Deterioration of Retroreflective Traffic Signs

BY KENT L. BLACK, SYED F. HUSSAIN, AND JEFFREY F. PANIATI

R_A = coefficient of retroreflection

Traffic signs are essential to the efficient and safe movement of vehicles on our roadway system. They provide the means to disseminate necessary information to roadway users and to invoke a reaction or convey a message. *The Manual of Uniform Traffic Control Devices* (MUTCD) requires that signs ". . . shall be reflectorized or illuminated to show the same shape and color both day and night."[1] For the vast majority of traffic signs on our nation's roadways, nighttime visibility is achieved through use of retroreflective sheeting of various types. Over time, the retroreflective sheeting deteriorates, with a subsequent loss in its brightness, color, and contrast; the net effect is a reduction in its detection and legibility distance. This paper presents the results from the recently completed "Service Life of Retroreflective Signs" study conducted for the Federal Highway Administration (FHWA), which investigated the factors that effect the deterioration of retroreflective sheeting and ultimately reduce the effective service life of signs.

Retroreflection differs from mirror and diffuse reflection in that the incoming light rays, once reflected off the retroreflector, are directed back to the light source. Specifically, the retroreflective properties of traffic signs cause the light from a vehicle's headlamps to be redirected back to the vehicle (the light source), thereby making the traffic sign visible to the driver at night. The principle of retroreflection is shown in Figure 1. The measure of retroreflection is termed the coefficient of retroreflection (R_A).

The sign service life study focused on the two most commonly used sheetings—Type II, engineering grade (EG); and Type III-A, high-performance grade (HP). For detailed descriptions of retroreflection and sheeting properties see the FHWA report, "Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide."[2]

Objectives

FHWA has developed a sign management system as a tool for managing sign replacement programs and for ultimately assisting in maintaining a minimum level of sign retroreflectivity.[3] The sign management system has an operational computerized sign inventory database. Specific traffic signs can be logged into the database with descriptive fields for sign location, sign dimensions, sheeting type, date of installation, and so forth. The

The Feds have a db w/ all the signs

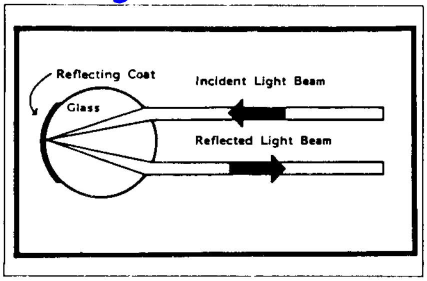

Figure 1. Priniciple of retroreflection.

structure of the sign management system also consists of two models that will be used in combination to predict when a sign is likely to need replacement:

- Required R_A model—This model will select minimum R_A levels required to provide adequate visibility based on sign type, color, placement, roadway speed, and so forth.
- Available R_A model—This model will use the results of the sign service life project to estimate the R_A values of in-service signs.

The ability to predict the service life of a traffic sign is essential to implementing the sign management system. With the ability to predict in-service R_A and with the establishment of minimum reflectance standards, signs nearing end of life could be highlighted in a computer inventory for field inspection and replacement in a consistent, efficient, and cost-effective manner. The system could also be used to develop future budgets by forecasting sign replacement needs.

To accomplish the goal, several specific study objectives were established. 1) The initial objective focused on the factors that cause sign sheeting deterioration and how these factors vary across the United States. To evaluate the deterioration factors, a national data collection effort was undertaken of in-service sign sheeting retroreflectivity. Using the identified deterioration factors and field retroreflectivity measurements (that is, in terms of R_A), mathematical equations were developed to predict in-service R_A

what were they???

· Are they guessing or do they have significant data?

based on the known deterioration variables. R_A is expressed as candelas per footcandle per square foot in the English system and as candelas per lux in the international system of units. The conversion between the systems is unity. The mathematical equations to predict in-service R_A or contrast ratio of traffic signs will be incorporated into FHWA's sign management system in the available R_A model.

This paper provides an overview of the data collection effort and selected results from the sample data set. The regression equations to predict in-service R_A can be reviewed in the final report[4]

Deterioration Variables

Pertinent literature was reviewed to identify variables that were purported to effect the retroreflective deterioration of traffic signs. Numerous variables were isolated from the literature review, and those considered in the sign service life project include the following:

Really?
- **Sheeting color.** Retroreflectivity varies significantly depending upon the sheeting color.
- **Contrast ratio.** Contrast between background and legend R_A has a major effect on overall sign legibility.
- **Sheeting type.** High-performance sheeting generally provides three to four times higher R_A values than engineering grade, but it costs nearly five times as much.
- **Orientation to sun.** Research has reported that sheeting facing north has higher retroreflectivity values than does sheeting facing south, because of the latter's longer exposure to the sun[5]
- **Ground elevation.** Influences of higher solar radiation levels and more severe weather were assumed to contribute to increased sheeting deterioration in high-elevation locations.
- **Area type.** Industrial and vehicular pollution were assumed to effect sheeting deterioration.
- **Sheeting age.** Duration exposure to climatological and other factors is quantified by in-service age of the sheeting material as defined by the date of installation or manufacture date.

Many of these variables were included in the deterioration equations developed for the available R_A model in the sign management system.

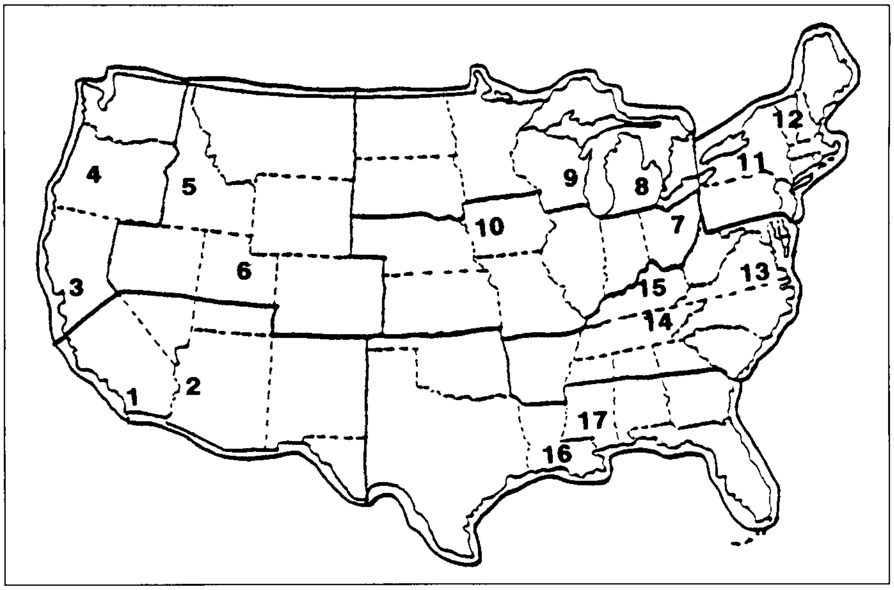

Figure 2. Location of data collection sites.

Data Collection

Retroreflectivity measurements were collected at 18 sites (number indicates site location in Figure 2):

State Agencies
Arizona [2]
Idaho [5]
Utah [6]
Vermont [12]

County Agencies
San Diego, California [1]
Lane, Oregon [4]
Oakland, Michigan [8]
Tompkins, New York [11]

City Agencies
San Francisco, California [3]
Milwaukee, Wisconsin [9]
Sioux City, Iowa [10]
Norfolk, Virginia [13]
Suffolk, Virginia [13]
Kingsport, Tennessee [14]
Bowling Green, Kentucky [15]
Lafayette, Louisiana [16]
Gulfport, Mississippi [17]

Other
Ohio Turnpike [7]

These agencies were selected based on several criteria, including the availability of a computerized sign inventory or sign dating program, distribution of sign type and ages, and geographic location. The

Figure 3. Operation of retroreflectometer.

Then how reliable is the data?

R_A measurements were collected using a retroreflectometer.* Figure 3 shows a retroreflectometer in operation. In addition to the R_A measurements, information on sheeting type, sheeting age, orientation to the sun, ground elevation, and so forth was collected.

Data Description

Coefficient of retroreflection readings were taken on approximately 6,275 traffic signs throughout the United States; 5,722 sign samples were suitable for analysis. Data that fell outside of realistic ranges of retroreflection were not included. Four sheeting colors—red, yellow, green, and white—and two sheeting

*Advanced Retro Techology, Inc., Spring Valley, California, Model 920.

types, engineering grade and high-performance grade, were surveyed on signs from 1 to 12 years in age. Four retroreflection readings were taken on each sheeting sample. The four retroreflectivity readings per sample were averaged for the subsequent analysis.

Table 1 provides a breakdown of total samples by sign type and age category.

Statistical Results

The results of statistical analysis for the sample population were segregated by sheeting color and type. Table 2 summarizes key statistical attributes of the data. All mean values of R_A except red high-performance sheeting exceed the minimum R_A values for new sheeting as found in FP-85.[6] The yellow and white high-performance sheeting tend to have a tighter grouping of R_A values.

The standard deviation and variance results for red sheeting are not unexpected in light of the fading problems of red ink. Red colored sheeting, as used on "stop" and "yield" signs, is typically manufactured by screening red ink over white retroreflective sheeting. Over time, the red ink fades, and more of the white background becomes visible. Because of this, retroreflectivity levels of the sign face actually increase over time; however, the contrast between legend and background decreases. It was found that for even the newest signs a considerable range of R_A values existed.

For Red ink

Table 1. Total Sign Samples by Age Category

Age Category[a]	Red EG	Red HP	Yellow EG	Yellow HP	White EG	White HP	Green EG	Green HP	Total
1	178	133	189	112	254	159	149	60	1,234
3	170	121	163	94	248	149	154	62	1,161
5	109	109	196	66	173	146	120	111	1,030
7	110	107	152	58	169	183	136	75	990
9	70	121	147	58	135	153	91	10	785
11	60	71	84	21	105	119	54	8	522
Total	697	662	931	409	1,084	909	704	326	5,722

Note: EG = Engineering grade sheeting (Type II), and HP = High-performance sheeting (Type III-A).
[a]Each age category represents a 2-year time period (for example, age category 11 indicates in-service ages of 11 and 12 years).

Yellow and white have tighter (+ higher) readings

Table 2. General Statistics by Sheeting Type

Sheeting Description	Number of Samples	Mean R_A	Standard Deviation	Variance	Minimum Value	Maximum Value[a]
Red EG	697	18.5	11.3	128.2	2.0	65.4
Red HP	662	42.1	16.6	275.8	10.1	144.9
Yellow EG	931	70.1	24.3	591.8	5.3	128.8
Yellow HP	409	231.6	31.4	983.5	140.0	319.9
White EG	1084	90.9	30.6	936.7	10.1	163.5
White HP	909	284.1	44.2	1955.3	148.7	393.9
Green EG	704	13.4	5.1	25.7	1.0	27.6
Green HP	326	46.8	14.2	202.5	10.4	74.8

[a]Coefficient of Retroreflectivety (R_A) expressed for 0.2° observation and −4° entrance angles.
EG = Engineering grade (Type II) sheeting, and HP = High-performance (Type III-A) sheeting.

Scatterplots

Scatterplots of the collected data are provided by sheeting color and type. A best-fit deterioration line has been imposed on each plot. In addition, the required values for new sheeting as specified in FP-85 have been included on the plots. Figure 4 provides a scatterplot for red sheeting using the data from all geographic areas. The plot provides average R_A by age category. As seen on the plot of red high-performance sheeting, the effects of color fade are pronounced. The plot of red high-performance sheeting shows increasing R_A in older age categories. This occurrence seems to be more pronounced in the high-performance signs as white high-performance sheeting typically has retroreflectivity values of more than 300. Additional analysis of legend to background contrast was conducted for the red sheeting samples.

Figure 5 provides a scatterplot for yellow sheeting. In general, a consistent R_A reduction was found as in-service age increased. Numerous outliers exist, but the major grouping of data supports a consistent downward trend in R_A values. Many yellow high-performance readings greatly surpassed the minimum R_A new value of 170 for yellow high-performance sheeting, even after 7 or 8 years of service.

Figure 6 shows the plots for white sheeting. As with the yellow sheeting, white engineering grade displays a consistent decrease in R_A with age. The downward trend of white high-performance sheeting was less dramatic. The white high-performance sheeting seems to retain a higher level of retroreflection at the older in-service ages.

As depicted in Figure 7, the green engineering grade plot shows small and steady degradation in R_A falling below required new R_A beyond 12 years of service. Few conclusions can be drawn about the high-performance characteristics since minimal samples were found older than 7 or 8 years. It does seem, however, that green high-performance sheeting retains much of its retroreflectivity (similar to green engineering grade sheeting) for up to 8 years of service.

The retroreflectivity levels of the signs sampled were generally quite high, with many older signs exceeding minimum new retroreflectance standards. Similarly, an Ohio study found that the majority of signs have maintained retroreflectivity levels above the Ohio Department of Transportation requirements.[7] Nonetheless, as the minimum values in Table 2 illustrate, there are in-service signs with dangerously low R_A levels. The scatterplots of R_A and age category showed the considerable variability in the data. While there was a reduction in R_A as the in-service age increased, the range (that is, maximum and minimum values) of R_A values was similar across all age categories.

Variable Screening

Information and data on numerous variables were collected with an objective of relating independent variables to the predicted on dependent variable (that is, in-service R_A). This evaluation investigated the basic relationships between the variables using correlation matrices. The initial screening investigated the correlation between the independent variables. Then the suitable independent variables were evaluated versus the dependent variable. The solar radiation, orientation to the sun, and precipitation variables were not found to be acceptable predictors of in-service R_A. The precipitation, ground elevation, and heating degree days variables had good correlations with the dependent variable and were used in the subsequent regression modeling.

Contrast

Because of the problem of red color fade, an additional evaluation of signs with red backgrounds and white legends was conducted. The contrast between background and legend R_A has a major effect on overall sign legibility. Evidence is available based on previous research that legibility distance increases with the introduction of increased contrast between legend and background.[8] A luminance ratio (that is, a contrast ratio) of 5 to 1 was suggested by Forbes as optimum for increasing legibility distance.[9] Above a luminance ratio of 5 to 1, legibility was found to increase only slightly. Other researchers have recommended

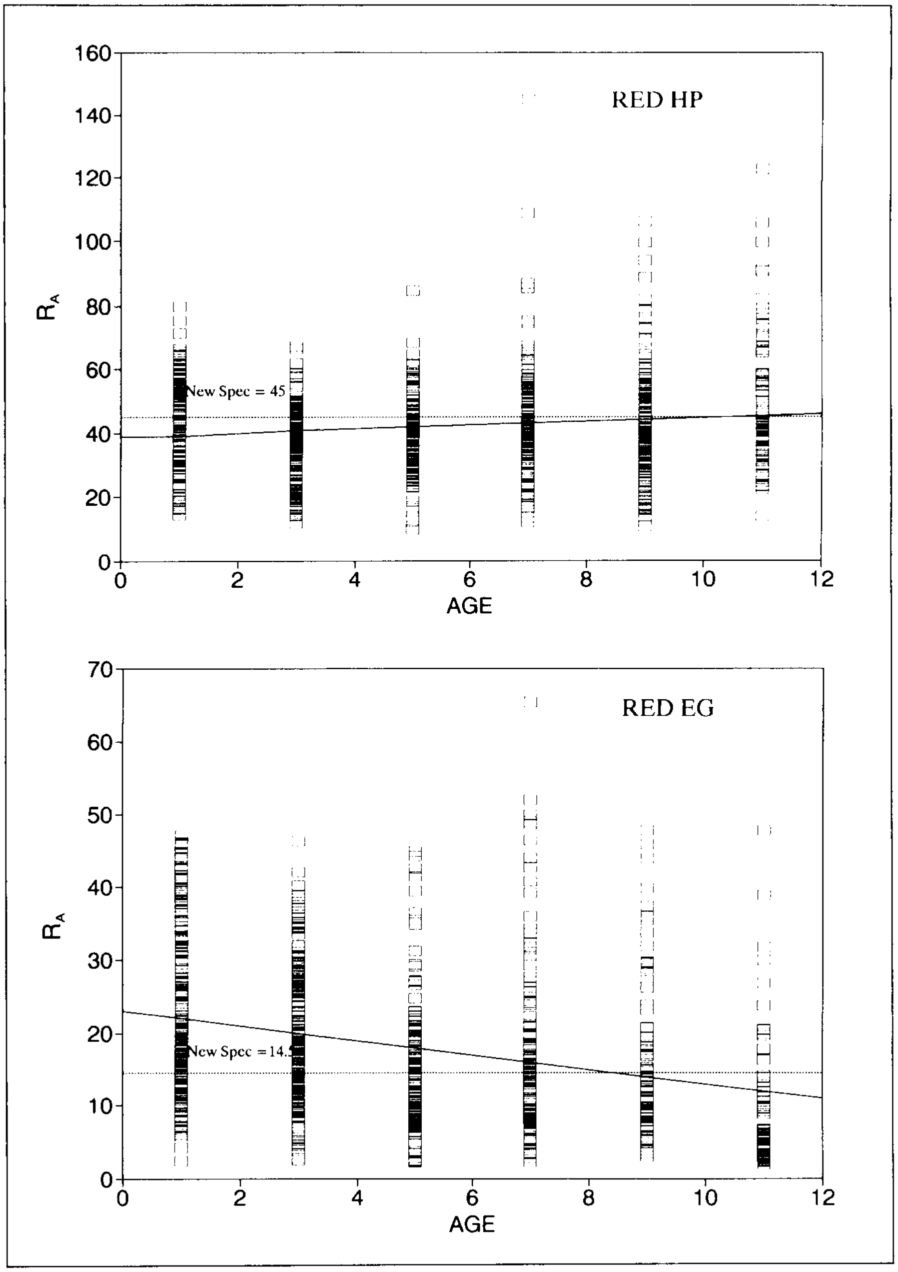

Figure 4. Red sheeting deterioration.

Table 3. Summary of Contrast Ratios

Age Category	Engineering Grade Sheeting: Average R_A[a] Red	White	Average Contrast Ratio[b]	Number of Samples	High-Performance Sheeting: Average R_A[a] Red	White	Average Contrast Ratio[b]	Number of Samples
1	18.0	108.3	7.8	116	42.2	290.5	7.7	80
3	16.4	94.3	8.0	117	38.6	276.1	8.2	85
5	16.4	91.1	11.5	66	37.2	270.9	9.0	162
7	15.5	83.9	8.7	79	46.5	268.1	6.4	75
9	16.5	80.0	7.9	44	42.1	257.8	7.7	99
11	9.1	54.0	6.9	38	48.1	275.1	7.0	44

[a]Average R_A by sheeting color, sheeting type, and age category.
[b]Average of contrast ratios calculated individually for each sign sample.

higher legend/background contrast ratios for optimal legibility in the range of 8–12 to 1.

Contrast ratios of white legend to red background were calculated for approximately 1,000 "stop" and "yield" signs. The average contrast ratios by sheeting type and age category are presented in Table 3, with the mean R_A values of the red and white components. As shown, little variation in contrast ratio between the age categories for engineering grade sheeting was found. This is consistent with the R_A plots in Figures 4 and 6 for red and white engineering grade sheeting. These plots depict a rather consistent R_A deterioration over time. With red and white engineering grade sheeting deteriorating at similar rates, little variation in the contrast ratios would be achieved. The plot for white high-performance sheeting in Figure 6 shows the consistent decrease in R_A as age category increases. As depicted in Figure 4, however, red high-performance sheeting (actually red paint screen printed on white high-performance sheeting), retroreflectivity tends to increase as the age category increases. Nearly all of the 1,000 signs sampled for contrast had ratios greater than 5 to 1. Minimum contrast ratios between 8–12 to 1 were also cited previously for red and white signs. Many of the signs sampled here failed to reach these higher minimum ratios for legend to background contrast.

Sign Washing

The primary objective of the sign service life study was to model the deterioration of sign retroreflectivity over time. It was therefore appropriate to wash all signs before readings were taken to determine the condition of the sign not affected by dirt. It was decided to determine how much washing could improve sign retroreflectivity. For about 10 percent (that is, 600 total samples) of the sign readings, both before and after sign washing readings were taken. A Washington State Department of Transportation study found that uniform layers of dirt did not have much effect on retroreflection readings.[10] As stated in a New York Department of Transportation research report, most signs receive little benefit from washing except possibly during the winter months.[11]

Every tenth sign was measured before

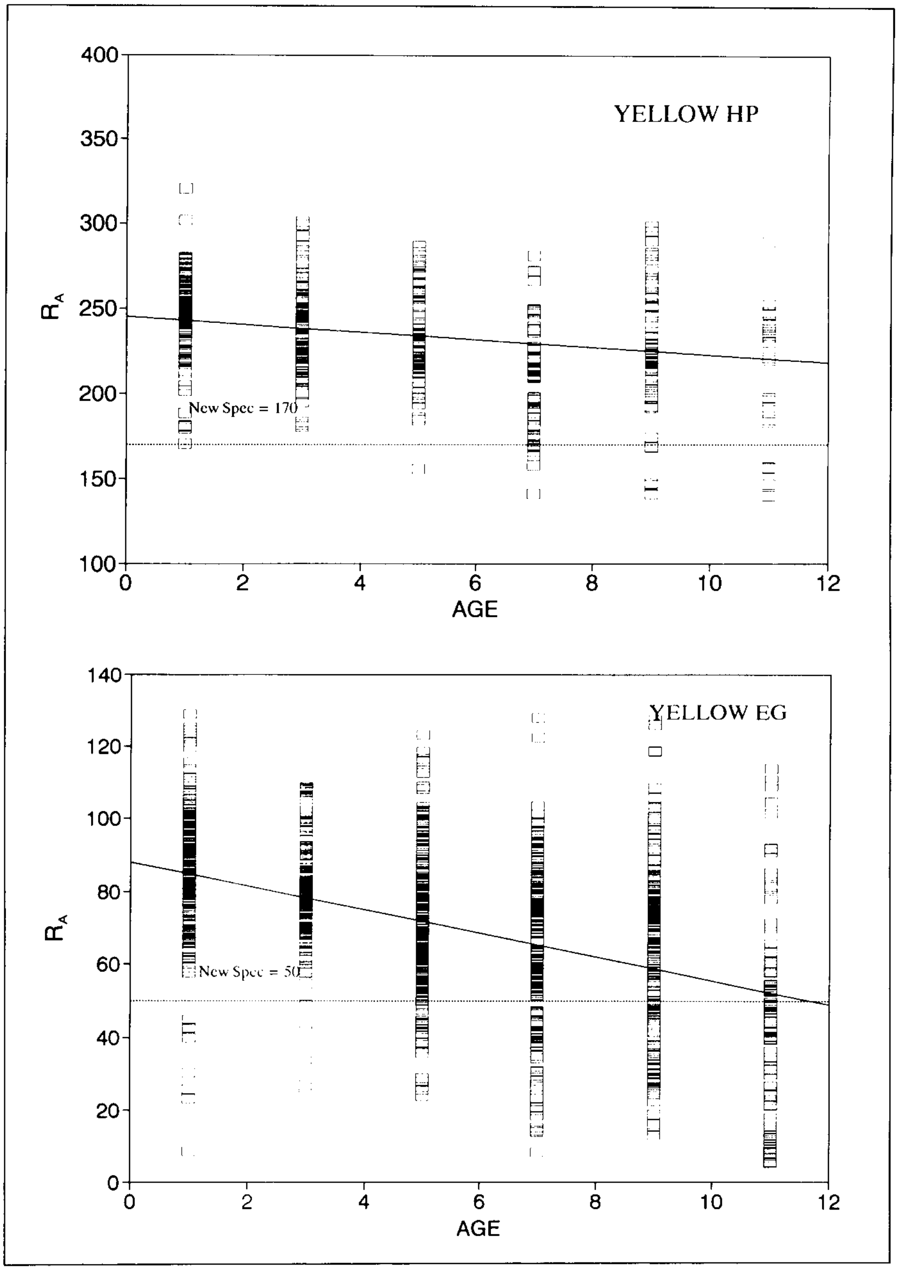

Figure 5. Yellow sheeting deterioration.

Table 4. Sign Washing Results

Sheeting Color and Type	*Number of Sign Samples*	*Increase in Retroreflectivity After Sign Washing (%)*
Red EG	66	7.1
Red HP	85	9.3
Yellow EG	104	13.5
Yellow HP	33	5.4
White EG	107	12.5
White HP	107	7.6
Green EG	59	13.5
Green HP	26	6.7
All Engineering Grade Samples	336	11.9
All High-Performance Samples	251	7.8

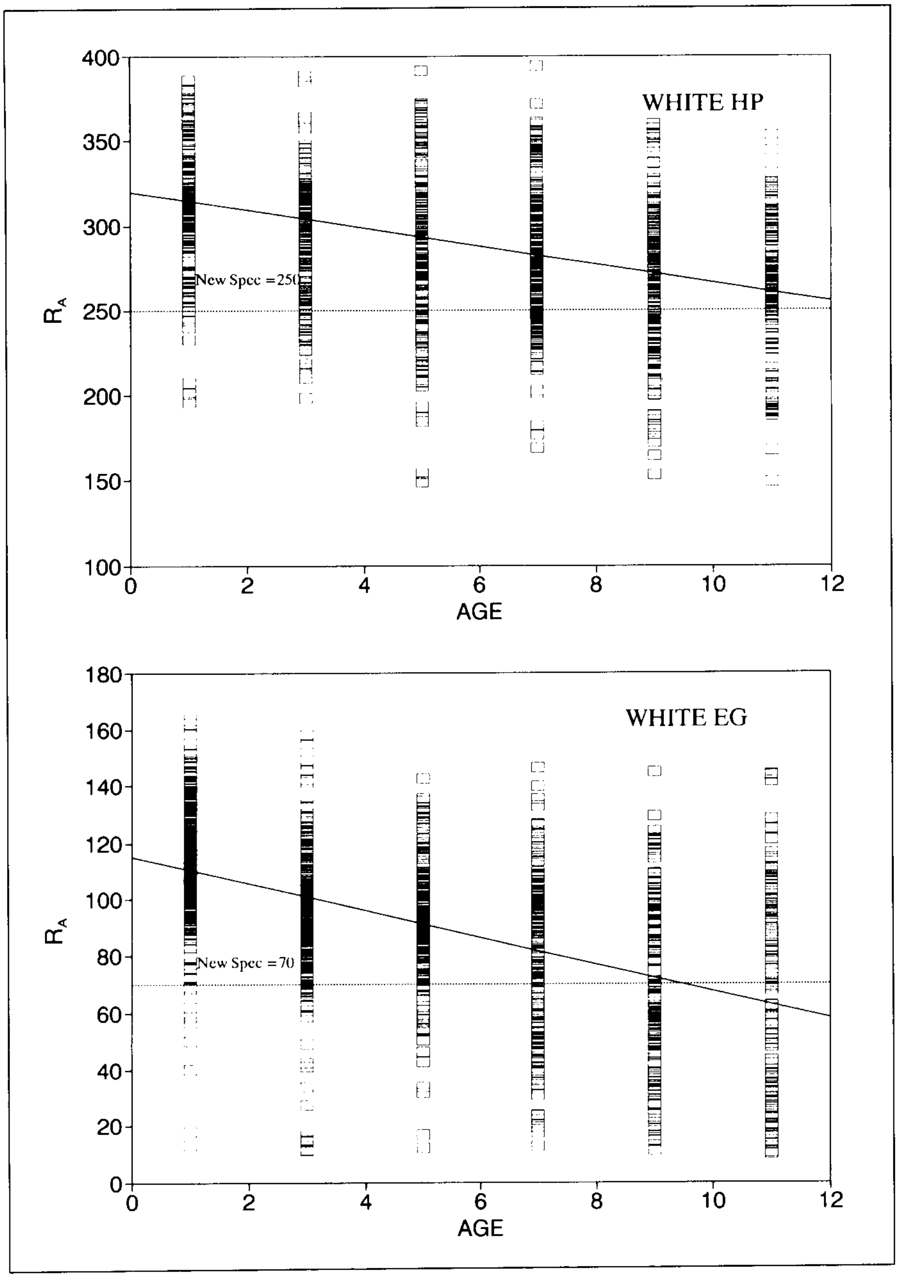

Figure 6. White sheeting deterioration.

and after washing. Table 4 provides a summary of the findings for each sheeting color and type. Engineering grade sheeting seemed to benefit more from sign washing. Several explanations of this result are apparent: (1) the population of engineering grade sheeting samples was older with a larger subjection to airborne pollutants, and (2) numerous signing personnel have mentioned the "slippery" qualities of high-performance sheeting, which would seemingly benefit more from rainfall and natural cleaning.

Conclusions

The sign service life study identified variables that effect sheeting deterioration and should therefore be included in the deterioration equations for FHWA's sign management system. It was found that sheeting age, precipitation, ground elevation, and heating degree days were significant predictors of in-service specific intensity per unit area. The R_A values for all sheeting colors and types were found to be quite variable, presumably because of the manufacturing processes. Because of the variability of new sheeting retroreflectivity it is recommended that an initial R_A reading be taken before sign installation. This information would improve the ability to model the sheeting deterioration.

The contrast between legend and background on red and white sheeting signs was also evaluated in the sign service life project. The average contrast ratio was found to be approximately 8 to 1. Research conducted to date has recommended ratios of 5–12 to 1 for optimal legibility distance. This study also completed an evaluation of the retroreflectivity increase after sign washing. Engineering grade signs experienced a nearly 12 percent increase in retroreflectivity after washing, while high performance signs benefited with an 8 percent increase.

The majority of the signs sampled pass the minimum retroreflectivity specifications for new material as specified in FP-85.[6] Nonetheless, the range of the data indicates that some of the signs sampled may not provide adequate nighttime visibility. It is hoped that the anticipated minimum in-service standards for retroreflectivity will ensure that all signs have adequate visibility to meet the driver's needs.

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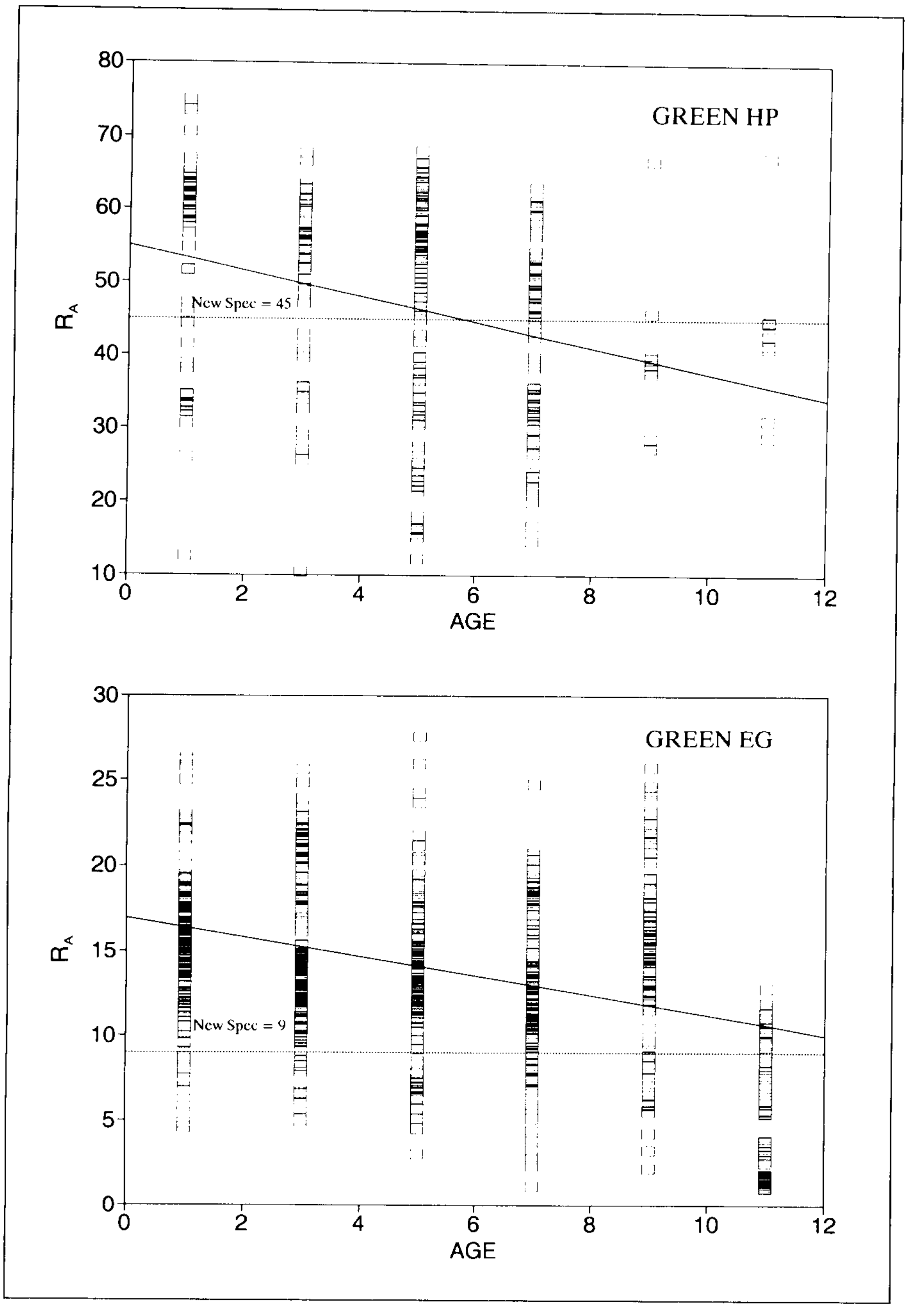
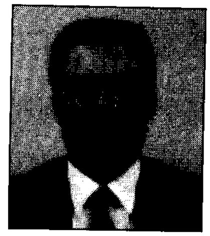


Figure 7. Green sheeting deterioration.



Kent L. Black, *P.E., is an associate engineer with Bellomo-McGee. Black was the principal investigator for the Service Life of Retroreflective Traffic Signs project (FHWA-RD-90-101) and has been involved in numerous other federal and state agency traffic sign studies. He has a B.S. degree in transportation engineering and an M.E. degree in civil engineering from the Pennsylvania State University. Black is an Associate Member of ITE.*

Syed F. Hussain, *P.E., is a senior engineer with Bellomo-McGee. He received his M.S.C.E. in transportation engineering from Georgia Institute of Technology. He has been involved in numerous research studies in the areas of nighttime visibility needs, highway safety, and highway safety problems of older drivers. He is a Member of ITE.*

Jeffrey F. Paniati, *P.E., is a highway research engineer with the Federal Highway Administration. Paniati was the FHWA technical representative for the Service Life of Retroreflective Traffic Signs project and has been involved in a variety of other research studies in the transportation engineering field. He has a B.S. degree in civil engineering from the University of Connecticut and has received a M.S. degree from, and is a Ph.D. candidate at, the University of Maryland. Paniati is an Associate Member of ITE.*