

Sign Life Expectancy

Final Report

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16. Abstract <p>This project investigated the degradation of traffic signs in South Carolina. Data from 1,600 SCDOT-maintained signs, collected over a nine-month period, were analyzed. The signs were selected to provide a representative sample in terms of geographic location and age. In addition to measuring the retroreflectivity of each sign, other sign data collected were: sign number, assembly number, height, offset, color, sheeting type, sheeting manufacturer, degree of shade, GPS coordinates, and sign facing direction. Both linear and non-linear regression models were developed to predict a sign's expected life (i.e., before its retroreflectivity falls below the required minimum standard). The variables, age, and degree of shade, were found to be statistically significant for all sign colors, while the variable, northwest facing direction, was found to be significant for red signs. Based on the results of the developed regression models, SCDOT historical replacement data, and measurements taken from older signs in Spartanburg, it is recommended that the sign replacement interval be extended to 12 years. The service life of signs, especially those located in shaded areas, can be extended via washing at regular intervals.</p>			
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EXECUTIVE SUMMARY

In this study, linear and non-linear regression models were developed to predict sign life using data collected from 1,600 traffic signs in South Carolina. The regression models were developed for four sign colors (red, yellow, white, and green) to determine which factors (i.e., explanatory variables) have an effect on the retroreflectivity of signs. This work introduced a new variable not considered in previous studies, degree of shade, which was found to have a significant effect on the degradation of sign retroreflectivity, primarily from mildew growth. The major findings from the regression models are the following:

- For red signs, the regression model with exponential form provided the best fit, while for white, yellow, and green signs, the regression model with quadratic form provided the best fit.
- The explanatory variables, age and degree of shade, were found to be statistically significant for all four sign colors. For red signs, the variable, northwest facing direction, was also found to be significant.
- All models have adjusted R^2 values greater than those reported in previous sign studies.

The developed regression models indicated that the sign replacement interval can be extended to 12 years. This finding is supported by both the SCDOT historical sign replacement data and measurements taken from older signs in Spartanburg. That is, very few signs replaced at the 10, 11, or 12 year mark are due to poor retroreflectivity, and all of the older signs (12 years or older) in Spartanburg have a higher retroreflectivity value than the minimum specified in the MUTCD.

The life of signs can be extended through sign washing. The team conducted a sign washing experiment, and our finding suggests that washing those signs in shaded areas can improve their retroreflectivity by 22.5%; this equates to about two years for yellow, white, and green signs, and about five years for red signs.

The sign management and maintenance practices implemented by other states were obtained via an online survey. A total of 16 state DOTs responded to the survey. The following summarizes key survey results.

- The majority of the DOTs (75%) used the nighttime visual inspection method as sign maintenance method. The second most commonly used method is expected sign life, by about 56% of the DOTs.
- The majority of the DOTs that utilize the nighttime visual inspection method perform their nighttime inspections on an annual or bi-annual basis.
- DOTs that utilize the blanket replacement method replace their signs every 10 to 15 years.
- Predictive regression models have developed by two other state DOTs.
- Sign washing is performed by one state DOT to extend the sign life.
- Most DOTs use some type of software applications for sign data collection
- Most DOTs record information about the sign number, sign facing direction, sign installation data, and MUTCD sign type in their database.

The project team also conducted follow-up phone calls to certain state DOTs who responded to the survey. The following summarizes key findings from the follow-up phone calls.

- Utah DOT performs maintenance of signs during larger repaving projects.
- Minnesota DOT currently uses Type XI sheeting for every color and replace signs on a corridor basis; that is, all signs in a specified corridor will be replaced when a sign replacement is scheduled.
- Texas DOT performs nighttime inspections every six months. Texas does not have any established sign life although it was stated that signs will usually last 10 to 15 years
- Vermont Agency of Transportation indicated that expected sign life of 15 years is used in the state and that the majority of the signs maintained by the agency are replaced with paving projects.
- In North Carolina, there is no age criteria for sign replacement and the replacement is based on performance. The primary maintenance is performed each winter using a retroreflectometer to measure larger high-cost highway signs in a division to determine whether a sign meets the minimum standards. During normally scheduled maintenance, sign washing is also performed.

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CHAPTER 1: INTRODUCTION

In 2007, the Federal Highway Administration (FHWA) (1) adopted new retroreflectivity standards for traffic signs to be implemented by agencies in their jurisdictions. The minimum standards are specified in the Manual on Uniform Traffic Control Devices (MUTCD) 2009 edition (2). The MUTCD states that regulatory signs, warning signs, guide signs, and object markers should be retroreflective. Along with these standards, agencies were to adopt a management method to maintain the minimum standards as outlined in the MUTCD. To maintain these retroreflectivity standards, Section 2A.08 of the MUTCD outlines five specific management methods as follows.

- Visual Nighttime Inspection – Trained sign inspectors conduct a visual inspection from a moving vehicle during the night. All signs visually below a certain standard should be replaced.
- Measured Sign Retroreflectivity – The retroreflectivity of signs are measured with a retroreflectometer. Signs below the minimum retroreflective standards are replaced.
- Expected Sign Life – The date of the installation of the sign is recorded. When the sign surpasses the expected sign life (based on the experience of sign degradation in a certain area), the sign is replaced.
- Blanket Replacement – All signs (of specific types) in a certain area are replaced at specified intervals, which is usually based on expected sign life.
- Control Signs – Control signs are identified in the field or in a maintenance yard. These signs are periodically monitored and when their retroreflectivities fall below the minimum standards then all other signs associated with the control sign are replaced.

To study how agencies implemented the standards specified in the MUTCD, the NCHRP (3) published a synthesis on traffic sign management in which 40 agencies were surveyed concerning the type of management used in their jurisdiction. Local agencies (towns, cities, counties, and one toll agency) most often employed the expected sign life method while States Department of Transportation (DOTs) mostly employed the visual nighttime inspection method. The report concluded that most agencies selected the methods based on simplicity or ease of use. This is the reason why the expected sign life and visual nighttime inspection are the preferred methods. The other methods require more equipment or more planning on the part of the agencies.

The SCDOT performs nighttime inspections to ensure that all signs are in compliance with the minimum MUTCD standards. Any signs not observed to meet the minimum standards are entered into a work request module. The following guidelines have been set forth by SCDOT when performing nighttime inspections (4):

- The inspections should be conducted at normal operating speeds.
- The inspections should be conducted using low beam headlights.
- The inspections should be conducted using a 2005 model year or newer full-sized pickup.

- Signs should be viewed at the typical viewing distance for that sign.
- Signs should be replaced if not legible to the inspector.

As specified by the SCDOT Engineering Directive 57, the SCDOT uses a combination of the Blanket Replacement and Expected Sign Life methods. Currently, the sign life expectancy is based on the sheeting warranty as set by the manufacturer, which is 10 years. Hence, signs are replaced on a 10-year interval. The SCDOT uses the nighttime inspection method as a quality control check (5).

This study investigates the expected life of traffic signs managed by the SCDOT and make recommendations concerning the replacement interval. To accomplish this, the retroreflectivity of signs were measured in different regions of South Carolina using a retroreflectometer. Other sign data collected include the sign number, assembly number, height, offset, color, sheeting type, sheeting manufacturer, degree of shade, GPS coordinates, and sign facing direction. Regression models were then developed with sign retroreflectivity as the dependent variable and the aforementioned collected data as explanatory variables. The output of the developed regression models, SCDOT historical sign replacement data, and measurements taken from older signs in Spartanburg were used to make recommendation concerning the blanket replacement interval. This study is the first to incorporate the explanatory variable “degree of shade” in retroreflectivity regression models. It was found to be statistically significant at the 95% confidence level for red, white, yellow, and green signs.

CHAPTER 2: LITERATURE REVIEW AND BACKGROUND

2.1 Literature Review of Sign Retroreflectivity

Sign retroreflectivity has been studied by the FHWA and a number of state DOTs (Oregon, Indiana, Louisiana, North Carolina, Vermont, Texas, Pennsylvania, Wyoming, and Minnesota). The goal of these studies is to develop models to predict the sign life. Studies have examined how age, orientation, offset from the road, height, geography, pollution, wind, dew, and frost affect retroreflectivity. The following provides a summary of these studies.

2.1.1 Age

The most studied factor in sign retroreflectivity reduction is age. As a sign ages, the retroreflectivity presumably decreases until a sign does not meet the minimum FHWA retroreflectivity standards. The majority of studies have shown that with time, retroreflectivity reduces. However, the retroreflectivity reduction with age is not consistent. The disparity in sign models developed in different studies can be seen in Table 2-1 for Type III sheeting. Notice the range of the predicted sign life. The discrepancy in sign models can be attributed to different sheeting manufacturers, sample size of the study, and the number of measurements taken per sign. Most sign models developed previously are linear regression models with low R^2 values.

Table 2-1 ASTM Type III Service Life Based on Predictive Models for White and Yellow Signs

Color	Author	Model	Predicted Failure (years)
White (RA \geq 50)	Jenkins & Gennaoui (6)	$294-4.05 \times \text{Age}$	60.25
	Black et al. (7)	$311.0-4.61 \times \text{Age}$	56.6
	Bischoff & Bullock (8)	$253.7-0.86 \times \text{Age}$	236.86
	Wolshon et al. (9)	$297.7-6.78 \times \text{Age}$	36.53
	Rasdorf et al. (10)	$262.6-0.71 \times \text{Age}$	299.44
	Kipp et al. (11)	$436.8 \times \text{Age}-0.355$	446.01
	Carlson et al. (12)	$265-6.2 \times \text{Age}$	34.68
	Pike & Carlson (13)	$261.57+0.8524 \times \text{Age}$	Never
	Huang et al. (14)	$105.271+1.5943 \times \text{Age}-0.1115 \times \text{Age}^2+0.0006 \times \text{Age}^3$	35.05
	Clevenger et al. (15)	$758.31-32.078 \times \text{Age}$	22.08
	Preston et al. (16)	$424.03-7.555 \times \text{Age}$	49.51
Yellow (RA \geq 50)	Black et al. (7)	$246.4-3.21 \times \text{Age}$	53.5
	Bischoff & Bullock (8)	$222.5-3.58 \times \text{Age}$	48.18
	Wolshon et al. (9)	$246.1-9.81 \times \text{Age}$	20.05
	Rasdorf et al. (10)	$216.4+1.27 \times \text{Age}-0.251 \times \text{Age}^2$	28.4
	Kipp et al. (11)	$329.9-78.8 \times \ln(\text{Age})$	34.88
	Carlson et al. (12)	$251-6.8 \times \text{Age}$	29.56
	Pike & Carlson (13)	$204.2+1.1171 \times \text{Age}$	Never
	Clevenger et al. (15)	$523.53-20.24 \times \text{Age}$	23.4
	Preston et al. (16)	$416.07-14.14 \times \text{Age}$	25.89

Red (RA >= 7)	Jenkins & Gennaoui (6)	$16+3.1\times\text{Age}$	Never
	Black et al. (7)	$38.7+0.61\times\text{Age}$	Never
	Bischoff & Bullock (8)	$51.8-2.03\times\text{Age}$	22.07
	Rasdorf et al. (10)	$59.6-2.66\times\text{Age}$	19.77
	Kipp et al. (11)	$72.9-4.35\times\text{Age}$	15.15
	Carlson et al. (12)	$52-1.0\times\text{Age}$	45
	Pike & Carlson (13)	$49.324+0.4731\times\text{Age}$	Never
	Clevenger et al. (15)	$94.055-4.0818\times\text{Age}$	21.33
	Preston et al. (16)	$74.858-0.822\times\text{Age}$	82.55
	Black et al. (7)	$55.2-1.82\times\text{Age}$	22.08
Green (RA >= 15)	Wolshon et al. (9)	$48.0-0.42\times\text{Age}$	78.57
	Rasdorf et al. (10)	$52.0+4.24\times\text{Age}-0.81\times\text{Age}^2$	9.86
	Kipp et al. (11)	$96.1\times\text{Age}-0.204$	8996.61
	Pike & Carlson (13)	$30.66+1.4328\times\text{Age}$	Never
	Huang et al. (14)	$19.57-0.137\times\text{Age}-0.0008\times\text{Age}^2+8\times 10^{-6}\times\text{Age}^3$	29.73
	Clevenger et al. (15)	$71.165-0.8512\times\text{Age}$	65.98
	Preston et al. (16)	$47.843+0.6521\times\text{Age}$	Never

2.1.2 Orientation

The orientation of signs (whether the sign faces north, south, east, or west) has also been studied extensively by researchers. Jenkins and Gennaoui (6) concluded that orientation has an impact on sign retroreflectivity reduction in Australia. A nationwide study performed by Black et al. (7) found that orientation was not significant in retroreflectivity reduction when an ANOVA analysis was performed. A study performed in Oregon by Kirk et al. (17) measured sign orientation. This study found that a strong trend did not exist, but the authors suggested that west-facing signs had a lower retroreflectivity recording for three of the four sign colors measured. Bischoff and Bullock (8) performed a study in Indiana and determined using a t-test that orientation does not play a significant role in affecting a red sign's retroreflectivity. Only red signs were measured due to a hypothesis that the red ink fades more rapidly on south facing signs than others. Wolshon et al. (9) concluded in their study performed in Louisiana that the orientation of the sign is not significant in affecting retroreflectivity reduction when the F-test was performed. A study performed in Vermont by Kipp et al. (11) analyzed the orientation of green Type III signs only. The authors categorized all signs as north or south facing because they hypothesized that south-facing signs would deteriorate more quickly than north-facing signs. The authors concluded that the orientation of the signs was not correlated to the service life of signs. Carlson et al. (12) found that the orientation of the signs was not a statistically significant factor in determining retroreflectivity reduction in Texas. In a study performed by Evans et al. (18) in Utah, it was found that high variability in retroreflectivity readings exist in high prismatic Type III and Type IX when signs face different directions. Although this study did not specifically mention retroreflectivity reduction, it shows that there is little consistency in sign orientation and retroreflectivity. Pike and Carlson (13) performed a study in Wyoming in which the orientation of the signs was measured. The authors concluded that orientation, and its contribution to retroreflectivity reduction, was statistically difficult to assess due to the number of factors involved. In summary, of all the studies that assessed the effect of sign

orientation on retroreflectivity reduction, only one found orientation to be a significant factor (the Australia study).

2.1.3 Offset

The offset is the distance from the edge of the asphalt pavement to the sign pole. Bischoff and Bullock (8) measured the offset of signs in their study in Indiana. The authors did not perform statistical testing or observe any correlation between the offset of the sign and retroreflectivity reduction. Wolshon et al. (9) performed a study in Louisiana in which the offset of signs was measured. It was found in their study that the offset was not statistically significant in its effect of retroreflectivity. The researchers concluded that although offset was not statistically significant there were still some effects of offset on retroreflectivity. Kipp et al. (11) studied the offset of signs in Vermont. Their study found that the offset of a sign did not affect the long term performance of a sign. Evans et al. (18) performed a study in Utah in which the offset was measured. However, the authors did not pursue statistical analysis to determine the relationship between retroreflectivity and offset.

2.1.4 Mount Height

The mount height is the distance from the ground to the bottom of the sign. The mount height was measured for a study in Indiana by Bischoff and Bullock (8). As with the offset data, statistical testing was not performed to determine whether the mount height significantly affects retroreflectivity reduction. Wolshon et al. (9) measured the mount height in their study performed in Louisiana. However, the mount height was not included in any of their predictive models, and thus, the effect of mount height on retroreflectivity was not examined. Kipp et al. (11) studied the mount height of signs in Vermont. The hypothesis of the department of transportation in Vermont was that the lower the sign is to the ground, the higher the rate of retroreflectivity reduction. The researchers concluded that mount height did not affect the long term performance of signs in Vermont. Evans et al. (18) measured the mount height of signs in Utah. However, the statistical significance of mount height was not determined.

2.1.5 Geographical Location

Jenkins and Gennaoui (6) concluded from their study performed in Australia that reduction in retroreflectivity was higher in Queensland north of Rockhampton than in other regions of Australia. The authors also concluded that the type of environment surrounding a sign has adverse effects on retroreflectivity. Black et al. (7) performed a nationwide study in the US in which they evaluated the retroreflectivity of signs in 18 areas around the country. The authors grouped the signs into eight regions based on similar climate and solar radiation levels. Using standard ANOVA methods, region was not found to be a significant factor in retroreflectivity reduction. Kipp et al. (11) performed their study in Vermont and divided the state into six regions based on the age and type of rock, landscape, and climate. The researchers did not observe any correlation or statistical significance between location and retroreflectivity reduction. Carlson et al. (12) measured retroreflectivity of signs in seven regions of Texas to evaluate how climate

and temperature affect retroreflectivity reduction. The ANOVA analysis indicated that region had a significant effect on retroreflectivity. Although the researchers determined that region had a significant effect on retroreflectivity, the difference was not large enough to warrant different management strategies for each region.

2.1.6 Pollution

Khalilikhah and Heaslip (19) performed an extensive study on the effect of pollution on signs in Utah. The data the researchers used were collected using LiDAR sensors. The researchers also used data from the Department of Environmental Quality to measure the amount of pollution in different areas throughout the state. Raster data was then created for the different air pollutants in the state, including carbon monoxide, ammonia hydroxide, nitrogen oxides, sulfur dioxide, coarse particulate matter, and volatile organic compound. The researchers then used a Chi-Square test to statistically show that there is a correlation between air pollution and retroreflectivity reduction. At least one other study alluded to the fact that there is greater reduction in sign retroreflectivity in industrial areas (6), but the amount of air pollutants were not actually measured. Therefore, no correlation assessment between pollution and retroreflectivity reduction was performed in these studies.

2.1.7 Wind

Kipp et al. (11) studied the effect of wind on retroreflectivity. Minimal wind data were collected. The researchers concluded that with the data they obtained a correlation between wind and retroreflectivity reduction could not be established.

2.1.8 Frost and Dew

Hildebrand (20) studied the effect of frost and dew on sign retroreflectivity. The author of this study selected new signs so that the sheeting was in new or like-new condition, which have little to no reduction in retroreflectivity. The conclusion of this study was that frost reduces retroreflectivity by an average of 79% and signs covered in dew have a retroreflectivity reduction by an average of 60%. The author suggested that new materials could be developed to mitigate the effect of frost and dew on signs and that the DOTs should be aware of the effect of frost and dew on signs in affected areas. The author did not study the long-term effect of frost and dew on sign retroreflectivity reduction.

2.2 State DOT Sign Survey Summary

An online survey was conducted as part of this study to obtain information about other states' sign management and maintenance practices. A total of 16 state DOTs responded to the survey. The survey was made available to DOTs from January 30, 2017, to February 20, 2017. The following summary will first list the question in *italic* followed by a summary of the responses.

What are the management and maintenance methods employed by your agency?

Table 2-2 shows the management and maintenance methods used by the different state agencies.

Table 2-2 Maintenance and Management Methods Used by Survey Respondents

Maintenance Method	No. of Positive Responses	Percent of Total Positive Responses
Visual Nighttime Inspection	12	75%
Measured Sign Retroreflectivity	2	13%
Expected Sign Life	9	56%
Blanket Replacement	6	38%
Control Signs	1	6%

The majority of the DOTs that use the nighttime visual inspection method perform their nighttime inspections on an annual or bi-annual basis. A few variations from that included inspecting 20% of total signs every five years and inspecting signs every month (this respondent was not confident that signs are inspected every month). The two DOTs that use the measured sign retroreflectivity method stated that signs are measured once a year. Among the nine agencies that use the expected sign life method, two responded that different colors have different sign lives. Another respondent stated that formal lifespans were not established but that they know blue and brown signs deteriorate quicker than the rest of the signs. Of the DOTs that use the blanket replacement method, most replace signs every 10 to 15 years. The exceptions to that schedule were that some signs are replaced every two years and that signs are typically replaced with larger projects. The one agency that uses the control signs method stated that the control signs are inspected every year.

Does your agency use predictive regression models for sign life expectancy?

Two agencies responded that predictive regression models have been developed for their states. Both of those states stated that the predictive models are used by their respective agencies.

Is maintenance performed to extend sign life?

One agency responded that sign washing is performed to extend sign life.

How is sign data obtained by your agency?

Table 2-3 provides a summary of the answers this question. Table 2-4 list the “other” answers given by respondents as written.

Table 2-3 Standard Methods for Obtaining Sign Data

Types of Apps Used for Data Collection	No. of Respondents
Customized App	4
Standard App	3

Table 2-4 Other Methods for Obtaining Sign Data

Varies by District. Usually app or handheld GPS device.

All sign attributes are obtained through field inspection by county offices.

calculated from Mile marker but newer installs are GPS

We developed a sign management system in house tied into our Transportation Management System

LIDAR data

old fashion spreadsheet but moving to workbooks

What information is recorded in your agency's sign database?

Figure 2-1 provides a summary of the answers to this question.

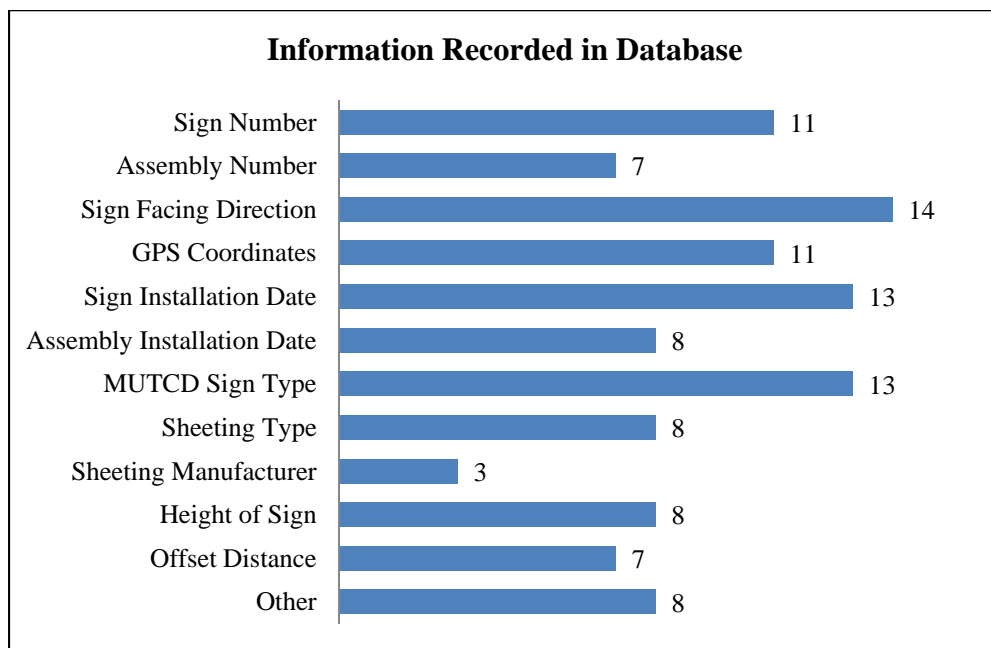


Figure 2-1 Type of Information Recorded in DOT's Databases

Table 2-5 lists the “other” information respondents record in their databases as written.

Table 2-5 Other Information DOTs Record in Databases

Sign size
Post type/Condition
Highway, MP, Side of Road, Width of sign, Est replace date, Substrate, Supports, Maint. history, Ref inspect date, and More
State route, Segment, Sign dimensions, Position, Post type
Comment column
Sign location (left overhead/ahead, right as well as condition/inspection history)
Milepost
Photos and Condition

How frequently is your agency’s sign database updated?

Table 2-6 provides a summary of the answers to this question.

Table 2-6 The Frequency of Updating Sign Databases

On an as-needed basis
When signs are installed/replaced
Varies by district
Every year
Continually day to day
Once every 10 years or during sign inspections
Roughly every other year during a LIDAR run
We have done it twice in 10 years
Every day

Follow-up phone calls were made to certain states that responded to the survey that were deemed to have best practices for sign management or are of interest to the SCDOT. In addition to North Carolina DOT which the SCDOT specifically requested the team to contact, four other states were contacted. The follow-up calls gave the research team the opportunity to gain greater insight into how individual states maintain their sign inventory. As part of the call, respondents were given the opportunity to provide the research team with any literature belonging to that state that would be of interest to the

study. Each person interviewed was asked which maintenance and management methods are used as well as specific questions tailored for that state based on prior knowledge about that state's practice.

One of the states the team interviewed was Utah. The Utah DOT performs maintenance of most signs during larger repaving projects (analogous to blanket replacement). If signs need to be replaced, before a project on a specific stretch of road, then it is replaced. When signs are replaced as part of a project, the contractor is responsible for the installation of the signs along the stretch of road being replaced. If a contractor is not responsible for obtaining signs for the DOT, the prison produces the signs. When the prison produces signs, they are the more common signs installed such as stop signs or speed limit signs. The majority of signs in the Utah use 3M manufactured sheeting. The day-to-day management of signs is controlled by one of 80 maintenance foremen over certain areas around the state. UDOT places heavy trust in their foremen and trusts the way all assets under their jurisdiction are managed. UDOT also maintains a database of signs; however, the database is used loosely to manage all signs. That is, all the signs are assigned sign numbers but the dates of installation are not tracked. Sign inventory is kept relatively low so most signs are produced on an as needed basis.

In discussing sign maintenance practices with the MnDOT representative, it was discovered that signs are replaced on a corridor basis. This means that whenever signs are scheduled to be replaced, then all signs in a specified corridor will be replaced. The MnDOT currently uses Type XI sheeting for every color. Because Type XI is used the expected life for signs under the MnDOT jurisdiction is at least 20 years. Because the sign life is so high for this type of sheeting, when signs are replaced the sign assembly is also replaced. The MnDOT also mentioned that there is a high priority to clean up the current database and ensure that all the data are current. Once the database is made current, the MnDOT will move forward with a hybrid maintenance plan that will include using control signs and nighttime inspections. The MnDOT plans to determine a statistically significant number of signs to measure and will then drive certain corridors to determine if signs still meet minimum standards. If the signs measured do not meet those minimum standards, then all signs that correlate to the sample will be replaced. For example, a group of 10-year old yellow warning signs will be identified. A statistically significant number of those signs will be inspected using the nighttime inspection method, and if a majority of the inspected signs fail then all signs associated with the sample will be replaced.

During the interview with Texas DOT, it was discovered that nighttime inspections are performed every six months in each of the 25 districts in the state. Each district is responsible for performing the inspection. Texas does not have any established sign life although it was stated that signs will usually last 10 to 15 years. Texas also fabricates signs in one of two sign shops in the state. The sign shops are placed to provide signs to half of the state. Texas also utilizes the prison system to produce their standard signs. If a big replacement needs to be performed it is contracted out by the state and the winning bidder is also responsible for the sign production. This is usually only performed for large access guide signs on the highway.

In the interview with the Vermont Agency of Transportation (VTrans) it was discovered that an expected sign life of 15 years is used in the state. The study performed by Kipp et. al. (11) is what led to the determination of the 15-year sign life in the state. The representative interviewed stated that the majority of the signs maintained by the agency are replaced with paving projects (analogous to blanket replacement). The signs to be replaced during a project are contracted out by the winning bidder of that specific project. The signs associated with a paving project are replaced even if the sign is about “seven” years old. The VTrans representative did state that it is not a hard number yet and that the agency is still determining the exact age when signs should be replaced with paving projects. VTrans also utilizes the prison system for the production of its signs. The signs produced by the prison system are mostly used for smaller replacements or if new signage is needed with a new signal. VTrans also maintains its own sign database recording sign location, color, size, install date, type of sign, and some assembly information. Due to the small size of the state, sign replacement is centralized and is uniform for the entire state. The VTrans representative said that having a uniform system has helped to prioritize the proper budget for sign replacement.

The last interview performed was with the North Carolina Department of Transportation (NCDOT). The state is separated into 14 divisions with four to six counties in each division. Each division is responsible for sign management and maintenance. The primary maintenance is performed each winter as each division uses a retroreflectometer to measure larger high cost highway signs in the division to determine whether a sign meets the minimum standards. The interviewee stated that the age criteria for sign replacement does not exist but that replacement is based on performance. A central sign inventory is not kept by NCDOT but by each division. The prison system manufactures approximately 90% of the signs for the state. Upon manufacture completion a tag is placed on each sign indicating the date of manufacture and the sign is placed in the field within a month of manufacture. Using a sticker helps maintenance crews to know the age of each sign in the field during regular maintenance. During normally scheduled maintenance power washing is also performed. The state representative stated that most divisions perform this maintenance. As North Carolina is in close proximity to South Carolina power washing is one technique that could be effectively employed.

2.3 Background

As part of this study, the project team visited the State Sign Shop to further understand sign types and the production process of signs in South Carolina. The operation of sign shops in Connecticut, New Mexico, and Iowa were also investigated to determine if any sign production processes differ from South Carolina. The State Sign Shop is the only DOT owned manufacturer of signs in the state. The Department of Corrections (DOC) also produces, on average, 15% to 20% of the signs for SCDOT. Before 2011, two other sign shops existed in Charleston and in Greenville. In 2011, sign manufacturing was consolidated to what is now called the State Sign Shop in Columbia. The State Sign Shop produces, on average, 400 to 600 signs per day and has seven full time employees who manufacture the different signs. The sheeting used by the SCDOT is manufactured by Avery Dennison. The DOC uses 3M manufactured sheeting for signs. The difference in appearance is shown in Figure 2-2.



Figure 2-2 Difference between Avery Dennison (left) sheeting and 3M sheeting (right).

The DOC manufactured sign (right), using 3M sheeting, has more visible, thick vertical lines when observed up close while the SCDOT manufactured sign has much thinner vertical and horizontal lines. The signs manufactured by the DOC are also marked with the inscription “DOC” followed by the month and year it was manufactured as seen in Figure 2-3. Having this label was helpful during sign data collection as it was an indicator to anyone collecting data that the sign was produced using 3M sheeting as opposed to Avery Dennison. For data collection purposes, the appearance and label on the sign were both used to confirm the manufacturer of the sign.



Figure 2-3 DOC label indicating production at Department of Corrections.

To manufacture traffic signs, the SCDOT uses three production techniques: 1) screen printing, 2) hand laid, and 3) extruded paneling. The screen printing technique is used for common signs that need to be mass produced (i.e., stop signs or warning signs). The

State Sign Shop creates different screens for the different signs that need to be mass produced. The individual screens are produced and stored on site for ease of use. To manufacture a screen-printed sign, a piece of sheeting is laid on the screen printer as seen in Figure 2-4. The symbol is printed on the sheeting and then removed as seen in Figure 2-5. The screen- printed signs are set to dry for about 24 hours and are then placed on aluminum panel and cut as seen in Figure 2-6.

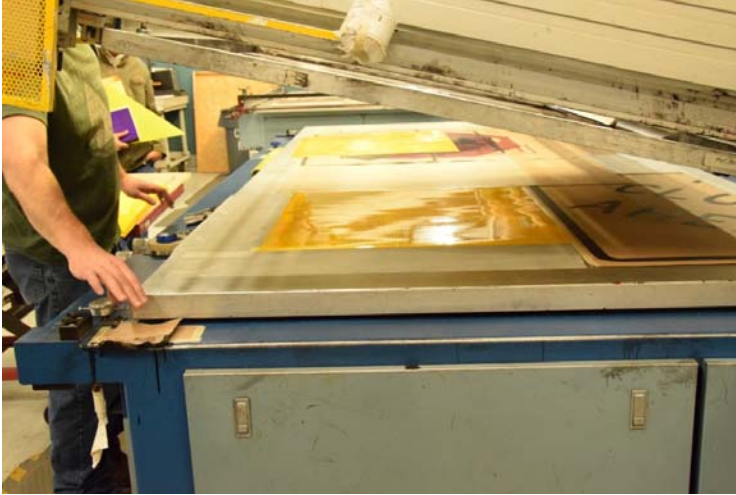


Figure 2-4 Screen printing setup.



Figure 2-5 After the symbol is printed the sign is set to dry.



Figure 2-6 The excess sheeting is hand cut around the aluminum.

The hand laid process is used for unique signs (i.e., signs showing mileage). The text of the sign is first printed, and then the letters are cut out by an employee as seen in Figure 2-7. Once the text is cut out, the background is prepared with the proper color and border. The text is then laid on the background as seen in Figure 2-8.



Figure 2-7 Sign text being cut out to be hand laid.



Figure 2-8 The hand laid process of placing text on the sheeting.

The extruded paneling process is used for large signs that hang over the highway or are placed on the side of the highway. Figure 2-9 shows a picture of the back of an extruded sign on the side of a highway. Each panel has sheeting placed on it with the letters laid on. The panels are then bolted together to make the front flush.



Figure 2-9 Extruded sign panel.

Once the signs are manufactured, they are stored in the State Sign Shop until requested by an individual county office. Upon request, the State Sign Shop delivers the signs to the Supply Depot to then be delivered to the individual counties with other requested items. The State Sign Shop visit provided the research team the opportunity to analyze signs that are no longer in use which helped the team to be able to differentiate between different types of grade (i.e., engineering grade, high intensity, and prismatic) while performing field work.

The Connecticut Department of Transportation (ConnDOT) operates a single sign shop with five full-time employees. The sign shop produces signs for state roadways as well

as for state properties. Signs are produced by screen printing or hand laid. The sheeting used could vary as the contract is rebid triennially.

The New Mexico Department of Transportation (NMDOT) operates three sign shops for the entire state, with six full-time employees at the main sign shop. The NMDOT uses 3M sheeting and produces the signs using either the screen printing process or the hand laid process. When using the screen printing process up to 200 signs can be produced per day. When performing the hand laid process up to 40 can be produced per day.

The Iowa Department of Transportation operates a single sign shop for the state with eight full time employees including the public service supervisor and a secretary. The Iowa DOT uses the silk screen and hand laid processes to produce signs for the state of Iowa. The larger overhead signs produced for the highways are manufactured by the DOC or outsourced to private companies. The Iowa DOT uses 3M high intensity prismatic and diamond grade cubed sheeting.

The SCDOT's State Sign Shop operates very similar to the three other states that responded to the research team's inquiry. Thus, it can be concluded that the SCDOT sign manufacturing process is similar to those other DOTs in the country.

CHAPTER 3: METHODOLOGY

3.1 Sign Data Collection and Description

The sign database was provided by the SCDOT. This database contains information such as sign number, assembly number, sign installation date, assembly installation date, sign type, sign facing direction, and GPS coordinates. The sign database was then imported into ArcMap to provide geographic location of the signs. Specifically, locations of signs that were 10 years or older were identified. Our data collection approach was to target older signs and while on site measure nearby signs to obtain signs of other ages. Figure 3-1 shows the map of SCDOT-maintained signs that are 10 years old and older. ArcMap was used to identify locations of signs that should be measured based on the data already collected. The project sought to ensure that the number of signs measured in each of the SCDOT's seven districts was proportional to the number of signs in that district.

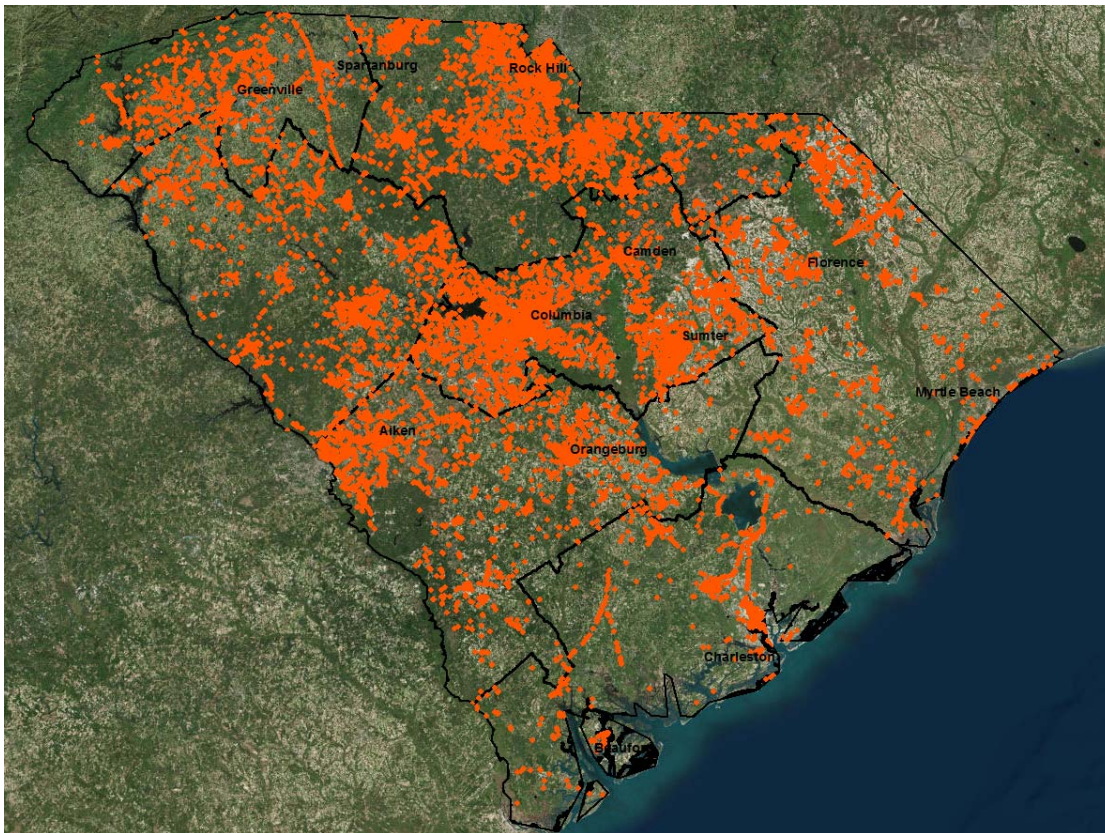


Figure 3-1 GIS map of SCDOT-maintained signs that are 10 years or older.

The following parameters were measured or identified for each sign: retroreflectivity, sign number, assembly number, installation date, sign facing direction, sign color, sheeting type, sheeting manufacturer, sign offset, sign height, and degree of shade. The retroreflectivity was measured using the RoadVista 922 retroreflectometer manufactured by Gamma Scientific. The retroreflectometer was set to measure retroreflectivity with a 0.2 observation angle and a -0.4 entrance angle. The following figure (Figure 3-2) illustrates the meaning of 0.2 observation angle and -0.4 entrance angle.

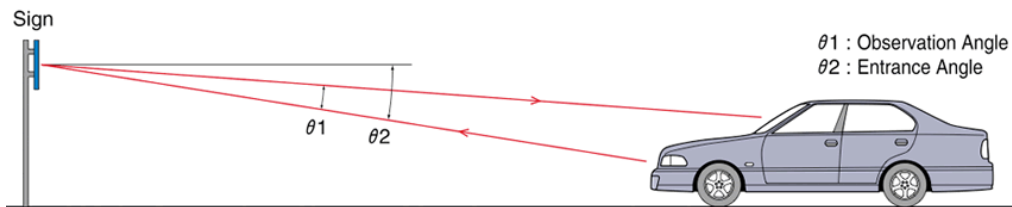


Figure 3-2 Pictorial representation of observation and entrance angle (Source: <http://reflective-tape.com/category/reflective-tape-types-and-intensities-class/>).

The unit of measurement employed for the retroreflectivity measurements is candela per incident lux per square meter. The SCDOT's sign database contains sign facing direction and they are classified as north, south, east, and west. The current practice for determining the sign facing direction is mostly done based on the route direction and not the actual sign facing direction. This study sought to record orientation more precisely by considering eight directions, adding northeast, northwest, southeast, and southwest. To measure the sign's facing direction, a compass app on smartphones was used. Each compass was set to use true north. When the measurement took place, the phone was placed against the assembly, and the direction was recorded.

When measuring the sign offset and sign height, a standard tape measure was used to measure these two parameters. To find the sign offset the measurement was taken from the middle of the assembly to the beginning of the asphalt. In many areas, sand or pine needles have spread to the street, in this situation the measurement was taken to where the asphalt could be seen indicating where cars would feasibly drive. When a sign was elevated on a hill, the tape measure was held level at the bottom of the sign and stretched straight over to the beginning of the asphalt. Similarly, when the road was elevated above the base of the sign, the tape measure was placed on the edge of the asphalt and kept level to the middle of the assembly. In measuring the height of a sign, the tape measure was placed on the ground and measured to the bottom of the sign.

This study introduced a new variable, degree of shade, which has not been considered in previous studies. The rating system seeks to quantify the amount of time throughout the time the sun is out that a sign will be covered by shade. The shade rating system was defined as follows: Full shade (75 – 100% covered), Mostly Shade (50 – 74%), Partial Shade (25 – 49%), No Shade (0 – 24%). To determine the degree of shade for each sign, the sign facing direction and general surroundings of the sign were considered. Figure 3-3 provides an example of each degree of shade measured. It was observed that signs in more shade tend to contain more mildew and dirt; thus, reducing their retroreflectivity.



Figure 3-3 *Shade rating system (from left to right): full shade, mostly shade, partial shade, and no shade.*

To obtain an accurate measurement of retroreflectivity, this study evaluated the number of measurements needed per sign. The RoadVista vendor recommended four readings per color per sign. Six and eight readings were evaluated to determine if it would be beneficial to do so. The data collected using four, six, and eight measurements were analyzed and it was found that measuring a sign six times yielded the lowest standard deviation. Figure 3-4 shows the locations measured on each type of sign. The most challenging sign to identify locations to measure was the yellow warning signs. This is due to the various symbols on the yellow warning signs installed on the road. To maintain consistency, the outside edges of the sign are chosen because these locations are always open on the warning signs.



Figure 3-4 *Location on each sign where measurements were taken.*

To record all the information gathered for each sign, a Google form was created which provided a convenient way for the data to be recorded using cell phones. Once the data from the RoadVista was uploaded to the computer, the data from the Google form and RoadVista were combined using Microsoft Access. Figure 3-5 shows the locations of signs measured throughout the state of South Carolina. A total of 1,600 signs were measured. This sample size is larger than any of the previous sign studies, except for the national study performed by the FHWA in which 6,275 signs were evaluated. At each location shown in Figure 3-5, approximately 10 to 20 signs were measured in its vicinity.

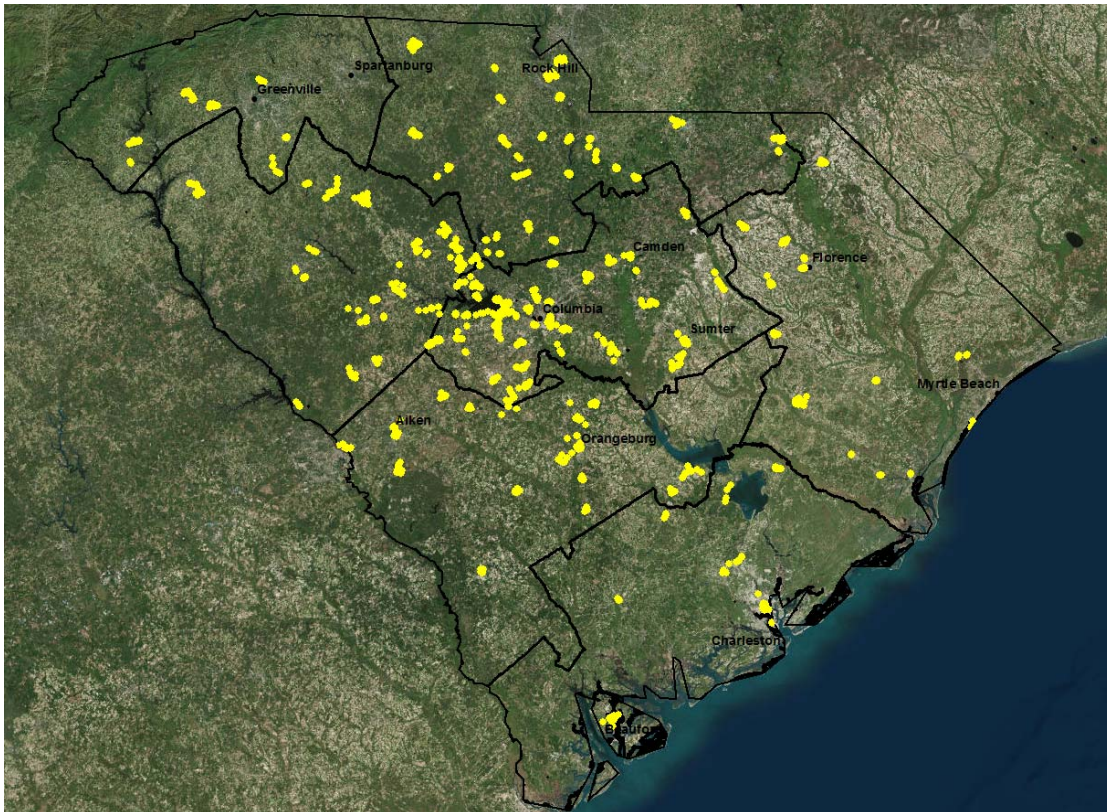


Figure 3-5 Location of signs measured in this study (sample size = 1,600); approximately 10 to 20 signs were measured at each location.

Figure 3-6 shows the age distribution of the signs measured in this study. The histogram reflects this study's focus to measure the retroreflectivity of older signs. It can also be observed that new signs comprise a large number of the signs measured due to the continual replacement of older signs.

Figures 3-7(a) to 3-7(d) show the age and retroreflectivity of each color sign measured in this study. It can be observed that the majority of signs that are eight years or older tend to have lower retroreflectivity. With this decrease in retroreflectivity, it was found that only 15 signs failed to meet the minimum standards across all colors.

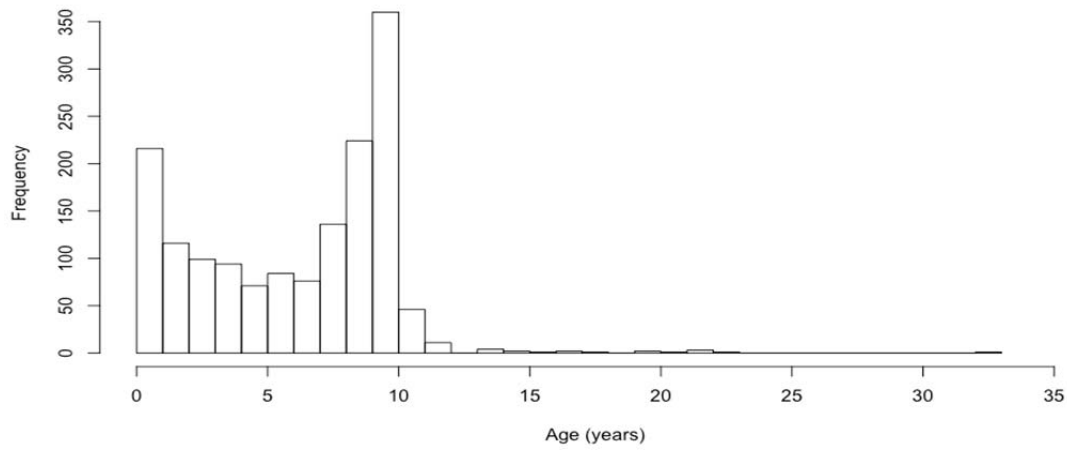


Figure 3-6 Histogram of ages of all signs collected.

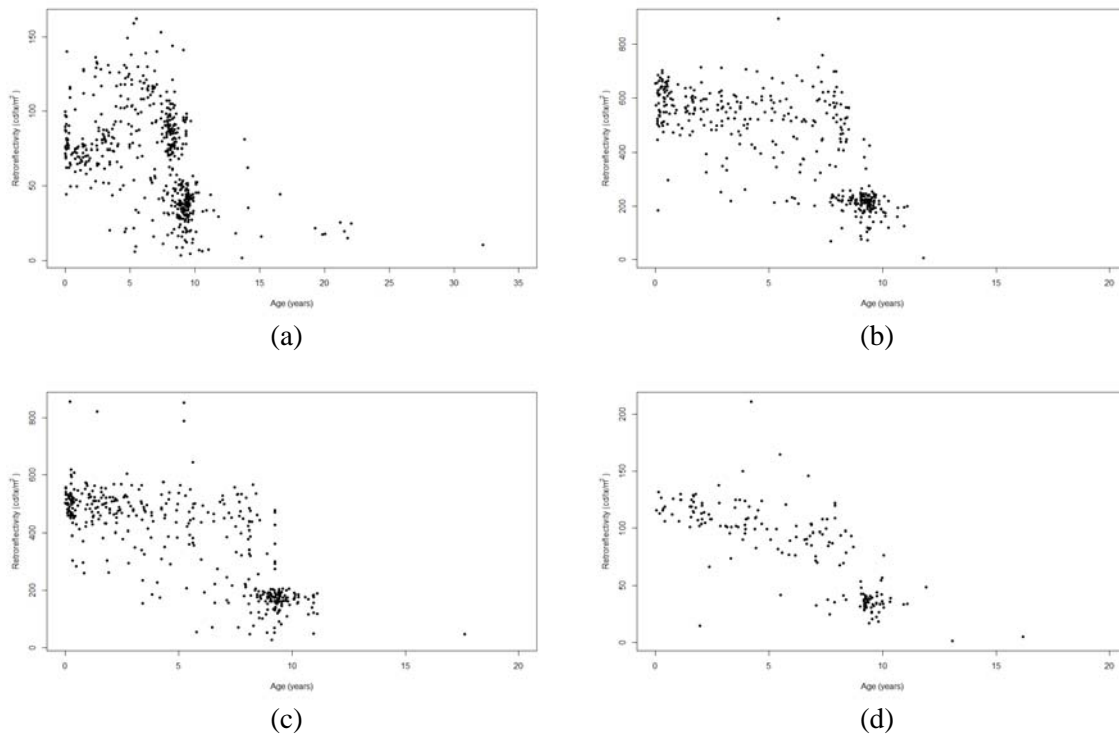


Figure 3-7 Retroreflectivity of signs and age in years: (a) red, (b) white, (c) yellow, and (d) green.

3.2 Linear Regression

In this study, regression models were used to determine which factors have an effect on retroreflectivity of signs. Regression analysis is one of the most widely used methods to study the relationship between a variable of interest and a set of explanatory variables (21). The variable of interest is called the dependent or response variable and the

predictor variables are called explanatory variables or independent variables. When performing a multiple regression, the following assumptions are made (22).

1. The dependent and independent variables have a linear relationship.
2. The errors are normally distributed.
3. The independent variables are not highly correlated with each other.
4. The variance of errors is similar across all independent variables.

Let $X = (x_1, x_2, \dots, x_k)$ be a set of explanatory variables and Y be the response variable. A multiple regression model indicated the relationship between X and Y as follows (23).

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon \quad (3.1)$$

where

β_j ($j = 0, \dots, k$) = set of estimated parameters (coefficients)

ε = the random error

k = number of explanatory variables

The sign and absolute value of estimated parameters determine the direction and magnitude of the effect of corresponding explanatory variables on the response variable, respectively. ε is a random variable that accounts for the model failure to exactly fit the data (23).

Parameters β_j ($j = 0, \dots, k$) are estimated through the fitting model to the data. The most common method to fit a model to the data is the least squares method which is based on the residuals. As shown in Figure 3-8, the residual is the difference between the estimated and actual values for an observation (24). The least squares calculate the best-fitting line for the observed data by minimizing the sum of the squares of the residuals.

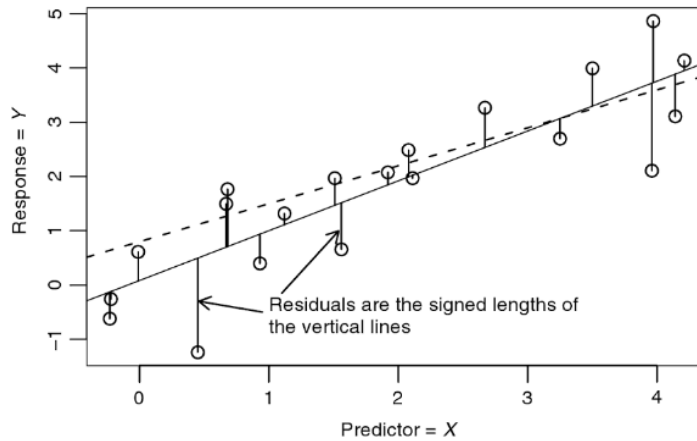


Figure 3-8 Illustration of the residuals (Source: (24)).

Assume, there are n observations and k of explanatory variables. The residual is defined as follows.

$$e_i = y_i - \hat{y}_i \quad (3.2)$$

where

y_i = actual value of the i^{th} observation

\hat{y}_i = predicted value of the i^{th} observation

The predicted value of the i^{th} observation is calculated using the fitted model as follows.

$$\hat{y}_i = \beta_0 + \sum_{j=1}^k \beta_j x_{ij} \quad i = 1, \dots, n \quad (3.3)$$

The sum of squared residuals is calculated as follows (25).

$$\sum_{i=1}^n e_i^2 = \sum_{i=1}^n \left(y_i - \beta_0 - \sum_{j=1}^k \beta_j x_{ij} \right)^2 \quad (3.4)$$

To minimize the sum of squared residuals for finding the best estimation of β_j , first the derivative of Eq. (3.4) with respect to all β_j ($j = 0, \dots, k$) are taken. Then all obtained equations are set to zero and solved for β_j which results in the best estimation of the coefficients.

To check the significance of estimated parameters (i.e., β_j), the p -value and t -statistic values are considered. The corresponding null and alternative hypotheses are as follows.

$$\mathbf{H}_0: \beta_j = 0$$

$$\mathbf{H}_a: \beta_j \neq 0$$

The test statistic is calculated as follows (26).

$$t^* = \frac{\beta_j}{se(\beta_j)} \quad (3.5)$$

where

t^* = the test statistic

se = standard errors of estimated coefficient j

The degree of freedom of t -test statistic is calculated using the following formula.

$$df = n - k \quad (3.6)$$

where

df = degree of freedom

other parameters as defined previously.

At the significance level α , we reject H_0 if and only if $p < \alpha$. When the null hypothesis is rejected, it can be concluded that the data provide convincing evidence that β_j is different from zero and the variable is statically significant. In this study, a variable is significant if it has t -statistics corresponding to the 95% confidence level or higher (i.e., p -values less than 0.05).

To compare the results of different models and to find the best model among them, the goodness-of-fit statistics such as R-squared (R^2) and adjusted R-squared ($R^2_{adjusted}$) are usually used (26) in the regression model. R^2 is a measure that indicates how well the regression model fits the data and is calculated as follows.

$$R^2 = 1 - \frac{SSE}{SST} \quad (3.7)$$

where

SSE = the error sum of squares

SST = the total sum of squares

SSE and SST are calculated as follows.

$$SSE = \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (3.8)$$

$$SST = \sum_{i=1}^n (y_i - \bar{y})^2 \quad (3.9)$$

where

\bar{y} = the sample mean

other parameters as defined previously.

R^2 is a number between 0 and 1; 0 means none of the observed points fall on the estimated regression model and 1 means all data points are fall on the estimated model. In general, a higher R^2 and closer it is to 1 indicates that the model fits the data better. A shortcoming of the R^2 statistics is that it increases when a variable is added to the model. Thus, this statistic can be misleading since a model with more explanatory variables will have a R^2 value, but it is not necessarily the better model. To address this problem, the adjusted R-squared (i.e., $R^2_{adjusted}$) is used and is computed as follows (27).

$$R^2_{adjusted} = 1 - \left(\frac{n-1}{n-k} \right) \frac{SSE}{SST} \quad (3.10)$$

The essential aspect of a linear model is that it is linear in the unknown parameters (i.e., β_j) (28). Eq. (3.1) shows the general form of a linear regression model. In addition to the general form of linear regression, this study used the quadratic form which has the following specification.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2^2 + \dots + \beta_k x_k + \varepsilon \quad (3.11)$$

In addition to linear models, one simple nonlinear model, the exponential regression model, was used in this study and it has the following specification.

$$Y = \beta_0 \exp(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k) + \varepsilon \quad (3.12)$$

Note that the above non-linear form can be linearized by taking the natural logarithm.

The statistical software *R* was used to estimate the regression models in this study. The dependent variable is retroreflectivity and the explanatory variables considered are age, sign height, offset, the degree of shade, and sign facing direction. Facing direction is coded as a binary variable (zero or one) for each of the eight facing directions, where a one indicates where the sign is facing. In selecting the functional forms for the regression, an Edisonian approach was used due to the large scatter in the data as shown. In the process of constructing the models, variables were retained in the specification if they have t-statistics corresponding to the 95% confidence level or higher (i.e., p-values less than 0.05).

In addition to all aforementioned specifications, 12 additional nonlinear functions including exponential functions, power functions, reciprocal function and sigmoid function were considered. Combination of these functions and decision variables result in more than 60 models for all four sign colors. The statistical software *SAS* was used to estimate the parameters of the nonlinear models. None of the non-linear models outperformed the linear models.

3.3 Historical Replacement Rate

The historical replacement rate, f_i , is calculated from data obtained from the SCDOT. The replacement rate is the probability of a sign being replaced at a given age. The following equation was used to calculate the replacement rate.

$$f_i = \frac{\text{Number of Signs Replaced at Age } i}{\text{Total Signs at Age } i} \quad (3.13)$$

where

i = the age of the sign in years.

CHAPTER 4: FINDINGS AND DISCUSSION

Table 4-1 shows the model that yield the largest adjusted R^2 value for each color. The table also provides the minimum retroreflectivity for each color, the best fit model specification, the adjusted R^2 value, and the expected minimum and maximum sign life. The sign life was calculated taking into account the degree of shade (one to four) and, for red signs, whether the sign is facing northwest.

Table 4-1 Best Fit Models for South Carolina Sign Data

Sign Color	Min Retro-reflectivity	Model	Adjusted R^2	Min Expected Sign Life	Max Expected Sign Life
Red	7	$142.97e^{-0.08 \times \text{Age} - 0.21 \times \text{Shade} - 0.28 \times \text{NW Direction}}$	0.35	25	37
Yellow	50	$543.32 - 9.34 \times \text{Age} - 2.31 \times \text{Age}^2 - 19.39 \times \text{Shade}$	0.62	12	12
White	50	$592.02 + 21.85 \times \text{Age} - 5.90 \times \text{Age}^2 - 20.64 \times \text{Shade}$	0.63	11	11
Green	15	$134.55 - 2.97 \times \text{Age} - 0.50 \times \text{Age}^2 - 7.92 \times \text{Shade}$	0.67	11	12

Table 4-2 shows the best fit model coefficients and their corresponding t-statistics and p-values. For red signs, age, shade, and northwest (NW) direction were found to be statistically significant predictors at the 99.99% confidence level. Holding all other predictors fixed, the retroreflectivity is found to decrease by about 1.08 cd/lx/m² each year. When the degree of shade increases, the retroreflectivity decreases. This finding is consistent with our field observation. Those signs located in the shade tend to contain more mildew and sap from trees, and therefore, they tend to have lower retroreflectivity. Note that higher degree of shade is assigned a higher value in the data (i.e., 1 for no shade and 4 for full shade). The red signs facing the NW direction are found to have lower retroreflectivity compared to those signs facing the other directions.

Table 4-2 Best Fit Model Coefficient, t-statistic, and p-value

Sign Color	Variable	Coefficient	t-stat
Red	Intercept	142.97 ***	84.76
	Age	-0.08 ***	-12.82
	Shade	-0.21 ***	-9.10
	Direction NW	-0.28 ***	-3.78
White	Intercept	592.02 ***	35.74
	Age	21.85 **	3.12
	Age ²	-5.90 ***	-8.81

	Shade	-20.64 ***	-3.65
Yellow	Intercept	543.32 ***	41.68
	Age	-9.34.	-1.90
	Age ²	-2.31 ***	-5.12
	Shade	-19.39 ***	-4.21
Green	Intercept	134.55 ***	23.56
	Age	-2.97 †	-1.65
	Age ²	-0.50 ***	-3.49
	Shade	-7.92 ***	-3.87

***' significant at p -value < 0.001; '**' significant at $0.001 < p$ -value < 0.01;

'*' significant at $0.01 < p$ -value < 0.05; '.' significant at $0.05 < p$ -value < 0.1

'†' significant at $0.1 < p$ -value

For white signs, a quadratic regression model yielded the highest adjusted R^2 value, where the statistically significant predictors are age, age², and shade. The coefficient of age² is negative (-5.90), so the relationship between age and retroreflectivity is concave. The model results indicate that the retroreflectivity of a white sign will not decrease until about 1.85 years. Those signs located in shaded areas are found to have lower retroreflectivity.

The yellow signs have the same model specification as white signs. However, retroreflectivity is found to decrease monotonically once the sign is installed in the field. Similar to white signs, those yellow signs located in shaded areas are found to have lower retroreflectivity.

The quadratic model specification was also found to yield the best fit for green signs, with age, age², and shade as the statistically significant predictors. Similar to yellow signs, their retroreflectivities are found to decrease monotonically once they are installed in the field, and those located in shaded areas are found to have lower retroreflectivity.

This study also examined the SCDOT historical sign replacement rate, which was constructed using data from the SCDOT sign database and is calculated as the ratio of the number of signs replaced at a given age to the total number of signs at that age. The reasons for replacement include: accident, poor reflectivity, storm damage, faded, vandalized, missing, or no longer needed. The historical sign replacement rate is shown in Figure 4-1. The data revealed that a significant portion of the signs are replaced around the 10-year mark, following the SCDOT's sign replacement schedule. Additionally, the data indicated that very few signs replaced at the 10, 11 or 12 year mark are due to poor retroreflectivity.

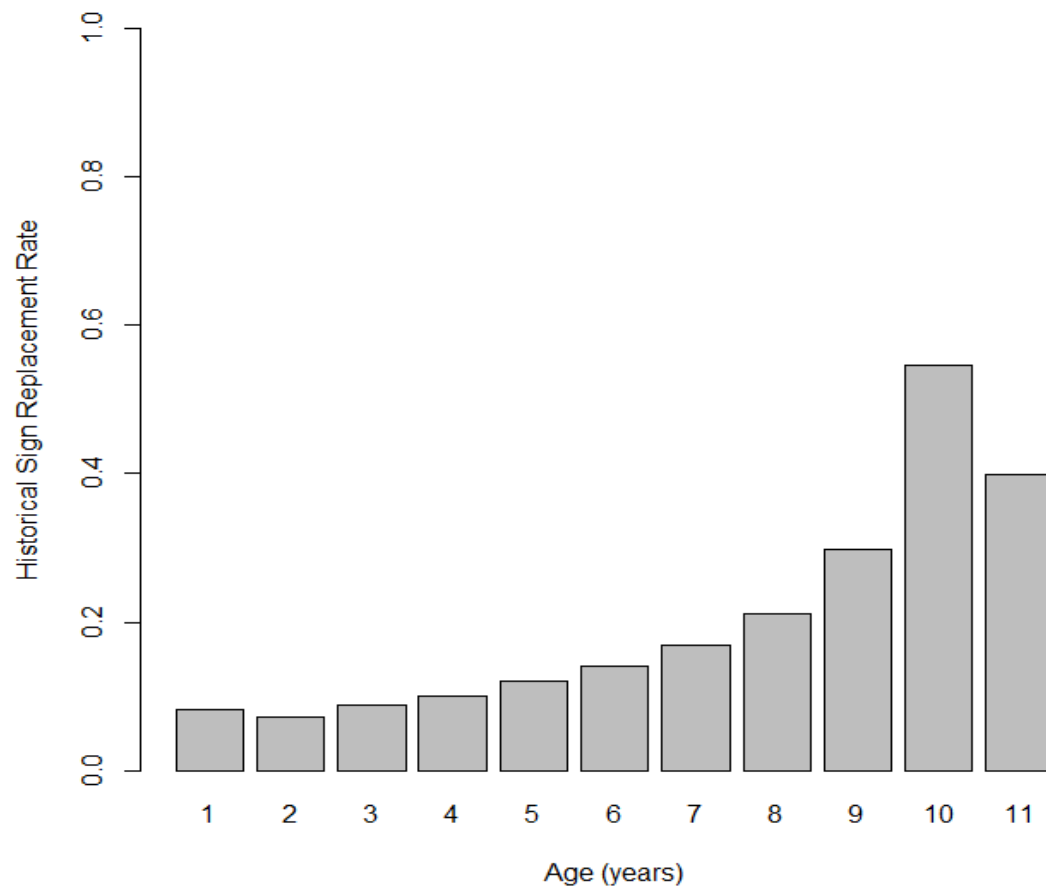


Figure 4-1 SCDOT historical sign replacement rate.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study developed regression models using data from 1,600 traffic signs in South Carolina. This sample size is larger than any of the previous sign studies, except for the national study performed by the FHWA. For red signs, the exponential form provided the best fit and for white, yellow, and green signs the quadratic form provided the best fit. All models have adjusted R^2 values greater than those reported in previous sign studies. This study introduced a new parameter, degree of shade, which was found to have a significant effect on the degradation of sign retroreflectivity, primarily from mildew growth. For red signs, the variable northwest facing direction was also found to be statistically significant.

Based on the calculated expected life of signs in South Carolina, it is recommended that the SCDOT extends the sign replacement interval to 12 years. This conclusion is supported by both the SCDOT historical sign replacement data and measurements taken from older signs in Spartanburg. That is, very few signs replaced at the 10, 11, or 12 year mark are due to poor retroreflectivity, and upon examination of older signs collected by the Spartanburg maintenance team, it was found that all of the type III signs (12 years or older) have a higher retroreflectivity value than the minimum specified in the MUTCD (additional information about the Spartanburg signs are provided in Appendix A).

5.2 Recommendations

A good number of signs may last beyond 12 years. Therefore, it is recommended that the SCDOT considers identifying control signs in various districts and monitor those signs with a retroreflectometer; instructions for using the RoadVista 922 retroreflectometer are provided in Appendix B. Based on readings of the control signs, the SCDOT can then make decisions on whether the associated signs need to be replaced. This approach will enable the SCDOT to incrementally extend the life of signs.

It is also recommended that the SCDOT periodically evaluates the effectiveness and benefits of using type XI sheeting. The Minnesota DOT currently uses Type XI sheeting for every color with an expected life of 15 years. A 2014 preliminary investigation by the Caltrans division of research, innovation, and system information reported that some state DOTs are using Type XI sheeting exclusively for overhead signs, while others have expressed reservations about it. Many state DOTs remain undecided about using Type XI sheeting for overhead signs due to mixed experience reported by other states (29):

- Delaware DOT uses Type XI exclusively because of its multifunctionality and longer service warranties over lesser grade sign sheeting.
- Nebraska DOT found that the cost increase associated with Type XI sheeting is offset by eliminating sign lighting hardware costs.
- Louisiana DOT reported no discernible difference to the driver in a test installation of Type XI sheeting alongside Type X on an overhead urban truss.

- Nevada DOT found Type XI sheeting used for both the background and legend created a halo effect or washed out the legend.

5.3 Implementation Plan

It is recommended that the SCDOT change the sign replacement interval from 10 to 12 years. In addition, it is recommended that the SCDOT incorporate sign washing in future sign maintenance activities to extend the life of signs. In previous studies, sign washing was found to be effective in extending sign life (9). In this study, a small number of signs (49 signs) that are located in fully-shaded areas were evaluated under washed and unwashed conditions. That is, the signs were first measured under unwashed conditions. Then the signs were measured after being washed by hand with a glass cleaner and paper towels. The average improvement among the measured signs was 22.5%; this equates to about two years for yellow, white, and green signs and about five years for red signs. It should be noted that the NCDOT performs sign washing as part of their regular sign maintenance activities. The recommended procedure for washing signs per Avery Dennison is as follows.

“The cleaning solution should have a pH range of 4 to 10 (within mild acid or mild alkaline limits). Use a mild soap or detergent along with warm water and a soft cloth or sponge. The cleaning solution should be non-abrasive and free of strong solvents. If it becomes necessary to clean and remove heavy soil and grease, use a damp chemical rag with kerosene, mineral spirits, heptane, or V.M. & P naphtha. Test the cleaner on a small section or sample of the material before use. Do not use high pressure sprays, and avoid direct sprays at sheeting edges. Spray or wipe (with a soft cloth or sponge) the cleaning solution over the entire surface of the film to be cleaned (avoid abrading the film surface with unnecessary scrubbing); thoroughly agitate and mix the cleaning solution into the dirt on the film’s surface; rinse the entire surface with clean water and let air dry or dab dry being careful not to lift film edges.”

Additional information about storing, handling, and cleaning Avery Dennison signs are provided in Appendix C.

Lastly, it is recommended that the SCDOT considers making the following procedural changes.

1. Add another category to the sign replacement database which specifies whether a sign was replaced because it has reached the end of its service life. Over time, this data will enable the SCDOT to better determine sign life.
2. Add a shade variable to the sign database. Over time, this data will enable the SCDOT to determine the effect of mildew and sap accumulation on sign retroreflectivity.
3. Use a smartphone or tablet “app” to update sign direction in the database. This procedure can be done whenever a new sign is installed.

REFERENCES

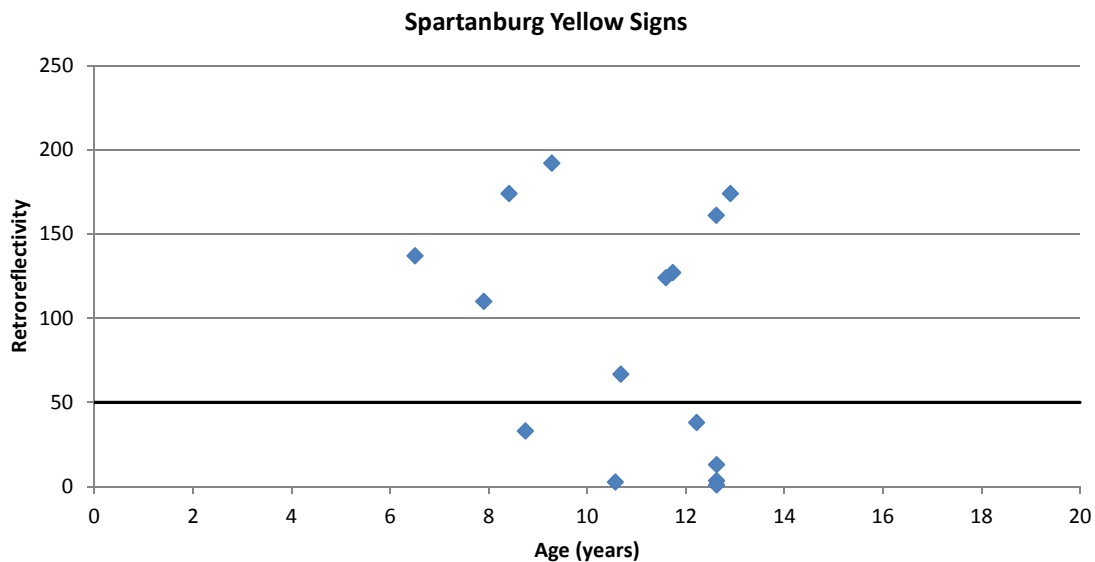
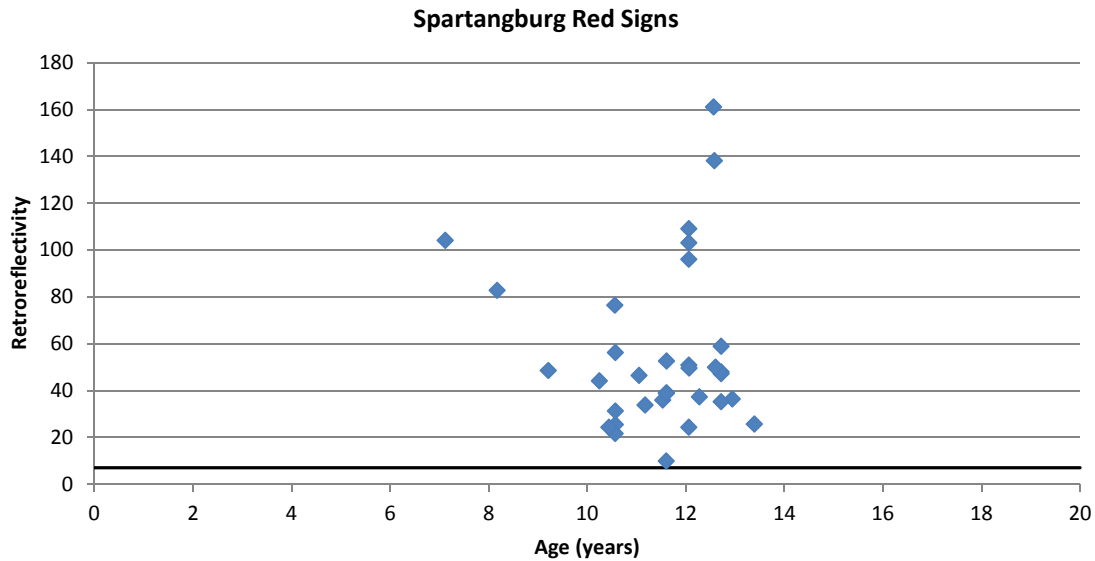
1. Federal Register. Vol. 72, No. 245.25 CFR Part 655, Final Ruling. December 21, 2007.
2. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2009
3. Re, J.M. and P.J. Carlson. National Cooperative Highway Research Program. Synthesis 431. Transportation Research Board, Washington, D.C., 2012.
4. South Carolina Department of Transportation (SCDOT). *Engineering Directive 8. Road Inspections*. March 3, 2011.
5. South Carolina Department of Transportation (SCDOT). *Engineering Directive 57. Maintaining Traffic Sign Retroreflectivity*. October 31, 2012.
6. Jenkins, S.E. and F.R. Gennaoui. National Survey of the Photometric Performance of Retroreflective Traffic Signs. Proceedings of the 15th Australian Road Research Board Conference, Victoria, Australia, 1990.
7. Black, K.L., H.W. McGee, S.F. Hussain, and J.J. Rennilson. *Service Life of Retroreflective Traffic Signs*, Publication FHWA-RD-90-101, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1991.
8. Bischoff, A.L., and D.M. Bullock. *Sign Retroreflectivity Study*. Publication FHWA/IN/JTRP- 2002/22. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2002.
9. Wolshon, B., R. Degeyter, and J. Swargam. Analysis and Predictive Modeling of Road Sign Retroreflectivity Performance. *16th Biennial Symposium on Visibility and Simulation*. Iowa City, Iowa, June 2–4, 2002.
10. Rasdorf, W.J., J.E. Hummer, E.A. Harris, V.P.K. Immaneni, and C. Yeom. *Designing an Efficient Nighttime Sign Inspection Procedure to Ensure Motorist Safety*. Report FHWA/NC/2006-08. North Carolina Department of Transportation, Raleigh, North Carolina, 2006.
11. Kipp, W.M.E. and J.M.V. Fitch. *Evaluation of Measuring Methods for Traffic Sign Retroreflectivity*. Publication 2009-8. Vermont Agency of Transportation, Montpelier, Vermont, 2009.
12. Carlson, P.J., L. Higgins, and J. Ré. *Research and Recommendations for a Statewide Sign Retroreflectivity Maintenance Program*. report FHWA/TX-12/0-6408-1. Texas Department of Transportation, Austin, Texas, 2011.
13. Pike, A.M., and P.J. Carlson. Evaluation of Sign Sheeting Service Life in Wyoming. In *Transportation Research Board 93rd Annual Meeting* (No. 14-0758).

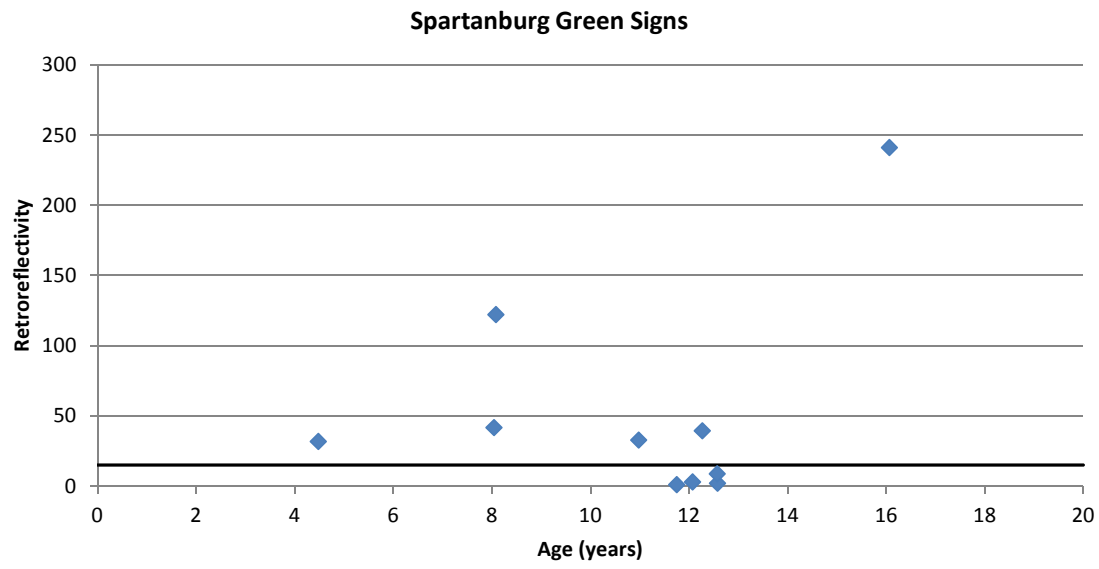
14. Huang, W.H., Hu, L.Q., and Jiang, M. Retroreflectivity and Deterioration Characteristics of Sheeting Used for In-Service Guide Signs. *Journal of Highway and Transportation Research and Development*, Vol. 7, No (2013) 88.
15. Clevenger, K., Colello, K., and Quirus, J. *Retroreflectivity of Existing Signs in Pennsylvania*. Report No FHWA-PA-2012-003-E01041-W09. April, 2012.
16. Preston, H., K.C. Atkins, M. Lebens, and M. Jensen. *Traffic Sign Life Expectancy*. Report MN/RC 2014-20. Minnesota Department of Transportation, St. Paul, Minnesota, 2014.
17. Kirk, A.R., E.A. Hunt, and E.W. Brooks. *Factors Affecting Sign Retroreflectivity*. Publication OR- RD-01-09. Oregon Department of Transportation, Salem, Oregon, 2001.
18. Evans, T., K. Heaslip, W. Boggs, D. Hurwitz, K. Gardiner. Assessment of Sign Retroreflectivity Compliance for Development of a Management Plan. *Transportation Research Record: Journal of the Transportation Research Board*. No. 2272, 2012, Transportation Research Board, Washington, D.C., pp. 103-112. <https://doi.org/10.3141/2272-12>
19. Khalilikhah, M. and K. Heaslip. *GIS-based Study of the Impacts of Air Pollutants on Traffic Sign Deterioration*. Transportation Research Board, Washington, D.C., 2016
20. Hildebrand, E.D. Reductions in Traffic Sign Retroreflectivity Caused by Frost and Dew. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1844, 2003. <https://doi.org/10.3141/1844-10>.
21. Seber GA, Lee AJ. Linear regression analysis, vol. 936. Hoboken, NJ: John Wiley & Sons, Inc. 2012.
22. Keith, T.Z. *Multiple Regression and Beyond: An Introduction to Multiple Regression and Structural Equation Modeling*. Routledge, 2015.
23. Montgomery DC, Peck EA, Vining GG. Introduction to linear regression analysis. John Wiley & Sons; 2012 Apr 9.
24. Weisberg S. Applied linear regression. John Wiley & Sons; 2005 Apr 1.
25. Rawlings JO, Pantula SG, Dickey DA. Applied regression analysis: a research tool. Springer Science & Business Media; 2001 Apr 6.
26. Faraway JJ. 2002, Practical regression and ANOVA using R.
27. Washington SP, Karlaftis MG, Mannering F. Statistical and econometric methods for transportation data analysis. CRC press; 2010 Dec 2.
28. Yan X, Su X. Linear regression analysis: theory and computing. World Scientific; 2009.

APPENDIX A

Spartanburg Sign Data

The Spartanburg data were measured on August 17, 2016. As shown in the figures below, most of these signs were not much older than the signs the team has measured in the field. All of the type III signs have a higher retroreflectivity than the minimum specified by the MUTCD. The 9 signs that failed had Type I sheeting.





APPENDIX B

Retroreflectometer Setup

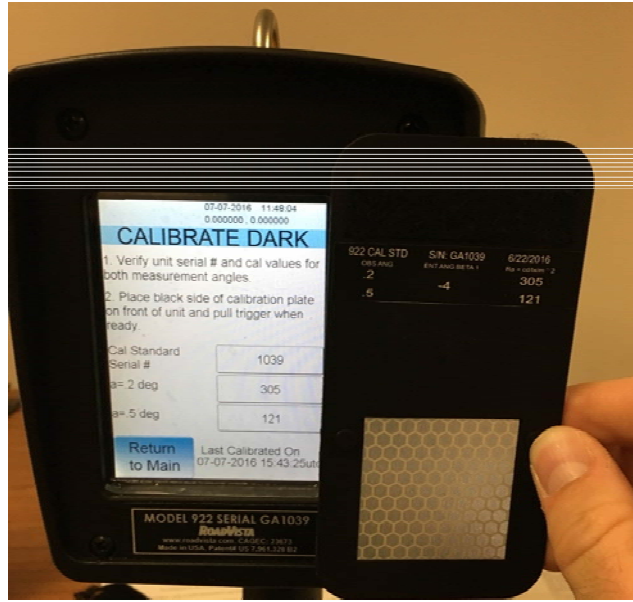
Initial Setup

1. From the main menu click the setup button
2. Disable the 0.5 Deg Enabled
3. Use the GPS time syncing function
4. Go back to the setup menu and click GPS Detail. This screen allows you to see the accuracy of the GPS
5. Blue bars will appear on the screen. More blue bars on the screen means that the GPS is more accurate. Position accuracy appears at the top of the screen. The best accuracy is around three meters
6. Return to setup
7. Return to setup

Calibration

Click calibrate from the Main Menu (at this time open the calibration plate not touching sheeting)

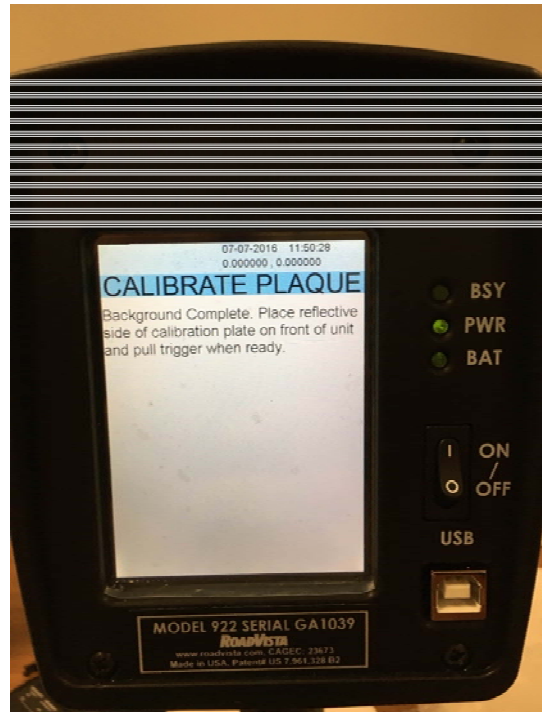
1. Verify the 0.2 deg and 0.5 deg Ra numbers from the calibration plate match the corresponding numbers seen on the screen. If the numbers do not match, click in the field that doesn't match and change the number to match what appears on the calibration plate



2. Firmly press the black felt side of the calibration plate against the front part of the retroreflectometer and pull the trigger. After the trigger is pulled you should hear two consecutive beeps (a long beep followed by a short beep)



3. Follow the instructions given on the device's screen. Make sure to hold the plate with the reflective sheeting over the circular hole on the front of the device



4. Once the reflective sheeting has been scanned, you will automatically be sent to the measure screen. Repeat step 3 by taking an actual measurement with the device to confirm the device has been properly calibrated. The number obtained should be within 3 points of the number shown on the calibration plate. If the reading is higher or lower than 3 points the device should be recalibrated
5. Press the comments button then click user comments and type "Calibration" then click return to comments
6. Return to measure
7. Click next sign

Calibration should be performed twice daily while measuring

Taking Measurements

1. Ensure the GPS date and time are accurate. The GPS takes a few minutes outside to obtain a signal
2. Place the device directly on the sign
3. Pull the trigger while the unit is on the sign
4. When multiple readings are taken for a background and legend, the average appears at the bottom of the screen
5. To save the readings hit next sign and the sign will automatically be saved
6. If a sign is measured incorrectly, you can click return to main menu and then click view data
7. Click delete this sign to delete undesired measurements

The device can store approximately 4,500 measurements

Transferring Data to the Computer

1. Open the RoadVista 922 Download Manager
2. Plug in the USB cable to the computer
3. Click the sound test beep button
4. Click upload data from 922
5. Go to file then save data. The data can be saved as a csv, kml, or shp file

APPENDIX C

Avery Dennison® Storage, Handling and Cleaning

Instructional Bulletin #8.00

Revised: April 2017

This document outlines mandatory procedures for contractors and installers of both flat stock, and extruded panel signage. For instruction on converting Avery Dennison retroreflective films in the sign fabrication process, please refer to our other Instructional Bulletins.

The purpose of this bulletin is to assist the installation process of highway signs. When an agency chooses Avery Dennison retroreflective film to cover a substrate, we wish like to ensure the end result is a clear, legible sign that will last for the duration of the warranty. With specifications put in place by state and government transportation agencies, our role is to see that all aspects of the contracts are followed closely, and the end results are satisfactory to all parties. This includes proper fabrication techniques, proper shipping, storage, handling, and installation.

If proper techniques are not followed, the sign may not deliver the message it was intended to give to a driver in a clear, unobstructed manner. Factors that detract from the intended sign performance include dents, scratches, dirt and oil residues, wrinkles, or bends in the panels. Most flaws acquired in the shipping or installation of the signage will stay for the life of the sign, causing the daytime image to appear marred, and the nighttime reflectivity to be affected. Any permanent variations to the surface of the reflective sheeting will lessen its ability to give drivers the proper information in the way it was designed to be given- bold by day and bright by night.

Storage and Conditioning of Retroreflective Films

Avery Dennison retroreflective sheeting should be used within one year from the date of purchase. All guarantees and warranties, expressed or implied, shall become null and void in all respects on materials stored prior to application for periods in excess of one year.

Avery Dennison retroreflective sheeting should be stored in a cool, dry area preferably at 65°-75°F (18.3°-29.7°C) and 45%-55% RH. If materials are stored in areas separated from the application or converting area, it is advisable to allow the material to acclimate at least 24 hours prior to use.

Rolls

Store rolls horizontally in the shipping carton suspended through the core or other means of suspending by the core. Do not lay the roll on a hard surface or reflectivity and surface defects may result.

Fluorescent products specifically need to be handled with extreme care. Incidental contact with a sharp object or folding of the material will cause a material stress defect that will be visible in the finished sign and may be rejected by the sign end user. Keep the protective packaging on the roll until lamination. Retain for later use.

Sheeted Material

Store sheets flat and allow to condition for 24 hours at shop temperature and humidity prior to printing. Recommended stacking method is face-to-back contact, with slip sheeting between each face-to-back contact. Liner may be used as slip sheeting by placing the siliconized (slippery) side next to the sheeting. Place a sheet of Masonite, plywood, or metal on top of each stack. Do not allow stacks to exceed 4" in height.

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Storage of Finished Signs

Mark all signs with the appropriate manufacturing information (manufacturing date, reflective film lot number, sign fabricator information, etc.) so the signs may be tracked at a later date. Allow any finished signs to set for 24 hours in the shop before installation. All guarantees and warranties, expressed or implied, shall become null and void in respects to improper handling and storage of finished signs.

Section 1: Proper Storage of Signs

Avery Dennison Reflective Sheeting should be used within one year from the date of purchase. All guarantees and warranties, expressed or implied, shall become null and void in all respects on materials stored prior to application for periods in excess of one year.

Avery Dennison Reflective Sheeting should be stored in a cool, dry area preferably at 65°-75°F (18.3°-29.7°C) and 45%-55% RH. If materials are stored in areas separated from the application or converting area, it is advisable to allow the material to acclimate at least 24 hours prior to use.

Flat Stock Signage Arrival and Storage Techniques

Signs should arrive from the fabricator in boxes, or handmade frames. They should arrive dry, and should be sorted upon arrival to ensure the proper signs were shipped (Figure 1).



Figure 1

Signs should arrive with either slip sheeting or foam padding between them to reduce the risk of abrasions during shipment. If signs arrive without proper padding inspect all signs prior to acceptance, as these damages will most likely be permanent.

These signs should not be stacked (Figure 2), rather stored on edge in a dry environment (Figure 3). Stacking signs flat may compress either the glass beads, or prisms in the sheeting, resulting in a loss of necessary reflectivity.

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Figure 2



Figure 3

Be sure to keep the padding materials between the sign faces when storing signs on edge. Removing the padding may result in the compression of sheeting on the signs bearing the most weight. This would most likely be the signs closest to the wall or support they are leaning against.

If signs are to be leaned against a surface that is not the entire width of the sign, like a beam or post, be sure that the first sign is facing away from the post, with the non-sheeted side against the support. If the face of the sign is resting against the post, damage will occur at the contact points.

In the same manner, the use of banding is not recommended for T-5500, T-6500, T-7500, T-9500 and T-11500 Sheeting (Figure 4). Signs that are banded may adopt the same compression at the pinch points on the signs. These small areas may also lose reflectivity permanently.



Figure 4

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What Happens if the Signs Become Wet?

As mentioned earlier, signs should arrive and be stored in a dry environment, free of both water and high levels of moisture or humidity until installed. If they are subjected to this environment at any time, it is imperative that the signs are unpacked, and the shipping materials removed from the sign face. As foam and paper both absorb and retain water, the signs will be permanently damaged if left alone. Possible screened image transfers and wrinkling of the face stock can occur with a forced presence of water on the surface.

Storing the signs in an enclosed, non-climate-controlled trailer is also not recommended in areas of high heat and humidity. These trailers can have a "greenhouse effect" on the signs within, causing pre-mature weathering and damage to the signs (Figure 5).

Many question why a sign cannot get wet in storage when it gets wet after installation. The difference is that the amount of moisture that comes in contact with a sign surface due to rain, humidity, or dew is nominal, and tends to run off or evaporate due to air circulation. When trapped between other signs, there is an absence of airflow that would normally assist in the drying process.



Figure 5

Never place wet signs in a batch oven, or attempt to dry them with the packing materials still in place. This will cause irreversible damage to the signs. Even if the packing materials are removed, signs should be air-dried naturally or with fans, not in an accelerated forced heat environment.

Under normal circumstances, it is recommended that the packing material not be removed from the face of the sign until installation. This gives an extra layer of protection against handling damages on the way to the job site. However, this should be disregarded if the signs become wet at any time during the handling or installation process.

Storage of Overhead or Guide Signs

Guide signs usually arrive from the fabricator in a crated form. These crates are commonly constructed from wood, and resemble a frame for the sign. These signs are usually crated face to face, with an air gap between the signs. If signs arrive loose in the crate, and appear to be touching each other with no padding between them, inspect them for damage before installation.

Guide signs should be stored indoors if they are to sit for a long duration of time. Storing signs in an enclosed, non-climate-controlled trailer is not recommended in a high heat environment, as it can have a negative effect on the desired performance of the sign.

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If signs must be stored outside, there must be spacing of at least 4" between the signs (Figure 6). This air gap will not only allow for proper moisture evaporation, but protection from compressing the reflective materials as well. It is also very important that the signs are not subjected to water runoffs or downspouts from buildings. Any packaging on the signs that would prevent proper airflow must be removed to prevent damage.

With both indoor and outdoor storage, signs can be left either free standing, or leaning against each other, as long as there is no pressure applied to the reflective face of the sign. A way to accomplish this successfully is to leave the signs in the crates they arrive in. If freestanding racks are available, signs can be removed from the crates and stored upright.

Under no circumstances should the signs be left leaning against each other. Even if foam padding is used, pressure points that compress sheeting and movement from forces such as wind gusts are unavoidable with such heavy substrates. If this damage takes place it is irreversible. (Figure 7)

If signs are to be left outside, it is imperative that they are not resting directly on the ground. The signs should be lifted off of the ground by placing them on non-treated timbers or other materials that will keep them free from standing water, mud, or other surfaces that may cause damage to the signs (Figure 8). This damage includes not only water and dirt penetration, but also dents and uneven setting caused by stones or other ground surfaces.

It is also not recommended to leave signs on the ground, due to the difficulty involved in picking these signs up without bending the panels. Bending of the sign may result in snapping the bolts from behind, or damaging the stiffener bars, both of which may cause permanent damage to the guide sign.



Figure 6



Figure 7

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If water or dirt is allowed to be in contact with the signs for an extended period of time, permanent wrinkling, discoloration, or loss of reflectivity is inevitable.



Figure 8

Section 2: Handling and Installation Transportation Notes for Flat Stock Signage

When preparing to install signs, it is important that the signs are not stored outdoors with the packing materials on the face (Figure 9).

If the packing materials are left on the signs outdoors, installers run the risk of causing permanent damage to the reflective properties of the signage. As paper slip sheeting has the tendency to absorb water and moisture, the damages may not only be to the face stock. If the paper then dries while in contact with the sign, installers run the risk of it bonding to the surface of the sign, making it very difficult, if not impossible, to peel off of the sign face without causing scratches or abrasions to the sign (Figure 10).



Figure 9

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When possible, keep the finished signs in the original shipping crates for transport. If sorting is necessary prior to transporting signs to the job site, keep the signs secured with the proper packing materials between each face.

Do not transport signs to the site loose in a container or a truck bed (Figure 11). Many problems can be caused by this transportation method. Signs will be subjected to permanent damage through bouncing and sliding while in transport. Also, if the job is not completely installed in one day, moisture, such as dew, can become entrapped between the signs, causing irreversible damage.



Figure 10

Figure 11



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Tools and Installation Techniques for Flat Stock Signage

To properly install Avery Dennison reflective signage, the following tools are needed: properly sized bolts and nuts, nylon washers*, offset box end wrench, and box end wrench with a ratchet. Variation from these tools may cause unneeded scratches to the surface of the signs.

*It is very important that nylon washers be used, as they will not oxidize or degrade throughout the life of the sign. These nylon washers are available through Avery Dennison.

Installation

Once the sign is in place, insert a nylon washer on the bolt, insert the bolt through the sign face, then through the post, and place a nut on the end. Once the nut is hand tightened until snug, grip the bolt head with the offset box wrench and hold firmly (Figure 13).

With the bolt held firmly from the front, tighten the nut with the box end ratchet from the rear of the sign. Be careful to not over tighten the nut in the installation process. This may cause the face sheeting to halo, and rise from the substrate around the plastic washer, causing permanent damage, which may lead to the premature aging of the sign.

If the proper installation holes are not present in the desired location, it is permissible to drill holes on site. All holes should be drilled through the face of the sign, to avoid unneeded damage to the face film (Figure 14). Be certain that the hole location is carefully measured, as this action is impossible to reverse.



Figure 13



Figure 14

If any aluminum shavings are left on the sign surface, be careful to not scratch the sign face while removing them. Different techniques can be used to accomplish this. Some of these include holding the sign upright and tapping the sign so they fall away, using an air gun to blow the shavings off the face, or using a soft bristled brush to sweep them away. Use of a rag, a hand, or a brush with metal bristles may result in the scratching of the sign surface.

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Section 3: Handling and Installation Transportation Notes for Overhead or Guide Signs

Guide signs can be transported to the job site in a number of ways. If they are in the proper installation order, they can be shipped in their original crates. If sorting is necessary, they can be transported in specially designed racks (Figure 15).

Caution must be taken so that the signs are unable to touch or rub against each other in these racks. Damage can occur if they are allowed to do so.

Installation

Because state agencies typically specify mounting procedures, they will not be discussed in this section. The supports and fastening methods used in mounting these signs vary from state to state. Different bolts, brackets, nuts and other pieces depend on what type of apparatus the sign is being mounted to. Differences in overhead structures as well as roadside mountings prohibit the uniformity of installation nationwide. Information on what mounting equipment should be used, as well as how these signs should be secured, can be found in the respective states' specification or engineering booklets.



Figure 15

Once on the job site, it is important that the stiffener bars are not removed until the sign is completely installed. Signs may buckle in the installation process if they are taken away prematurely (Figure 16).

Do not attempt to lift oversized signs without proper vertical bracing on the rear of the sign. If demountable copy or shields are present on the sign, this deflection can cause the rivets to either loosen or snap, resulting in a damaged sign that would require field repair.



Figure 16

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Prior to lifting signs, be sure to check that there are no obstructions that may endanger the lives of the installation crews. These risks are including but not limited to uneven ground for the crane, close moving traffic, or power lines. These all represent a hazard for installation crews and should be avoided at all costs.

Signs can be lifted in a number of ways. Custom rigs with "J" hooks can be used to lift the signs from the top, straps can be used around the stiffener bars, or hooks and clamps can be mounted to the backs of the signs (Figure 17).

Whenever a sign is lifted, even if there is no prevailing wind, tag lines should be used to steady a sign while moving. These lines can reduce any swinging, or twisting of the sign from either wind, or momentum caused by the crane (Figure 18).



Figure 17

The fewer times the signs are handled, the better it is for the sign. As the number of times the sign is moved increases, so does the risk of damage to the sign face, fasteners, and supports.

Do not strap the signs across the face under any circumstances when lifting. This may cause chipping of the material on the bottom and top of the sign, as well as scratches across the face.



Figure 18

Additional Safety Checks

- Due to the varying sizes and weights of overhead signs, special care should be used in selecting which supporting method will be used.
- Additional caution should be used when any part of the lifting system has welded areas, as these welds must be able to hold the weight of the entire system.
- Whenever a sign is overhead, all workers in the area should be careful to not position themselves in a dangerous spot, such as directly underneath the moving sign, or in an area they cannot escape from freely and quickly, should the sign become loose.

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Section 4: Sign Cleaning

The cleaning solution should have a pH range of 4 to 10 (within mild acid or mild alkaline limits). Use a mild soap or detergent along with warm water and a soft cloth or sponge. The cleaning solution should be non-abrasive and free of strong solvents. If it becomes necessary to clean and remove heavy soil and grease, use a damp chemical rag with kerosene, mineral spirits, heptane, or V.M. & P naphtha. Test the cleaner on a small section or sample of the material before use. Do not use high pressure sprays, and avoid direct sprays at sheeting edges.

Spray or wipe (with a soft cloth or sponge) the cleaning solution over the entire surface of the film to be cleaned (avoid abrading the film surface with unnecessary scrubbing); thoroughly agitate and mix the cleaning solution into the dirt on the film's surface; rinse the entire surface with clean water and let air dry or dab dry being careful not to lift film edges.

This bulletin provides information to the user for proper application, storage, and other requirements. Please refer to Product Data Bulletins or your local Avery Dennison Representative for warranty information. Find the latest information on the Avery Dennison website, www.reflectives.averydennison.com. We encourage you to check our website periodically for updates.

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