Analysis of In-Service Traffic Sign Retroreflectivity and Deterioration Rates in Texas

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Roadway traffic signs are a fundamental medium for conveying critical information to the road user. In 2009, the *Manual on Uniform Traffic Control Devices* (MUTCD) set minimum retroreflectivity requirements for such signs. Developing sign management strategies on the basis of service life is one approach to achieving compliance with minimum MUTCD sign retroreflectivity requirements. Generating deterioration rates and prediction models from a sample of in-service sign measurements is one method for establishing expected service life. In 2009, researchers collected a sample of 859 ASTM D4956 Type III retroreflectivity signs in seven regions of Texas. The objective of this study was to assess the compliance of Type III signs throughout Texas and to generate useful data that would improve sign maintenance practices. The overall sign sample compliance rate was 99%. The observed likelihood of failure was 2% for signs that were between 10 and 12 years old and 8% for signs that were 12 to 15 years old. The linear prediction models revealed differences in deterioration rates between the regions. The differences ranged from –2 to –8 candelas (cd)/lx/m^2 per year for white sheeting and –1 to –12 cd/lx/m^2 per year for yellow sheeting. Models exhibited poor correlations between predicted and measured data, and the *R*-squared values ranged from .10 to .30. Despite the weak relationships, the models revealed insightful trends and provided a broad perspective on the Texas Department of Transportation's current sign practices. Deterioration rates and prediction models can be valuable components in a comprehensive sign maintenance program, but by themselves they do not ensure compliance with sign retroreflectivity requirements.

Roadway traffic signs are a fundamental medium to convey critical information to the road user. Drivers should be able to view and comprehend such signs in both daytime and nighttime conditions. For nighttime visibility, signs not internally illuminated should use retroreflective material on their surfaces. Retroreflective materials return light back to the original source with a minimum scattering of light. Light from a vehicle's headlamps is reflected from the sign's surface back to the driver, and it gives the sign an illuminated appearance. The efficiency or capability of sign material to reflect light is quantified by the coefficient of retroreflection (R_A), which is the ratio of light returned, as opposed to the light that strikes a defined section of sign surface area. R_A is expressed in units of candelas per lux per meters squared (cd/lx/m^2) and is typically measured at an observation angle of 0.2° and an entrance angle of –4.0°.

In 1993, Congress required the Secretary of Transportation to revise the *Manual on Uniform Traffic Control Devices* (MUTCD) to include "a standard for a minimum level of retroreflectivity for pavement markings and signs which apply to all roads open to public travel" (U.S. Department of Transportation and Related Agencies Appropriations Act of 1992, Public Law 102-388, 106 Statute 1520, Section 406).

The 2009 MUTCD contains minimum maintained retroreflectivity requirements and stipulates that "public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels" (*1*). There are two fundamental approaches to sign maintenance strategies: assessment and management. Assessment methods involve retroreflective evaluations of individual signs by either nighttime visibility inspection or sign retroreflectivity measurements. Management methods include the expected sign life, blanket replacement, and control signs method. All three management methods are on the basis of the expected service life of specific sign sheeting types. The service life is the longest length of time that a sign will be used in the field while it remains compliant with the minimum retroreflective requirements.

Use of manufacturer warranty values as a measure of expected service life is practical and widely accepted. Each manufacturer provides a warranty year as assurance of adequate sign performance under certain conditions. The Texas Department of Transportation (DOT) warranty period and expected service life is 10 years for Type III, high-intensity, beaded sheeting (Departmental Materials Specification 8300, Sign Face Materials). Warranty values, however, incorporate a factor of risk on the part of the manufacturer and are inclined to be fairly conservative. Signs may last longer than the warranty period, which has led to additional retroreflective research and exploration. States, such as Delaware, Kansas, Maine, Missouri, and North Dakota, are exploring the use of a 12-year service life for Type III sheeting (*2*). Apart from public agencies, commercial companies offer sign management software with service life projections and sign replacement scheduling applications. In this study it was assumed that some of the strategies of the state agencies and commercial companies were established from in-service sign retroreflective measurements and deterioration modeling. In theory, models generated from in-service measurements should estimate sign retroreflectivity and predict when a sign may need replacement.

In the fall of 2009, researchers at the Texas Transportation Institute initiated a project that would recommend a comprehensive sign

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maintenance strategy for Texas DOT. One task in the project was to obtain a sample of retroreflective sign measurements throughout Texas. The sample included measurements from 859 Type III signs in seven statewide regions. The objective was to assess the compliance rates of Type III signs throughout Texas with MUTCD minimum retroreflectivity requirements for traffic signs and to generate useful data to improve sign maintenance practices. The key elements in the overall objective were to

- Assess compliance rates in Texas with MUTCD minimum retroreflectivity requirements for traffic signs,
- Identify factors that significantly affect sign retroreflectivity,
- Generate sign deterioration rates and service life projections, and
- Determine the usefulness of the models and estimates.

The 1st paper I read

BACKGROUND

One of the first studies to assess deterioration rates was conducted in 1992 by Black et al. for FHWA (*3*). The objective was to determine factors that contributed to sign retroreflective degradation and to formulate models on the basis of significant factors to accurately estimate retroreflectivity. The researchers collected retroreflective readings from 5,722 signs in 18 locations throughout the United States. Along with measurements, the collection process included identification of sheeting color, type, contrast ratio, sign direction, ground elevation, area type, and sheeting age. The measurements revealed that Type III signs performed adequately for up to 12 years. Within the generated scatter plots, variability was high and data points widely dispersed. Values for white Type III sheeting at 5 years, for example, ranged between 150 and 390 cd/lx/m^2. For Red Type III sheeting, values were between 10 and 90 cd/lx/m^2. The analysis determined that sheeting age, ground elevation, and temperature were significant factors in sign deterioration. The sign direction and solar radiation variables were not found to be acceptable predictors of in-service sign retroreflectivity. With the significant factors, linear prediction models were created for each Type III sheeting color. The linear prediction models estimated the retroreflectivity of a specific sheeting type on the basis of the installation age. The equations were deemed to be reasonable predictors of retroreflectivity, but model correlation was poor, and the *R*-squared values ranged from .20 to .50. (*R*-squared values range from 1 to 0 and are used to establish model adequacy or goodness of fit. A value close to 1 indicates that there is little variance between the independent and dependent variables, and a value close to 0 indicates that there is little to no meaningful correlation in the model.)

Aka, said that was study faulty

Ten years later, the Louisiana Department of Transportation and Development produced another study that generated retroreflectivity deterioration models. The objectives of the study by Wolshon et al. were to assess current compliance rates, determine influential factors, and create statistical models to predict retroreflectivity relative to age (*4*). The data collection included the measurement of 237 signs in Louisiana and the identification of key environmental factors that might affect sign deterioration. The Louisiana Department of Transportation and Development results showed that 92% of the signs under the 10-year warranty performed above the minimum requirements. Of the signs past the warranty period, 43% were in compliance. Linear deterioration models were generated for each type and color of sign sheeting. The Type III models tended to be relatively flat. Sign orientation and the offset distance to the road were not statistically significant contributory factors to retroreflective deterioration (*4*). The correlation between the models and field data varied so much that the study recommended application of the models to local and site-specific data only.

A study at Purdue University, West Lafayette, Indiana, by Bischoff and Bullock applied an approach similar to the one employed by Wolshon et al., but the main objective of the Purdue University study was to determine if Indiana's current Type III, 10-year service life needed to be shortened or could be extended (*5*). In total, 1,341 Type III roadway sign retroreflectivity measurements were recorded and sheeting colors included red, yellow, and white. Many of the signs exceeded the 10-year warranty period and installation ages went up to 16 years. Overall, the analysis found only seven signs that did not comply with the minimum requirements, and signs that were more than 10 years old performed adequately. Linear prediction models were created, which showed that red Type III sheeting produced the highest *R*-squared value at .32, and white Type III sheeting displayed the lowest at .02. Much disparity was seen in the regression models, and differences became more evident as sign age increased. In the end, the prediction models could not be fully supported. The study did, however, recommend that the service life of white and yellow Type III sheeting be extended to 12 years, while red Type III sheeting remain at 10 years.

The most recent expected service life study was conducted in 2006 by Rasdorf et al. for the North Carolina DOT (*6*). The objectives and approach were similar to those of the previous studies. Measurements were compiled from 1,057 Type I and Type III signs in North Carolina and included the four colors. Models were generated from linear, logarithmic, polynomial, power, and exponential functions. Most of the models exhibited poor correlation, and the *R*-squared values ranged from .01 to .48. Within the sheeting types, white had the weakest relationship, while red showed the strongest. These findings were similar to those found in the Bischoff and Bullock study (*5*). Despite the poor correlation, most Type III signs performed well, and the models projected long-term retroreflective compliance beyond 10 years.

Overall, a review of the research showed that Type III, high-intensity, beaded sign sheeting appeared to outlast the typical 10-year warranty period, although variability was high within the data sets, and most of the prediction models exhibited weak correlations. Table 1 contains the *R*-squared values for the studies that provided linear regression models. For each model, the dependent variable was retroreflectivity, and the independent variable was sign age. It was assumed that the linear regression models were generated by simple statistical software and on the basis of the method of least squares. The *R*-squared values in the table ranged from .35 to .01, which indicated weak relationships between predicted and measured values.

Models and deterioration rates also differed greatly between studies. The rate of change in retroreflectivity for red Type III sheeting in the Purdue University and North Carolina DOT studies, for example, were in the range of –2.0 to –2.5 cd/lx/m^2 per year, while the FHWA had a positive value of 2.5 cd/lx/m^2 per year. The difference in rates might have resulted from differences in sign fabrication. The FHWA study contributed the positive rate to the silkscreen sign manufacturing process, in which transparent red ink was screened over white Type III sheeting (*3*). Over time, the red ink faded, and the retroreflectivity increased because of the underlying white sheeting. Conversely, more of the red signs in the Purdue University and North Carolina DOT studies might have been fabricated with the overlay process, in which electrocut films were placed over the white sheeting.

It seems like researchers are trying to provide a model/life exptenancy that fits all signs. Not working out too great.

TABLE 1 Previous Type III Retroreflective Linear Prediction Model Results

Sheeting Color	Study	Linear Equation	R^2	Predicted R_A Values (cd/lx/m^2) at 5 Years	10 Years	15 Years	Projected Service Life (years)
Red	FHWA	$y = 2.50x + 19.8$	.13	32	45	57	NA
	Purdue	$y = -2.03x + 51.8$	.32	42	32	21	22
	NCDOT	$y = -2.66x + 59.6$	.35	46	33	20	20
White	FHWA	$y = -4.81x + 304.1$	.19	280	256	232	53
	Purdue	$y = -0.86x + 253.7$	.02	249	245	241	236
	NCDOT	$y = -0.71x + 262.6$	.01	259	255	252	298
Yellow	FHWA	$y = -4.58x + 247.9$	.31	225	202	179	38
	Purdue	$y = -3.58x + 222.5$	.19	205	187	169	41
	NCDOT	$y = -1.51x + 218.6$	.06	211	204	196	95

NOTE: Data and equations were extracted from Black et al. (*3*), Bischoff et al. (*5*), and Rasdorf et al. (*6*). R_A = coefficient of retroreflection; NA = not applicable; NCDOT = North Carolina DOT.

Another noticeable difference was observed among the white Type III equations (Table 1). Of the white sheeting equations, the 10-year predicted retroreflective values were close; they differed only by 11 cd/lx/m^2. Although the models were assumed to be similar, they differed considerably. The FHWA equation exhibited a rate of about −5 cd/lx/m^2 per year, whereas the Purdue University and North Carolina DOT studies had a rate of about −1 cd/lx/m^2 per year. These models may be appropriate for 10-year projections but not when it comes to forecasting the end of sign service life. The last column of Table 1 shows service life projections generated by the models. For instance, the black on white sheeting minimum requirement in the MUTCD is 50 cd/lx/m^2. The FHWA model projected sign compliance for 53 years and more than 200 years for both the Purdue University and North Carolina DOT studies. Similarly, the yellow projected service life periods were also high and ranged from 38 to 95 years. The probability that Type III sheeting would remain in compliance after 53 years was highly unlikely let alone for 298 years.

Overall, it was difficult to place a great deal of confidence in some estimates, and certain models might have had limitations or isolated applications. Despite these limitations, however, the prediction models did provide a basic and broad understanding of the observed trends from various studies.

DATA COLLECTION

This section explains the methodology that was employed to collect retroreflective sign measurements. Effective techniques from earlier studies were used, with modifications to address specific needs. Overall, the goals were to ensure reliable and representative sign measurements, and to ensure safety by minimizing worker exposure to the roadway.

Sign Measurements

Data collection entailed the use of a handheld contact retroreflectometer to measure traffic sign retroreflectivity. Measurements were collected at an observation angle of 0.2° and an entrance angle of −4.0°, as noted in the 2009 MUTCD (*1*). Data collectors measured signs with Texas DOT installation or fabrication stickers only. If a sign did not have a Texas DOT sticker, or if a sticker was not legible, measurements were not taken. A minimum of three readings per sign color (excluding black) were recorded for each sign. This study encompassed measurements from unwashed red, white, and yellow Type III, high-intensity, beaded signs.

Some deliberation took place on whether to measure washed or unwashed signs. Dirt and dust buildup could vary from sign to sign, and the measurement of washed signs might lead to more direct comparisons. The Wolshon et al. study determined about a 25% increase in retroreflectivity when Type III signs were washed (*4*). In contrast, the Bischoff and Bullock study concluded that sign washing did not significantly affect the retroreflectivity (*5*). In the study reported here, it was decided to measure signs that were unwashed, because that was the condition in which they were seen by drivers on the roadway, and Texas DOT staff evaluated unwashed signs during nighttime visual inspections.

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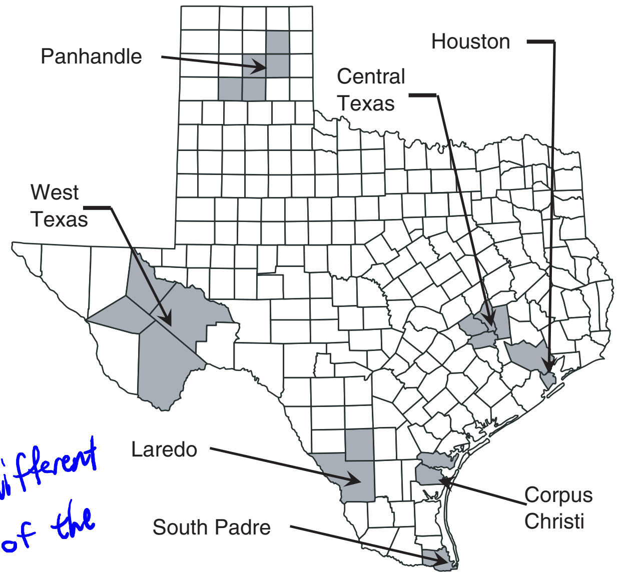
Similar debate occurred as to whether signs should be classified by the fabrication process, by the specific manufacturing vendor, or both. An FHWA study determined that silkscreen and overlay stop signs produced different deterioration rates and measurements (*3*). It could be assumed that various manufacturing vendors fabricated slightly different sheeting products. A single vendor might modify a product from year to year or discontinue sheeting lines. Classification by fabrication, vendor, or both, might be beneficial, but it could lead to complications and problems with the sign sample. Ultimately, the current Texas DOT classification method was selected, which groups sheeting into five categories on the basis of ASTM and material type (beaded or prismatic).

sheeting

Data collectors also assessed the visual condition of measured signs, which included daytime appearance, message integrity, and general condition. Assessment of the daytime visual condition relied on the data collectors' personal judgment. The categories were the following:

- Good. The sign's color, surface, message integrity, and overall appearance showed no notable damage, vandalism, weathering, or distress.
- Adequate. The sign showed moderate weathering or distress that did not affect the message integrity.
- Poor. The sign's message integrity and overall appearance were compromised by damage or distress, and the sign should be replaced in a timely manner.



Many different parts of the state

FIGURE 1 Selected study regions in Texas.

Study Regions and Sampling

Data collection was needed to obtain a diverse and broad cross section of signs that varied in sign type, location, and installation age. In 1996, Hawkins et al. estimated approximately 2.3 million traffic signs on the state roadway system (*7*). Acquisition of a sign sample that was distributed in every Texas DOT district would have proved costly and difficult.

For this study, several different and distinctive regions were the focus. Study regions needed to exhibit unique characteristics, which would differentiate them from other parts of the state. These unique characteristics might have affected sign performance and accelerated deterioration rates. It was reasoned that, if sign performance was adequately addressed in regions with harsh or intense conditions, then signs in other regions should perform at a similar or better level. Climate, land use, precipitation, and geography were some of the characteristics taken into consideration when the final selection was made. Figure 1 depicts the locations of the seven selected regions, which were Panhandle (PAN), Central Texas (CT), Houston (HOU), Corpus Christi (CC), South Padre (SP), Laredo (LRD), and West Texas (WT).

Table 2 contains annual and average data for each selected region. In the table, the high and low temperature values were averages from the three hottest and three coldest months, and the snow and precipitation were cumulative, annual amounts. Regions were diverse and included a variety of conditions (e.g., tropical storms, intense sunshine, high temperatures, powerful winds, constant exposure to petrochemical exhaust). The WT region's summer-high and winter-low temperatures fluctuated by 69°F. Most of the regions exhibited little snowfall but the PAN region had about 15 in. of snow per year. The National Climatic Data Center determined that a city in the PAN region exhibited the third highest, annual, average wind speed of all major cities in the contiguous United States (*9*). The difference in total precipitation between the HOU and WT Regions was about 39 in. per year. Relative humidity also varied greatly, and the CC and SP regions exhibited the highest rates at 74%, while the WT region had the lowest at 50%. Land-use ranged from urban industrial to extremely remote. The distance between the two farthest data collection points was approximately 700 mi (i.e., about the same distance from Indianapolis, Indiana, to Jacksonville, Florida). Although it was not feasible to collect data in every part of Texas, the regions studied did cover an extensive area and included many different conditions.

Top priorities of the study were to minimize data collector exposure to the roadway and ensure their safety. Poor shoulder conditions and unapproachable sign supports made some sign measurements precarious. Ultimately, data collectors were free to measure signs that offered safe and favorable locations to stop. The data collectors were able to measure between 10 to 15 signs per hour. The rate of sign measurements was estimated to be about two to four signs per mile in rural areas and six to 10 signs per mile in urban areas.

FINDINGS

This study measured a total of 859 Type III signs in 21 counties, on 83 roadways, and across 1,013 centerline miles. The average numbers of measured signs in each region for red, white, and yellow signs were approximately 28, 73, and 21, respectively. Table 3 contains basic age distribution information for each sign color. Overall, it was determined that 86% of all in-service signs were less than 10 years old. White signs exhibited the lowest mean age of 4.7 years, and only

TABLE 2 Annual and Average Regional Data (*8*, *9*)

	Region						
Variable	PAN (plains and prairie)	CT (forest and plains)	HOU (urban and industrial)	CC (Gulf Coast)	SP (Gulf Coast)	LRD (brush and plains)	WT (desert and mountains)
High temperature (°F)	89	93	89	93	93	97	97
Low temperature (°F)	23	40	43	47	51	45	28
Total precipitation (in.)	20	38	48	31	26	19	9
Total snowfall (in.)	15.4	0.2	0.4	0.0	0.0	0.0	4.6
Probability of sunshine (%)	73	60	58	61	60	60	78
Relative humidity (%)	56	72	72	74	74	62	50
Wind speed (mph)	13.5	8.5	7.6	12.0	11.3	9.5	11.1

TABLE 3 Sample Distribution Information in Years

Sheeting Color	Mean Age	Standard Deviation	Percentile 15th	Percentile 85th
Red	6.3	4.2	1.5	10.8
White	4.7	2.2	2.1	7.2
Yellow	8.9	3.1	5.8	12.2

TABLE 4 ANOVA Analysis Results

Model	Region	Visual Condition	Direction	Age
All signs	**.00**	**.00**	.43	**.00**
Red	.16	.79	.92	**.00**
White	**.00**	.34	**.00**	**.00**
Yellow	**.00**	.21	.46	**.00**

NOTE: Significantly different independent variables have a *P*-value of less than .05 and are denoted by bold text.

one white sign exceeded the age of 10 years. The red and yellow sign samples had older and more dispersed age distributions. The mean age was 6.3 years for red signs and 8.9 years for yellow signs. Both red and yellow sign samples contained measurements that ranged between 10 and 15 years, but this was not the case for white signs.

The Type III sign sample exhibited an MUTCD compliance rate of 99%. The observed likelihood of failure for signs between the installation ages of 10 to 12 years was 2%, and it was 8% for signs that ranged from 12 to 15 years. Just eight signs fell below the minimum levels, which included one red, three white, and four yellow signs. The red sign failed as a result of the contrast ratio, and the others were background failures. The average installation age for the failed signs was approximately 12 years, with the earliest failure at 6.5 years and the oldest at 18 years. Data collectors deemed all of the failed signs to be in either good or adequate visual condition, and none of the signs exhibited major surface defects or delamination. Directionally, four failed signs faced west, three faced east, one faced north, and none faced south. The CT, HOU, CC, and SP regions each exhibited one failure, while the LRD region had four failures. The basic assessment showed that a large majority of the sampled signs were in compliance and under the typical warranty period. In a more in-depth analysis, the retroreflectivity measurements were analyzed by using an analysis of variance (ANOVA) statistical model.

The ANOVA model was used to determine significant factors that affected sign retroreflectivity. The dependent variable was sign retroreflectivity, and the independent variables were region, visual condition, sign direction, and age. The ANOVA models used a confidence interval of 95% to determine variable significance. The analysis generated one model for all Type III sign data and three models for individual sheeting colors: red, white, and yellow. Table 4 contains the ANOVA results and shows which independent variables were significant. Both the direction and visual condition variables were only significantly different in one of the four models. Sign direction was shown not to be a significant factor in other research, and the results in Table 4 agree with those findings. Increased sunlight exposure as a consequence of sign direction might have affected retroreflectivity but was not consistently significant over all models. Visual condition was not a good indicator of retroreflectivity either. The eight failed signs appeared to be in good or adequate visual condition during daytime hours. Data collectors acknowledged this trend and added that many poor or distressed signs exhibited high retroreflectivity levels. The ANOVA results did determine that sign age was a significant factor in all four models, and the region variable was significant in three of the four models. The region variable was not significant in the red-sign sheeting model, but the results were close to the threshold of significance. All things considered, sign installation age significantly affected sign retroreflectivity, and signs performed differently across regions.

Use of linear regression models was a practical way to further investigate both sign age and regional variables. Similar to the models in earlier research, the dependent variable was retroreflectivity, and the independent variable was sign age. Simple statistical and computation software generated each linear regression model. Table 5 contains the linear regression equations and *R*-squared values for each model. The top row of the table contains the results from the "all" model, which included data from all seven regions.

TABLE 5 Regional Linear Prediction Models Results

Region	Red R^2	Red Equation	Red SL[a]	White R^2	White Equation	White SL	Yellow R^2	Yellow Equation	Yellow SL
All	.09	$y = -1.0x + 52$	44	.08	$y = -6.2x + 265$	35	.19	$y = -6.8x + 251$	26
PAN	.02	$y = -0.4x + 53$	129	.07	$y = -3.6x + 285$	34	.62	$y = -11.2x + 315$	21
CT	.02	$y = -0.3x + 50$	112	.28	$y = -6.9x + 281$	65	.4	$y = -9.2x + 281$	23
HOU	.01	$y = -0.6x + 55$	28	.14	$y = -6.2x + 271$	104	.02	$y = -1.5x + 194$	80
CC	.41	$y = -2.0x + 51$	86	.07	$y = -5.4x + 253$	35	.19	$y = -5.4x + 208$	24
SP	.04	$y = -0.4x + 36$	76	.02	$y = -2.2x + 323$	82	.31	$y = -7.8x + 243$	21
LRD	.06	$y = -1.0x + 50$	42	.06	$y = -7.7x + 236$	24	.57	$y = -12.3x + 258$	15
WT	.26	$y = -2.0x + 63$	22	.04	$y = -2.2x + 279$	38	.01	$y = -1.0x + 225$	155

[a]Service life (SL) projections were generated from the most conservative MUTCD minimum requirements.

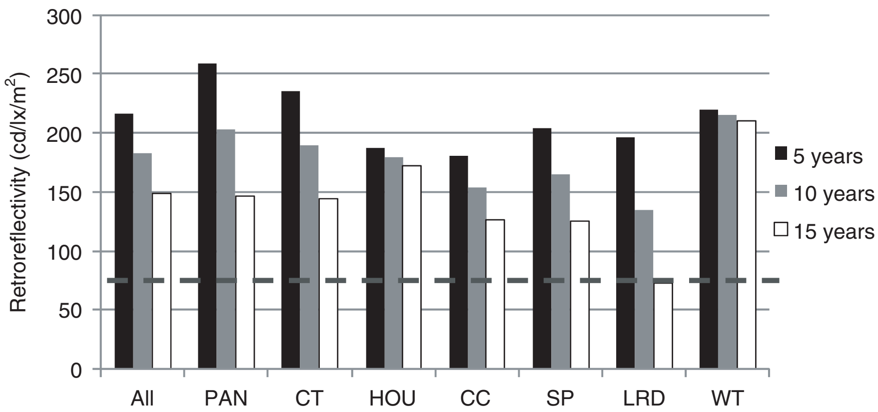


FIGURE 2 Region model predictions for yellow Type III sheeting. Dashed gray line is more conservative MUTCD minimum requirement (75 cd/lx/m^2) for black on yellow signs.

A trend was noticed in the large differences and inconsistencies in the rate of change in each of the regions. Deterioration rates for white sheeting ranged from about –2 to –8 cd/lx/m^2 per year, and yellow rates were between –1 to –12 cd/lx/m^2 per year. The PAN and WT regions typically exhibited the lowest rates, while the LRD region had the highest. When compared with the earlier linear models (Table 1), some of the equations were quite similar and some differed considerably. Two of the equations in Table 5 were similar. Overall, however, the results varied and were inconsistent when viewed together. A closer look at the yellow sheeting models illustrates and magnifies the differences.

Figure 2 shows an example of the deterioration rates and predicted values for yellow Type III sheeting for each region. The figure depicts the predicted values in 5-, 10-, and 15-year intervals, and the deterioration rates could be visually assessed between the intervals. The figure illustrates the differences and inconsistencies among the regions. Again, the predicted values for the WT region were the highest and had the lowest rate of change, whereas the LRD region exhibited the highest deterioration rate. The CC, SP, and LRD regions were relatively close in geographic location, but the 15-year predicted values deviated by about 60 cd/lx/m^2. The LRD region illustrated regional differences and a comprehensive, or all-inclusive, state model might not have been representative of certain regions.

The *R*-squared values in Table 5 were low. The *R*-squared values from the "all" model ranged from about .10 to .20, which was similar to the values from other studies (Table 1). The red and white correlation values ranged from .01 to .30, and the yellow *R*-squared values were slightly higher. Regardless, the linear relationships were consistently weak, which indicated a large disparity between the predicted and measured values. The poor correlation added uncertainty to the projection of sign service life and replacement periods. Some of the projected service life values were long in length and spanned up to 155 years. This trend was similar to that generated in other research. Large differences were found in regional projections also. The differences between the maximum and minimum regional projections were 84 years for white and 140 years for yellow sheeting. It was difficult to place great confidence in the service life projections as a result of the unrealistic estimations and the large disparity between values.

CONCLUSIONS

A literature review showed it could be difficult to develop a robust prediction of traffic sign retroreflectivity on the basis of in-service measurements. Research has shown poor correlations and predicted unrealistic service life on the basis of MUTCD minimum retroreflectivity levels.

The study reported in this paper showed that Texas DOT's current traffic sign maintenance practices were effective. An analysis of 859 Type III signs showed that 99% of the signs met the MUTCD retroreflectivity requirements. The research also demonstrated that assessment of daytime visual conditions was not a reliable method to determine retroreflectivity. ANOVA testing determined that both the sign age and region variables were significantly different. The linear prediction models revealed differences in deterioration rates among the regions, but these differences had no practical significance in most cases.

Furthermore, most of the *R*-squared values were relatively low: they ranged from .10 to .30. The low *R*-squared values limited the confidence for the service life projections. The data indicated that the service life for Type III beaded sign sheeting, however, could exceed the typical 10-year warranty period. In the Texas data set, the observed likelihood of failure was 2% for signs with installation ages between 10 and 12 years and 8% for signs with ages between 12 and 15 years.

The models offered a broad perspective of sign conditions, but they did not provide exact values or definite sign service life periods. Practitioners that employ findings from this study, other research, or commercial software programs should consider that there may be differences between the predicted and in-service retroreflective values. Differences could be caused by many factors (e.g., geography, climate, manufacturing vendor, roadway maintenance practices). No service life projection or model is absolute or always appropriate. The data may indicate that a certain sign type will last more than 12 years, but this longevity may not always apply to all signs. The 12-year service life may provide a basic and conservative estimation for various sign management methods, but it is beneficial to also implement robust maintenance practices and periodic nighttime visual inspections to assess the need to replace signs that do not meet the projection. There is no single silver bullet model or sign

*A lot of studies have confirmed whether or not their signs (as a state) are good, but none have been able to predict anything.

management technique. Deterioration rates and prediction models can be valuable components of a comprehensive sign maintenance program, but they do not by themselves ensure sign retroreflectivity compliance.

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