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The Current State of Research on the Long-Term Deterioration of Traffic Signs

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ABSTRACT

The minimum retroreflectivity standard for traffic signs in the Manual on Uniform Traffic Control Devices requires that transportation agencies replace signs when they deteriorate beyond a prescribed minimum level of retroreflectivity. There are many sheeting products available with a variety of initial retroreflectivity levels for agencies to choose from when they need to install signs, but one primary concern agencies may have is their expected life. This paper serves as a compilation of studies related to the long-term deterioration of traffic signs to present what research has been completed in this area. The research compiled here shows that some signs may have an unrealistically long expected lifespan, a conclusion resulting from limitations in the study designs and their assumptions. A controlled long-term study of the deterioration of traffic signs with respect to retroreflectivity and color is encouraged to provide agencies the information necessary to select appropriate traffic sign products.

INTRODUCTION

In 2007 the Federal Highway Administration (FHWA) established, as regulation, minimum maintained retroreflectivity levels of traffic signs that became incorporated in the Manual on Uniform Traffic Control Devices (MUTCD) (1, 2). Agencies responsible for the traffic signs in their jurisdiction were provided with 7- and 10-year time frames to bring their signs in compliance with these standards. There is a wide assortment of products available for agencies replacing their signs, including the more-common beaded to a variety of prismatic sheetings.

The retroreflectivity of a traffic sign, which is a significant determinant of its conspicuity and detection distance, is measured in terms of the amount of light reflected back to its source. The coefficient of retroreflection, R_A, with units of $cd/lx/m^2$, is used to describe this. ASTM standard D4956-11 (3) classifies seven types of sheeting that may be used for permanent signs on highways (Types I, II, III, IV, VIII, IX, and XI). The classification is based on the retroreflectivity for each color at different observation and entrance angles, with a general trend of higher requirements for higher types. Apart from the level of retroreflectivity of a sign and the initial cost, the other primary issue for agencies to consider is the expected life of the sign, or in general terms, how long a sign will provide at least a minimum amount of retroreflectivity as required by the FHWA standard or the agency. The FHWA minimums, as they appear in the 2009 MUTCD, are shown in Table 1.

Table 1 Minimum Maintained Retroreflectivity Levels ($cd/lx/m^2$) (2)

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
	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			Size ≥ 48 in
	Y*; O*	Y ≥ 75; O ≥ 75			Size < 48 in
White on Red	W ≥ 35; R ≥ 7				Contrast ≥ 3:1
Black on White	W ≥ 50				—

* Indicates a sheeting type that shall not be used for this color and application
Note: Actual table in MUTCD contains more information

As part of the MUTCD standards, agencies are required to develop and implement a sign maintenance program to ensure signs are in compliance with the retroreflectivity levels shown in Table 1. A recently released synthesis study for the National Cooperative Highway Research Program (NCHRP) discusses the maintenance methods recommended by the Federal Highway Administration (4). A survey of 24 local agencies in the NCHRP study found eleven that are primarily using the expected sign life to determine when a sign should be replaced. Eleven other agencies use the expected sign life as a secondary measure. Four of sixteen state departments of transportation (DOTs) use the expected sign life as a primary measure and five use it as a secondary measure. The first objective of this paper is to compile all of the available information regarding long-term sign deterioration into one source for agencies that are developing sign maintenance programs based on expected sign life. Based on the number of agencies using expected sign life for their maintenance programs, this information will be relevant to many agencies. The second objective of this paper is to make recommendations for future research on sign deterioration based on the limitations of the studies presented here.

LONG-TERM SIGN DETERIORATION RESEARCH

Because the material used in retroreflective sheeting is susceptible to deterioration from the natural elements (the most notable being solar radiation), traffic signs have a limited lifespan. The end of service life of a sign is now better defined with the use of the minimum levels in the MUTCD. As agencies' resources are limited, with an increasing need to provide as much serviceable life as possible for the least reasonable cost, there is a high demand for accurate information about the durability of retroreflective sheeting products.

The National Transportation Product Evaluation Program (NTPEP) conducts 3-year exposure tests of sign sheeting products, evaluating their performance at designated intervals. The weathering is conducted with the signs facing south at a 45-degree elevation angle, which accelerates the deterioration process. The assumption of these tests is that the weathering is accelerated at a 2:1 ratio (5), though this assumption may be outdated or not even applicable for prismatic sheeting. The data from these tests are used by transportation agencies as they identify the products to use for signs in their jurisdictions.

Unfortunately, the NTPEP studies have one significant limitation: 6 years of data (from a 3-year accelerated exposure) is generally not long enough to determine the time required for a sign to fail. This exposure length is insufficient to provide enough information about the service life of sign sheeting for agencies to make key decisions with substantial financial implications.

To address the issue of sign life (with respect to retroreflectivity), a number of studies have been completed that evaluated the retroreflectivity of traffic signs or sign sheeting products with respect to age. Summaries of these studies and their findings are presented here in approximate chronological order. Most of them even published predictive equations that help identify the point at which it is expected for signs to fail in retroreflectivity. Sheeting products have changed substantially in recent years and the results of the earliest studies given here are over 20 years old. They are included because their findings still have relevance due to their exhaustive efforts to establish a foundation for estimating service life. After the study summaries below, Table 2 and Table 3 list the main predictive models they developed for ASTM Type I and Type III signs, respectively. One study developed predictive models for yellow and yellow-green Type IX signs, which are given in Table 4. The predictive equations for retroreflectivity given in the tables use the age of signs in years.

FHWA Study

In 1991 Black et al. (6) completed a nation-wide sign deterioration study, giving retroreflectivity deterioration curves with respect to sign age from a sample size of 5,722 signs. The performance of white, yellow, red, and green Engineering Grade and High Intensity (ASTM Types I and III) signs were evaluated. The sample size was very extensive, allowing the researchers to evaluate the effect of sign orientation, elevation, solar radiation levels, heating degree days (a temperature-based metric), and precipitation. Linear equations of predicted retroreflectivity by age were given (shown in Table 2 and Table 3), though the FHWA report also includes other models with the additional climate- and geographic-based variables. Sign orientation and solar radiation levels were not significant variables in any of the models. One additional finding was that signs 1-2 years of age have considerable variability in retroreflectivity.

Australia Study

Jenkins and Gennaoui (7) evaluated the retroreflectivity by age of 2,144 in-service signs from all six Australian states. The study was completed in 1990. At that time, there were no in-service retroreflectivity requirements in Australia. However, Australian Standard number 1906.1 (similar to ASTM D4956) regulates the minimum retroreflectivity levels of new Class 1 (the equivalent of High Intensity, ASTM Type III) and Class 2 (the equivalent of Engineering Grade, ASTM Type I) sheeting. Standard 1906.1 had been established in 1976.

No significant effect from sign orientation was discovered (north-facing signs were expected to deteriorate faster), though the researchers noted consistently higher deterioration rates in industrial areas. Deterioration curves were not developed for Red Class 2 (ASTM Type I), Yellow Class 1 (ASTM Type III), and Green Class 1 (ASTM Type III) signs due to small sample sizes or lack of correlation with age. The deterioration curves given in the study are reproduced in Table 2 and Table 3.

Purdue University Study

In 2001 and 2002 Bischoff and Bullock (8) measured the retroreflectivity of 1341 in-service ASTM Type III red, white, and yellow signs in Indiana, and found a high level of conformance with FHWA minimum requirements. Focusing on signs that were approximately 10 years old, they measured sign retroreflectivity before and after wiping the sign face with a dry sponge. Deterioration models based on age were developed for each color of sign under wiped or unwiped conditions, but only the models from unwiped signs (given in Table 3) used averages of each sign’s three retroreflectivity readings. Sign orientation was also analyzed, but no difference in retroreflectivity with respect to orientation was found, even when accounting for the age of the signs. There was, however, a noticeable increase in variability of retroreflectivity for south-facing red signs. Though they found no statistical correlation with retroreflectivity, the researchers also measured the sign height and the distances from the pavement and lane edges.

Oregon Study

The Oregon DOT (ODOT) (9) measured the retroreflectivity of 137 white, yellow, green, and red ASTM Type III in-service signs. An average of ten readings per sign was used. The signs were washed prior to taking measurements. In addition to age, the orientation of the sign was evaluated. No model equations were given for the retroreflectivity by age, but linear relationships are shown in Figure 1, copied from the ODOT report. The effects of orientation on retroreflectivity were also examined, though no statistical test was performed. Retroreflectivity values were lowest for white, yellow, and green backgrounds in west-facing signs and red backgrounds in south-facing signs. There was no consideration for age in the orientation evaluation. As noticed in Indiana, there was substantial variability in the retroreflectivity of south-facing red signs.

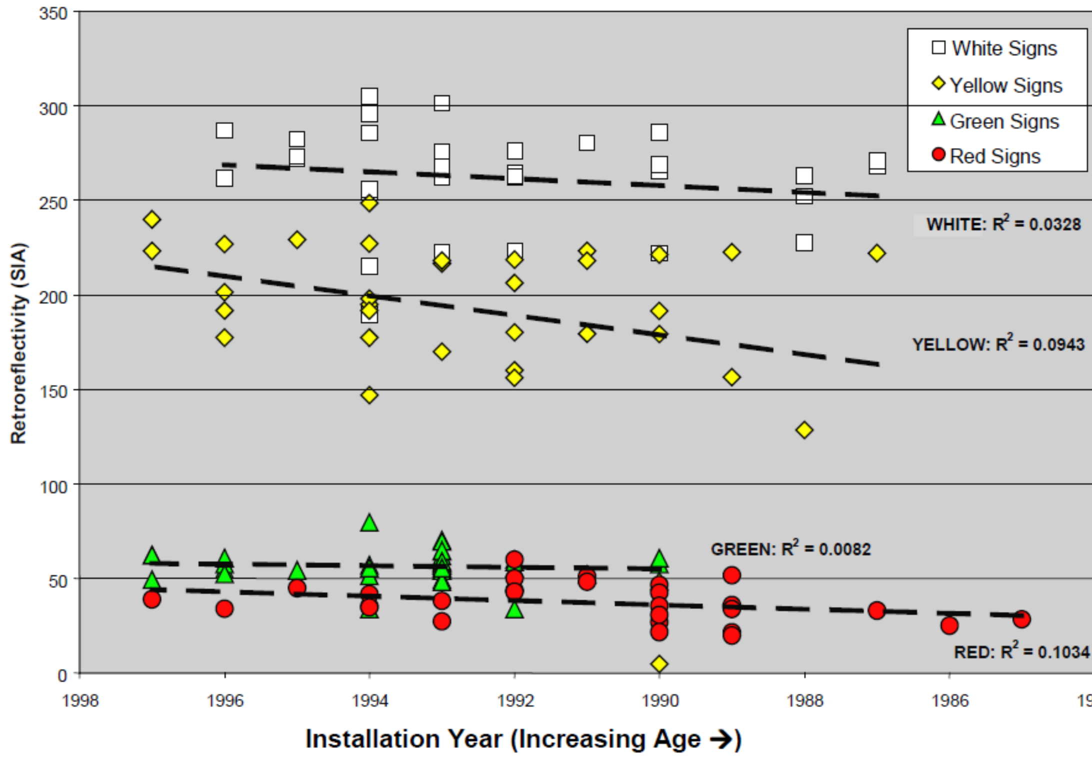

Figure 1 Linear deterioration models from Oregon signs (9).

Louisiana State University (LSU) Study

Wolshon et al. (*10*) measured the retroreflectivity of 237 in-service white, yellow, and green ASTM Types I and III in-service signs before and after washing the signs. Predictive models for average retroreflectivity were developed using the variables age, edge of pavement distance, and orientation, though edge of pavement distance and orientation were not statistically significant factors. In the interest of evaluating retroreflectivity with respect to age only, the effects of orientation and edge of pavement distance have been removed from the models given in Table 2 and Table 3.

North Carolina State University (NCSU) Study

Rasdorf et al. (*11*) measured the retroreflectivity of 1,047 white, yellow, red, and green ASTM Types I and III in-service signs in 2005. By the time follow-up measurements were made in 2006, 192 signs (18 percent of the original sample) had been replaced. The most common replacement was a Type III sign replacing a Type I sign. The researchers estimate that an 18 percent replacement rate is unusual and used documented expenditures and average cost calculations to assert that only 6.0 percent of all signs were replaced in 2005: 3.1 percent due to low retroreflectivity or natural damage and 2.9 percent due to vandalism.

The researchers generated five deterioration models for each color and type of sign using different relationships of retroreflectivity and age and selected "best-fit" curves based on R^2 correlation. These models are given in Table 2 and Table 3. More than one best-fit curve was identified for some of the eight color and sign types. When this was the case, only the linear model is shown in the table here.

Vermont Study

In 2008 the Vermont Agency of Transportation (*12*) measured the retroreflectivity of 398 white, yellow, green, and red Type III in-service signs and 220 yellow and yellow-green Type IX in-service signs. The Type IX signs had only been in service for 6 years. Similar to other studies discussed above, orientation and offset distance were measured, but no significant correlation was noted. North-facing signs were observed to have higher retroreflectivity than south-facing signs, though the authors note the limitations of the small sample size in the study. The deterioration models for the Type III and Type IX signs are shown Table 3 and Table 4, respectively. Only the Type III signs have a linear deterioration relationship with time.

Texas Transportation Institute (TTI) Studies

In 2009 TTI (*13*) measured the retroreflectivity of 859 white, yellow, and red Type III in-service signs in seven regions of Texas to identify the rate of compliance with MUTCD minimum requirements. Ré et al. found a 99 percent compliance rate for all measured signs, with a 2 percent failure rate for sign age 10 to 12 years and 8 percent failure rate for sign age 12 to 15 years. As has been done in other studies, the researchers measured the sign orientation but found no strong correlation with retroreflectivity. Linear prediction models were generated and are given in Table 3.

TTI has also used accelerated weathering racks to perform experiments on fluorescent orange and white, yellow, red, green, and orange non-fluorescent Types I to IX sheeting (*14, 15*). The accelerated weathering was conducted similar to the NTPEP program, but for 24 months for the fluorescent sheeting and 10 years for the non-fluorescent sheeting. Both of the studies show that color fading is as significant of an issue in sign deterioration as retroreflectivity. Although these studies were more controlled than the in-service evaluations, their conclusions are limited because the sample sizes were insufficient, the true effects of accelerated weathering compared to regular weathering are not certain, and the sheeting products had not been fully manufactured into signs.

Table 2 Predictive Models for ASTM Type I Signs (6, 7, *10*, *11*)

Color (Min. R_A)	Study	Location of Signs	Publication Year	Washed or Unwashed	Sample Size	Prediction Model	Years to Failure (2009 MUTCD)
White (R_A=50)	FHWA	U.S.	1991	Washed	1084	115.1-4.85×Age	13.4
	Australia	Australia	1990	Washed	N/A	116-5.62×Age	11.7
	LSU[a]	Louisiana	2002	Unwashed	40	89.2-6.41×Age	6.1
	LSU[a]	Louisiana	2002	Washed	40	101.7-6.10×Age	8.5
	NCSU[b]	North Carolina	2006	Unwashed	335	68.8-1.41×Age	13.4
Yellow (R_A=75)	FHWA	U.S.	1991	Washed	931	88.2-3.39×Age	Not Used
	Australia	Australia	1990	Washed	N/A	96-5.07×Age	Not Used
	LSU[a]	Louisiana	2002	Unwashed	42	61.7-2.73×Age	Not Used
	LSU[a]	Louisiana	2002	Washed	42	72.0-2.59×Age	Not Used
	NCSU[c]	North Carolina	2006	Unwashed	351	62.7-2.04×Age	Not Used
Red (R_A=7)	FHWA	U.S.	1991	Washed	697	22.9-0.95×Age	16.7
	NCSU[c]	North Carolina	2006	Unwashed	50	13.1-0.63×Age	9.6
Green (R_A=7)	FHWA[d]	U.S.	1991	Washed	704	16.3-0.56×Age	16.6
	Australia	Australia	1990	Washed	N/A	22-1.02×Age	14.7
	LSU[a]	Louisiana	2002	Unwashed	42	12.9-0.57×Age	10.3
	LSU[a]	Louisiana	2002	Washed	42	15.9-0.62×Age	14.3
	NCSU[c]	North Carolina	2006	Unwashed	46	13.3-0.45×Age	13.9

a Original model included variables for edge of pavement distance and orientation (though not significant). Their effects have been averaged to show age as the only independent variable.

b Due to low correlation, the researchers did not officially recommend using any model for this color and type. Regardless, the linear model is shown here.

c The study also includes other recommended models. Only the linear model is shown here.

d The study specifically mentions that overhead guide signs were not included in the evaluation.

Table 3 Predictive Models for ASTM Type III signs (6–8, *10–13*)

Color (Min. R_A)	Study	Location of Signs	Publication Year	Washed or Unwashed	Sample Size	Prediction Model	Years to Failure (2009 MUTCD)
White (R_A=50)	FHWA	U.S.	1991	Washed	909	311.0-4.61×Age	56.6
	Australia	Australia	1990	Washed	N/A	294-4.05×Age	60.2
	Purdue	Indiana	2002	Unwashed	683	253.7-0.86×Age	236.0
	LSU[a]	Louisiana	2002	Unwashed	35	297.7-6.78×Age	36.5
	LSU[a]	Louisiana	2002	Washed	35	317.9-3.66×Age	73.2
	NCSU[b]	North Carolina	2006	Unwashed	56	262.6-0.71×Age	298.0
	Vermont[c]	Vermont	2009	Unwashed	108	$436.8\times Age^{-0.355}$	740.4
	TTI	Texas	2012	Unwashed	511	265-6.2×Age	34.7
Yellow (R_A=75)	FHWA	U.S.	1991	Washed	409	246.4-3.21×Age	53.5
	Purdue	Indiana	2002	Unwashed	243	222.5-3.58×Age	41.2
	LSU[a]	Louisiana	2002	Unwashed	32	246.1-9.81×Age	17.4
	LSU[a]	Louisiana	2002	Washed	32	279.7-10.06×Age	20.5
	NCSU	North Carolina	2006	Unwashed	79	$216.4+1.27\times Age-0.251\times Age^2$	26.4
	Vermont[c]	Vermont	2009	Unwashed	91	329.9-78.8×Ln(Age)	25.4
	TTI	Texas	2012	Unwashed	147	251-6.8×Age	25.9
Red (R_A=7)	FHWA	U.S.	1991	Washed	662	38.7+0.61×Age	Never
	Australia	Australia	1990	Washed	N/A	16+3.1×Age	Never
	Purdue	Indiana	2002	Unwashed	415	51.8-2.03×Age	22.1
	NCSU[d]	North Carolina	2006	Unwashed	84	59.6-2.66×Age	19.8
	Vermont[c]	Vermont	2009	Unwashed	94	72.9-4.35×Age	15.1
	TTI	Texas	2012	Unwashed	196	52-1.0×Age	45.0
Green (R_A=25)	FHWA	U.S.	1991	Washed	326	55.2-1.82×Age	16.6
	LSU[a]	Louisiana	2002	Unwashed	46	48.0-.42×Age	55.2
	LSU[a]	Louisiana	2002	Washed	46	61.8-0.75×Age	49.3
	NCSU	North Carolina	2006	Unwashed	46	$52.0+4.24\times Age-0.81\times Age^2$	8.9
	Vermont[c]	Vermont	2009	Unwashed	105	$96.1\times Age^{-0.204}$	740.4

a Original model included variables for edge of pavement distance and orientation (though not significant). Their effects have been averaged to show age as the only independent variable.

b Due to low correlation, the researchers did not officially recommend using any model for this color and type. Regardless, the linear model is shown here.

c Few signs in the sample were older than six years in age.

d The study also includes other recommended models. Only the linear model is shown here.

Table 4 Predictive Models for ASTM Type IX Signs (*12*)

Color (Min. R_A)	Study	Location of Data	Publication Year	Washed or Unwashed	Sample Size	Prediction Model	Years to Failure (2009 MUTCD)
Yellow (R_A=75)	Vermont[a]	Vermont	2009	Unwashed	89	310.74×Exp(-0.0192×Age)	74.0
Yellow-Green (R_A=75)	Vermont[a]	Vermont	2009	Unwashed	131	484.59×Exp(-0.024×Age)	77.7

a Only six years of data were available at the time of this study.

CURRENT STUDY LIMITATIONS

One concern practitioners have with conducting sign deterioration studies over a long time period is that products change within the time frame of the weathering, analysis, review, and dissemination processes. Because sheeting products are constantly evolving, with a general movement to more efficient sheeting, there will be new products to evaluate by the time an original study concludes. Additionally, the material composition of products meeting the ASTM D4956 criteria may change over time, even if the ASTM standard does not change. This leads to changes to the true estimated service life of a given type of sheeting.

It has been over twenty years since the completion of the only national (United States) sign deterioration study to date, with signs evaluated before 1990. The 5,722 signs from that study were taken from a total of eight regions selected by geography and climate (6). Like most studies, the FHWA effort only included in-service signs. Of particular interest is the information in the report about the ages of the in-service signs. Figure 2, created from tabular data in the report, shows that the number of signs in the data set decreases with age. The FHWA study is not the only one to show the number of signs by age. Table 5, with data from Australia, also shows a decrease in number of signs by age. Data provided by Vermont, shown in Figure 3, also shows a decrease. Note that most signs in the Vermont study are younger than six years.

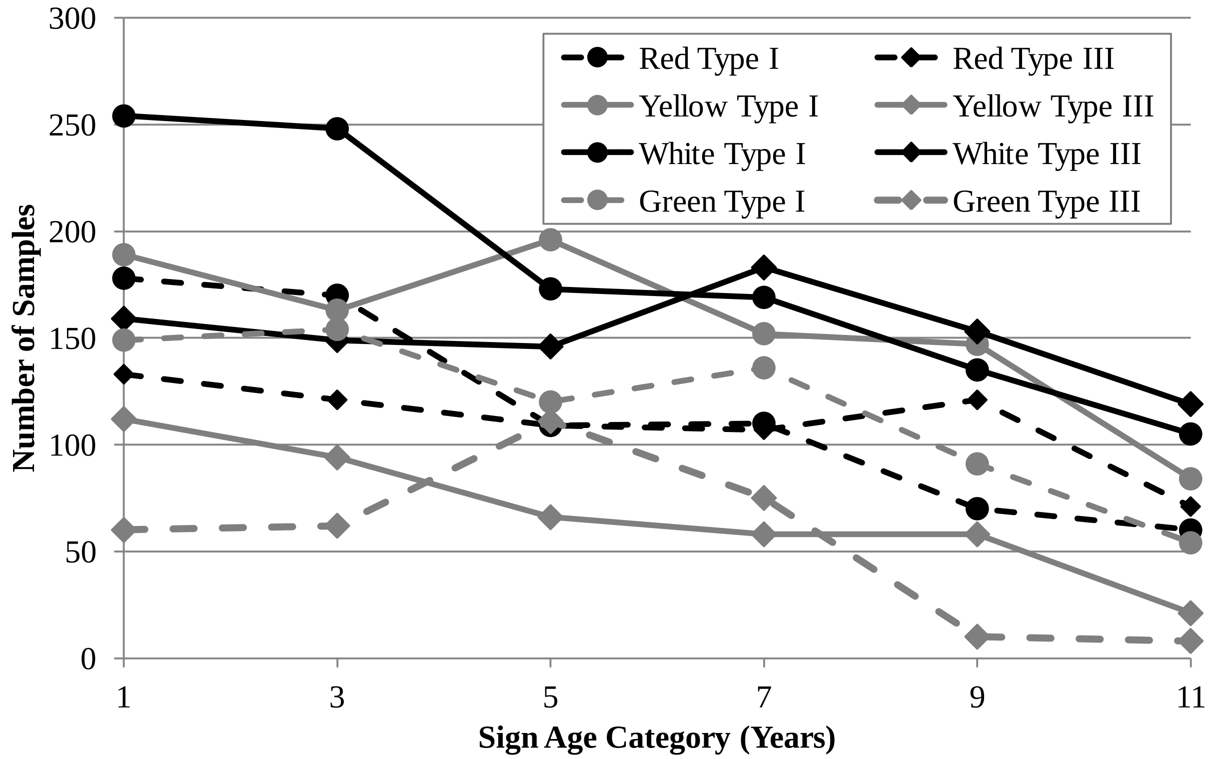

Figure 2 Number of samples in FHWA study by age group (6).

Table 5 Percent of Tested Signs by Age in Australia (7)

Up to 4 years	41%
5-7 years	20%
8-12 years	30%
12-19 years	9%

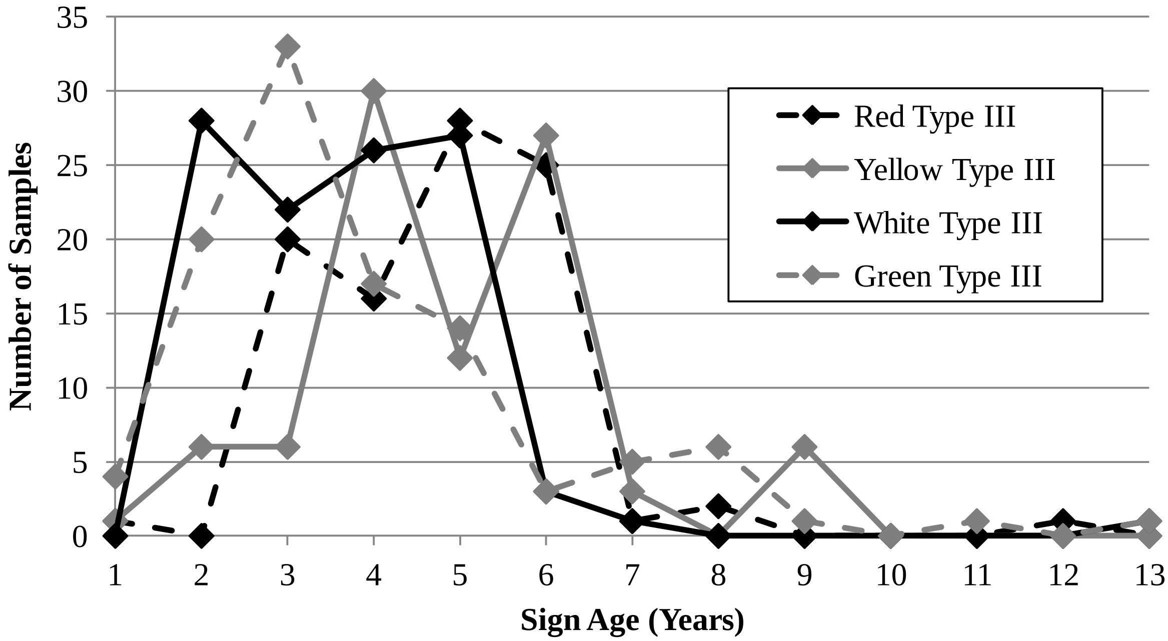

Figure 3 Number of samples in Vermont study by age (*12*).

NCHRP Report 346 (*16*), *Implementation Strategies for Sign Retroreflectivity Standards*, provides information relevant to agencies developing a sign maintenance program. The study provides data on the ages of traffic signs in Kossuth County, Iowa, which are relevant here. The data, though as old as the report published in 1992, are shown in Figure 4. No explanation is given for the unusual increase in number of signs at four years of age, though the downward trend in number of signs by age would be clearer if this outlier were ignored. Sixty percent of the signs are less than five years old.

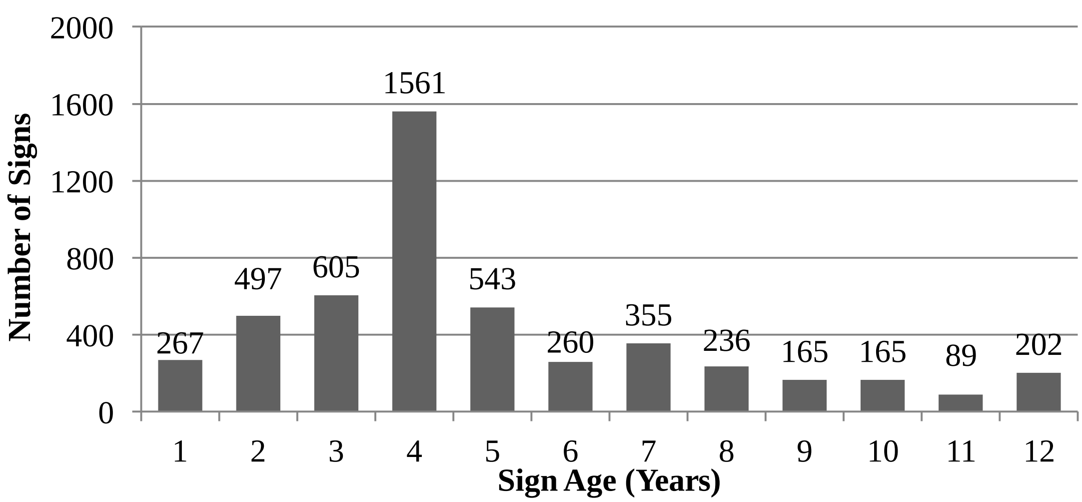

Figure 4 Number of signs by age for NCHRP study in Kossuth County, Iowa (*16*).

If the samples from the retroreflectivity studies discussed here were all selected in an approximately-random manner, as some of the reports claim, there are two likely reasons for the presence of more "young" signs than "old" signs. One is that agencies are placing signs in service more often than signs are being retired: there is a yearly net increase of signs. The other reason is that as old signs deteriorate, which sometimes occurs quicker than anticipated, they are replaced with new signs. The significance of this issue must not be understated and has been poorly addressed. When signs that have deteriorated are replaced by new signs, it is impossible for the deteriorated signs to be included in a study that only measures in-service signs. The predictive equations are thus applicable only to signs that will never fail in retroreflectivity. The prediction cannot account for the signs that deteriorate and fail before expected and are replaced early. This is why some of the deterioration studies predict an unusually long lifespan for signs, as shown in Table 3. If agencies rely on these results alone, they will invariably over-predict the service life of their signs.

Most of the studies discussed here attempted to identify a relationship between sign orientation and deterioration. The FHWA, Australia, Purdue, Oregon, LSU, Vermont, and TTI studies each investigated the effect of sign orientation on deterioration (6–*10, 12, 13*). Earlier studies conducted in New York and North Dakota also attempted to identify sign orientation as a significant factor in deterioration (*17, 18*). None of the studies provide evidence that the direction a sign faces has a significant impact on deterioration. Because these studies only measured in-service signs, which are replaced when they fail in retroreflectivity, it is not surprising that no correlation between orientation and deterioration has been found.

Studies based on in-service signs do not account for the signs' initial retroreflectivity. ASTM D4956-11 (3) contains minimum requirements for different types of sheeting, but individual products may exceed the ASTM standard and possess unique initial values of R_A. This issue was discussed in the FHWA report in which the researchers observed substantial variability among relatively young signs. A sign with a higher initial level of retroreflectivity will likely have a longer service life.

RESEARCH NEEDS

The issue of a controlled study for sign deterioration was addressed over 30 years ago by Kenyon et al., who studied the deterioration of signs in New York (*17*). They noted the inherent bias of an in-service sign evaluation that disregards signs removed because of failure in retroreflectivity, vandalism, damage, or other causes. They state that "to obtain an unbiased estimate of sheeting service life, it would be necessary to start with a sample of new signs and follow the history of each to failure. However, even such an effort might be unproductive because of manufacturing changes that result in changes in the actual sheeting installed over time. Thus, by the time average sheeting life is reliably estimated, the material supplied may differ considerably from that tested." At the time of the study, enclosed-lens sheeting (ASTM Type I) and high-intensity sheeting (ASTM Type III) were the most common sheeting products. Although the material compositions of the sheeting may have changed during the previous 30 years, the warranty periods for the signs have mainly remained consistent. Other sheeting types have now been available for a long time, but little information has been produced regarding their expected life.

Of all the sign types and colors evaluated and discussed here, there was rarely a statistically significant contribution to deterioration from any factor other than age. Other than age, sign orientation was the factor most often included for additional study despite repeated findings that its effect could not be found. There must be a reason for researchers to consistently hypothesize that south-facing signs deteriorate at a faster rate than signs facing other directions (or north-facing signs in the southern hemisphere, as hypothesized in Australia). A study completed by TTI in 1996 (*18*) included surveys with sign crews from the Texas DOT that asked about what factors, in their experience, contribute most to the service life of signs. The direction a sign faces was the top answer. It is clear that the data in an in-service study are not sufficient to identify the effect of sign orientation on deterioration rates.

The Vermont study (*12*) noted that, at a recent NTPEP annual conference, state departments indicated that fading pigments and a decrease in contrast between sign sheeting background and legend may be a more important factor in determining sign life than decreasing retroreflectivity. The long-term TTI studies confirm that color fading is occasionally more noticeable than deterioration of retroreflectivity, especially for red, orange, and yellow signs (*14*, *15*). There is an apparent lack of research regarding sign durability with respect to color and the effect color fading has on retroreflectivity.

There is a significant gap in the available knowledge about the deterioration of traffic signs. Although the long-term performance of retroreflective signs has been analyzed a number of times, the methods used have been insufficient for identifying trends that can extend to all signs. A controlled experiment of sign deterioration has not yet been conducted, with only experimental methods proposed by NCSU in 2009 (*19*). With a wide array of sheeting products to select from, agencies need better information regarding their expected life. Manufacturer warranties, though helpful, cannot be relied upon alone because they tend to provide conservative estimates of service life to reduce the manufacturers' risk. More accurate information, with statistical validity, will improve the practices of agencies that use a sign's expected life as the primary method of replacing signs in their maintenance programs.

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