	**≥55**
Two-lane roads with centerline markings only[2]	n/a	100	250
All other roads[2]	n/a	50	100

1. Measured at standard 30-m geometry in units of mcd/m^2/lux
2. Exceptions:
    A. When RRPMs supplement or substitute for a longitudinal line (see Section 3B.13 and 3B.14), minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions.
    B. When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.

ASTM E1710-11, Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer, ASTM International, West Conshohocken, PA, 2011.
http://www.astm.org/Standards/E1710.htm

This standard describes the 30 meter geometry for determining the coefficient of retroreflected luminance. This geometry has a viewing distance of 30 meters, a headlight mounting height of 0.65 meters above the pavement stripe, and an eye height of 1.2 meters above the pavement. This geometry results in an observation angle of 1.05° and an entrance angle of 88.7°. The figure below is illustrative of this geometry.

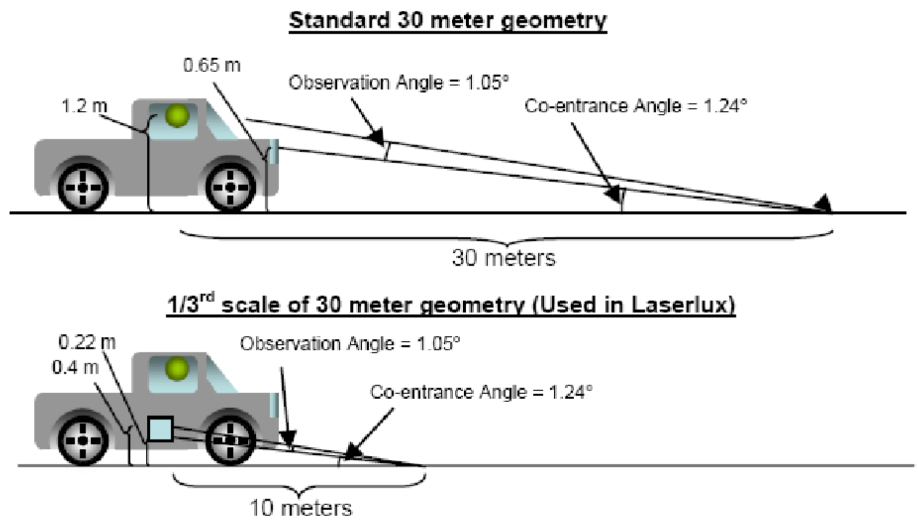

Figure 3. Standard 30 meter geometry described in ASTM 1710 – 11. The figure is taken from page 18 of *Serviceable Pavement Marking Retroreflectivity Levels: Technical Report.* (See page 8 of this report for full reference).

"Guide to Retroreflection Safety Principles and Retroreflective Measurements." Richard L. Austin, Robert J. Schultz, January 2009.
http://www.gamma-sci.com/wp-content/uploads/2012/06/Retroreflectivity-Guide-RoadVista.pdf

This paper details the science behind retroreflection. It describes the luminance, luminous intensity, glass beads in pavement markings, measurements of retroreflection in roadway markings and signs, and retroreflection measurement geometry.

"Minimum In-Service Retroreflectivity of Pavement Markings" Zwahlen H.T. and T. Schnell. *In Transportation Research Record 1715*, 2000.
http://dx.doi.org/10.3141/1715-09

Abstract: Minimum in-service retroreflectivity values for pavement markings are presented based on visibility computations performed with the CARVE (Computer-Aided Road-Marking Visibility Evaluator) computer model. CARVE accurately computes all geometric and photometric relationships for each headlamp separately; applies the human visual luminance contrast threshold database from Blackwell (Part III, 1946) adjusted by a field factor function that has been obtained from a number of pavement marking visibility field experiments; and provides retroreflectivity values for the pavement markings for any selected single-point geometry (e.g., ASTM 30-m geometry, observation angle = 1.05°, entrance angle = 88.7°). Based on the CARVE computation results, a set of in-service pavement marking retroreflectivity values are derived for fully marked, dark, straight, and dry roads using paint-and-beads pavement markings. The derived minimum retroreflectivity values for fully marked roads without raised pavement markers (RPMs) are highly speed dependent, because the computations are based on a constant minimum preview time of 3.65 s (3.0 s true preview and 0.65 s for eye-fixation duration). A separate set of minimum retroreflectivity values, based on a constant preview time of 2.0 s, is provided for fully marked roads with RPMs in good working order. It was found that the minimum retroreflectivity requirements for pavement markings could be substantially relaxed if RPMs (in good photometric working condition) were used. The proposed minimum retroreflectivity values are based on a 62-year-old driver (about the 85th percentile of the licensed driver population, about the 95th percentile of the nighttime driver population based on trip frequency data as a function of the time of day).

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