Traffic Sign Life Expectancy

Final Report
February 2021

Iowa LTAP
Local Technical Assistance Program

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

Traffic signs provide warning and guidance information to drivers 24 hours a day. These signs also represent a significant maintenance and replacement concern and cost for agencies with the advent of retroreflectivity requirements. In some cases, agencies choose to replace their signs in conjunction with the end of the manufacturer warranty period or other time intervals to ensure that signs maintain their retroreflectivity. However, this could result in signs being replaced while they still exceed their minimum retroreflectivity requirements with labor and material costs being incurred years before necessary.

The research team evaluated retroreflectivity data from in-service signs in Iowa to determine expected sign life values for agencies. The researchers acquired sign retroreflectivity data from two Iowa counties and one city for analysis. The team utilized 10,799 retroreflectivity data points across three different sheeting materials for a variety of sign types. The researchers used linear regression to evaluate the two components of greatest interest to the research: the age of a sign versus its respective retroreflectivity value.

The researchers developed 65 linear regression models to evaluate signs by sheeting type and Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) category (regulatory and warning), as well as sign orientation (north, south, east, and west).

The results of the analysis indicated that all sheeting materials, sign types, and sign directions were predicted to have lives of at least 10 years before falling below MUTCD minimums. Plots of sign retroreflectivity versus sign age indicated that many retroreflectivity readings still remained well above the MUTCD minimums at the predicted age where failure was expected. In general, the predicted lives for a material/sign type/direction combination were greater than five years longer than the manufacturer warranty periods. For conservative purposes, agencies could consider a sign to be approaching the MUTCD minimum retroreflectivity level at approximately five years past the manufacturer warranty based on the results of this research.

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TRAFFIC SIGN LIFE EXPECTANCY

Final Report
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EXECUTIVE SUMMARY

Traffic signs provide warning and guidance information to drivers 24 hours a day. These signs also represent a significant maintenance and replacement concern and cost for agencies, particularly at the local level.

Sign maintenance and replacement requirements have increased with the advent of retroreflectivity requirements. Agencies have a number of different approaches to select from for an assessment of or management method to maintain sign retroreflectivity, including approaches that rely on some aspects of the age of a sign to determine replacement.

While sign sheeting warranty information or other guidance from manufacturers provide recommended service life estimates, some signs may be replaced while still exceeding minimum retroreflectivity requirements. The result is that agencies may change out signs at a significant cost when the signs may still have years of service life remaining.

To address this issue, this project evaluated retroreflectivity data from in-service signs to determine expected sign life values for agencies to consider in managing their roadway signage.

A review of past research indicated that previous studies often focused on Type I and/or Type III sheeting materials and did not examine larger samples of other sheeting materials. The studies that were reviewed used linear regression to model the relationship between sign retroreflectivity and age. These models produced mixed results in sufficiently explaining the relationship between retroreflectivity and sign age, as demonstrated by generally low coefficient of determination (R^2) values. While some studies did indicate that failure rates for signs falling below the minimums were generally lower than 10 percent, only a few studies focused to any extent on the orientation of the sign and the role that may play in predicting the life of a sign by color and material.

The research team acquired sign retroreflectivity data from two counties and one city in Iowa for analysis in this project. Quality control checks and formatting were performed to facilitate data analysis, with the resulting data set containing 10,799 retroreflectivity data points across three different sheeting material types (Type I, Type III/IV, and Type IX) for a variety of sign types.

The researchers used linear regression to evaluate the two components of greatest interest: the age of a sign versus its respective retroreflectivity value. The researchers also evaluated the third component of interest, sign directionality, by considering sign direction data in individual groups. The use of linear regression allowed for a determination of the point (age) where the retroreflectivity of a sign would fall below the Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) minimum level.

The research team developed 65 linear regression models to evaluate signs by sheeting type and MUTCD category (regulatory and warning), as well as by sign orientation (north, south, east, and west).

The results of the analysis indicated that all sheeting materials, sign types, and sign directions were predicted to have lives of at least 10 years before falling below MUTCD minimums. Plots of sign retroreflectivity versus sign age indicated that many retroreflectivity readings still remained well above the MUTCD minimums at the predicted age where failure was expected. In general, the predicted lives for a material/sign type/direction combination were greater than five years longer than the manufacturer warranty periods for a respective sheeting material. For conservative purposes, agencies could consider a sign to be approaching the MUTCD minimum retroreflectivity level at approximately five years past the manufacturer warranty based on this research.

The key conclusion of the work is the observation that signs of all types and sheeting materials were expected to last more than 10 years before retroreflectivity falls at or below the MUTCD minimums. Suggested expected sign life values of 12 to 16 years are recommended for agency consideration. These suggested values are largely conservative, particularly when compared to the predicted age that a sign would fall below MUTCD minimums, which were generally well above 15 years of age.

In general, the results produced by the research were similar to those of past studies, including R^2 values and the general trends produced when plotting retroreflectivity data over time. Finally, while not conclusive from a statistical perspective, the results of the evaluations conducted in this research did not indicate that the retroreflectivity of south- and west-facing signs deteriorated at any greater rate than for signs facing other directions (i.e., north or east). This is true of both the estimated age trend lines as well as the general data plots of retroreflectivity values.

CHAPTER 1. INTRODUCTION

Traffic signs are a critical component in providing drivers with warning and guidance along roadways. They also represent a significant maintenance and replacement concern and cost for agencies, particularly at the local level. Maintenance and replacement requirements have increased following the Federal Highway Administration's (FHWA's) Manual on Uniform Traffic Control Devices (MUTCD) (2009) compliance date requirement of June 2014 for agencies to implement and use an assessment or management method for maintaining sign retroreflectivity.

The purpose of these assessment or management methods is to maintain minimum retroreflectivity standards for regulatory and warning signs. Retroreflectivity is the characteristic of sign sheeting material that reflects light off the sign back to its source (vehicle headlights).

Agencies have a number of different approaches to select from for an assessment or management method, including the management methods of Expected Sign Life and Blanket Replacement, both of which use the installation date of a sign in the field order to track its age. The age of the sign in the field is compared to an expected sign life value (the age a sign is expected to degrade below minimum retroreflectivity values), and once a sign has exceeded that age, the sign is replaced. Table 1 presents the MUTCD minimum retroreflectivity levels by sign color and sheeting type.

Table 1. MUTCD minimum retroreflectivity levels

Sign Color	Sheeting Type (ASTM D4956-04)				Additional Criteria
	Beaded Sheeting			Prismatic Sheeting	
	I	II	III	III, IV, VI, VII, VIII, IX, X	
White on Green	W*; G ≥ 7	W*; G ≥ 15	W*; G ≥ 25	W ≥ 250; G ≥ 25	Overhead
White on Green	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			[2]
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 75; O ≥ 75			[3]
White on Red	W ≥ 35; R ≥ 7				[4]
Black on White	W ≥ 50				–

[1] The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m^2 measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Bold Symbol Signs

- W1-1,2 – Turn and Curve
- W1-3,4 – Reverse Turn and Curve
- W1-5 – Winding Road
- W1-6,7 – Large Arrow
- W1-8 – Chevron
- W1-10 – Intersection in Curve
- W1-11 – Hairpin Curve
- W1-15 – 270 Degree Loop
- W2-1 – Cross Road
- W2-2,3 – Side Road
- W2-4,5 – T and Y Intersection
- W2-6 – Circular Intersection
- W2-7,8 – Double Side Roads
- W3-1 – Stop Ahead
- W3-2 – Yield Ahead
- W3-3 – Signal Ahead
- W4-1 – Merge
- W4-2 – Lane Ends
- W4-3 – Added Lane
- W4-5 – Entering Roadway Merge
- W4-6 – Entering Roadway Added Lane
- W6-1,2 – Divided Highway Begins and Ends
- W6-3 – Two-Way Traffic
- W10-1,2,3,4,11,12 – Grade Crossing Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3,4,16-22 – Large Animals
- W11-5 – Farm Equipment
- W11-6 – Snowmobile Crossing
- W11-7 – Equestrian Crossing
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow
- W16-5P,6P,7P – Pointing Arrow Plaques
- W20-7 – Flagger
- W21-1 – Worker

Fine Symbol Signs (symbol signs not listed as bold symbol signs)

Special Cases

- W3-1 – Stop Ahead: Red retroreflectivity ≥ 7
- W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35
- W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7
- W3-5 – Speed Reduction: White retroreflectivity ≥ 50
- For non-diamond shaped signs, such as W14-3 (No Passing Zone), W4-4P (Cross Traffic Does Not Stop), or W13-1P,2,3,6,7 (Speed Advisory Plaques), use the largest sign dimension to determine the proper minimum retroreflectivity level.

Source: FHWA 2009

As the MUTCD points out, the expected life of a particular sign is based on "…weathering deck results, measurements of field signs, sign sheeting warranties, or other criteria" (FHWA 2009).

Sign sheeting warranty information or other guidance from a manufacturer also provide a recommended life estimate. However, over time, observations of older signs have revealed retroreflectivity levels well above the minimums on signs that have been in service much longer than the manufacturer warranty period. The implications of this are clear: some signs may be replaced based on the recommended life value yet still exceed minimum retroreflectivity requirements. Consequently, agencies replace their signs at a significant cost based on a given time cycle when the signs may still have several more years of service life remaining.

At present, there is a basic understanding of the service life of signage in the field. Knowing how long a sign will maintain adequate retroreflectivity and remain in acceptable condition is essential in avoiding potentially unnecessary maintenance or replacement costs.

This project attempted to evaluate the retroreflectivity service life of in-service signage to determine expected sign life values. The information and analysis produced through this project should be of value to agencies in Iowa in understanding the service life of signs in the field and more effectively applying their selected assessment or management method of sign maintenance and replacement.

Project Goal and Objective

The goal of this project, as stated above, was to investigate and determine what the expected sign life values, based on retroreflectivity measurements for different categories/types of signage, are and how these compare to manufacturer warranty ages. As part of the work, past in-service sign retroreflectivity research is documented, local agency retroreflectivity data were collected, data analysis and comparisons were performed, and conclusions and recommendations were developed based on the analysis.

The primary objective of this report is to provide local agencies information in a format useful in understanding the expected life for their different signage in the field based on its characteristics (i.e., sheeting type, color, and directional orientation).

Research Approach

The approach taken to complete the project was as follows. The researchers performed a literature search and review of published research and resource documents, focusing on past studies that examined the deterioration rates of sign sheeting. These documents and their results are summarized in Chapter 2.

Concurrently with the literature review, the researchers identified local agencies in Iowa that had been using a retroreflectometer to measure and record sign retroreflectivity data as part of their assessment or management approach toward maintaining minimum retroreflectivity requirements. Those agencies were asked if they were willing to share their data for analysis as part of this research. The researchers acquired the data from the agencies that were willing to share their data in support of the subsequent analysis.

Next, the team performed data quality control activities to ensure that the data to be evaluated were formatted and complete. This was followed by determining the analysis approach to use to evaluate the retroreflectivity data, in part based on what similar efforts have been used, as well as on what was most appropriate for the data. With the data analysis approach established, the researchers performed data analysis to determine the expected service life for a particular sheeting material, sign color, sign orientation/direction, etc. and developed conclusions and recommendations based on those results.

The final task was to compile this final report to assist local agencies in understanding the expected service life of signs in the field and more effectively apply or modify their selected sign assessment or management method(s).

Report Content

This report document is organized as follows. Chapter 1 has provided an introduction to the project and the problem being addressed, as well as the objectives and research approach. Chapter 2 presents a literature review of past work related to the estimation of service life for sign sheeting. Chapter 3 discusses the efforts related to acquiring the retroreflectivity data, formatting and quality control activities, and data analysis and results. Finally, Chapter 4 provides conclusions and recommendations based on the findings of the work.

CHAPTER 2. LITERATURE REVIEW

State, county, and municipal jurisdictions own and manage thousands of signs. The regulatory, warning, and guidance information that these signs convey to drivers serves an important safety function, both during the day and at night. Sign retroreflectivity is a critical aspect in ensuring signs are visible to drivers at night, and, to this end, departments of transportation (DOTs) and local agencies expend significant labor and financial resources to ensure that regulatory and warning signs meet the minimum requirements as laid out in the Manual on Uniform Traffic Control Devices Section 2A.08 (FHWA 2009).

Sign retroreflectivity can have various impacts on transportation agencies. From a monetary standpoint, some agencies rely on using a manufacturer's estimated service life values or warranty periods to guide their sign management program and meet MUTCD retroreflectivity compliance. In using such an approach, signs are replaced in conjunction with the end of those timeframes, even if the retroreflectivity of the sign itself still exceeds the minimums specified in the MUTCD. The result is that new signs may be purchased and installed before replacement of the prior sign is necessary, with unnecessary material and labor costs being incurred.

Some agencies collect direct measurements of sign retroreflectivity values, and this activity also has a cost in terms of labor, particularly if all signs in a jurisdiction are measured on a shorter timeline (yearly, bi-yearly). Cost and time savings could be achieved if the duration between measurement intervals could be extended (and possibly supplemented by nighttime drive-by inspections), even if that extension is only one extra year.

To address these issues, several studies have evaluated sign retroreflectivity data collected from in-service signs to determine the expected sign lives for different colors and sheeting materials. This literature review summarizes that work as well as its results.

FHWA, 1991

In an early FHWA study, Black et al. (1991, 1992) looked at the deterioration of sign retroreflectivity using data from state agencies (Arizona, Idaho, Utah, and Vermont) as well as counties and cities in other states (California, Iowa, Kentucky, Louisiana, Michigan, Mississippi, New York, Oregon, Tennessee, Virginia, and Wisconsin,). A sample size of 5,722 red, yellow, green. and white Type I and Type III signs were evaluated. Linear regression models were developed that showed sign age was the dominant predictor of sign deterioration. The research found that retroreflectivity fell as sign age increased. The only inconsistency to this finding was that red Type III sheeting retroreflectivity increased as signs aged. This appeared to be the result of red ink being screened on to white sheeting, with that red color fading over time and exposing more of the white background color. Other factors, including precipitation, temperatures, and elevation only showed a small effect on the deterioration of sign colors and sheeting types.

Oregon, 2001

Kirk et al. (2001) examined the relationship between sign age and retroreflectivity for 137 red, yellow, white, and green signs of Type III sheeting in Oregon. Average sign retroreflectivity values were plotted against the installation year of the signs. Weak relationships between sign age and retroreflectivity were found by this approach, evidenced by low coefficient of determination (R^2) values from the plots. The researchers attributed this to insufficient time passing to provide a complete picture of sheeting performance, as well as the potential for the variability of sign retroreflectivity to increase over time. Evaluation of signs by orientation indicated that, while there was no strong trend, west-facing signs for white, yellow, and green colors had slightly lower retroreflectivity compared to signs facing in other directions.

Louisiana, 2002

Wolshon et al. (2002) evaluated the performance and deterioration characteristics of different sheeting materials to develop models to predict future sign performance in Louisiana. Retroreflectivity measurements were collected from 237 white, green, and yellow signs of Type I and Type III sheeting. Linear regression models were developed whose parameters included sign age, distance from edge of the pavement, and orientation. Only sign age was found to be positively correlated to sign deterioration, but the other factors were retained because their effect was not shown to be nonexistent. The models developed for Type I deterioration showed consistent deterioration rates over time and performed satisfactorily before and slightly after the end of the warranty period. For Type III sheeting, yellow signs were found to deteriorate fastest, while white and green signs produced flat trend lines and better performance.

Indiana, 2002

Bischoff and Bullock (2002) developed linear regression models for sign retroreflectivity versus age for 1,341 red, white, and yellow signs in Indiana. The work focused on Type III sign sheeting, with retroreflectivity data from signs that were up to 10 years old at the time. The models that were developed showed varying correlations between sign age and retroreflectivity. White signs produced an essentially flat line, indicating little downward trend in retroreflectivity with age. Yellow signs showed a downward trend with age, although this was not as steep as the downward trend for red signs. The performance of red signs was attributed to the nature of the color/sheeting itself being more susceptible to the effects of weathering (i.e., fading). The researchers also found there was an increase in retroreflectivity variability for south-facing signs, as one would expect.

North Carolina, 2006

Rasdorf et al. (2006) examined data from 1,057 white, yellow, red, and green signs on Type I and Type III sheeting in North Carolina. The researchers used linear, logarithmic, polynomial, power, and exponential regression to establish a fit for Type I red signs. Different deterioration trends were found using these models, although 40 percent of red signs fell below FHWA minimum values for Type I sheeting. Following this, the same five model types were employed for models of the other seven color and sheeting type combinations. Based on the model results, it was found that no model types produced curves that fit for Type I and Type III white signs. Type I yellow and red and Type III red signs fit linear, polynomial, and exponential curves. Type III yellow and green signs fit polynomial curves, while Type I green signs fit linear and polynomial curves.

North Carolina, 2009

Immaneni et al. (2009) collected retroreflectivity readings from 1,057 in-service signs in North Carolina to develop different regression models (linear, polynomial, and exponential) for estimation of sign deterioration rates. The North Carolina data were analyzed in conjunction with data from previous US studies (national data and data from the Indiana, Louisiana, and Oregon studies summarized above) to identify the best deterioration rate estimates. Models were developed for white, yellow, red, and green signs using Type I and Type III sheeting. Based on the results using the models, the best-fit models for different colors of signs and materials were of linear form, with the exception of Type III yellow signs, where a polynomial form was the best fit for the data. Aside from the determination of the best model forms for different sign types, the researchers concluded that further work was needed to develop models that incorporate multiple years of data rather than retroreflectivity readings that represent a snapshot in time.

Texas, 2011

Ré et al. (2011) presented the results of analysis of in-service sign retroreflectivity and deterioration rates in Texas. The work evaluated data from 859 Type III signs from seven regions in the state. Linear regression models were developed to predict service lives for red, white, and yellow signs in the different regions, with the results indicating predicted service lives of 44 years for red signs, 35 years for white signs, and 26 years for yellow signs. However, the researchers noted that these results gave a broad perspective of sign conditions but did not provide an exact value of definitive service life periods (Ré et al. 2011).

Vermont, 2009

Kipp and Fitch (2009) conducted research on in-service sign retroreflectivity to generate recommendations for cost effective replacement to meet MUTCD requirements. The researchers evaluated measurements from 398 white, yellow, red, and green Type III and 220 yellow and fluorescent yellow-green Type IX signs. Non-linear regression models were developed for each of the sheeting material types and sign colors. Results for Type III signs estimated service lives of 74.04, 25.4, 15.1, and 74.04 years for white, yellow, red, and green colors, respectively. For type IX signs, they had estimated service lives of 74.0 and 77.7 years for yellow and fluorescent yellow-green colors, respectively. Based on these results, a blanket replacement of signs on a 15-year cycle was supported.

Pennsylvania, 2012

Clevenger et al. (2012) collected and analyzed sign retroreflectivity data from a subset of DOT-owned signs along roadways throughout Pennsylvania. A total of 1,000 yellow, white, red, and green Type III signs were evaluated using linear regression. Most of the signs in the data set were between 13 and 15 years old. Out of these, only 2.8 percent of the 1,000 signs in the data set failed to meet minimum retroreflectivity requirements. Those that did fail to meet minimums were an average of 14.1 years old. Based on this relatively low number of failures at that age, it was concluded that a life of 15 years was reasonable before considering replacement. Using a standard normal distribution analysis, it was also determined that there was a high probability that signs of all colors between the ages of 16 and 18 years would also exceed minimum retroreflectivity levels.

Wyoming, 2014

Pike and Carlson (2014) evaluated sheeting service life for signs in Wyoming. The researchers measured the retroreflectivity of 525 in-service signs throughout the state and used that data to determine the expected service lives of the sign sheeting materials. The majority of the signs evaluated used Type III or Type IV sheeting materials. Linear regression was used to evaluate the relationship between retroreflectivity and sign age for the different sheeting types and colors. The researchers noted that not enough additional data were available to support a statistical analysis of the impacts of elevation, cardinal sign direction, or the sign legend material (film versus ink). The researchers found that the white, yellow, green, and red Type III sheeting had been in service 13 to 14 years and had no clear end of service life based on the regression analysis of retroreflectivity measurements (Pike and Carlson 2014). Type IV sheeting had a range of expected service lives depending on the color of the material and the directional orientation of the sign. White material was estimated to have a service life range of 17 to 143 years, yellow material of 15 to 226 years, green material of 19 years to no clear end of service, and red material of 21 years to no clear end of service (Pike and Carlson 2014). Based on the findings of the research, it was concluded that the sheeting materials evaluated would not need to be replaced any sooner than a 15-year cycle and that reasons other than retroreflectivity (i.e., vandalism) might be the determinant for replacing a sign sooner than that timeframe.

Minnesota, 2014

Preston et al. (2014) analyzed retroreflectivity data from 340 in-service signs from eight local agencies throughout Minnesota. An outdoor test deck of signs was also established to obtain retroreflectivity data during the course of the research. The intent of the work was to provide data about sign life based on color and retroreflectivity degradation over time (Preston et al. 2014). Linear regression models were developed for the different sheeting types (Type I, IV, IX, and XI) and sign colors (red, white, yellow, and green). These models, with the exception of a few instances, produced low R^2 values, and a number of the models produced trend lines with positive slopes. Results of the analysis indicated that sign life exceeded manufacturer's warranties, with the results inferring an estimate for an expected sign life of 12 to 20 years for beaded sheeting and 15 to 30 years for prismatic sheeting (Preston et al. 2014). However, the researchers concluded there was not sufficient retroreflectivity data available to definitely establish sign life with a high degree of statistical reliability (Preston et al. 2014).

Additional Research of Interest

Evans et al. (2012) conducted an analysis of traffic sign performance for the Utah Department of Transportation (UDOT) as part of the establishment of a maintenance plan to meet MUTCD retroreflectivity requirements. Sign retroreflectivity measurements were directly collected from 1,433 signs throughout the state. This information was then used to determine the overall compliance with minimum retroreflectivity requirements for signs throughout Utah. Results indicated that 91 percent of the signs measured were in compliance with minimum retroreflectivity levels. When Type I signs were removed from the sample, retroreflectivity compliance rose to 97 percent. Signs with Type I sheeting have lower levels of reflectance and shorter service lives, and agencies generally do not use this sheeting material as a result. These results provided UDOT with a verification that its sign inventory had a high rate of retroreflectivity compliance.

The results covered by Boggs et al. (2013) further analyzed Utah sign data by examining the causes of sign damage and failure. The causes of damage and failure are of interest because, in some instances, these can lead to a reduction or loss of retroreflectivity. The work found that average annual precipitation, elevation, seasonal temperature changes, and exposure (sign orientation) all were contributing factors to sign damage. Examining precipitation data for each sign location, it was found that damage was three times as likely when rainfall exceeded 16 inches per year (Boggs et al. 2013). Elevation was also found to play a role in sign damage. With increased elevation came increases in precipitation (i.e., snowfall) and the associated damage that came from debris strikes during plowing operations (Boggs et al. 2013). Evaluation of seasonal temperature data found that sign locations that had lower seasonal temperature change swings (less than 50+ degrees Fahrenheit) experienced a lower rate of sign damage. Examination of wind gust speeds found a counterintuitive damage trend, with locations experiencing wind gusts of 20 miles per hour or greater exhibiting a decreased rate of sign damage (Boggs et al. 2013). Back bracing was used on signs in these locations, which accounted for the lack of damage.

Brimley and Carlson (2013) summarized the current state of research and identified research needs related to the long-term deterioration of signs. The authors summarized the results of several past studies that had used linear regression to develop prediction models to estimate the years to failure for different sheeting materials and sign colors. Of particular interest to this project was the summary of limitations in past research. Past studies had tried to identify a relationship between sign orientation and deterioration, but none found evidence that orientation had a significant impact on deterioration (Brimley and Carlson 2013). Additionally, no past studies had accounted for the initial retroreflectivity of a sign (i.e., the baseline measurement that the sign began with). The most noteworthy conclusion drawn from past work, however, was that prior studies relied on one-time measurements of retroreflectivity as opposed to multiple readings over time (Brimley and Carlson 2013). The use of multiple readings over time would, in theory, provide a more accurate estimation of remaining sign life.

Summary

Based on the research reviewed and summarized in this chapter, the researchers were able to draw several conclusions as follows.

Until more recently, many studies did not examine larger samples of Type III or other sheeting materials. Past studies have consisted of a mix of cleaned and uncleaned signs, but natural field conditions (i.e., without clean signs) should give a better representation of signs that drivers see at night. Similarly, unless the data were collected as part of a dedicated effort, it is difficult to control the measurement practices (i.e., cleaning or not cleaning before measurement) of different, geographically dispersed agencies. In such cases (and in this research as well), researchers need to work with the data that are available.

Another drawback of prior studies, as mentioned, is that they relied on one-time measurements of sign retroreflectivity. In other words, the potential deterioration of an individual sign over time was not incorporated into the data sets and trend lines that were developed. That said, most studies that reported such information indicated that failure rates for signs falling below the minimums were generally lower than 10 percent. Only a few studies focused to any extent on the directional orientation of the sign and the role it may play in predicting the life of a sign by color and material. It stands to reason that south- and west-facing signs may show faster deterioration rates due to increased sun exposure, but the results from past studies on this potential impact were not necessarily conclusive.

The studies summarized and the models developed have not been able to sufficiently explain the relationship between retroreflectivity and sign age, as evidenced by lower R^2 values. Extrapolating a trend line that intersects the MUTCD minimum value for a specific color is not predictive of the true service life of a sign, as regression analysis generally cannot predict beyond the observed values. However, with a sample of retroreflectivity readings that extends over a long enough timeframe, such data could provide a better idea and trend line plot of where the intersection of retroreflectivity readings and minimum values lie. Of course, supplemental factors that cannot be directly measured and incorporated, which might include weathering, vandalism, etc., can contribute to these inconclusive findings.

One notable finding from past research is the potential for red Type III signs to increase in retroreflectivity over time. While this is not a surprising phenomenon given how the sign is manufactured (red color applied over a white material base), it is a finding that aligns with prior experience when directly measuring faded Stop signs. This underscores the need for not only direct measurement (if that approach is employed in managing retroreflectivity), but also visual inspections and the application of common sense in determining when a sign should be replaced.

In light of these findings from past literature, the current work offers an opportunity to explore new and expanded avenues. These include an additional sheeting type aside from Type I and Type III, larger sample sizes for most sheeting types, initial retroreflectivity measurements at installation (i.e., for new signs), and a breakdown of performance by sign orientation.

CHAPTER 3. DATA COLLECTION, ANALYSIS, AND RESULTS

The intent of this research was to evaluate the performance of in-service signs at the local agency level to determine expected sign life values. Through relationships with local agency staff, it was known that some Iowa counties and cities collected direct measurements of sign retroreflectivity and maintained these measurements in databases. The availability of these data provided the opportunity to evaluate the long-term performance of signs for different materials and colors across the state to better establish when retroreflectivity levels fell below established MUTCD minimum thresholds. This chapter discusses the efforts related to acquiring the retroreflectivity data, formatting and quality control activities, and, finally, the data analysis and results.

Data Acquisition

The researchers reached out to local agencies to determine those that had and/or were currently collecting sign retroreflectivity measurements. Contact was made with agencies that collected retroreflectivity data to see if they were willing to share that data for use in this research. Based on inquiries, data were provided by five Iowa local agencies: Carroll County, Clinton County, Montgomery County, the City of Ames, and the City of Waukee.

The data sets provided by these agencies contained varying data in different formats, and so the initial activity undertaken was to determine whether the most critical items in support of the analysis were present. These items included a unique identifier for each sign (i.e., a sign ID), its directional orientation, the MUTCD sign designation (e.g., R1-1), the sign legend (e.g., Stop), the sign installation date, the retroreflectivity measurement date(s), the background (and legend, if applicable), retroreflectivity measurements (0.2° observation angle), and sheeting material. The data sets from Clinton County and the City of Waukee did not have sign installation dates listed and were not included in the subsequent analysis. The other three agencies provided a prospective 23,418 individual sign data points for the analysis, prior to formatting, quality control, and data cleanup activities.

Data Formatting and Quality Control

While more than 23,000 sign readings were collectively available, not all of these data points were ultimately included in the analysis for various reasons. For example, each data set had records for many signs that been retired prior to having any retroreflectivity readings taken. While these signs were counted in the total number of data points stated above, in fact, they did not represent a retroreflectivity data point. Similarly, in some cases barricades at the end of roadways had retroreflectivity measurements recorded, but these are not traditional signs and not included in the evaluation as a result. A limited number of fluorescent yellow-green signs were present in the data from each agency, and these were also not considered when building the sign retroreflectivity database to support the analysis.

Aside from the cases where sign records did not have retroreflectivity readings recorded, additional cleanup and quality control measures resulted in the removal of other data points that did have retroreflectivity readings available. Procedures used in cleanup and quality control efforts included the following:

- Removal of retired signs (as noted above).
- Removal of signs without retroreflectivity data recorded (as noted above).
- Removal of signs with 0.2° readings that were unrealistic, regardless of the sheeting material. For example, 0.2° exceeding 1,000 or values of zero.
- Removal of signs that had retroreflectivity data recorded but for which an installation date was not available. This resulted in the removal of the Clinton County and City of Waukee data sets from the analysis.
- Removal of signs that had retroreflectivity data recorded but no measurement date provided.
- Removal of signs with retroreflectivity readings below MUTCD minimums that also had an age of zero. These would represent new signs that did not meet retroreflectivity minimums, which is unrealistic.
- Signs with measurement dates occurring before installation dates were assumed to be errors where the two dates had been reversed, and these were swapped with one another accordingly.
- Signs that only had one retroreflectivity measurement, but that consisted of two colors (i.e., red and white Stop signs) were retained for the analysis, as the individual color measured and recorded still would add to the collected measurement sample for evaluation purposes.

Consequently, with these quality control and cleanup measures, 10,799 retroreflectivity data points were available for the analysis. The breakdown of the data set by material and sign type is presented in Table 2.

Table 2. Summary of data set by sheeting type and sign type

	Sign Type/Color(s)			
Sheeting Material	**Regulatory (White and Red)**	**Regulatory (Black and White)**	**Warning (Black and Yellow)**	**Guide (White and Green)**
Engineering Grade (Type I)	69	275	992*	N/A
High Intentisty Prismatic (Type III/IV)	805	86	7,936	143
Diamond Grade (Type IX)	458	N/A	35	N/A
Total	**1,332**	**361**	**8,963**	**143**

* The MUTCD states that this material shall not be used for this type of signing

Note that the analysis itself does not take into account whether certain color combination ratios exceeded the MUTCD's minimum ratio. Specifically, the ratio of white to red retroreflectivity must be 3:1 or greater. In the context of this research, that would include Stop and Yield signs. Calculations using the legend and background readings found that 20 of 69 Engineering Grade, 90 of 805 High Intensity, and 432 of 458 Diamond Grade signs exceeded this ratio.

However, these figures are misleading given the data set from Montgomery County included only background color readings. As a result, the number of signs classified as meeting the MUTCD minimum ratio appears to be lower due to the absence of legend readings. This is evidenced by the trend presented by Diamond Grade signs, where Carroll County was the only agency using such signage, and the number of signs exceeding this ratio was nearly all. A breakdown of the individual signs from each agency is presented in Table 3.

Table 3. Summary of signs by agency

		Sign Type/Color(s)			
Sheeting Material	**Agency**	**Regulatory (White and Red)**	**Regulatory (Black and White)**	**Warning (Black and Yellow)**	**Guide (White and Green)**
Engineering Grade (Type I)	Ames	-	-	-	-
	Carroll Co.	23	139	461*	-
	Montgomery Co.	46	136	531*	-
High Intentisty Prismatic (Type III/IV)	Ames	49	40	277	131
	Carroll Co.	50	14	3,682	12
	Montgomery Co.	706	32	3,977	-
Diamond Grade (Type IX)	Ames	-	-	-	-
	Carroll Co.	458	-	35	-
	Montgomery Co.	-	-	-	-

* The MUTCD states that this material shall not be used for this type of signing

The newest retroreflectivity data in the data set were from 2017, while the oldest data were from 2008. Most of the retroreflectivity readings in the collective data set were from after 2011, which makes sense in light of the MUTCD retroreflectivity requirements that came about when the MUTCD was updated and released in 2009. In terms of the age of signs, the range was from zero (or new) to 20 years.

Before moving on to the discussion of the data analysis approach and results, a few caveats related to the sign data should be discussed. While it is assumed that the data provided by the agencies that remained in the data set following quality control and cleanup was of good quality, some anomalies and potential errors may have still been present. For example, instances of multiple retroreflectivity measurements at the same sign over time were observed across sheeting types and colors. In some cases, this may have been the result of bleed through, where the underlying material is white and was overlaid with a different color (most typically red). This phenomenon of high retroreflectivity for a faded sign has been observed by the researchers in the case of Stop signs in the past. These instances of rising retroreflectivity were retained in the data set, as it is impossible to exclude such signs from consideration without making a firsthand observation to determine whether they were in fact faded and in need of replacement (given a pink Stop sign is not a Stop sign in a color sense) or still in acceptable condition.

In speaking with agencies, the retroreflectometers used in data collection were maintained in a calibrated state, including manufacturer checks when needed. Therefore, it was assumed that the retroreflectometers used in the data collection by each agency were providing accurate readings. However, this may or may not be the case, and an uncalibrated retroreflectometer would collect erroneous data that could impact the results of this research.

Similarly, agencies attempted to clean their signs prior to collecting retroreflectivity readings, and it is assumed that this indeed took place uniformly. In reality, it is impossible to confirm whether all signs that were measured were cleaned (and, if so, adequately) prior to the collection of readings. The collection of data from a dirty sign could impact the readings collected and the results of the analysis.

Finally, as the sign totals indicate, there are instances where only one agency used a specific type of sheeting material for a particular sign. It is assumed that the reported sheeting material type for each individual sign recorded in each agency's database are accurate. In reality, it is possible that a sign may have been reported as using one type of sheeting material in some cases but was in fact made of another material type. For example, a sign may have originally been installed in 1990 using Engineering Grade sheeting and recorded in a database accordingly, but has since been replaced in later years using High Intensity sheeting. While the sign replacement event itself was recorded, the change in sheeting material may not have been recorded in the database. There is no specific evidence of this occurring in the data set compiled for and used in this research, but the possibility that it occurred, albeit to a limited extent, does exist.

Data Analysis Approach

For multi-color signs, such as Stop signs, the retroreflectivity of both the background and legend were evaluated. While it is possible for potential measurement error with legend text (background and legend retroreflectivity being measured together because of smaller/narrow text), it was decided that the sign life information generated through an analysis of legend retroreflectivity would still be beneficial and add to the knowledge base.

The data analysis approach selected for this work was that most frequently used by past research: linear regression. Linear regression models were selected for the analysis as it allowed for an evaluation of the two components of greatest interest to the research, the age of a sign versus its respective retroreflectivity value. While the changes to sign retroreflectivity do not necessarily follow a linear process, the deterioration of a sign does point to a specific period in time when the retroreflectivity of a sign will generally fall below a certain threshold, or minimum.

Different factors contribute to the aging of a sign and, hence, its retroreflectivity, including weathering, solar radiation levels, localized shading, etc.; however, these different factors are not recorded in agency sign inventory databases. Indeed, only one additional factor that contributes to sign aging was uniformly recorded in agency data sets: sign orientation. This factor was incorporated into the analysis when data points for sign types and sheeting materials were evaluated for each respective sign orientation direction. In the absence of additional factors that could be considered as part of a different approach (such as multiple regression), linear regression was the analysis approach employed.

Linear regression uses a sample of observations on pairs of values (in this work sign age and retroreflectivity) to make inferences on the parameters that describe the model. The common form of linear regression is $y = \beta_0 + \beta_1 x + \varepsilon$, where β_0 is the slope intercept, , β_1 is the slope of the regression line (i.e., the change in y corresponding to the change in x), and ε is the error term. In the context of this work, y is the MUTCD minimum retroreflectivity level, while x is the point on the slope (i.e., number of years of sign age) that the trend line crosses that particular y value. The result of the linear regression in this research is an estimate of the point where the retroreflectivity versus age trend line crosses the MUTCD minimum threshold for that particular sheeting material and color.

To check the measure of fit between the data and the model, R^2 values are calculated. R^2, or the coefficient of determination, is a measure of the relative strength of the corresponding regression that represents the proportion of variance for the dependent variable explained by the independent variable in the model. An R^2 of zero indicates there is no correlation between the variance in the dependent variable being explained by the independent variable. Conversely, an R^2 of 1.0 indicates complete correlation between the variance of the independent variable and the dependent variable.

Past modeling efforts did not generally produce high R^2 values, but they did provide a general trend line based on the data that could be used to guide in understanding the point where sign life may cross the MUTCD minimum retroreflectivity level for a particular material and color. The extrapolation of a trend line to intersect the MUTCD minimum value for a specific color is done here for reference purposes, as this approach is not predictive of the true service life of a sign. This is because regression analysis generally cannot predict beyond the observed values.

In most of the instances evaluated here, retroreflectivity data from signs up to 20 years of age were available. In some of these cases, the estimated trend line crossed the MUTCD minimum within the available data range. This was not true of all evaluations though. Still, with a sample of retroreflectivity readings that extends over a long enough timeframe, the trend lines and data plots provide a better idea of where the intersection of retroreflectivity readings and minimum values lie, as well as the general performance trends as a material ages.

The warranty period for sheeting materials can vary—from no warranty for Type I Engineering Grade (but a life expectancy of 5 to 7 years), to 10 years for Type III/IV High Intensity Prismatic, and 12 years for Type IX Diamond Grade. These values provided a lower boundary for the range of prospective sign lives and to compare to the estimates generated by regression. It is also reasonable to conclude through a review of the sign data provided for this research that, for the most part, agencies replaced signage prior to 20 years of age, which provided an upper boundary for a sign life range. In short, when conducting a linear regression using the available data, even models with low R^2 values that produce a trend line within these boundaries could still provide a reasonable indication of the expected life of a sign for agencies to consider for a particular combination of sheeting material and color.

To complete the linear regression analysis, sign retroreflectivity (y axis) was plotted against sign age (x axis) for each sign on graphs in Excel. Signs were examined by sheeting type and MUTCD category (regulatory and warning) collectively, as well as broken out by sign orientation (north, south, east, and west). Trend lines for the regression equation were added to each plot that was developed, and the regression equations for each of these lines were also provided by the software to assist in estimating the point at which the expected sign life fell below MUTCD minimums. As part of this process, R^2 values were also produced to provide an indication of how well the respective model fit the respective data being examined.

The following sections present the results of the various plots and models that were developed. The results are presented by sheeting type, with regulatory, warning, and guide signs presented separately. The results further examine sheeting and sign type by sign orientation to determine whether signs that are exposed to more harsh conditions, i.e., south-facing signs with higher sun exposure, age at a faster rate than others.

Type I Sheeting Analysis and Results

Type I sheeting, frequently referred to as Engineering Grade sheeting, is a material where glass beads have been applied to sheeting without a discernable pattern (as opposed to a diamond or prism shape). As indicated in Table 2, warning signs were the predominant use for this sheeting material, with only a limited number of Stop signs using it. However, other regulatory signs (i.e., weight limits) also used Engineering Grade sheeting. No agencies that provided data for the research used this sheeting material for guide signs, which conforms to the MUTCD requirement that this material shall not be used for green and white color combinations.

Type I Regulatory White and Red Signs

White legend and red background signs include Stop signs and Yield signs. In this sheeting type, only Stop signs were present in the data set. A total of 20 legend measurements and 69 background measurements were available for analysis. This was the result of the Montgomery County data set only containing background retroreflectivity measurements. The years in service of the signs ranged from zero (or new) to 15 years. Given that Stop signs have both a legend and background color whose retroreflectivity can be measured, two sets of data were plotted. Figure 1 presents the results of the plot of retroreflectivity versus age data for the white legend text.

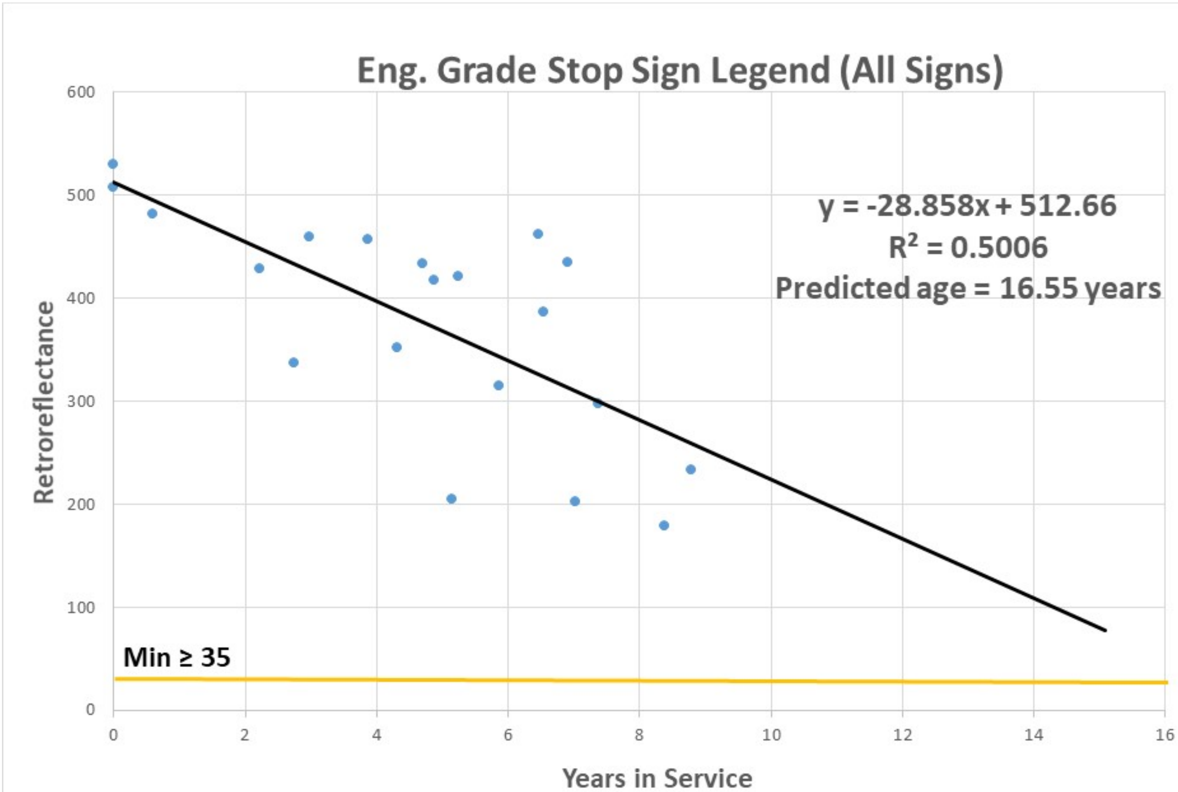


Figure 1. Engineering Grade legend: all Stop signs

This is followed by Figure 2, which presents the plot of retroreflectivity versus age for the red background.

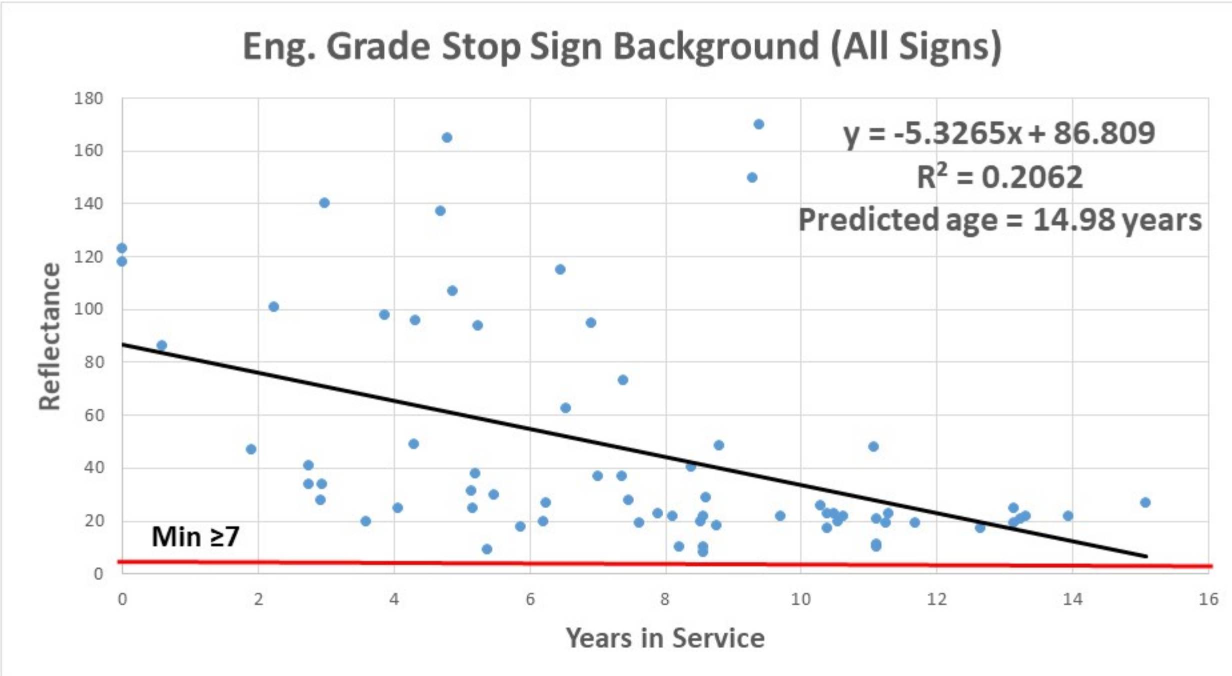


Figure 2. Engineering Grade background: all Stop signs

Both plots have the MUTCD minimum retroreflectivity value superimposed on the graph for reference. Note that the MUTCD also requires a retroreflectivity ratio of greater than or equal to 3 to 1 (white to red) for this color combination. This ratio was not taken into account in the process of modeling, as the data from Montgomery County only included background retroreflectivity measurements.

As the results of Figure 1 indicate, the expected sign life based on white background retroreflectivity is 16+ years based on the calculated trend line. The R^2 value of 0.50 indicates that approximately half of the variance in sign age is explained by the retroreflectivity measurements. These results are for all Engineering Grade white legends for Stop signs, and additional evaluations based on sign orientation are presented below. Still, the results from the analysis of all signs, and particularly the scatter plot of retroreflectivity measurements, point toward this type of material providing satisfactory service through at least 10 years of sign life.

Figure 2 provides the results of the analysis of the regression performed on a sample of 69 sign background retroreflectivity measurements. As the results indicate, the expected sign life for Engineering Grade background material was 14.98 years (or essentially 15 years). The R^2 value of 0.20, while relatively low, indicates that at least some of the predicted sign life is based on the retroreflectivity data.

Once again, the overall scatter plot of the retroreflectivity readings illustrates that all measurements were above the MUTCD minimum of 7 cd/lux/m^2, which anecdotally points to the material providing adequate service in most cases up to that predicted 15-year life. Still, as mentioned previously, it is possible for particular color signs, and specifically red signs, to increase in retroreflectivity as they age, on account of having a white base color. Therefore, it is critical for agencies to monitor not only the retroreflectivity of such signs but also their overall appearance to ensure that they retain their overall representative color.

Figure 3 presents the results of white legend retroreflectivity measurements for Type I signs evaluated by the directional orientation of the sign.

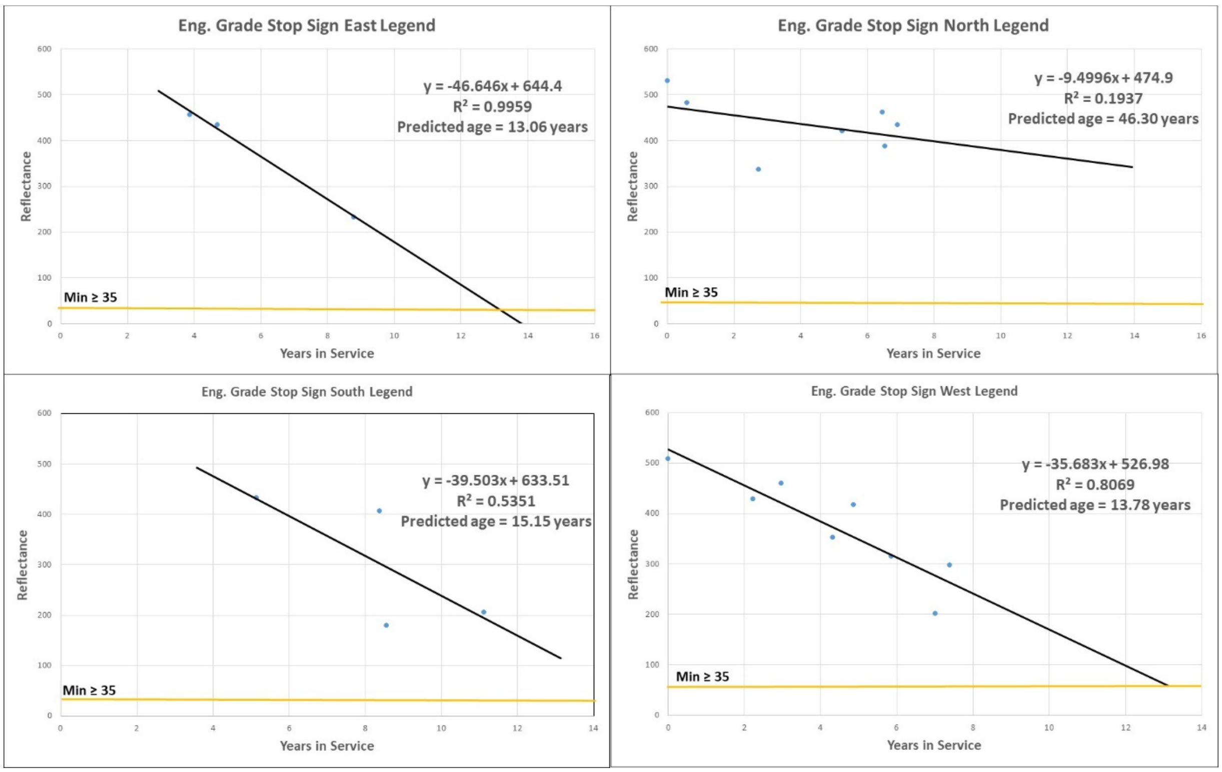


Figure 3. Engineering Grade legend: east, north, south, and west orientation Stop signs

As the graphs in the figure indicate, the predicted sign lives ranges from 13.06 years to 46.30 years. Obviously, the small sample of north-facing signs contributed to the 46+ year sign life prediction, but it also points toward that portion of sites slightly increasing the overall legend sign life estimate for all signs combined.

Of greater interest is that signs that would be expected to age more quickly due to higher sun exposure, and specifically south- and west-facing signs, showed only a marginal lifespan difference from that of east-facing signs. High R^2 values were produced for the east- and west-facing analyses, and, while the number of retroreflectivity readings plotted for each respective sign orientation is low, the similarity of these results pointing toward a predicted life of 13+ years provides a reasonable indication for agencies of the timeframe that they can expect a sign to fall below MUTCD minimums.

Figure 4 presents the results of red background retroreflectivity measurements for Type I signs evaluated by the directional orientation of the sign.

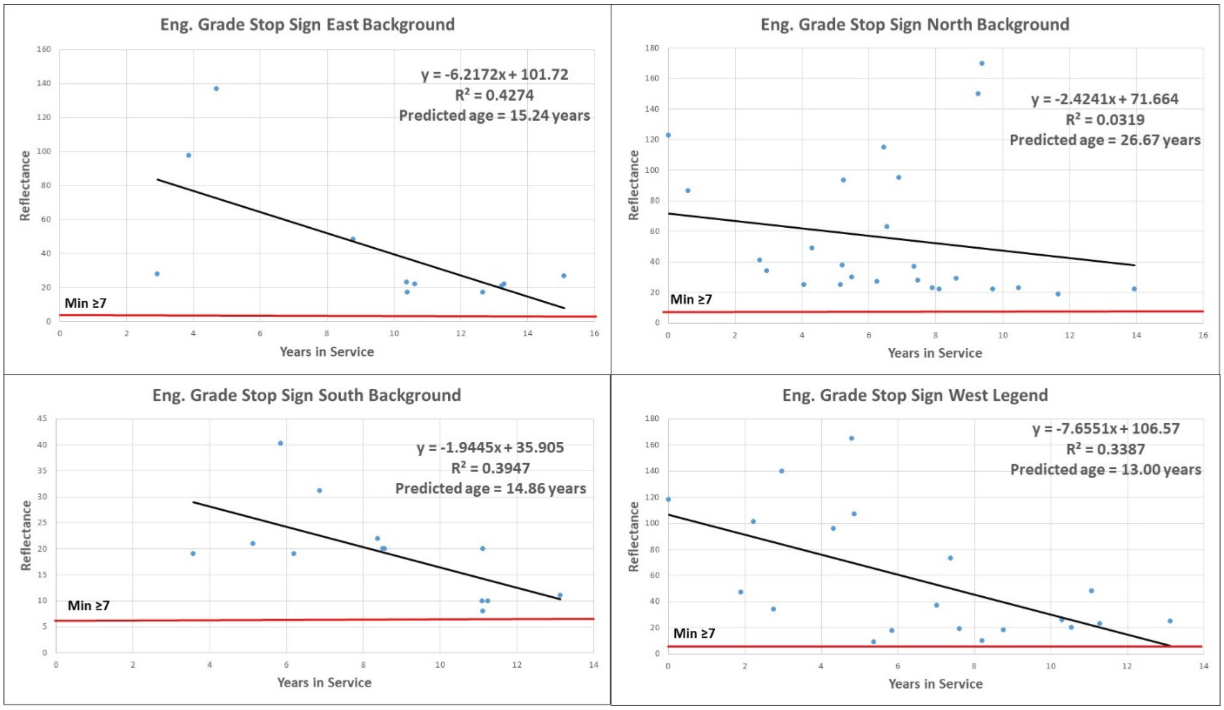


Figure 4. Engineering Grade background: east, north, south, and west orientation Stop signs

The increased sample size of background measurements allowed for more points to be plotted for each of the respective sign directions. Interestingly, despite the additional data points, the R^2 values were lower than those for legends. The predicted sign lives range from 13.00 to 26.67 years. Once again, it can be observed that south- and west-facing signs do not show much of a difference in predicted age compared to east-facing signs. North-facing signs had an estimated 10 years longer life, which may be the result of some higher measurements taken after approximately nine years of service life. Collectively, the results of Figure 4 point toward a predicted life for Type I red backgrounds of 13+ years before falling below MUTCD minimums, similar to white legends.

Type I Regulatory White and Black Signs

Type I regulatory signs, such as Speed Limit signs, only have a white background color that is monitored for meeting MUTCD minimums (as black legend text is not retroreflective). Figure 5 provides the results of the analysis of the regression performed on a sample of 275 sign background retroreflectivity measurements.

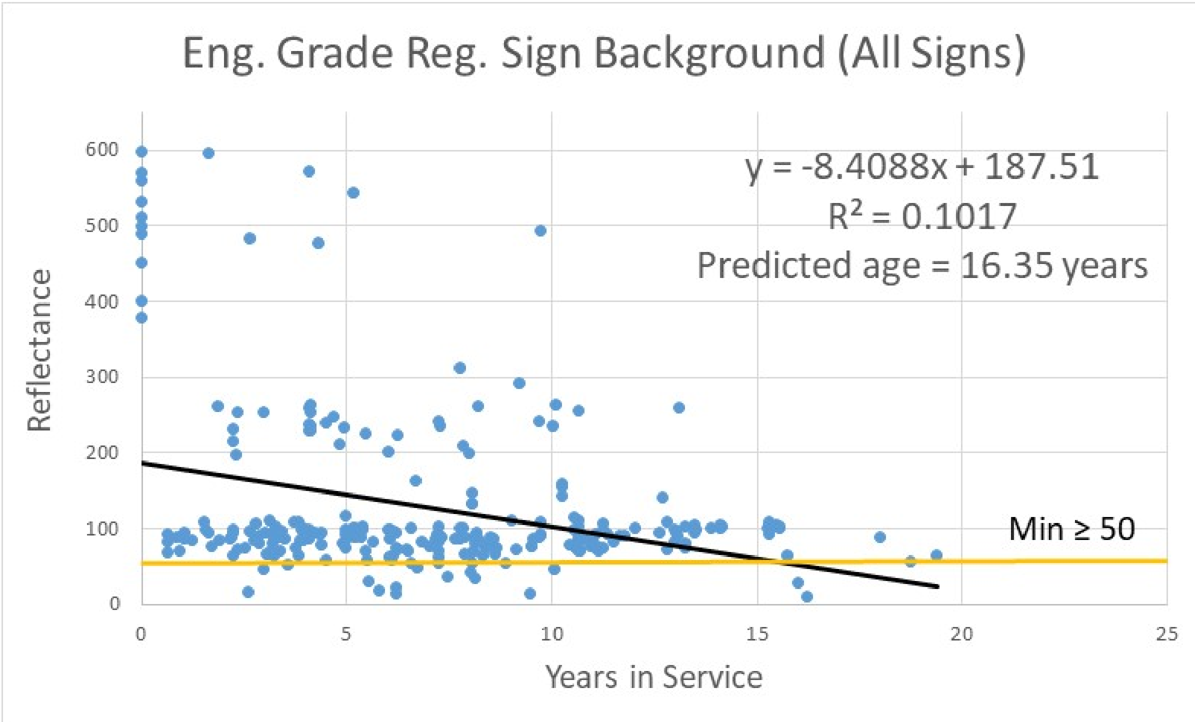


Figure 5. Engineering Grade background: all regulatory signs

The years in service of the signs ranged from zero (or new) to 19 years. As the results indicate, the predicted sign life for the white background color of these signs is 16.35 years. However, this regression produced a low R^2 value, which indicates that little of the predicted sign life could be explained by the retroreflectivity measurements. This particular sheeting did provide several in-service measurements that fell below the MUTCD minimum of 50 cd/lux/m^2, although, as the graph illustrates, most readings fell above this threshold. This overall result points toward a predicted life for Type I white backgrounds of 15+ years before falling below MUTCD minimums.

Figure 6 presents the results of white background retroreflectivity measurements for Type I signs evaluated by the directional orientation of the sign.

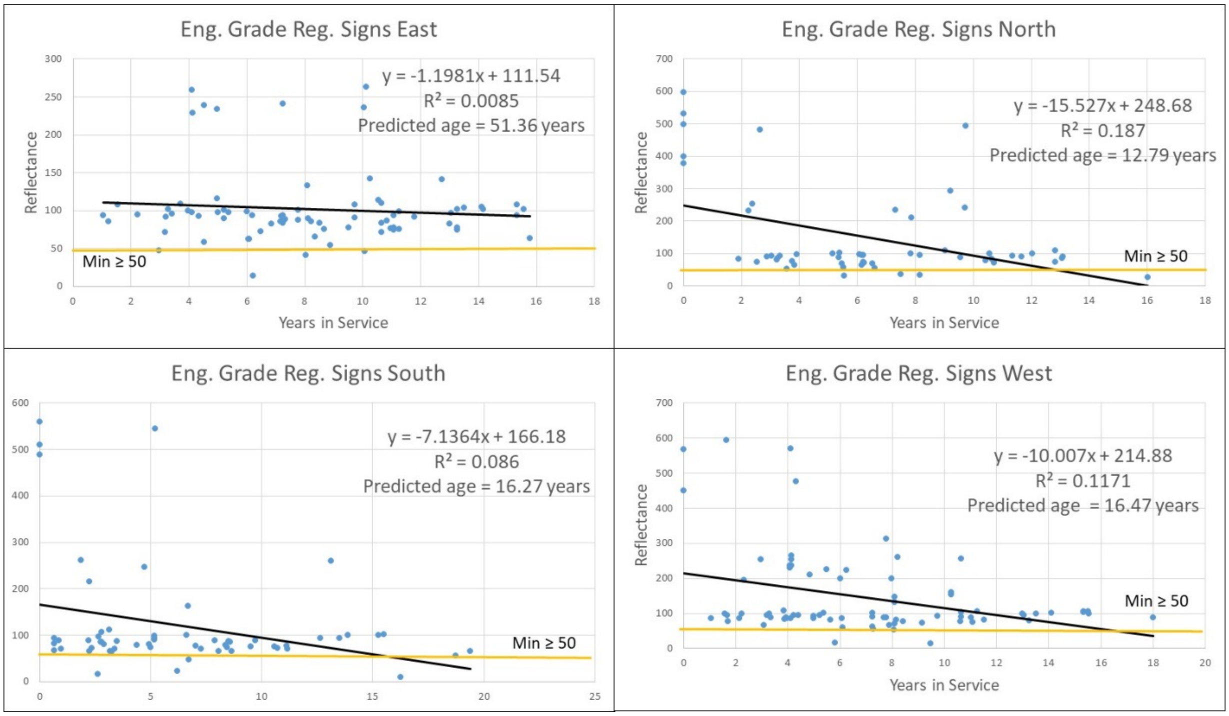
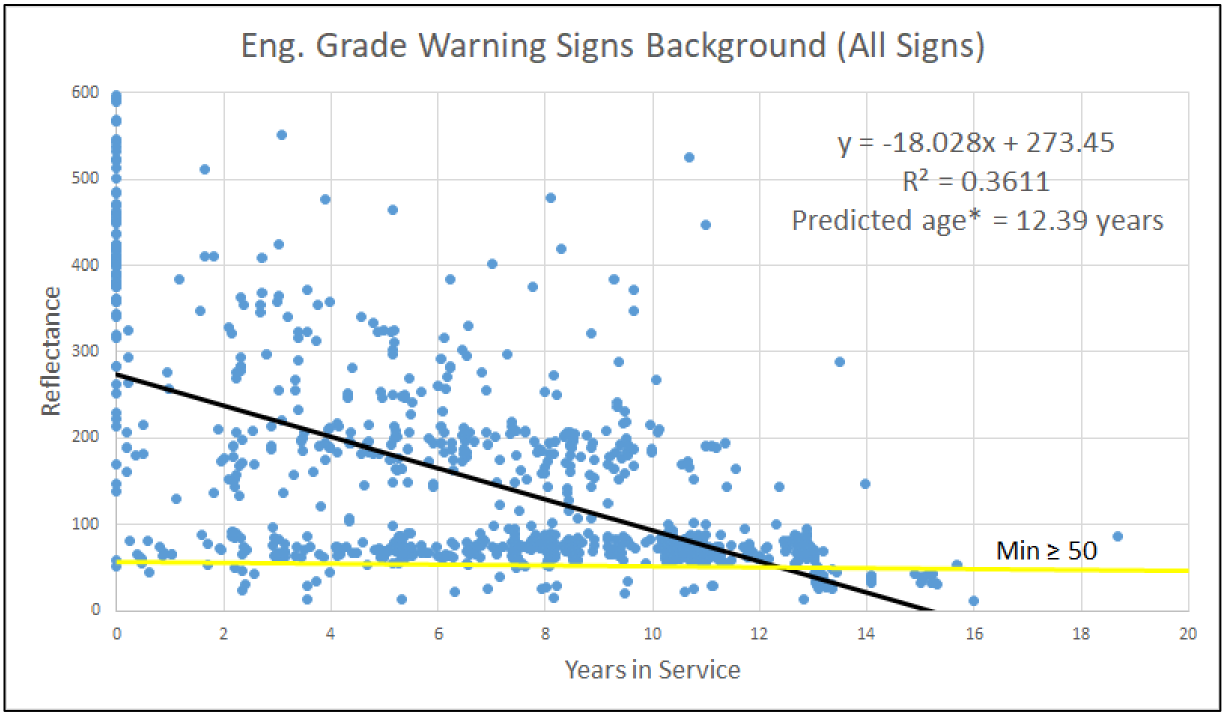


Figure 6. Engineering Grade background: east, north, south, and west orientation regulatory signs

Mixed results were produced for sign lives by orientation with east-facing signs having a predicted life of 51.36 years. However, the R^2 value of essentially zero indicates that retroreflectivity was not a predictor of sign life for this group of signs. On the other hand, the other sign directions produced more promising results with modestly better R^2 values. The range of sign lives for the remaining directions was between 12.79 and 16.47 years before retroreflectivity was expected to fall below MUTCD minimums. This age range was similar to what was observed for the white legend measurements produced for Stop signs and further indicates that this sheeting provides a roughly 15+ service year life.

Type I Warning Yellow Signs

Type I warning signs only have a yellow background color with a black legend. The MUTCD states that Type I sheeting <u>shall not be used</u> for black on yellow warning signs. However, to provide general performance information, readings for this sheeting material were evaluated and the results presented here. For the purposes of comparison, the minimum retroreflectivity value employed in this evaluation was 50 cd/lux/m^2, which is used for Type II, or super engineer grade sheeting. The years in service of these signs ranged from zero (or new) to 19 years. Figure 7 provides the results of the analysis of the regression performed on a sample of 992 sign background retroreflectivity measurements.



* The MUTCD minimum value of 50 cd/lux/m^2 was used as a minimum for this and other types of warning signs using super engineering grade, or Type II sheeting, as the majority of signs came from high-speed county roadways where larger sign sizes are employed.

Figure 7. Engineering Grade background: all warning signs

The predicted sign life for the yellow background color of these signs is 12.39 years, as shown in Figure 7. This regression produced a moderate R^2 value, which indicates that at least a portion of the predicted sign life could be explained by the retroreflectivity measurements. This particular sheeting had a moderate number of in-service measurements that fell below the MUTCD minimum of 50 cd/lux/m^2. This overall result points toward a predicted life for Type I yellow backgrounds of 12 years before falling below MUTCD minimums, although once again, this type of material shall not be used and a replacement plan for existing signage using the material should be in place.

Figure 8 presents the results of yellow background retroreflectivity measurements for Type I signs evaluated by the directional orientation of the sign.

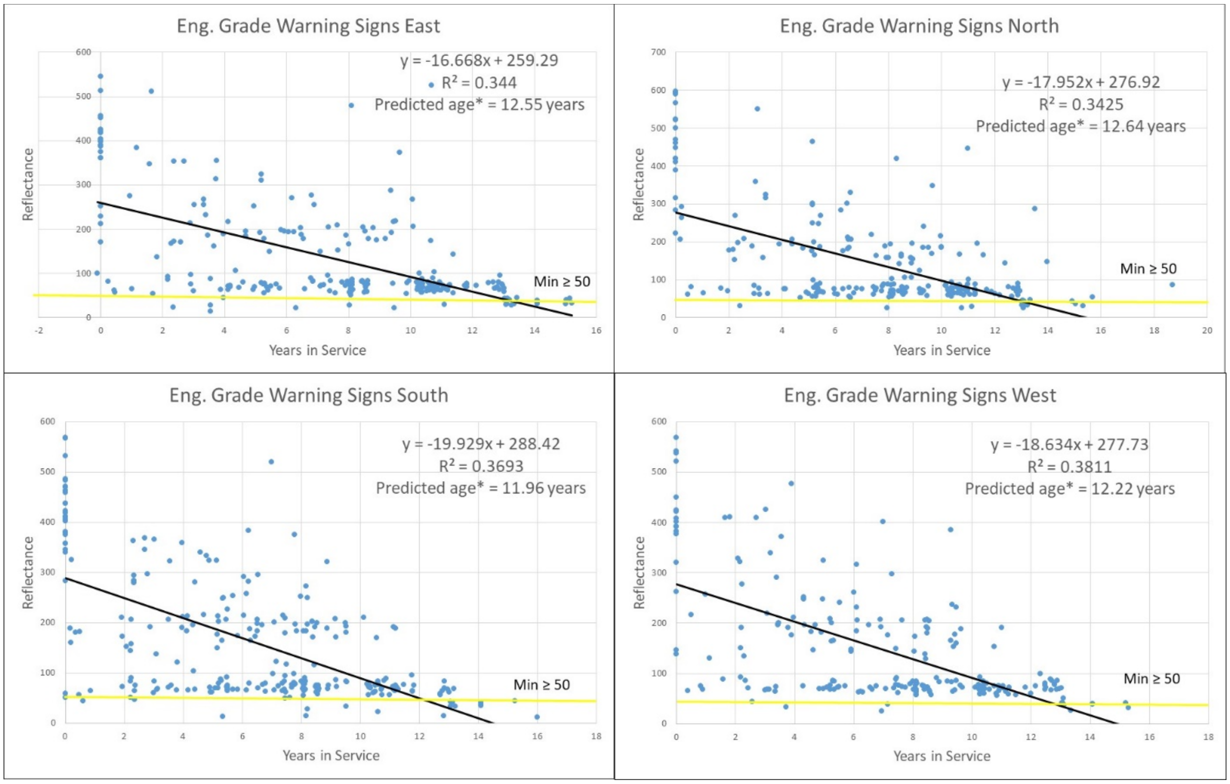


Figure 8. Engineering Grade background: east, north, south, and west orientation warning signs

The results produced for all sign orientations were fairly uniform across the board. South-and west-facing signs did not show any marked difference in life compared to north-and east-facing signs. Similar R^2 values were produced for signs in each direction, which again indicates that at least a portion of the predicted sign life could be explained by the retroreflectivity measurements. These graphs and the resulting estimates of sign lives are indicative that this sheeting provides a roughly 12-year service life, which should be considered when putting together a replacement plan for signs that employ this particular type of sheeting. They also underscore why this particular material is no longer used for warning signs.

Type III/IV Analysis and Results

The second type of sheeting material evaluated by this work was Type III/IV, commonly referred to as High Intensity Prismatic sheeting. This material, as the name suggests, is highly reflective, with a microprismatic pattern embedded within the sheeting to provide a wide angle of reflective surface. From Table 2, Stop signs are a frequent application for this sheeting, but warning signs were its predominant use in this study. Other regulatory signs (i.e., Speed Limit) also use this sheeting material. In addition, agencies use this material for green and white guide signs.

Type III/IV Regulatory White and Red Signs

For this sheeting type, only Stop signs were present in the data set. A total of 97 legend measurements and 805 background measurements were available for analysis. Once again, the Montgomery County data set only contained background retroreflectivity measurements, resulting in this discrepancy. The years in service of the signs ranged from zero (or new) to 18 years. Figure 9 presents the results of the plot of retroreflectivity versus age data for the white legend text.

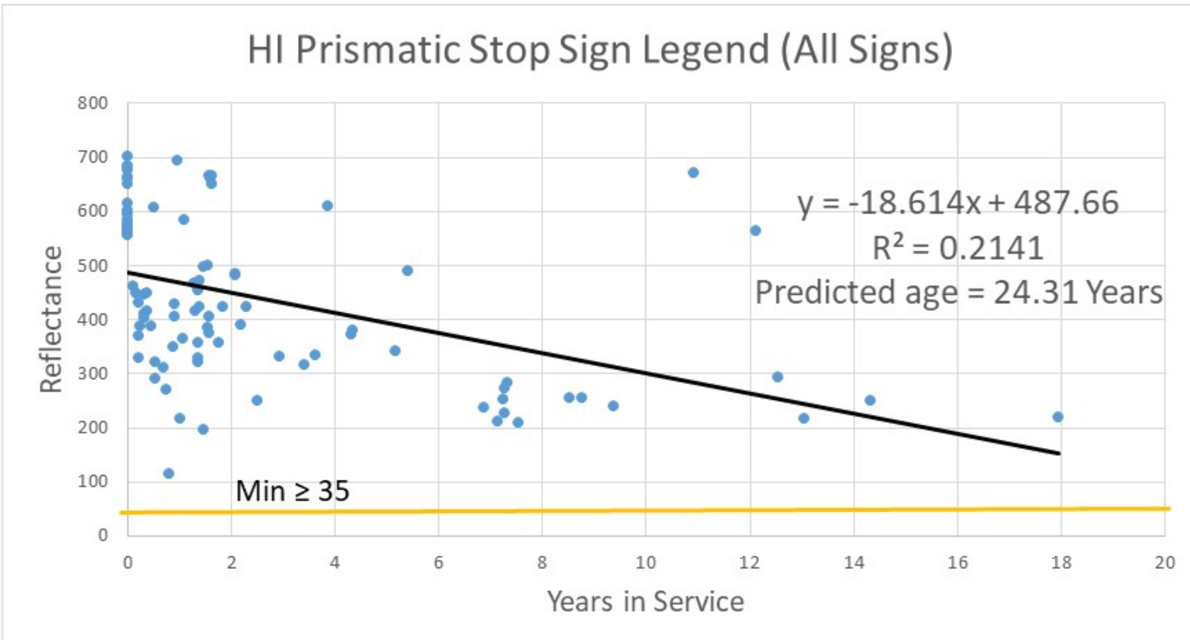


Figure 9. High Intensity Prismatic legend: all Stop signs

This is followed by Figure 10, which presents the plot of retroreflectivity versus age for the red background.

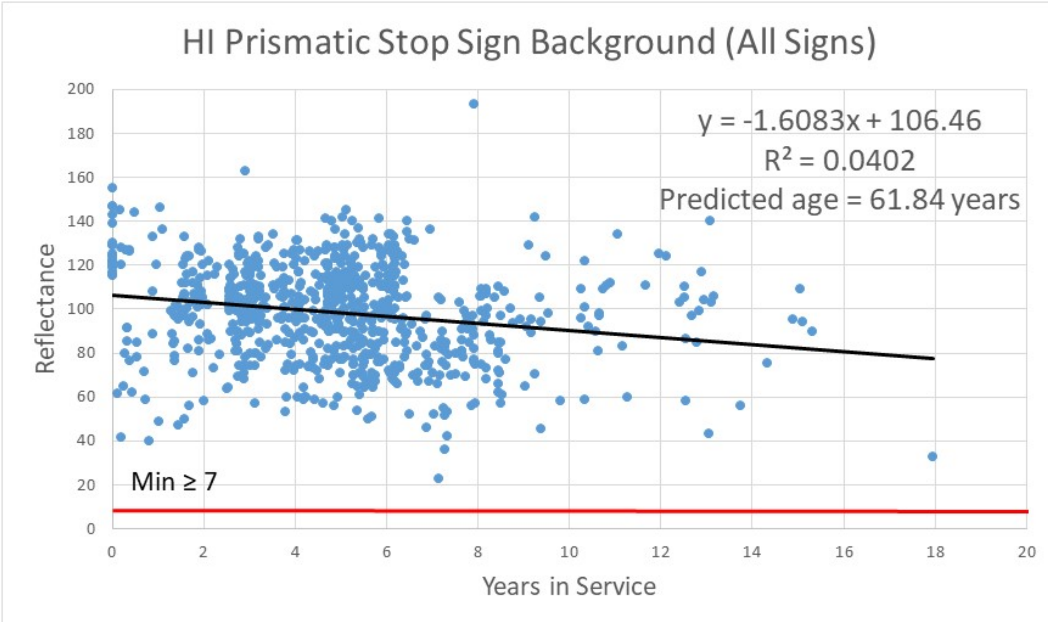


Figure 10. High Intensity Prismatic background: all Stop signs

The white to red ratio was once again not taken into account due to the absence of Montgomery County legend measurements.

As the results of Figure 9 indicate, the expected sign life based on white background retroreflectivity is 24+ years. The R^2 value of 0.21 indicates that that at least a small portion of the expected sign age is explained by the retroreflectivity measurements. The plot indicates that the majority of measurements were taken from signs that were still relatively new (0 to 4 years of age). As a result, it is not necessarily clear how a large sample of white legend measurements will perform over a longer period. However, the few data points that are plotted in the figure for older signs point to the likelihood that retroreflectivity will still be well above the MUTCD minimum even after 10+ years.

Figure 10 provides the results of the analysis performed on the 805 sign background retroreflectivity measurements. As the results indicate, the expected sign life for Type III/IV background material is 61.84 years. However, the R^2 value of 0.04 is quite low, indicating that little of the estimated sign life can be based on the retroreflectivity data.

Once again, the overall scatter plot of the retroreflectivity readings illustrates that all measurements were above the MUTCD minimum of 7 cd/lux/m^2, even after 12+ years. Still, keep in mind that red signs can potentially increase in retroreflectivity as they age on account of having a white base color. Therefore, agencies should monitor not only the retroreflectivity of such signs but also their overall appearance to ensure that they retain their overall representative color.

In terms of a realistic life expectancy, it is unlikely that the analysis of sign backgrounds by orientation will provide any better indication. Realistically, for High Intensity Prismatic signs with white legends and red backgrounds, the expected sign life of the legend may need to serve as a guide.

Figure 11 presents the results of white legend retroreflectivity measurements for Type III/IV signs evaluated by the directional orientation of the sign.

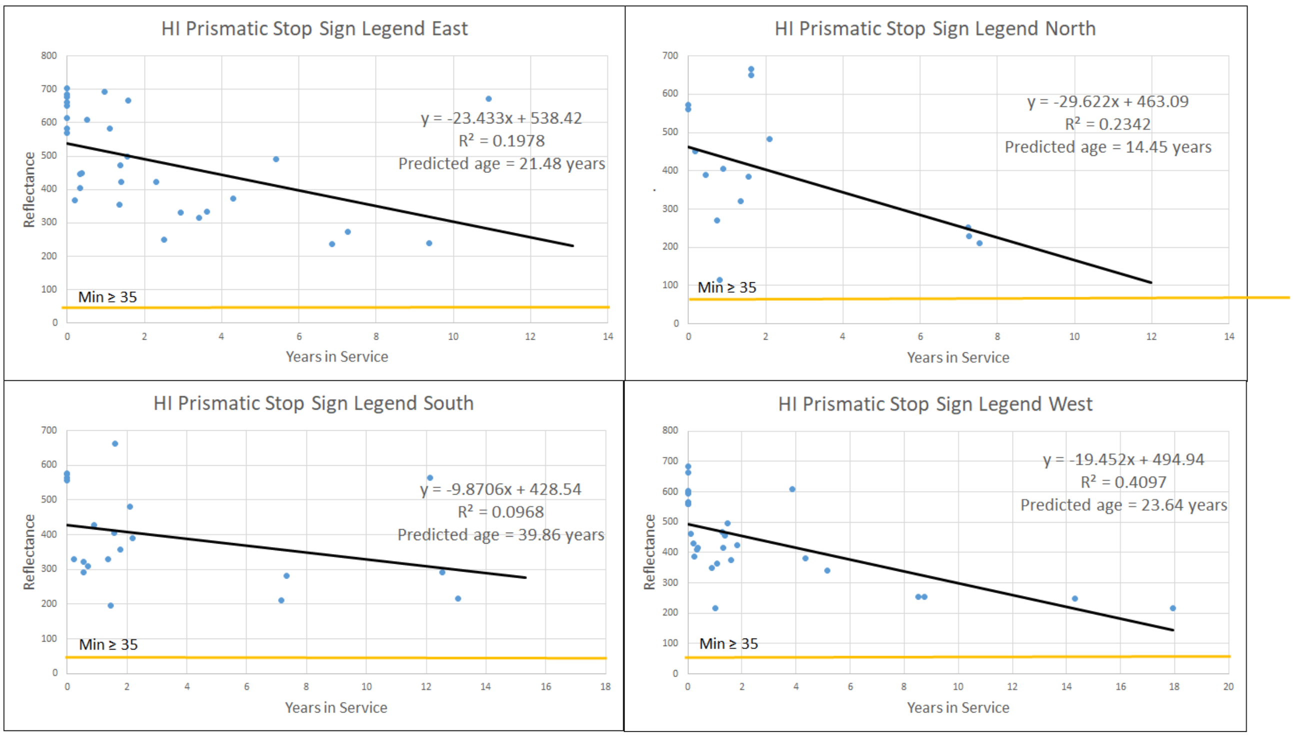


Figure 11. High Intensity Prismatic legend: east, north, south, and west orientation Stop signs

As the graphs indicate, the predicted sign lives range from 14.45 years to 39.86 years. The lower number of retroreflectivity readings for south-facing signs, combined with the high readings themselves, contributed to a high predicted sign life for this group. It should be noted that south-facing represented the largest sample size for this sign group, and that larger sample size and higher legend retroreflectivity readings combined to produce a higher predicted life when all signs were evaluated together, as presented in Figure 9. When the signs were evaluated by direction rather than collectively, the east-, north- and west-facing signs predicted lower ages that were similar to one another.

Overall, directionality did not result in any reduction in the life of one sign orientation versus another. R^2 values varied between each direction, with west-facing signs having the highest value. These results do not necessarily provide a better indication of the predicted sign life compared to the estimate made for all signs. However, the lowest estimate of 14.45 years for the north-facing signs provides a reasonable indication for agencies of the timeframe for which they can expect a sign to fall below MUTCD minimums.

Figure 12 presents the results of red background retroreflectivity measurements for Type III/IV signs evaluated by directional orientation.

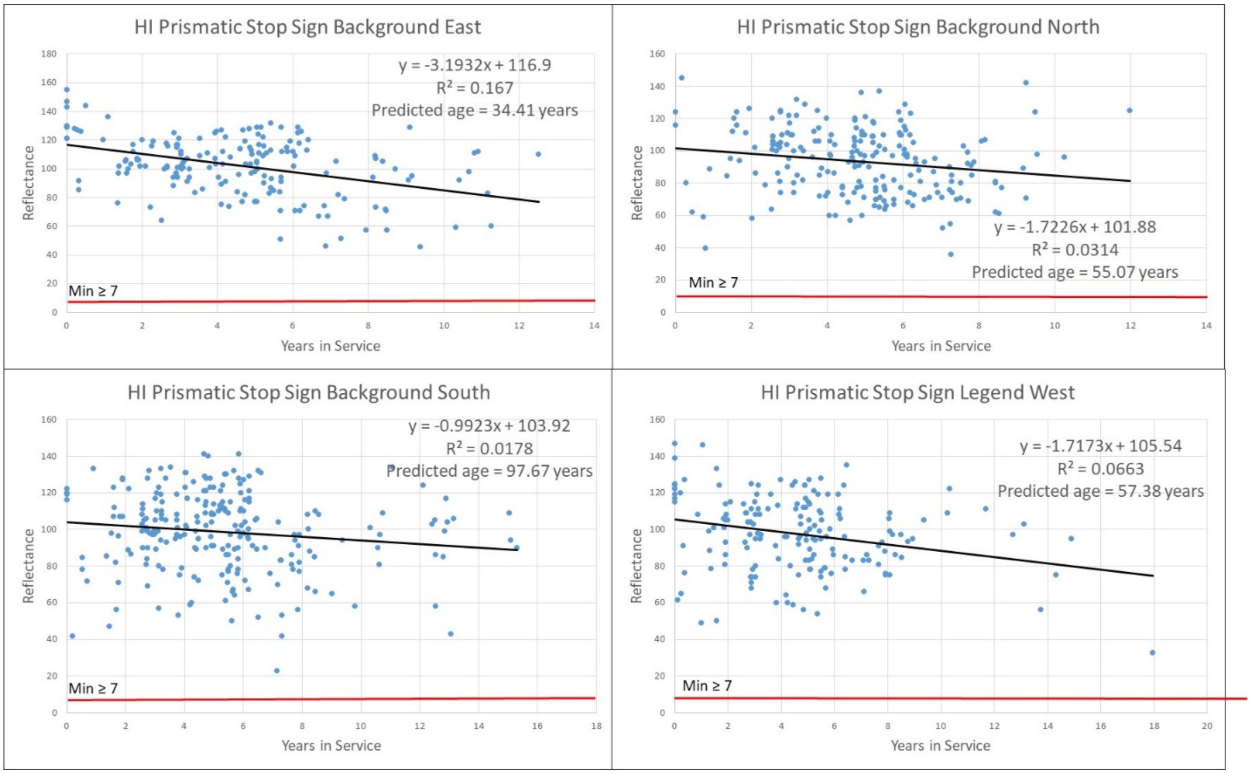


Figure 12. High Intensity Prismatic background: east, north, south, and west orientation Stop signs

The increased sample size of background measurements allowed for more points to be plotted for each of the respective sign directions. Despite this, the R^2 values were lower than those for legends across the board. The predicted sign lives range from 34.41 to 26.67 years. No sign orientation produced a realistically lower estimate of sign life compared to another. Rather, it would appear that the life of Type III/IV Stop signs is more likely to be dictated by the retroreflectivity of the white legend rather than that of the red background.

In light of the white background's estimated life of 14+ years, it is realistic to establish a base expectation of red background sign lives of 15+ years. Once again, agencies still need to monitor the overall condition and appearance of each sign to ensure that it meets all MUTCD expectations, not just minimum retroreflectivity (i.e., a Stop sign should be red, not faded pink).

Type III/IV Regulatory White and Black Signs

Type III/IV regulatory signs, such as Speed Limit signs, only have a white background color that must meet MUTCD minimums. Figure 13 provides the results of the analysis of the regression performed on a sample of 338 sign background retroreflectivity measurements.

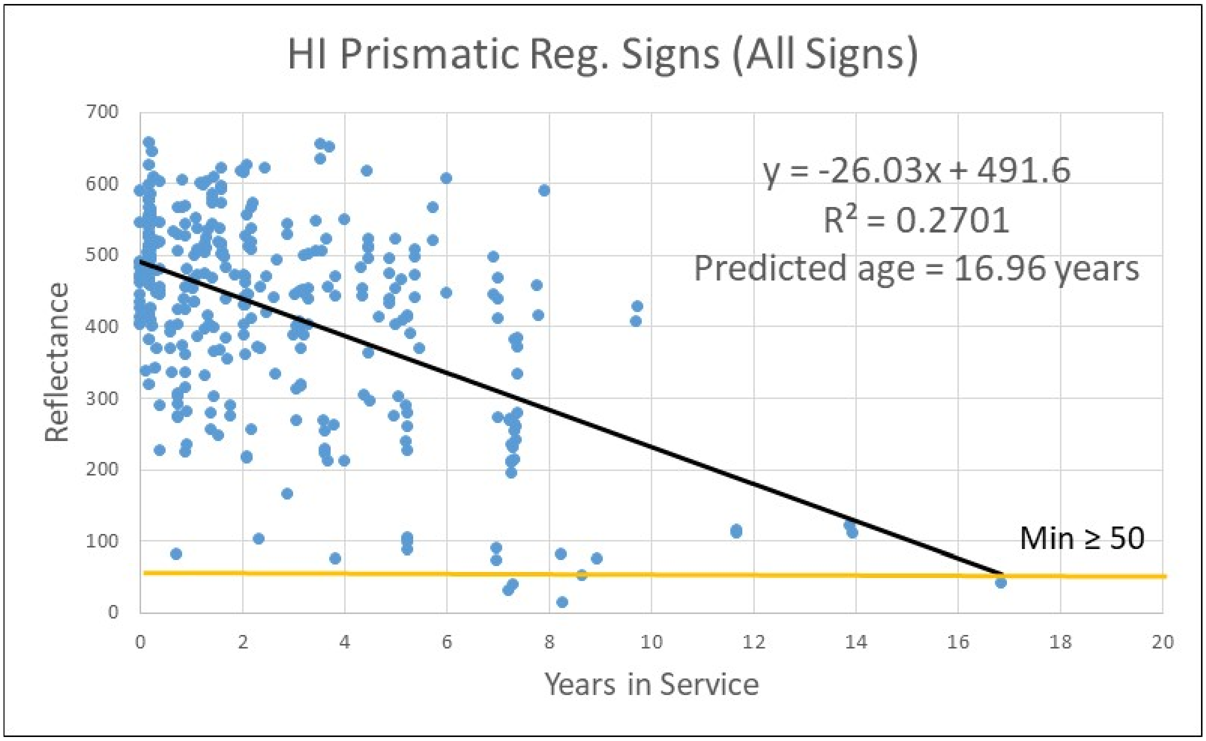


Figure 13. High Intensity Prismatic background: all regulatory signs

The years in service of the signs ranged from zero (or new) to 17 years. As the results indicate, the predicted sign life for the white background color of these signs is 16.96 years. This regression produced a modest R^2 value, which indicates that some of the predicted sign life could be explained by the retroreflectivity measurements.

This particular sheeting did provide a small number of in-service measurements that fell below the MUTCD minimum of 50 cd/lux/m^2. As the figure illustrates, essentially all other readings fell well above this threshold. However, this majority of signs had also been in service for eight or fewer years. While the overall result points toward a predicted life for High Intensity white backgrounds of 16+ years before falling below MUTCD minimums, for the purposes of being conservative, a life of 15+ years might serve as a reasonable threshold until future studies evaluate signs with longer service lives.

Figure 14 presents the various predicted sign lives of Type III/IV white signs by directionality.

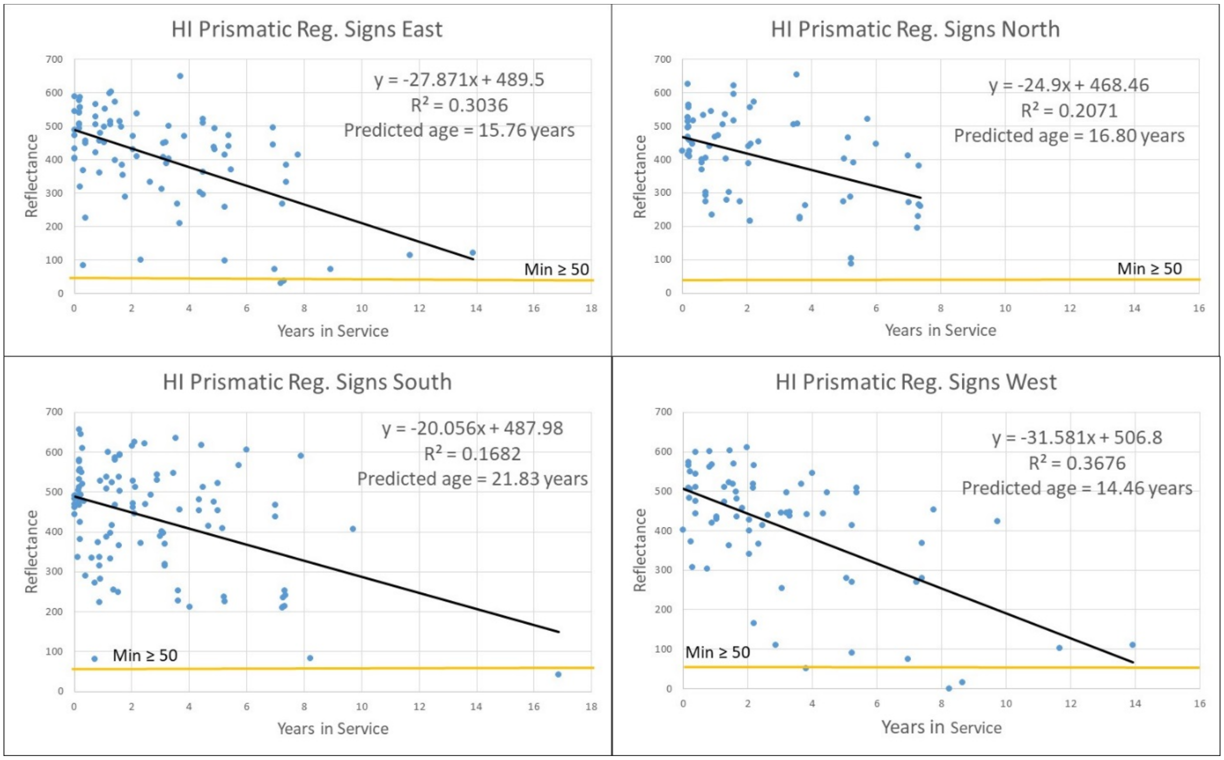


Figure 14. High Intensity Prismatic background: east, north, south, and west orientation regulatory signs

As the graphs indicate, moderate R^2 values were produced for each direction. The range of predicted service lives ranged from 14.46 years to 21.83 years. Interestingly, south-facing signs were predicted to have a longer service life than other signs based on the MUTCD minimum threshold of 50 cd/lux/m^2. In reality, the oldest sign with retroreflectivity data for this sign was 18 years of age and fell below this threshold. This sign also produced the lowest R^2 value for the group, which points toward the estimate being less reliable. The higher R^2 values of the east- and north-facing signs, combined with their lower predicted ages, point toward adopting a more conservative sign life in line with the values for these signs of approximately 15 years.

Type III/IV Warning Yellow Signs

The Type III/IV signs evaluated are warning signs with a yellow background and black legend. These signs are used in a variety of applications and this sign type is widely used by all agencies that provided retroreflectivity data, as evidenced by the 7,936 signs in this data set. The years in service of the signs ranged from zero (or new) to 20 years. As the results in Figure 15 indicate, the predicted sign life for the yellow background color of these signs is 17.18 years.

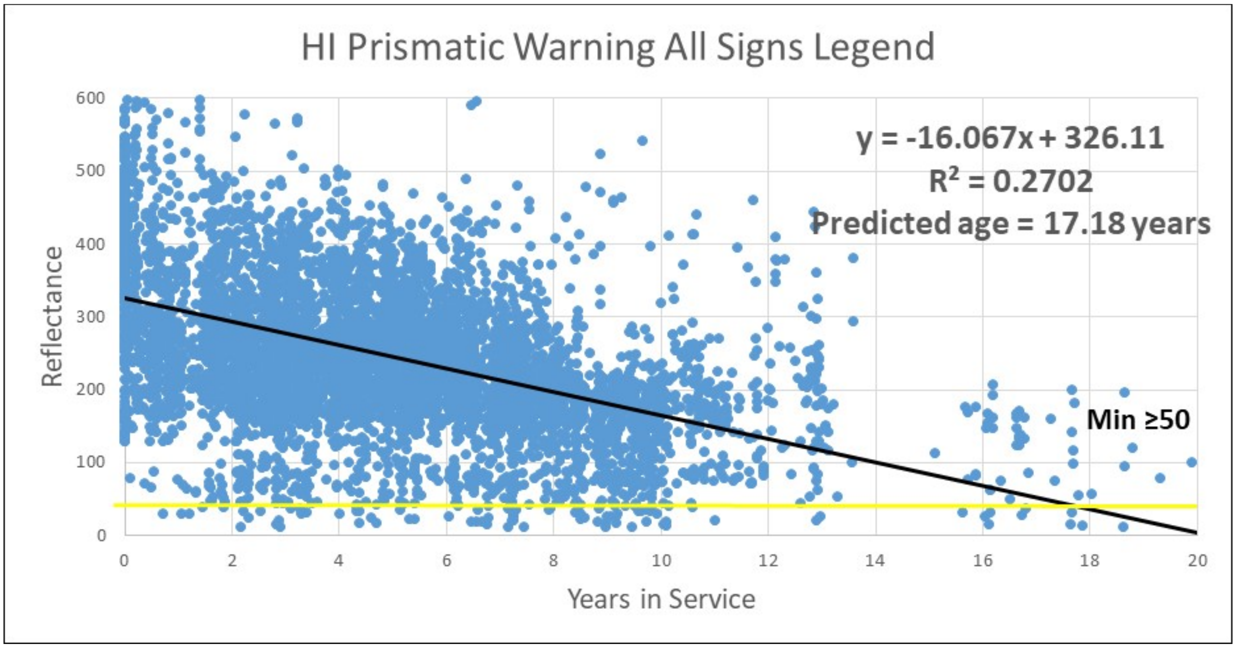


Figure 15. High Intensity Prismatic background: all warning signs

This regression analysis produced a modest R^2 value, which indicates that some of the predicted sign life could be explained by the retroreflectivity measurements. Given the size of the sample, this particular sheeting and color combination provided 129 measurements that fell below the MUTCD minimum of 50 cd/lux/m^2. Conversely, the vast majority of readings for warning signs fell well above this threshold.

Most of these signs had been in service for 13 or fewer years. Given the sample size and general trend displayed by the graph, it is reasonable to use the predicted sign life of 16 years for these signs. This conservative estimate is further supported in the directionality discussion that follows.

Figure 16 presents the various predicted sign lives of Type III/IV signs by directionality.

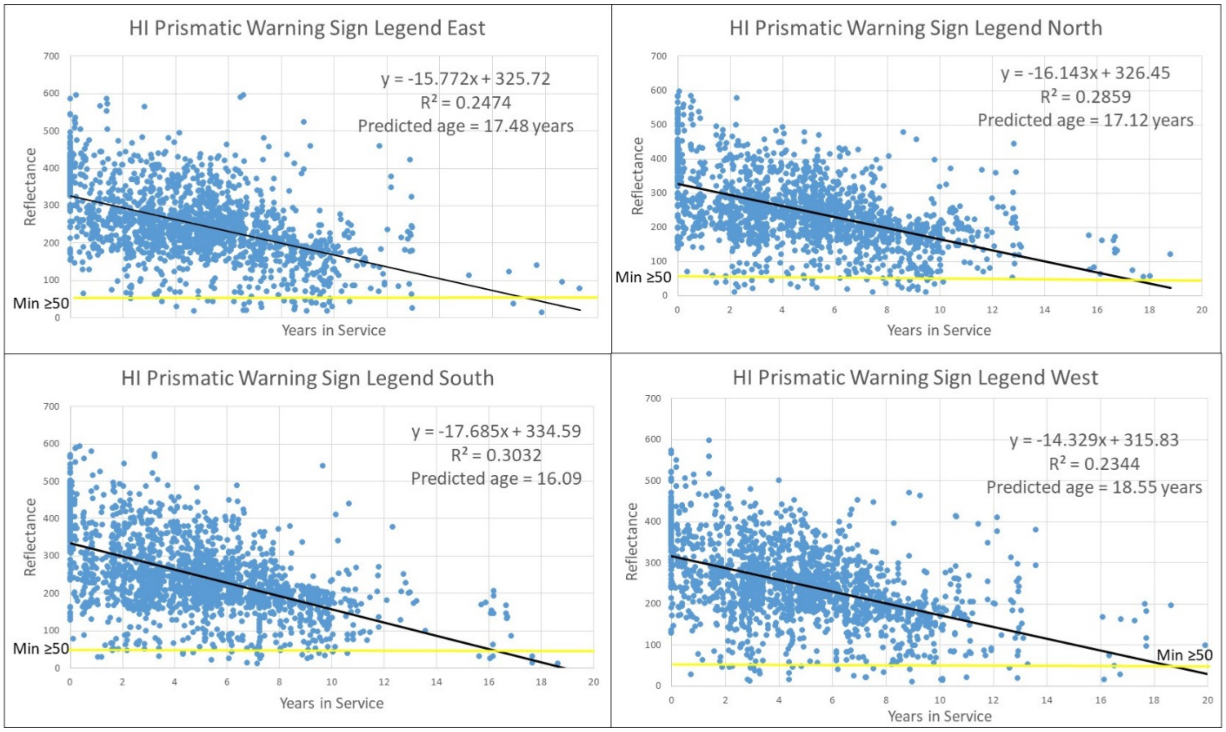


Figure 16. High Intensity Prismatic background: east, north, south, and west orientation warning signs

Similar to the findings of all warning signs of this type, moderate R^2 values were produced for each direction. The range of predicted service lives ranged from 16.09 years to 18.55 years. South-facing signs were predicted to have a shorter service life than other signs based on the MUTCD minimum threshold of 50 cd/lux/m^2. However, this difference was small, generally only one year shorter than signs facing other directions. The south-facing sign evaluation also produced the highest of the four R^2 values. In light of this, it is reasonable to use an age of 16 years to serve as the predicted sign life for Type III/IV warning signs.

Type III/IV Guide White and Green Signs

The final Type III/IV sign evaluated was guide signs with a white legend and green background. The signs in this category were provided primarily from the City of Ames and consisted of street name signs. A handful of guide sign data were also included in the Carroll County data set. A total of 144 signs were available for analysis in this group. The years in service of the signs ranged from zero (or new) to 6 years. As the results in Figure 17 indicate, the predicted sign life for the white legend color of these signs is 81.06 years, which is an overly high estimate.

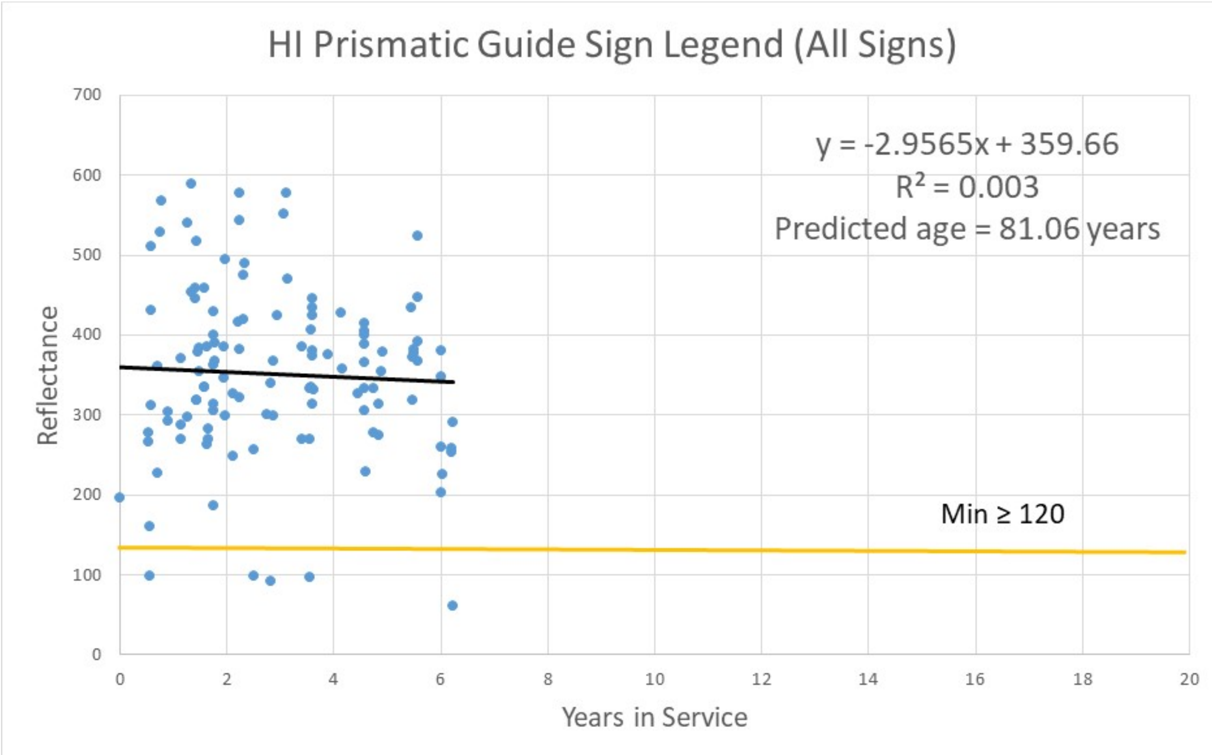


Figure 17. High Intensity Prismatic legend: all guide signs

This is evidenced by the poor R^2 value (essentially zero), which indicates that none of the predicted sign lives could be explained by the retroreflectivity measurements. Additionally, a few of measurements fell below the MUTCD minimum of 120 cd/lux/m^2. Essentially, all signs had been in service for six or fewer years and there was no evident deterioration trend, unlike what could be noted in the plots made for other sheeting and color combinations. Based on the absence of evidence that can provide a conclusive estimate of an expected life based on the white legend, the traditional manufacturer warranty period of 10 years is the most conservative value to employ, at least until further data from this type of sign is evaluated in the future.

Figure 18 presents the results of the evaluation of the green background of Type III/IV guide signs.

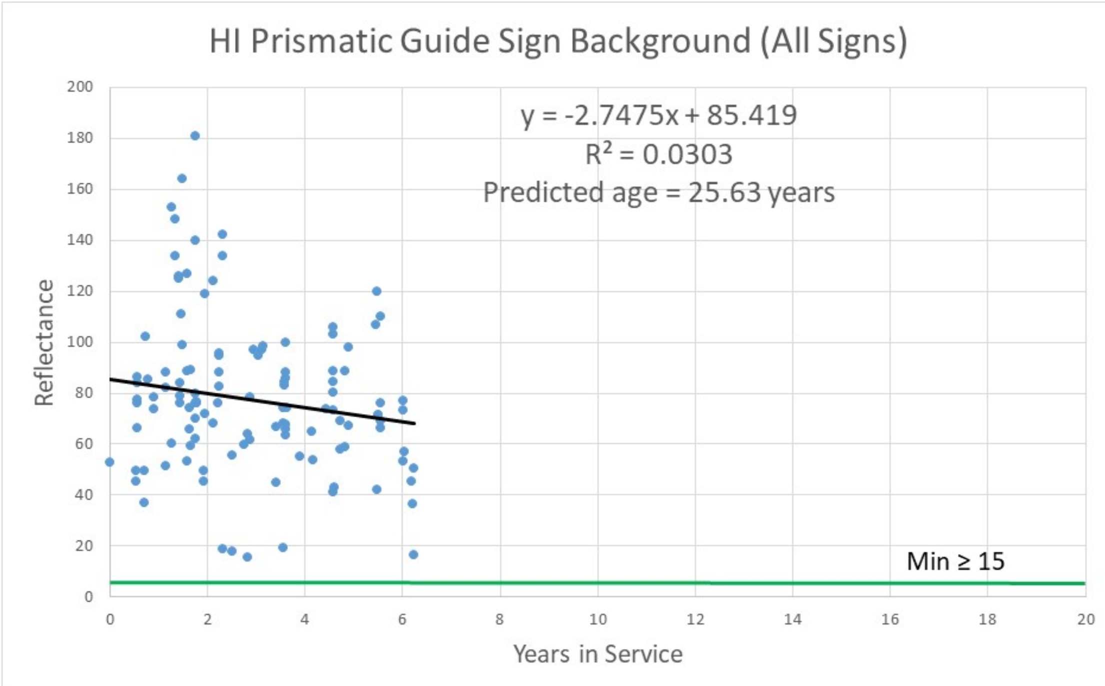


Figure 18. High Intensity Prismatic background: all guide signs

Similar to the white legend for these signs, the green background produced a somewhat reasonable estimated service live of 25.63 years. The low R^2 value, once again, indicates that very little of the predicted sign life could be explained by the retroreflectivity measurements. The scatterplot of the data does not provide any guidance on what a realistic expected life of this color and sheeting combination might be either. As a result, the traditional manufacturer warranty period of 10 years is the most conservative value to employ in establishing an expected sign life.

Figure 19 presents the different predicted sign lives of Type III/IV guide sign legends by directionality.

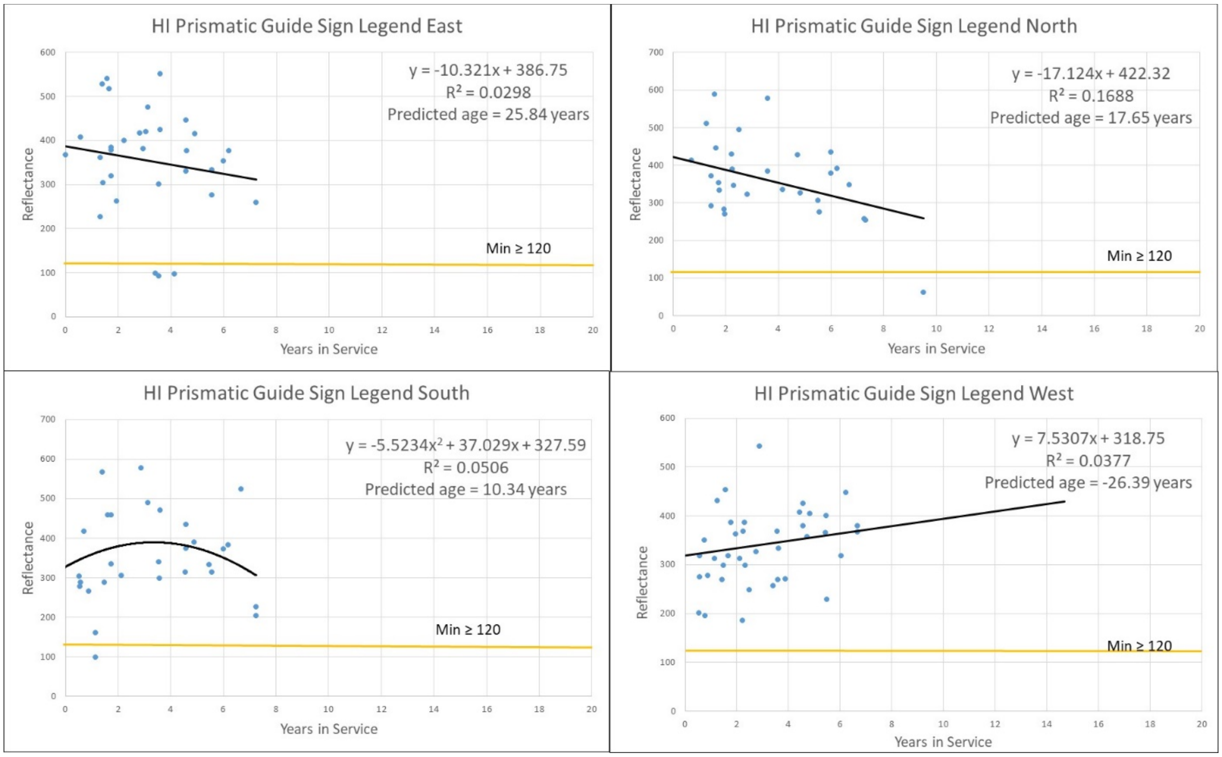


Figure 19. High Intensity Prismatic legend: east, north, south, and west orientation guide signs

Similar to the findings of all warning signs of this type, very low R^2 values were produced for each sign direction. The range of predicted service lives ranged from 10.34 years to 25.84 years. In the case of west-facing signs, the sign life prediction was -26.39 years, but, in reality, the projection indicated sign life continued to infinity, which is an unrealistic condition.

Similar to the evaluation of all signs combined, the use of a 10-year service life for guide sign legends as previously discussed is further supported based on the estimated sign lives produced here. Further data from signs whose years in service extend beyond the data evaluated may allow for the extension of that service life figure.

Similar to the estimates of white legend service lives, the predicted service lives of green backgrounds for Type III/IV sheeting in Figure 20 produced varied results by directionality.

Figure 20. High Intensity Prismatic background: east, north, south, and west orientation guide signs

The low R^2 values for each regression show only a small correlation between retroreflectivity and sign age. The results from the south-facing sign group were particularly poor, with an estimated service life of 48.09 years, which is unrealistic. The remaining sign orientation groups produced more representative estimated sign lives ranging from 14.45 years to 17.91 years. Still, the accuracy of these estimates is limited as evidenced by the low R^2 values.

An additional factor is that all of the sign data came from relatively young signs fewer than nine years of age. Without any older signs to provide even a small indication of performance, it is not possible to determine a general trend to suggest an estimated service life.

Once again, the use of a 10-year service life for guide sign backgrounds is a conservative approach to employ based on manufacturer warranties. Further data from signs whose years in service extend beyond the data evaluated may allow for the extension of that service life figure.

Type IX Analysis and Results

The third type of sheeting material evaluated by this work was Type IX sheeting, commonly referred to as Diamond Grade sheeting. This material, as the name suggests, uses diamond-shaped prismatic patterns embedded within the sheeting to provide enhanced reflective performance compared to other sheeting types. From Table 2, Stop signs are a frequent application for this sheeting, with a small number of warning signs also using the material.

A total of 493 signs in the data set used Type IX sheeting, all coming from Carroll County. This material type has not been widely evaluated in past studies, and the results from this study offer a new perspective on its performance.

Type IX Regulatory White and Red Signs

Among regulatory signs, only Stop signs were present in the data set for this particular sheeting type. A total of 445 legend measurements and 457 background measurements were available for analysis. The years in service for these signs ranged from zero (or new) to 20 years. Figure 21 presents the results of the plot of retroreflectivity versus age data for the white legend text.

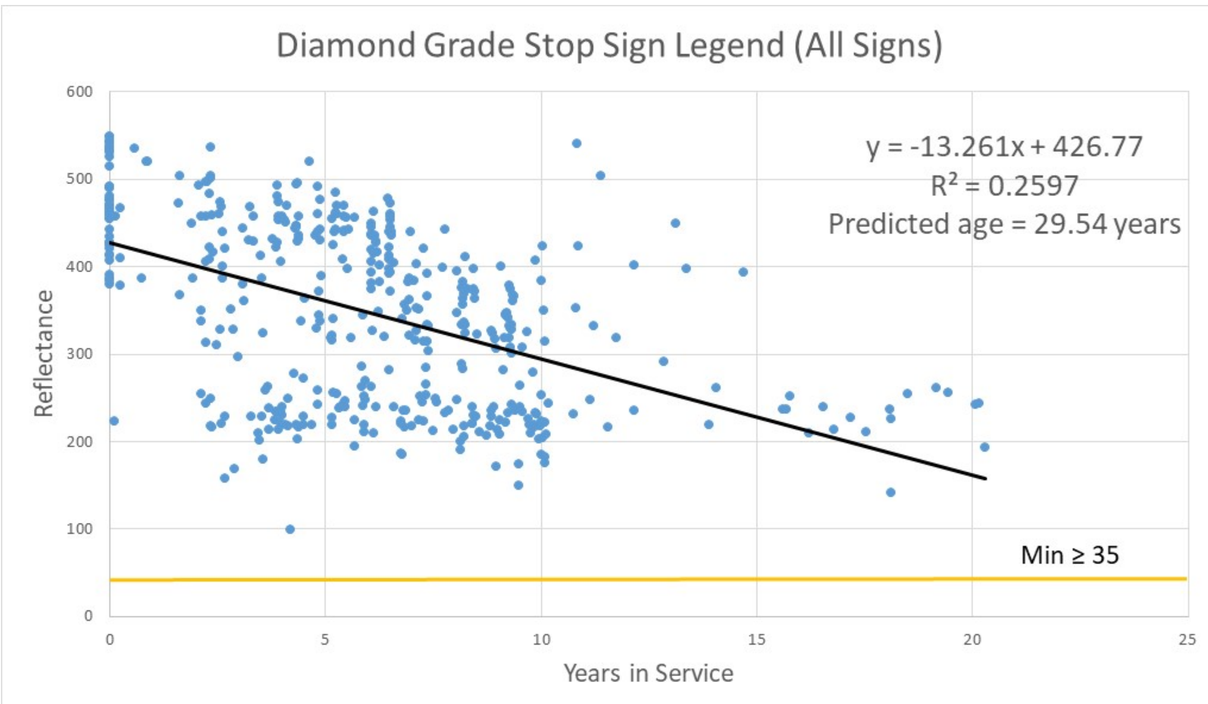


Figure 21. Diamond Grade Prismatic legend: all Stop signs

This is followed by Figure 22, which presents the plot of retroreflectivity versus age for the red background.

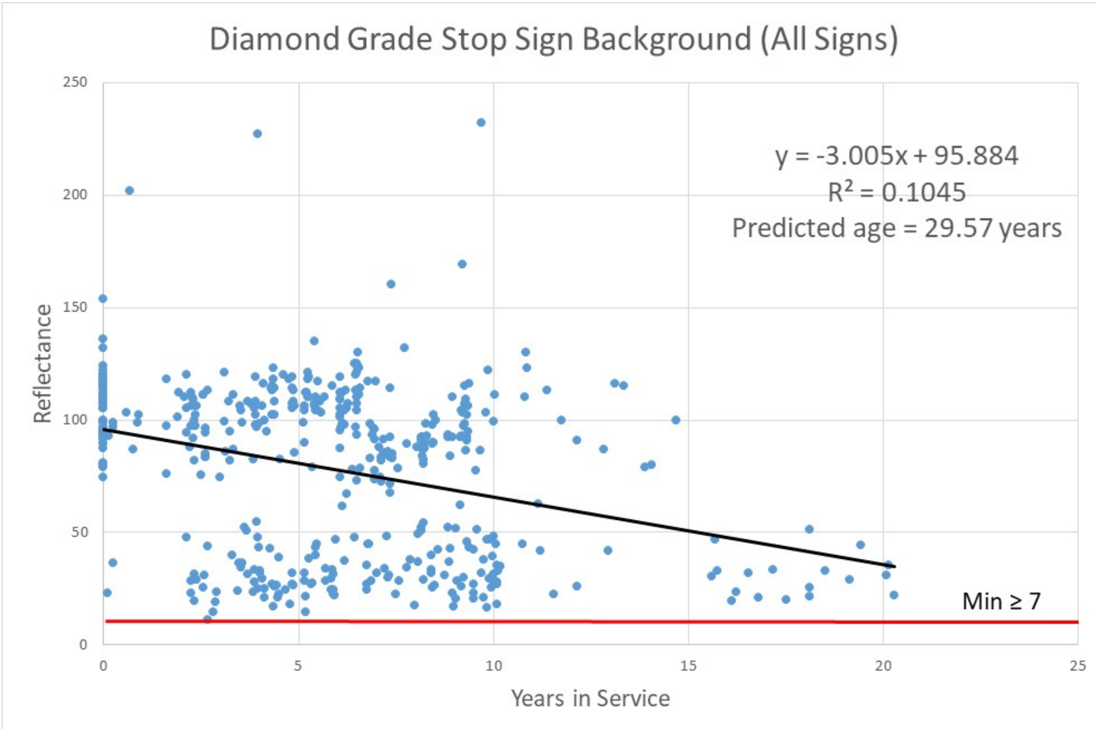


Figure 22. Diamond Grade Prismatic background: all Stop signs

As the results of Figure 21 indicate, the expected sign life based on white legend retroreflectivity is 29.54 years. The R^2 value of 0.25 indicates that that at least some of the expected sign life is explained by the retroreflectivity measurements. Most of the signs in the data set were still relatively new (fewer than 10 years old). However, it is interesting to note that the majority of data readings from signs older than 10 years still provided relatively high retroreflectivity readings. None of the readings in the data set approached the MUTCD minimum for white legends of 35 cd/lux/m^2.

Figure 22 provides the results of the analysis performed on the 457 sign background retroreflectivity measurements. As the results indicate, the expected sign life for Diamond Grade background material is 29.57 years. However, the R^2 value of 0.10 is low, indicating that little of the estimated sign life can be based on the retroreflectivity data. Once again, the overall scatter plot of the retroreflectivity readings illustrates that most measurements were above the MUTCD minimum of 7 cd/lux/m^2, even up to 20 years.

In terms of life expectancy, it appears that 15 years to 20 years is a realistic expectation. However, evaluation of the background by sign orientation for this material may provide a better indication of whether this is the case.

Figure 23 presents the results of white legend retroreflectivity measurements for Type IX signs evaluated by the directional orientation of the sign.

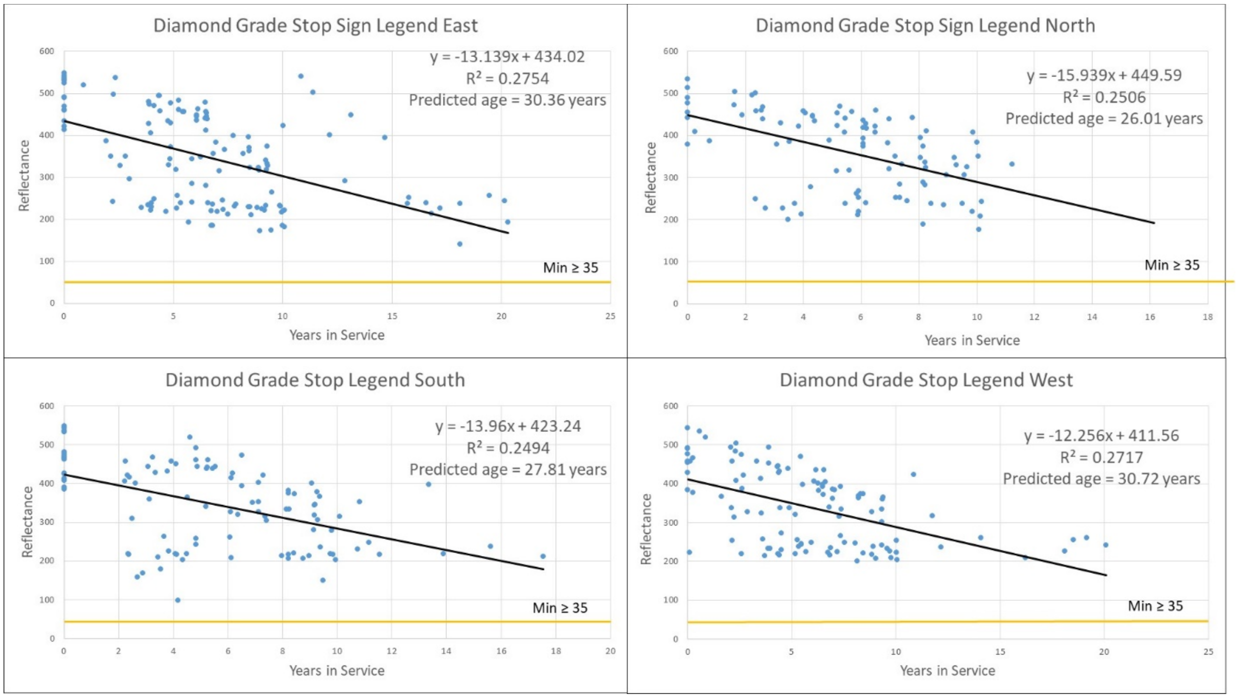


Figure 23. Diamond Grade Prismatic legend: east, north, south, and west orientation Stop signs

As the graphs indicate, the predicted sign lives range from 26.01 years to 30.72 years. The directionality of the signs had no impact in terms of lowering the expected age of a sign, and all directions produced similar expected ages. Likewise, the R^2 values were similar among directions, with all indicating that retroreflectivity contributed at least a small amount to the expected sign life.

These results do not necessarily provide a better indication of the predicted sign life compared to the estimate made for all signs. Consequently, the estimated service life for these signs based on the white legend can reasonably be expected to range between 15 years and 20 years.

Figure 24 presents the results of red background retroreflectivity measurements for Type IX signs evaluated by directional orientation.

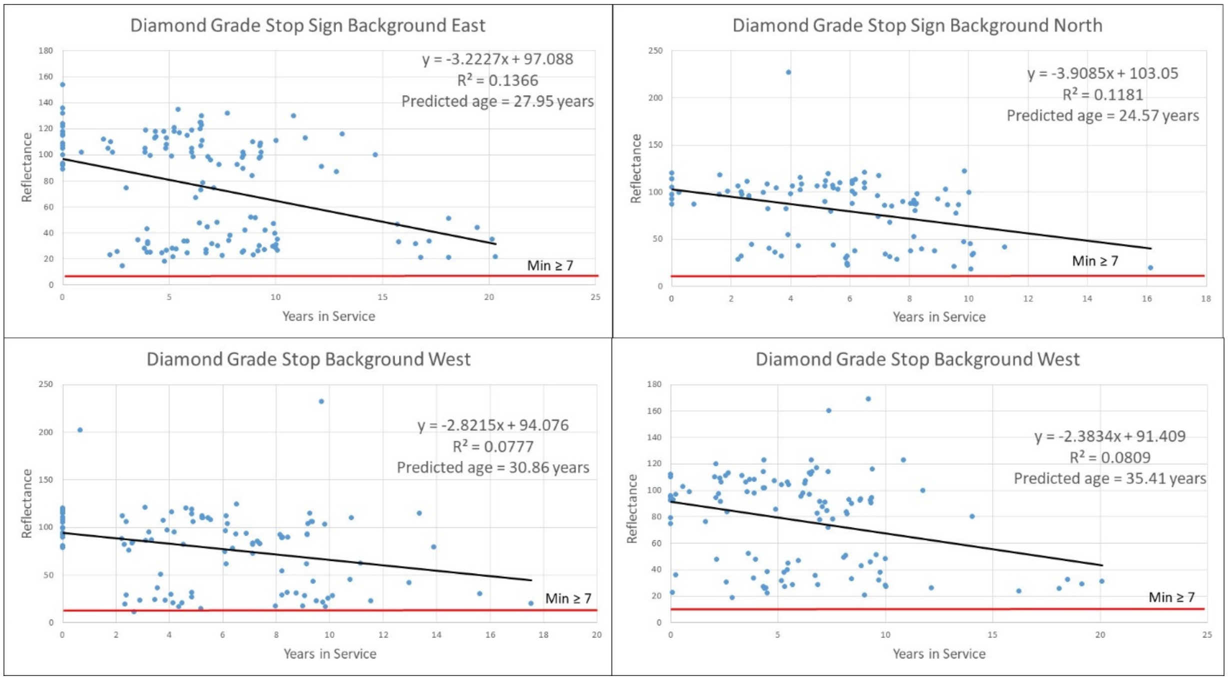


Figure 24. Diamond Grade Prismatic background: east, north, south, and west orientation Stop signs

Predicted sign lives range from 24.57 years to 35.41 years. The R^2 values were lower than those for the directional legend evaluations as well. For the most part, the expected lives predicted by the background evaluations produced similar ages to those of the white legends. Given that the R^2 values from the evaluation of legends by directionality were higher, it would appear that the life of Type IX Stop signs is more reliably tied to the retroreflectivity of the legend rather than the background for Stop signs. Therefore, the expected sign life for Type IX Stop signs can be expected to be 15 years at a minimum, but more likely closer to 20 years. Once again, agencies still need to monitor the overall condition and appearance of each sign to ensure that it meets all MUTCD expectations and not just minimum retroreflectivity.

Type IX Warning Yellow Signs

The data set for Type IX signs also included 35 warning signs. Once again, all of these signs were from Carroll County. The years that these signs have been in service ranged from zero (or new) to 12 years. As indicated in Figure 25, the expected sign life for this type of sign is 29.22 years.

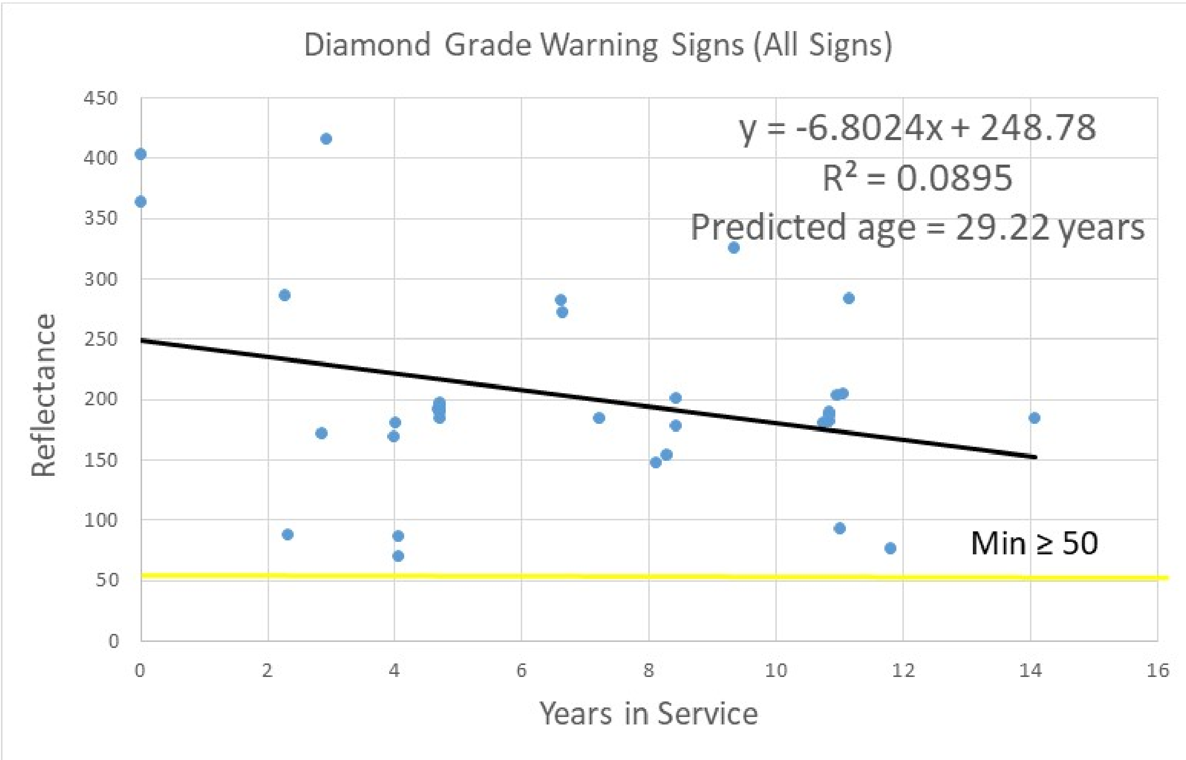


Figure 25. Diamond Grade Prismatic background: all warning signs

The relatively low R^2 value of 0.08 indicates that only a small amount of the expected sign life is predicted by retroreflectivity. As the figure illustrates, most readings were well above the MUTCD minimum of 50 cd/lux/m^2, although a handful of readings were near this level. These readings were from signs that had been in service from 2 years to 12 years. Although the sample size is somewhat small, the overall trend for expected sign life points toward a minimum of 15 years, if not longer. The further evaluation of these signs by directional orientation may provide additional insight into this value.

Figure 26 presents the various predicted sign lives of Type IX warning signs by directionality.

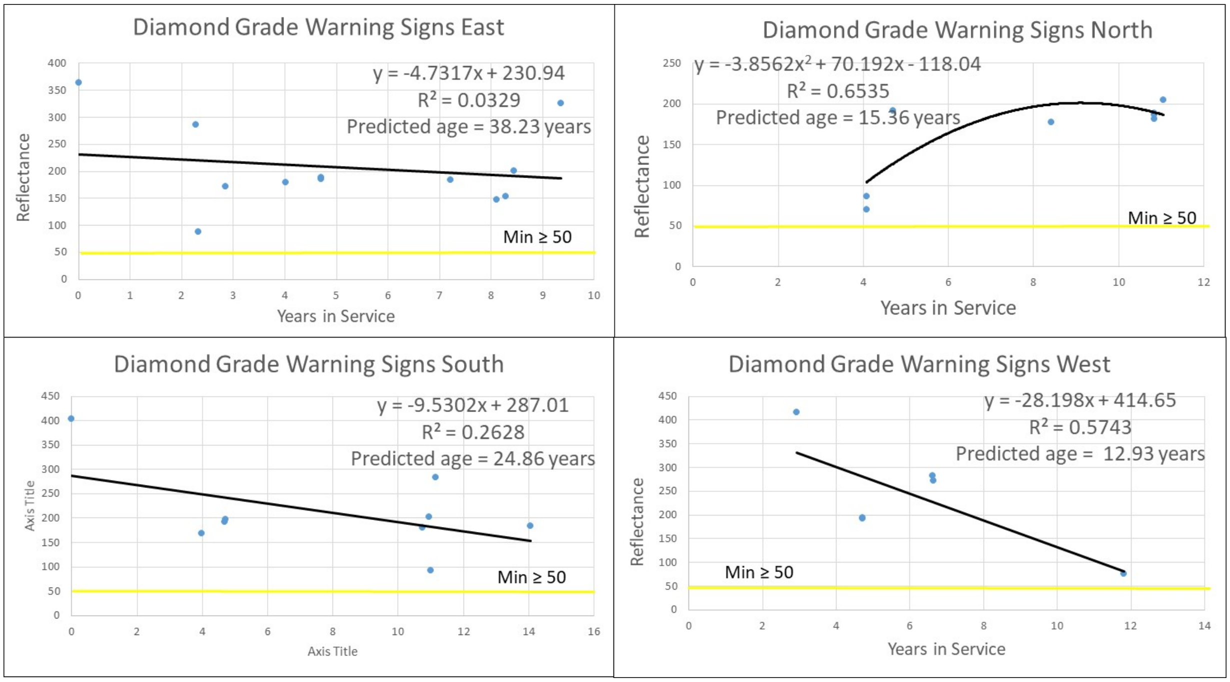


Figure 26. Diamond Grade Prismatic background: east, north, south, and west orientation warning signs

The range of predicted service lives is from 23.93 years to 38.23 years. The directional evaluations provided mixed R^2 values. In the case of east-facing signs, the R^2 value was low. The R^2 value for south-facing signs was better at 0.26, but still relatively low. However, the R^2 values for north- and west-facing signs were relatively high, at 0.65 and 0.57, respectively. West-facing signs were predicted to have a shorter service life than other signs based on the MUTCD minimum threshold of 50 cd/lux/m^2. This difference was large when compared to south-facing signs, which would also be expected to deteriorate at a faster rate due to sun fading. The observed differences in predicted sign lives for each direction are likely, at least in part, due to the smaller overall sample sizes that were evaluated. Given the overall trend observed for all signs combined, it appears that an expected sign life of 15 years is reasonable for Type IX warning signs.

Summary of Findings

The researchers developed a series of 65 different linear regression models to estimate the age at which signs of a given sheeting material, color, and directional orientation could be expected to fall below the MUTCD minimum retroreflectivity values previously provided in Table 1.

From these analyses, it is possible to provide suggested values for expected sign life for general application (i.e., regardless of sign directionality). The predicted age that a particular sheeting material, sign color, and sign direction would fall below MUTCD minimums is summarized in Table 4.

Table 4. Predicted sign life age versus suggested sign

Sheeting Material	Sign Type	Color	Predicted Age (years)					Suggested Sign Life (years)
			All Signs	East	North	South	West	
Engineering Grade (Type I)	Stop	White	16.55	13.06	46.3	15.15	13.78	13
		Red	14.98	15.24	26.67	14.86	13.00	13
	Regulatory	White	16.35	51.36	12.79	16.27	16.47	15
	Warning*	Yellow	12.39	12.55	12.64	11.96	12.22	12
High Intensity Prismatic (Type III/IV)	Stop	White	24.31	21.48	14.45	39.86	23.64	14
		Red	61.84	34.41	55.07	97.67	57.38	15
	Regulatory	White	16.96	15.76	16.8	21.83	14.46	15
	Warning	Yellow	17.18	17.48	17.12	16.09	18.55	16
	Guide	White	81.06	25.84	17.65	10.34	infinity	10**
		Green	25.63	14.45	17.91	48.09	16.58	10**
Diamond Grade (Type IX)	Stop	White	29.54	30.36	26.01	27.81	30.72	15
		Red	29.57	27.95	24.57	30.86	35.41	15
	Warning	Yellow	29.22	38.23	15.36	24.86	12.93	15

* The MUTCD states that this material shall not be used for this type of signing. Results for this sheeting and sign type combination are for reporting purposes only.

** The manufacturer's warranty period is suggested for use with these signs, as inadequate data were available to establish reasonable age predictions

As the table indicates, all signs were expected to last more than 10 years before retroreflectivity falls at or below the MUTCD minimums. While some of the predictions presented in the table were generated from small sample sizes for a particular material, sign color, and/or directional combination, most of the estimates presented were produced from sample sizes of hundreds, or in some cases thousands, of sign readings. In only one instance (white font on green background guide signs) was it not possible to include a predicted age.

The Suggested Sign Life column (far right) presents age figures that agencies can apply when considering the age at which the replacement (or at least increased inspections) of a sign could be expected. The suggested values are largely conservative, as a comparison to the Predicted Age columns indicate. However, given the low R^2 values that were produced by many of the models, applying some caution in setting suggested sign ages was necessary.

Aside from model consideration, the general plots of the sheeting, sign color, and sign direction data were also reviewed when developing suggested sign life values. In examining the data plots, the majority of sign retroreflectivity readings still remained well above the MUTCD minimums at the predicted ages. This may have been the result of lower retroreflectivity readings contributing to the predictions reaching MUTCD minimums earlier, despite most sign readings pointing toward lasting beyond the predicted ages.

Of course, the opposite is true for predictions of sign ages that were lengthy. This was particularly true for cases like High Intensity Prismatic Stop signs, where predicted sign age, regardless of orientation/directionality, exceeded 30 years, and in most cases 50 years.

Logic dictates that no sign, regardless of how good a sheeting material might be, is going to do that well for that long. Rather, a maximum life of 20 to 25 years is likely at the high end of expectations. This is the result of the simple fact that signs can be vandalized, knocked down, and otherwise damaged by abrasion, weathering, etc. during the course of normal service. In other words, even if a sign were to last to the predicted age from a sheeting material standpoint, other factors would likely conspire to require its replacement.

Additionally, as has been pointed out repeatedly in this report, sign retroreflectivity can remain high (or even increase) as time passes for some colors, and especially for Stop signs, while the underlying sheeting color (white) begins to bleed through over time as the red fades. A Stop sign may have a high retroreflectivity measurement, but also be pink if this occurs. This change in color results in a failure to meet another requirement of the MUTCD in terms of sign color.

Conclusion

This chapter presented the data collection and analysis approach, as well as the results of evaluations to determine the expected sign life for different sheeting types, sign colors, and directional orientation. Sign retroreflectivity data from three counties and two cities in Iowa were initially acquired in support of the research.

During the process of data quality control checks, the researchers determined that sign installation dates were not included as part of the data sets from one county and one city. As a result, data from two counties and one city were ultimately used in the data analysis.

Additional anomalies in the different data sets were identified through quality control checks, such as retroreflectivity readings without the date of the measurement, and removed from the data set as well. Finally, the data sets were combined into a common format to facilitate data analysis. The result was a total of 10,799 retroreflectivity data points that were available for analysis across three different sheeting material types (Type I, Type III/IV, and Type IX) for a variety of sign types.

Following the quality control and formatting of the data, the approach to data analysis was identified. The data analysis approach selected for this work was that used by past research: linear regression. Linear regression was selected as it allowed for an evaluation of the two components of greatest interest to the research, the age of a sign versus its respective retroreflectivity value. The third sign component of interest, directionality, was also evaluated by considering sign direction data in individual groups.

The use of linear regression allowed for a determination of the point (age) where the retroreflectivity of a sign would fall below the MUTCD minimum level. Signs were examined by sheeting type and MUTCD category (regulatory and warning) collectively, as well as broken out by sign orientation (north, south, east, and west). As part of the analysis, R^2 values were also produced to provide an indication of how well the respective model fit the data being examined.

The results of the analysis indicated that all the sheeting materials, sign types, and sign directions evaluated were predicted to have lives of at least 10 years, and typically much longer, before retroreflectivity levels fell below the MUTCD minimums. Some of the predictions were more reliable than others, as evidenced by the respective R^2 value for the particular model.

In general, the predicted lives based on the respective retroreflectivity data for a material/sign type/direction combination were more than five years longer than the manufacturer warranty periods. Still, for conservative purposes, local agencies are encouraged to consider a sign to be approaching the MUTCD minimum retroreflectivity level at approximately five years past the manufacturer warranty.

This approach can be used by local agencies in planning and managing their respective approach to meeting the MUTCD sign retroreflectivity requirements for their sign assessment and management methods.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Traffic signs provide drivers with warning and guidance information along roadways. However, roadway signing presents agencies with management, maintenance, and replacement needs, with corresponding budgetary impacts. Maintenance and replacement requirements have increased, particularly following the establishment of MUTCD minimum retroreflectivity requirements.

Agencies are tasked with ensuring that certain regulatory, warning, and guide signs meet minimum MUTCD retroreflectivity levels, either through observational or direct measurement approaches. Regardless of the assessment or management approach employed, the in-service performance of sign retroreflectivity over time is of interest to local agencies given the time and costs associated with maintaining roadway signage. To address these issues, the work completed during this project evaluated retroreflectivity measurements of in-service signs versus the ages of the signs to determine expected sign lives.

The results of this project are expected to be of value to agencies in understanding the in-service life of signs and in applying this information as necessary to their selected assessment or management method for determining inspection intervals, replacement cycles, etc. The remainder of this chapter presents the conclusions and recommendations that have resulted from the work.

Conclusions

A number of conclusions can be drawn from the work presented in this report. These include the following:

- Most prior studies only focused on evaluating the expected life of in-service Type I and Type III sheeting material.

- The models developed in past studies did not always explain the relationship between retroreflectivity and sign age, as evidenced by generally low R^2 values. Some past studies did observe the potential for red Type III signs to increase in retroreflectivity over time.

- It has been reported in the literature that failure rates for signs falling below MUTCD minimums were generally lower than 10 percent.

- The data available to this research were assumed to have been collected uniformly. In reality, this was may not have always been the case. Different agencies and data collectors likely employ different approaches (cleaning versus not cleaning signs, number of readings collected per sign, etc.) when measuring sign retroreflectivity.

- This research developed 65 different linear regression models to estimate the age at which signs of a given combination of sheeting material, color, and directional orientation could be expected to fall below the MUTCD minimum retroreflectivity values.

- Based on the estimated ages produced from the various regression equations and plots of retroreflectivity versus age for different combinations, all signs were expected to last more than 10 years before retroreflectivity fell at or below the MUTCD minimums.

- Some of the estimated sign ages are more reliable than others, as evidenced by the R^2 values that were produced by some models.

- Suggested expected sign life values of 12 to 16 years are recommended for agency consideration. These suggested values are largely conservative, particularly when compared to the predicted age that a sign would fall below MUTCD minimums, which was generally above 15 years of age.

- Plots of sign retroreflectivity versus sign age indicated that many retroreflectivity readings still remained well above the MUTCD minimums at the predicted age where failure was expected.

- In some cases, the presence of many retroreflectivity readings that were well above MUTCD minimums even at an older sign age likely contributed to some of the larger, more unrealistic expected sign life estimates (i.e., 25+ years to failure). This was particularly true for cases like High Intensity Prismatic Stop signs.

- In general, the results produced by the research were similar to those of past studies, including R^2 values and the general trends produced when plotting retroreflectivity data over time.

- For most sheeting materials and sign types/colors, it appears that the expected sign lives extend beyond the manufacturer warranty period by approximately five years.

- While not conclusive from a statistical perspective, the results of the evaluations conducted in this research did not indicate that the retroreflectivity of south- or west-facing signs deteriorated at any greater rate than that of other signs. This is true of both the estimated age trend lines as well as the general data plots of retroreflectivity values.

- Agencies should employ some form of inspection procedure past the warranty age to ensure that signs do not fail to meet MUTCD retroreflectivity requirements prematurely. However, by employing the baseline of five additional years of service beyond the warranty period, an agency can reasonably expect to produce cost savings through reduced sign purchasing requirements on an annual basis.

Recommendations

In terms of recommendations based on the research, the following items could be considered by agencies when managing their sign programs and meeting MUTCD retroreflectivity requirements:

- When an agency uses the direct retroreflectivity measurement approach, all signs being measured should be cleaned before retroreflectivity readings are taken to ensure that the full retroreflectivity of the sheeting is measured.
- In general, the age values in Table 4 could assist in guiding agencies in identifying the expected sign life for various sheeting material and sign type combinations. For example, these could be considered in terms of scheduling inspections if retroreflectometer measurements are collected.
- When referring to Table 4, note that the MUTCD states Type I sheeting shall not be used for yellow and black warning signs, and the results presented in this report are for reference only and do not contradict the MUTCD standard.
- Alternatively, an agency could consult the sign age prediction values in Table 4 to establish a general targeted replacement age. As a sign ages (i.e., approaches 10 years of age), more frequent retroreflectivity measurements or observations/inspections would need to be taken (i.e., yearly) to ensure that premature sign failures are identified.
- Agencies that manage sign retroreflectivity by replacing signs at the end of the manufacturer warranty period could consider a conservative approach of extending that replacement date by approximately five years based on the observations of this work. A parallel approach, such as nighttime inspections, should be done to identify signs that may be deteriorating at a faster rate before the replacement age has been reached.
- Aside from the results and recommendations presented here, agencies must continue to monitor sign condition for failure factors other than retroreflectivity, such as ensuring that signs retain their intended color (i.e., red and not faded pink for a Stop sign), are clean, are not vandalized, etc.
- When a sign is replaced, particularly when sign retroreflectivity measurement is the management approach being used by an agency, the sheeting material of the sign should be updated in the sign database. In other words, if a Type III sign is installed to replace a Type I sign, the database should be updated accordingly to reflect the current material (while still retaining the historical documentation related to the prior material).
- Future research could investigate modeling approaches that incorporate multiple factors that impact sign retroreflectivity in combination. For example, solar radiation levels, weathering

exposure, foliage shading, and other related data could also be collected and incorporated into a more robust modeling approach. The collection of that site-specific data is likely to be time consuming and costly and would require a large-scale, dedicated research project collecting all of the relevant data from start to finish.

- Future research should evaluate larger sample sizes for certain materials and sign types/colors that were underrepresented in this project (green and white guide signs, for example).

- Future research should also consider the manufacturer of a particular sheeting material. Unfortunately, in the current research, the manufacturer of the sheeting material for each sign was not tracked in the agency databases. It would be of interest to determine through future work whether there are any aging differences between manufacturers for the same type of sheeting material.

- In future research, it would be preferable to track sign retroreflectivity from the installation date through retirement, at least for a sample of signs in the field to track trends for specific signs on a reliable timeline. This recommendation is based on observations made from the sign databases accessed during this research, where it was clear that a sign had been replaced at a given point in time, and yet retroreflectivity readings from before that replacement date were also present in the data set. Ideally, a research effort would start with a sample of new signs and follow the history of each to failure. Such an evaluation would likely last over the course of decades.

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