Retroreflectivity of Existing Signs in Pennsylvania

FINAL REPORT

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By McCormick Taylor, Inc.

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16. Abstract

The Pennsylvania Department of Transportation (PennDOT) Bureau of Highway Safety and Traffic Engineering initiated this research effort in response to the release of the new 2009 Manual on Uniform Traffic Control Devices (MUTCD) which mandates that all states shall have a sign maintenance method designed to maintain traffic sign retroreflectivity at or above the established minimum levels in place by January 2012. The goal of this research effort was to collect and analyze sign retroreflectivity measurements on a subset of PennDOT owned and maintained signs throughout the Commonwealth of Pennsylvania in order to better understand the potential service life of signs with regard to nighttime visibility in Pennsylvania. As PennDOT implements its sign management system, with respect to compliance with the minimum retroreflectivity levels, the findings of this research will assist PennDOT in better determining when signs may need replaced. Retroreflectivity levels were measured on a sample of 1,000 traffic signs using a DELTA Light and Optics RetroSign 4500 retroreflectometer. In order to obtain regional variety, an equal portion of signs (one third in each county) were measured in Lackawanna, Lehigh and Lancaster counties to represent the northern, central and southern tiers of the state. The number of yellow warning signs, white regulatory signs, green directional signs and red Stop, Yield, Do Not Enter and Wrong Way signs to be measured was determined using the proportion of each sign color's overall population in the state. PennDOT's current standard specifications for reflective sheeting require the use of Type III or Type IV sheeting for post-mounted sign installations and the sign sheeting manufacturer warranties are typically 10 years; therefore the data collection efforts were limited to Type III signs aged 10 years or older. The study recommends an expected sign life of 15 years for yellow, white, red and green signs in Pennsylvania.

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Bureau of Highway Safety and Traffic Engineering

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Executive Summary

The 2009 release of the new Manual on Uniform Traffic Control Devices (MUTCD) mandates that all states shall have a sign maintenance method designed to maintain traffic sign retroreflectivity at or above the established minimum levels in place by January 2012. McCormick Taylor was retained by The Pennsylvania Department of Transportation (PennDOT) Bureau of Highway Safety and Traffic Engineering (BHSTE) to conduct a research study to better understand the potential service life of signs with regard to nighttime visibility. This report summarizes the study tasks which included a review of previous related studies, outreach to sign sheeting manufacturers for sign sheeting warranties and life expectancy information, outreach to the other 49 state Departments of Transportation to determine their sign management practices and policies and a field data collection effort and analysis on 1000 existing signs in Pennsylvania.

Retroreflectivity levels were measured on a sample of 1,000 traffic signs using a DELTA Light and Optics RetroSign 4500 retroreflectometer. In order to obtain regional variety, an equal portion of the signs (one third in each county) were measured in Lackawanna, Lehigh and Lancaster counties to represent the northern, central and southern tiers of the state. The number of yellow warning signs, white regulatory signs, green directional signs and red Stop, Yield, Do Not Enter and Wrong Way signs to be measured was determined using the proportion of each sign color's overall population in the state. PennDOT's current standard specifications for reflective sheeting require the use of Type III or Type IV sheeting for post-mounted sign installations and the sign sheeting manufacturer warranties are typically 10 years; therefore the data collection efforts were limited to Type III signs aged 10 years or older.

The data shows that the service life of traffic signs In Pennsylvania with regard to the FHWA minimum retroreflectivity levels is much greater than the manufacturer's warranty period. There were no distinguishable differences in the data from region to region. Similar to previous studies, the data analysis of this study did not show a strong correlation between retroreflectivity and age. However, given the large sample size of this study and the fact that of the 1,007 signs inspected, only 28 (2.8%) failed to meet minimum retroreflectivity requirements at an average age of 14.1 years old, we have a high degree of confidence that the service life of Type III sheeting in Pennsylvania is at least 15 years. Given the results of this study, an expected sign life of 15 years is recommended for yellow, white, green and red signs in Pennsylvania.

I. Introduction

The Pennsylvania Department of Transportation (PennDOT) Bureau of Highway Safety and Traffic Engineering initiated this research effort in response to the release of the new 2009 Manual on Uniform Traffic Control Devices (MUTCD) which mandates that all states shall have a sign maintenance method designed to maintain traffic sign retroreflectivity at or above the established minimum levels in place by January 2012. The 2009 MUTCD describes five different assessment or management methods that agencies should use to maintain their signs at the required levels. One method or a combination of methods can be used. The goal of this research effort was to collect and analyze sign retroreflectivity measurements on a subset of PennDOT owned and maintained signs throughout the Commonwealth of Pennsylvania in order to better understand the potential service life of signs with regard to nighttime visibility in Pennsylvania. As PennDOT implements its sign management system, with respect to compliance with the minimum retroreflectivity levels, the findings of this research will assist PennDOT in better determining when signs may need replaced.

The research efforts included a review of related literature and studies on sign service life, outreach to the other 49 states to determine the basis for their sign management systems, outreach to the two sign sheeting manufacturers that supply the majority of PennDOT's sign sheeting (Avery Dennison and 3M) and data collection and analysis of sign retroreflectivity measurements on a subset of PennDOT owned and maintained signs. PennDOT's current standard specifications for reflective sheeting require the use of Type III or Type IV sheeting for post-mounted sign installations and the sign sheeting manufacturer warranties are typically 10 years; therefore the data collection efforts were limited to Type III signs aged 10 years or older. These efforts are detailed in this report.

II. Background

A. Overview of Accepted Sign Assessment / Management Methods

The 2009 MUTCD and the supplemental 2007 FHWA Report *Maintaining Traffic Sign Retroreflectivity* describe five assessment / management methods that agencies should use to maintain sign retroreflectivity at the minimum required levels. One or more of the methods should be used (*1*). These methods are categorized as either assessment methods (Visual Nighttime Inspection and Measured Sign Retroreflectivity) or management methods (Expected Sign Life, Blanket Replacement and Control Signs). Assessment methods require evaluation of individual signs within an agency's jurisdiction and management methods provide an agency with the ability to maintain sign retroreflectivity without having to assess individual signs (*3*). The report *Sign Retroreflectivity: A Minnesota Toolkit* also provides detailed descriptions of the procedures, advantages and disadvantages of the five assessment / management methods.

1. Visual Nighttime Inspection

For this approach, trained inspectors visually assess the retroreflectivity of existing signs in the field from a moving vehicle at night. Signs that are identified to have retroreflectivity below the minimum levels should be replaced (*1, 3*).

There are three different procedures that can be used: calibration signs, comparison panels, or consistent parameters. In the calibration signs procedure, calibration signs at or above the minimum retroreflectivity level are viewed prior to inspection. During inspection, signs are evaluated in comparison with the calibration signs viewed earlier. For the comparison panel procedure, comparison panels are clipped to the sign under inspection and viewed by the inspector. For the consistent parameters procedure, inspectors follow 3 consistent parameters: inspections must be conducted during nighttime, using an SUV or pick-up truck model year 2000 or newer and the inspector must be at least 60 years old (*15*).

The advantages of this method are that factors other than sign reflectivity, such as damage or obstructions, can be assessed. Also, a sign inventory can be established as the inspector(s) drives around. This method reduces sign waste, thereby maximizing sign life. The disadvantages of this approach are that it is highly subjective and can be time consuming. Also, the inspectors need proper training and must work nighttime hours (*15*).

2. Measured Sign Retroreflectivity:

This approach involves manually measuring the retroreflectivity of sign using a retroreflectometer. Four measurements should be taken for each color on the sign and the measurement should then be averaged to obtain an overall measurement of the retroreflectivity of each color. Signs with retroreflectivity below the minimum levels should be replaced (*1, 3*).

The advantages of this approach are that it provides the most direct means of obtaining retroreflectiveness and removes all subjectivity inherent in visual inspection methods. The disadvantages of this approach are that retroreflectometers are expensive (approximately $10,000) and this approach can require a significant amount of time if every sign is to be measured. Few agencies implement this practice on all signs and use it more as a supplement to other methods (i.e.: measuring retroreflectivity of a sample set of signs as an assessment of their total inventory) (*15*).

3. Expected Sign Life:
For this approach, the installation date of every sign must be labeled or recorded when the sign is installed. The age of the sign is compared to the expected sign life which is based on the experience of sign retroreflectivity degradation in a geographical area compared to the minimum levels. Signs older than the expected sign life should be replaced (*1, 3*).

Some agencies put a sticker on the front or back of the sign indicating the installation date. Computerized sign management systems can be used to track the age of signs. For expected sign life, most agencies use the manufacturer's warranty period, although many agencies are beginning to extend their expected sign life based on new research. The advantages of this approach are that it is easy to identify aging signs. Also, the retroreflectivity of signs can be measured at the end of their expected life and findings can be used to adjust the expected sign life. The disadvantages of this approach are that little data is available on how different types of sheeting and colors deteriorate over time in a given climate and whether orientation affects the rate of deterioration. Basing sign life solely on age may result in removing signs before their service life is complete (*15*).

4. Blanket Replacement:
For this approach, all signs under either a spatial or strategic basis are removed and replaced at the same time, on the same schedule. For spatial basis, all signs in a given area or set of roads are replaced together; whereas for strategic basis, all signs of a specific type (regulatory, warning, guide, etc.) are replaced on the same schedule. The replacement interval is based on the expected sign life, compared to minimum levels, for the shortest-left material used on the affected signs (*1, 3*).

Of the agencies that use this method, most replace Type I signs every 7 to 10 years, Type III signs every 10 to 15 years, and Types VI, VII, and IX signs every 15 years. (Type III sheeting is most common). The advantages of this approach are that it is a very simple method that does not require knowledge or tracking of sign age or retroreflectivity. It is only necessary to record when the blanket actions were undertaken and when they need to be repeated. This method also ensures that signs will not be skipped or overlooked. The disadvantages are that signs may be wasted by removing them prior to the end of their service life, especially with the first replacement schedule and in locations where signs have been added or replaced after the last replacement cycle. Replacement times can vary depending on the type of sheeting, color, etc (*15*).

5. Control Signs:
For this approach, when new signs are installed, control signs are designated and monitored either in the field or in a maintenance yard and act as a sample of the whole population of signs. Retroreflectivity is measured on the control signs to determine the condition of the rest of the population. A minimum of 3 signs per type of sheeting and color should be monitored (*15*).

The advantage if this approach is that it is not as labor intensive as testing or inspecting each individual sign. Signs that may be past their warranty or expected service lives but still meet minimum retroreflectivity levels are not prematurely removed (as in the blanket replacement or service life methods). The disadvantage of this approach is that there is no specific guidance on the proper sample size for more reliable results. There is also no guidance on how often a new set of control signs should be established or how often the control signs should be checked for retroreflectivity (*15).*

B. Previous Studies

As part of the research efforts, several recent research papers on sign sheeting retroreflectivity and deterioration were reviewed. Table 1 on the next page provides a brief description of the papers reviewed. A more detailed summary of each paper is provided in the section that follows Table 1.

Table 1: Literature Review Summary

#	Title and Author	Date	Summary
1	*Sign Retroreflectivity - A Minnesota Toolkit (Report # 2010RIC02)* Marti and Kuehl	June 2010	Toolkit for local governments with guidance on FHWA's sign retroreflectivity requirements and resources including sample sign management programs and replacement schedules that can be used to meet the compliance deadlines.
2	*An Analysis of In-Service Traffic Sign Retroreflectivity and Deterioration Rates in Texas (Report # TRB 11-2542)* TTI - Re, Miles and Carlson	March 2011	TTI study to identify factors that significantly affect sign retroreflectivity, generate sign deterioration rates and service life projections and determine the usefulness of the models and estimates. Data collected on 859 signs in seven different regions of Texas, in a variety of locations and climates.
3	*Analysis of Retroreflectivity and Color Degradation in Sign Sheeting (Report # TRB 11-2148)* TTI - Brimley, Hawkins, and Carlson	November 2011	TTI study evaluated durability of retroreflective sign sheeting. Nine different materials tested on outdoor weathering racks for over 10 years real time with a 2:1 accelerated degradation rate to simulate over 20 years of service. Researchers evaluated failure of sign sheeting in terms of: retroreflectivity, chromaticity, luminosity and surface defects.
4	*Analysis of Traffic Sign Asset Management Scenarios* NCSU - Hummer, Rasdorf, Immanemi, Harris and Yoem	TRB 2007 Annual Meeting (June 2005)	Study evaluated traffic sign asset management practices in North Carolina and developed a simulation model that any DOT can use to evaluate up to 30 different sign asset management scenarios in terms of annual maintenance cost per sign and percent of signs not compliant with FHWA standards.
5	*Synthesis of Sign Deterioration Rates Across the US* Hummer, Rasdorf, Immanemi, Harris and Yoem	N/A	NCSU Study developed one component of the NCDOT simulation model: retroreflectivity deterioration rates for different colors and types of sheeting. Researchers combined data from five previous studies to produce new best-fit retroreflectivity versus age Curves.
6	*New Standards, New Signs: Determining Sign Performance Under Controlled Conditions* Hummer, Rasdorf, Immanemi and Harris	IMSA Journal Jan/Feb 2008	Article about the development of an experimental sign retroreflectivity measurement facility (ESRMF) for the North Carolina Department of Transportation to achieve a better understanding of Type III and IX long-term sign deterioration.
7	*Tapping into the Power of a Traffic Sign Inventory to Meet the New Retroreflectivity Requirements* Ellison	ITE 2008 Annual Mtg & Exhibit (April 2007)	Pierce County, WA study assessed retroreflectivity of their existing signs. The county's existing sign inventory was used to identify the oldest signs in service. Retroreflectometer readings were taken on a subset of these signs (3 readings per each color per sign and averaged) and results analyzed.
8	*Comparison of Observed Retroreflectivity Values with Proposed FHWA Minimums (Report # TRB 02-2502)* Purdue University - Nuber and Bullock	N/A	Indiana DOT study measured retroreflectivity of 10 or 11 year old signs in Indiana using a retroreflectometer. Data used to create histograms showing relative frequency of signs measured at given retroreflectivity compared to FHWA minimums. Charts of retroreflectivity vs. time for different colors and types of signs with linear trend lines and r-squared values were developed.
9	*Factors Affecting Sign Retroreflectivity - Final Report - SR 514 (Report # OR-RD-01-09)* OregonDOT - Kirk, Hunt and Brooks	January 2001	Oregon DOT study investigated factors that may affect sign retroreflectivity to assist in development of appropriate sign replacement schedules. Readings collected on red, yellow, green and white high intensity (Type III) signs. Ten readings taken per sign on background only (not legend). Signs washed and dried prior to measurements. Age and physical orientation recorded for each sign.
10	*Maintaining Traffic Sign Retroreflectivity: Impacts on State and Local Agencies (Report # FHWA HRDS-05)* Opiela and Andersen	April 2007	FHWA report focuses on negative impacts of new retroreflectivity requirements and concerns of participants at the 2002 FHWA Sign Workshops. Provides overview of how new requirements will affect agencies in terms of sign cost and upgrading sign sheeting to from Type I to Type III or higher.

1) Sign Retroreflectivity – A Minnesota Toolkit

The Minnesota Local Road Research Board (LRRB) developed a toolkit in March 2010 to provide local governments with guidance on FHWA's sign retroreflectivity requirements as well as resources that can be used to meet the compliance deadlines. The toolkit focuses on the January 2012 deadline requiring all agencies to establish a sign assessment or management method. The authors strongly recommend creating a sign inventory as part of the process of establishing a sign assessment / management method to increase maintenance efficiency in the future. The toolkit contains: sample letters to be sent to small local agencies that maintain their own signs, information on Minnesota's requirements, a summary of FHWA guides and resources, sign inventory examples, sign assessment / management examples and sample sign management agreement documents.

One sample management program for local governments uses nighttime visual inspection to rate signs as either fail, marginal, or adequate. Once signs are replaced, their installation dates are recorded and the Expected Sign Life method is used to maintain minimum retro levels. A basic replacement schedule is included:

- Engineer Grade (Type I) Sheeting – 8 year interval
- High Intensity Beaded (Type III) – 10 year interval
- Prismatic Sheeting – 12 year interval

The report includes an additional "Generic Rural County" Maintenance Procedure that also uses the nighttime visual inspection and sign life strategies with the following replacement schedule:

- Engineering Grade – 8 years
- HI or HIP
  - 10 Years (South facing)
  - 11 Years (East/West Facing)
  - 12 Years (North Facing)
- VIP or DG3
  - 13 Years (South facing)
  - 14 Years (East/West Facing)
  - 15 Years (North Facing)
- E-911 (HIP) - 12 Years
- E-911 (DG#) - 15 Years

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

The Texas Transportation Institute (TTI) undertook a study in 2009 to assess the compliance of Type III signs throughout the state with the federal retroreflectivity requirements and to generate useful data that could benefit sign maintenance practices. The researchers sought to identify the factors that significantly affect sign retroreflectivity, generate sign deterioration rates and service life projections and determine the usefulness of the models and estimates.

The study began with a review of four previous studies: 1992 FHWA study, 2002 Louisiana Department of Transportation and Development (LDOTD) study, 2002 Purdue University Study and a 2006 North Carolina State Department of Transportation (NCDOT) Study. The findings of these studies were consistent: sign sheeting was often found to meet the minimum retroreflectivity requirements longer than the manufacturer's warranty of 10 years and the study data showed poor correlation of various variables with prediction models.

The data collection efforts for the TTI study encompassed collecting 859 samples in seven different regions in Texas. A variety of location and climates were chosen. Researchers reasoned that if sign performance was adequately addressed in regions with harsh or intense conditions, then signs in other regions should be performing at a similar or better level. The researchers classified signs into 5 different categories based on ASTM and material type. The researchers did not wash any signs and they recorded daytime visual condition as good, adequate, or poor. The study found that overall sign compliance rate was 99% for Type III signs and the observed likelihood of failure was 2% for signs 10-12 years old and 8% for signs 12-15 years old. Linear predictive models revealed differences in deterioration rates among regions; however, the models exhibited poor correlation between predicted and measured data. ANOVA (analysis of variance) models, which identify what factors may influence a given data set, showed that visual condition and sign orientation are not good indicators for reflectivity, but sign age and regional differences were relevant factors. The study concluded that deterioration rates and prediction models can be valuable components to a comprehensive sign maintenance program – but they do not by themselves ensure sign retroreflectivity compliance. Also, the 12-year service life may provide a basic and conservative estimation, but it is beneficial to implement robust maintenance practices and periodic nighttime visual inspection to replace non-compliant signs.

3) Analysis of Retroreflectivity and Color Degradation in Sign Sheeting

Another study was initiated at TTI in 1999 and concluded in 2010 to evaluate the durability of retroreflective sign sheeting materials. Nine different materials were tested on outdoor weathering racks for over 10 years in real time with a 2:1 accelerated degradation rate to simulate more than 20 years of service. The researchers evaluated the failure of the sign sheeting in terms of four criteria: retroreflectivity, chromaticity, luminosity and surface defects. With regard to retroreflectivity alone, each material was found to last as long as its warranty. The report concluded that there were many limitations in this “unfunded and limited attempt to assess the long-term performance of retroreflective sign sheeting” and that “a more thorough effort is needed.”

4) Analysis of Traffic Sign Asset Management Scenarios

This study, submitted to the 2007 TRB Annual Meeting, evaluated traffic sign asset management practices in North Carolina and developed a simulation model that any DOT can use to evaluate up to 30 different sign asset management scenarios in terms of annual maintenance cost per sign and percent of traffic signs not compliant with the FHWA standards. The parameters for the model are: Maintenance Strategy (all of them except for control sign method), Rejection Threshold (certain retroreflectivity level or age), Rate of Conversion of Type I to Type III signs as they are replaced, and Inspection Frequency. Maintenance costs were developed as a function of inspection frequency and average sheeting cost. For each inspection there is a labor and materials cost that varies based on inspection method. For example, an inspection cost of $0.55 per sign was determined for the visual nighttime inspection method, while the manually measured retroreflectivity method yielded a cost of $2.80 per sign due to high equipment costs and the additional time it takes to stop and manually inspect each sign.

The analysis found that the methods that are most expensive (blanket replacement, expected sign life, and manual measurement) result in less non-compliant signs, while the sign inspection methods can be much cheaper but result in a higher rate of non-compliant signs. Other DOT's can use this model by adjusting the parameters based on their own current practice or proposed plan.

5) Synthesis of Sign Deterioration Rates Across the US

North Carolina State University (NCSU) conducted this study in response to the addition of federal minimum retroreflectivity requirements in the 2003 MUTCD. The purpose of the study was to determine deterioration rates for sign retroreflectivity to assist the North Carolina Department of Transportation (NCDOT) with their sign management program. The study consisted of a review of five previous studies and a data collection effort of over 1000 signs in North Carolina. The researchers first analyzed the results of five previous retroreflectivity studies (1991 FHWA Study, 2001 State of Oregon Study, 2002 Louisiana State Study, 2002 Purdue University Study, 2006 North Carolina State University Study and an ongoing AASHTO Study). The researchers then took the raw data from the Purdue and Oregon studies as well as the raw data from the NCSU data collection effort and analyzed the data using the five different regression types (linear, polynomial, logarithmic, exponential and power) to determine the best-fit curve for retroreflectivity versus age, or in other words, the best predictive model for deterioration of sign retroreflectivity.

The study found that the linear regression model was the best-fit curve for retroreflectivity versus age based on R-squared for all of the seven sign color / sheeting combinations except for one. However, the R-squared values in the data analysis show a low correlation between retroreflectivity versus age for both the NCSU-collected data and the data from the previous studies and the study states that the standard errors in the data analysis are not as low as the researchers would like. The study states that the research was limited to sign age because it was considered by the researchers to be the most important factor. The researchers conclude that the study results likely mean that factors other than age influence the rate at which sign retroreflectivity deteriorates. The researchers state that these factors include measurement error, reflectometer error and uncontrolled field conditions and that while the effect of each of these factors on their own may be low, it is the combination of all of these factors which cause the scatter in the data.

6) *New Standards, New Signs: Determining Sign Performance Under Controlled Conditions*
This 2008 article is about the development of an experimental sign retroreflectivity measurement facility (ESRMF) for the North Carolina Department of Transportation to achieve a better understanding of Type III and IX long-term sign deterioration. The article mentions five uncontrolled sign deterioration studies (the same FHWA, Oregon, LSU, Purdue and NCSU studies mentioned above) and concludes that these studies focused on Type I signs and had trouble creating well-defined deterioration models. Further, the previous studies found very few Type III signs in the field older than 15 years and could only make limited conclusions about how these signs deteriorate, which is why ESRMF's should be established to obtain data on the new sheeting types for the future.

7) Tapping into the Power of a Traffic Sign Inventory to Meet the New Retroreflectivity Requirements
The Peirce County Traffic Division, Pierce County, Washington initiated this study in 2007 to assess their existing signs using the recommended federal minimum retroreflectivity levels. The study evaluated the five sign assessment / management methods described in the MUTCD. The county had an established sign inventory system which was used as a starting point for the study. A query was run using the sign inventory to identify the oldest signs still in service. A subset of the oldest sign group of each color (the control group) was identified for retroreflectivity measurements. Retroreflectometer readings were taken on the control group (3 readings per each color on a sign and averaged) and the results were analyzed.

The researchers found that all of the 10-12 year old Type III High Intensity signs were still well above the minimum MUTCD levels. The County selected a sign assessment / management method that uses elements of Measured Retroreflectivity, Expected Sign Life and primarily the Control Signs method. The researchers concluded that using a sign inventory as a foundation in combination with one or more of the five recommended maintenance methods works effectively with a minimal amount of additional workload or system administration. In addition, the study noted that placing date-stamped serial numbers on all new signs will assist in identifying signs and their age in the future.

8) Comparison of Observed Retroreflectivity Values with Proposed FHWA Minimums
This paper details the research efforts undertaken by the Indiana Department of Transportation in 2001 to compare measured retroreflectivity on existing signs in Indiana with the FHWA minimum retroreflectivity requirements. For the data collection efforts, the researchers took samples from 10 or 11 year old signs using a retroreflectometer set at +0.2 degree observation angle and a -4 degree entrance angle. The data was entered into a database to run queries and create histograms showing the relative frequency of signs measured at given retroreflectivity and how these values compare to the FHWA minimums. The data was also used to make charts of retroreflectivity vs. time for different colors and types of signs for which linear trend lines and their r-squared values were produced. The study found that only 4% of the 10 or 11 year old signs tested were below the absolute minimum for any sign. The researchers concluded that FHWA minimums on retroreflectivity should be simplified to one minimum for each color of sheeting.

9) Factors Affecting Sign Retroreflectivity – Final Report – SR 514

The purpose of this 2001 study was to investigate factors that may affect sign retroreflectivity, in order to develop criteria for appropriate sign replacement schedules for the Oregon Department of Transportation. The research methods included collecting readings on 80 high intensity (Type III) signs – 20 each of red, yellow, green and white signs. Ten readings were taken per sign, on the background only (not on the legend). The signs were washed and dried prior to taking measurements. The age and physical orientation (east, west, north, south) were recorded for each sign. An additional 57 signs were tested after the researchers determined the sample size was not large enough.

The study found that there is no clear relationship between sign retroreflectivity and age, nor is there any strong trend between the physical orientation of signs and their retroreflectivity. West and south facing signs were found to have more retroreflectivity variability, but gradation in the average levels was not as evident. The study recommended that sign locations, installation dates and orientations should be recorded on the back of sign and in the Oregon DOT sign database and that maintenance departments should invest in a retroreflectometer to collect readings from new signs and track them periodically for future analysis.

10) Maintaining Traffic Sign Retroreflectivity: Impacts on State and Local Agencies

This FHWA report focuses on the negative impacts of the new retroreflectivity requirements and the concerns brought up by participants at the FHWA Sign Workshops in 2002. It provides an overview of how the new requirements will affect agencies in terms of sign cost and upgrading sign sheeting to from Type I to Type III or higher. The report details the elements of sign costs and the factors affecting these costs, as well as the cost and factors for sign management processes. Previous studies done by TexasDOT, Indiana DOT, and North Carolina DOT are briefly reviewed. The negative impacts discussed include:

- Administrative Impacts – additional personnel, training, sign documentation
- Fiscal Impacts – increased replacement rates, training staff and paying overtime for nighttime inspections, cost of evaluation equipment/software, etc
- Implementation Impacts – The cost and effort of implementing these practices may be too much of a burden for some agencies
- Tort Impacts – How the new MUTCD requirements can affect agency’s tort liability

C. Information Obtained from Other States

As part of the background research, researchers contacted the AASHTO Traffic Engineering Subcommittee members from the other 49 states to determine what type of sign management programs their states are using. The states were asked the following 4 questions:

1) Are you using the expected sign life approach, blanket approach, control signs approach or an assessment method?
2) If you are using the expected sign life approach, are you using the manufacturer's warranty (typically 10 years for Type III sheeting material) or other values?
3) If you are using other values, what research if any is that based on?
4) Are there any other criteria you consider critical in addition to sign age (i.e. orientation, type of sheeting, etc.)?

Overall, 27 of the 49 states responded (55%). Of those 27 states, 13 states plan on utilizing the expected sign life approach for their sign management / replacement policy. Five of the 12 states that are using the expected sign life method are coupling it with the blanket replacement approach in order to get specific corridors on the same replacement schedules. The states using the expected sign life method include:

- Delaware
- Indiana*
- Kentucky
- Louisiana
- Maine
- Michigan
- Mississippi*
- New York*
- Ohio*
- South Dakota
- Vermont
- Virginia
- Wisconsin*

*Coupling with blanket replacement method

Most states are using past experience and previously published research papers for the basis of the expected sign life they employ. However, a few of the states that responded have either conducted their own research or are planning to and this information is discussed below. A summary of the information received from all states that responded can be found in the Appendix.

Indiana

The Indiana Department of Transportation (INDOT) uses a combination of methods, typically expected sign life, but they are trying to get their sheet signs in a corridor on the same cycle. They have conducted field studies to establish an 18 year expected life for Type III and higher sign sheeting. Their field study looked at different colors in different orientations. The study found that Type III sheeting exceeded the MUTCD minimums at 18 years. Type I sheeting will not and is nearly phased out. INDOT switched to minimum Type IV sheeting two years ago. INDOT indicated that there is currently limited data available on Type IV sheeting and that they will likely extend their 18 year age in the future, as Type III signs are phased out.

INDOT provided the 2010 study they conducted to determine if they could extend their previous 14 year replacement schedule. The study collected retroreflectivity and color measurements from signs of various colors, ages and locations. A total of 211 ground-mounted signs were tested from northern and southern Indiana with a minimum of 36 of each color (yellow, white, green and red sheeting) and at least 72 signs facing north and 72 facing south. 42 signs (20%) were between 10-12 years old, 154 signs (73%) were between 13 and 16 years old, and 15 signs (7%) were over 16 years of age. The study's findings show that most signs exceeded the minimum retroreflectivity levels. All green signs passed inspection while 4% of red signs, 4% of white signs and 12% of yellow signs failed to meet minimum requirements. Based on these findings, INDOT proposed a life cycle for sheet signs at 18 years and plans to conduct a follow up study in the next four years.

Vermont

The Vermont Department of Transportation is using a combination of methods. For their smaller signs (<= 20 sq ft) they use an expected sign life cycle of 15 years based on a research study conducted by their Materials & Research section. For their larger signs, they are considering using a control group of signs to determine the replacement cycle. At this time, they have yet to finalize the method and specifics for accomplishing that task.

Vermont DOT provided a link to the research study they conducted on sign retroreflectivity. Similar to the PennDOT study, retroreflectivity was measured as a function of time in the Vermont study, but data correlation was completed with consideration to additional variables such as sheeting type, manufacturer, roadway type, orientation, condition and region. When performing the statistical analysis of the data, researchers found that none of those variables correlated to retroreflectivity levels, except for sheeting manufacturer. They found that Avery-Dennison sheeting outperformed 3M sheeting, although noted that a cluster of highly reflective Avery-Dennsion signs may not be representative due to their close proximity to one another. The sample size of Avery-Dennison signs was much smaller than that of 3M signs as well.

The study sample size consisted of 618 total signs, which included red, green, yellow and white Type III sheeting, ranging in age from 7 to 12.5 years, and yellow and yellow-green Type IX sheeting ranging in age between 5.4 to 6.4 years. Given the best fit trend lines and predicted retroreflectivity over time, the study recommended a life cycle of 15 years for red sheeting and noted that 15-20 years may be reasonable for green, white and yellow sheeting. Of the 618 signs tested, all exceeded minimum retroreflectivity levels. The study recommended additional data collection on the sample population in approximately five to seven years once the signs have experienced further deterioration, to paint a better picture of long term service life.

Virginia
The Virginia Department of Transportation (VDOT) is evaluating in-house sheeting samples after extended accelerated weathering. VDOT is moving forward with the expected sign life methodology in combination with spot audits of visual nighttime inspection. VDOT believes that following the manufacturer's warranty may result in premature replacement of signs and has established an initial assumption for expected life is a 15-year life cycle. They are considering doing their own testing and verification through sampling to establish the typical extended retroreflectivity life span of the sheeting material. They will be evaluating in-house sheeting samples after extended accelerated weathering (3 + years). Some of the criteria other than age that Virginia DOT may utilize in the management plan include: roadway classification and speed, sign type, sheeting type, life cycle, orientation, contrast ratio and road segment crash history.

Wisconsin
The Wisconsin department of Transportation (WisDOT) is utilizing both the expected sign life method and blanket replacement method. The blanket replacement method is utilized on roadway construction/improvement projects on which they normally include all sign replacements as part of the project. For the expected sign life method, WisDOT utilizes a 12 year replacement cycle which is currently based on their experience of utilizing the Type III sheeting. In order to make their policy more objective, WisDOT has established a control signs test deck at their central sign shop in Madison, which is also one of the approved MUTCD assessment/management method. The goal of the test deck is to provide support to their replacement criteria. As time progresses, the 12 year criteria may change. They are also evaluating the ASTM Types III, IV, IX and XI on the signing test deck with different colors. They are planning to begin evaluating the deterioration of colors and will factor that into their sign replacement criteria. All signs on their test evaluation deck face south to get the maximum sunlight and UV rays. At this time, their replacement criteria are based on south facing signs.

Ohio / Oklahoma
The Ohio Department of Transportation (ODOT) did not conduct their own study, but used a study conducted by the Oklahoma Department of Transportation as the basis for their replacement interval and shared that study information with us. ODOT currently uses the blanket replacement method, which is described in Section 260-5 of the ODOT Traffic Engineering Manual. They initiated their program in 2001 in anticipation of the upcoming federal requirements and recognition of the value of highly reflective signs to the motoring public. They use ASTM D 4956 Type III sheeting or higher (Type VII or higher for reflective legends on overhead signs), and a 15 year replacement interval. The 15 year replacement interval is based on a 1994 Oklahoma Department of Transportation study (Report number FHWA/OK 95(02)). ODOT provided page 60 of the report, which concludes an average service life of 15 years for Type IIIA sheeting based on data obtained from Oregon DOT divisions, sheeting manufacturers, and published literature. The study found that the application of regression equations resulted in very long service lives due to the shortcomings of the predictive equations.

D. Information Obtained from Sign Sheeting Manufacturers

As part of the background information review for this paper, the two sign sheeting manufacturers that supply PennDOT with the majority of their sign sheeting, Avery Dennison and 3M, were contacted to discuss their sign sheeting warranties. Both manufactures warranty their ASTM Type III and IV sign sheeting (white, yellow, red, green and blue colors) for 10 years. It should be noted that the product bulletins for both manufacturers indicate that the reflectivity measurements are to be taken after sign cleaning.

Avery Dennison

Avery Dennison provided the product bulletins for the T-6000 and W-6000 HIP Series High Intensity Microprismatic Retroreflective Film, which meets the specifications of ASTM D4956 Type III and IV sign sheeting. Both product types have warranties for 10 years (for white, yellow, red, green and blue colors) and 3 years (for orange), subject to the provisions in the warranty.

Avery Dennison provided additional information regarding the basis of their product warranties.

- Avery Dennison's testing is based on a comparison against known product durability and performance, and not against expected sign life.
- They commonly conduct forty five degree, south facing, outdoor weathering to anticipate the degradation patterns of their materials, but they have not invested in a broader project to categorize the failure modes for all sign installations.
- The durability testing models the worst case constructions, installations and weather, which are far harsher than what is expected expect in the majority of installations.
- Their product warranties are not designed to approximate the life of their products, but instead they are intended to guarantee that their products are manufactured appropriately for the safety installation for which they are intended.
- The warranties protect public agencies against manufacturing defect, but the goal is to create products that far outlast the warranty period.

3M

3M provided the product bulletins of their High Intensity Prismatic Reflective Sheeting Series 3930 (white, yellow, red, green, and blue colors) which meets the specifications of ASTM Type III and Type IV Sign Sheeting. 3M's High Intensity Prismatic Reflective Sheeting Series 3930 has a ten year warranty to remain effective for its intended use and meet the stated minimum values for coefficient of retroreflectivity subject to the provisions of the warranty.

III. Research

A. Field Research Methodology

The methodology employed for this study's data collection was measuring sign retroreflectivity. The procedure involved manually measuring the retroreflectivity of signs using a DELTA Light and Optics RetroSign 4500 Retroreflectometer, which the researchers borrowed from PennDOT BHSTE. The advantages of this methodology are that it provides the most direct means of obtaining retroreflectiveness and removes all subjectivity inherent in visual inspection methods. The field work was conducted from September 2011 to December 2011. Signs were not cleaned or wiped before the retroreflectivity measurements were taken. Three retroreflectivity measurements were taken for each color on the sign and were averaged to obtain an overall measurement of the retroreflectivity of each color on the sign.

The retroreflectivity of post-mounted yellow warning signs, white regulatory signs, green guide signs and red stop or yield signs was measured for this study. Because most sign sheeting manufacturers warranty their sign sheeting for 10 years, signs older than 10 years were selected for this study. A total sample size of 1000 signs 10 years of age or older was the goal. The sample size included a geographical representation of signs from the northern, central and southern tiers of Pennsylvania and included both silk screened and cutout legend signs. Signs in Lackawanna County (District 4-0) were used to represent the northern tier; signs in Lehigh County (District 5-0) were used to represent the central tier and signs in Lancaster County (District 8-0) were used to represent the southern tier.

B. Overview of Study Sign Selection Method

PennDOT has an existing SAP sign database which lists every state maintained sign installed on state-owned routes for every county in the Commonwealth. This database includes the nomenclature and sign description, installation date, sign dimensions, post type, as well as detailed sign location information including the route number, segment and offset, latitude and longitude coordinates, direction that the sign faces along the route (either ascending or descending along the route) and side of road the sign is located on. For this study, PennDOT personnel queried the signs in each of the three counties selected for the data collection efforts (Lackawanna, Lehigh and Lancaster counties) in their database and provided a spreadsheet for each county to the researchers. First, researchers removed all blue informational signs, township name signs, route markers and their plaques from the query results and then removed all signs with installation dates less than 10 years old resulting in a list of signs that meet our initial criteria.

Next, using GIS, the remaining data in the three spreadsheets were graphically placed on maps to illustrate the white, yellow, red and green sign locations by color throughout each county. From these figures, it quickly became clear that the quantity of red and green signs is much less than the quantity of yellow and white signs along PennDOT-owned routes; therefore, the red and green sign locations controlled the data collection route selection. The PennDOT Video Log was used to select corridors with ample shoulder room and favorable geometry and terrain for researchers to safely conduct the sign retroreflectivity measurements in the field.

In each of the spreadsheets, the researchers arranged the sign location data for each route in order of segment and offset in the direction of travel to simplify the field data collection process. Approximately 500 signs were included on each county list, anticipating that some signs would be skipped due to physical constraints of collecting the field data. The goal was to collect the retroreflectivity measurement on 333 signs in each district (334 in District 8-0) to total 1,000 signs for this study. **Table 2** below shows the sample size calculation for each sign color per county.

Table 2: Planned Sample Size Distribution Per County

Sign Type	PA State Total		Per County	
	# of Signs	% of Total	# of Signs	% of Total
Red Signs*	107,648	17.4%	58	17.4%
Green Directional Signs	21,269	3.4%	11	3.4%
White Regulatory Signs	222,224	36%	120	36%
Yellow Warning Signs	266,679	43.2%	144	43.2%
Total	617,820	100%	333	100%

*Red signs include Stop (R1-1), Yield (R1-2), Do Not Enter (R5-1), and Wrong Way (R5-1A)

C. Data Analysis

Below are summary tables of the collected field data for each sign color measured. The tables show the sample size, average (mean) age of signs measured, average (mean) retroreflectivity measured and the percentage of signs measured that did not meet the MUTCD established minimum retroreflectivity levels. For each color, these results are reported first for each county and then for the three counties combined. Table 2A-3 from the MUTCD which contains the federal minimum retroreflectivity levels is included directly below for reference.

Table 3: MUTCD Table 2A-3 Minimum Maintained Retroreflectivity Levels

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

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

Bold Symbol Signs

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

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

Special Cases

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

White Signs:
Minimum Maintained Traffic Sign Retroreflectivity Levels for Black on White signs = W ≥ 50 cd/lx/m² *(1)*

Table 4: White Sign Data

WHITE SIGN DATA					
	Planned Sample Size	Actual Sample Size	Mean Age	Mean White R*	% Non-Compliant
Lackawanna	120	125	13.1	337.1	0
Lehigh	120	122	13.5	353.8	0
Lancaster	120	121	15.1	245.6	0
Total	360	368	13.9	312.8	0

* R = Reflectivity (cd/lx/m²)

All of the white signs studied were found to be well over the minimum retroreflectivity level. Out of 368 signs tested, the lowest average retroreflectivity level was 109 cd/lx/m²)for a seventeen year old sign compared to the MUTCD required minimum of 50 cd/lx/m²).

Yellow Signs
Minimum Maintained Traffic Sign Retroreflectivity Levels for Black on Yellow signs for all sizes of bold symbol signs and text and fine symbol signs measuring at least 48" = W ≥ 50 cd/lx/m² *(1)*

Minimum Maintained Traffic Sign Retroreflectivity Levels for Black on Yellow signs for text and fine symbol signs measuring less than 48" = W ≥ 75 cd/lx/m² *(1)*

Table 5: Yellow Sign Data

YELLOW SIGN DATA					
	Planned Sample Size	Actual Sample Size	Mean Age	Mean Yellow R*	% Non-Compliant
Lackawanna	144	149	13.1	287.4	2
Lehigh	144	145	15.6	204.6	7.5
Lancaster	144	147	14.8	196.5	4.7
Total	432	441	14.5	229.7	4.8

* R = Reflectivity (cd/lx/m²)

95.2 % of the total yellow signs were well above the MUTCD minimum retroreflectivity level of 50 cd/lx/m² with a mean retroreflectivity level of 229.7 cd/lx/m². The remaining 4.8% of yellow signs that did not meet the minimum levels are detailed below.

- Lackawanna County: 3 out of 149 (2%) yellow signs tested did not meet minimum retroreflectivity levels. The 3 signs that failed were 18, 19 and 26 years old.

- <u>Lehigh County:</u> 11 out of 145 (7.5%) yellow signs tested did not meet minimum retroreflectivity levels. The 11 signs that failed were 16, 17(5 signs), 19(2 signs), 24(2 signs) and 28 years old.

- <u>Lancaster County:</u> 7 out of 147 (4.7%) yellow signs tested did not meet minimum retroreflectivity levels. The 7 signs that failed were 14, 15, 16, 17(3 signs) and 22 years old.

<u>Red Signs</u>

Minimum Maintained Traffic Sign Retroreflectivity Levels for White on Red signs = W ≥ 35 cd/lx/m² and R ≥ 7 cd/lx/m², with a Minimum Sign Contrast Ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity) *(1)*

Table 6: Red Sign Data

RED SIGN DATA							
	Planned Sample Size	Actual Sample Size	Mean Age	Mean Red R*	Mean White R*	Mean Contrast Ratio	% Non-Compliant
Lackawanna	58	61	12.8	37.3	343.6	29.3	8.2
Lehigh	58	66	14.6	34	302.7	9.9	0
Lancaster	58	58	13.1	46.4	340.6	8.9	3.4
Total	174	185	13.5	38.8	328.1		3.8

* R = Reflectivity (cd/lx/m²)

96.2 % of the total red signs were above but close to the MUTCD minimum retroreflectivity value of 35 cd/lx/m² with a mean retroreflectivity of 38.8 cd/lx/m². The remaining 3.8% of red signs that did not meet the minimum levels are detailed below.

- <u>Lackawanna County:</u> 5 of the 61 (8.2%) red signs tested did not meet minimum retroreflectivity levels for red (R ≥ 7). All 5 of these signs were 13 years old and were located at the same interchange, which suggests that these signs are not indicative of the rest of the population.

- <u>Lehigh County:</u> All 66 red signs collected exceed the minimum retroreflectivity levels.

- <u>Lancaster County:</u> 2 of the 58 (3.4%) red signs tested did not meet minimum standards. One 14 year old sign did not meet minimum retroreflectivity levels for red (R ≥ 7), while one 10 year old sign failed for white-to-red contrast ratio (W:R ≥ 3:1) after an abnormally high average red retroreflectivity reading of 183.

Green Signs

Minimum Maintained Traffic Sign Retroreflectivity Levels for White on Green signs for ground-mounted sign: G ≥ 15 cd/lx/m² and W ≥ 120 cd/lx/m² *(1)*

Table 7: Green Sign Data

GREEN SIGN DATA						
	Planned Sample Size	Actual Sample Size	Mean Age	Mean Green R*	Mean White R*	% Non-Compliant
Lackawanna	11	5	13.6	52.4	321.2	0
Lehigh	11	1	9.0	43.0	610	0
Lancaster	11	7	17.7	63.6	325.0	0
Total	33	13	15.9	57.6	315.8	0

* R = Reflectivity (cd/lx/m²)

Our goal was to collect retroreflectivity measurements on 33 green signs total; however, we were only able to collect usable data for 13 green signs. In the counties selected for our data collection efforts, the total population of ground-mounted directional green signs is very small in comparison to the amount of yellow warning, white regulatory and red stop, yield, do not enter and wrong way signs. When trying to locate the limited green signs that met our study criteria (10+ years old), we found that most green signs did not have manufacture or installation dates, so the age of the signs could not be confirmed. Many of the signs were fabricated and installed by contractors, so the typical PennDOT procedure of marking/dating signs was not followed. Of the green signs that did have dates, many were recently installed and did not meet the 10+ years old age criteria for this study. We also found that many green signs were mounted too high to reach with a ladder and therefore, would require equipment beyond the scope of this study to measure the signs.

All 13 of the green signs that we were able to collect with known ages exceeded the minimum retroreflectivity requirements for both green and white sheeting.

Retroreflectivity versus Age

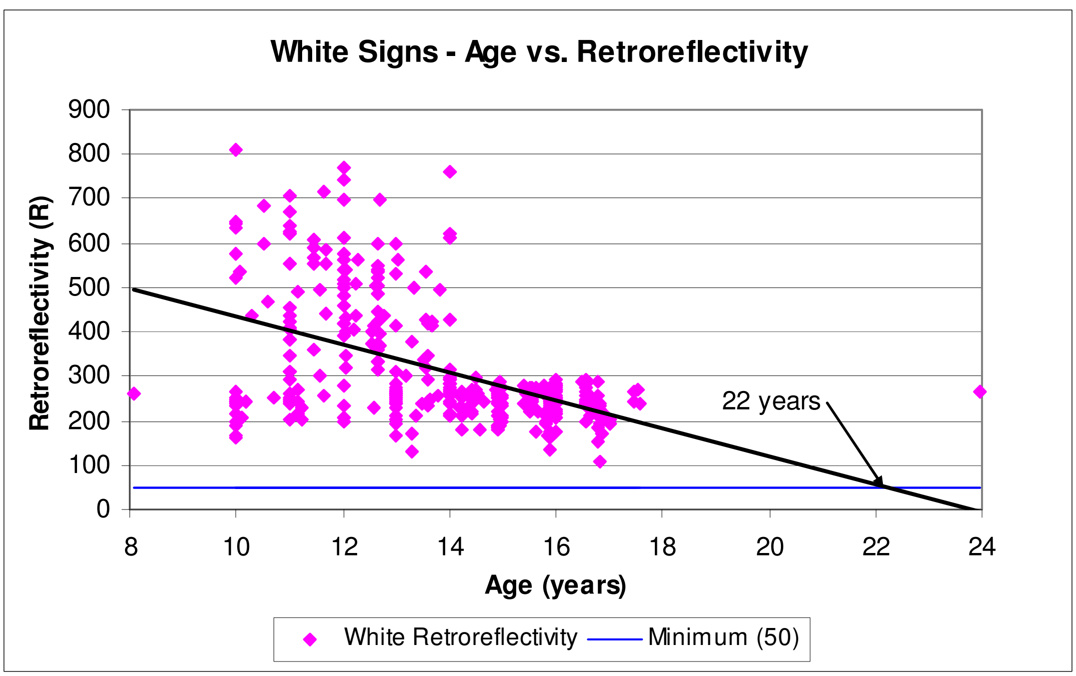
The data presented above shows that a majority of the signs measured have retroreflectivity values well above the minimum required retroreflectivity levels. When reviewing the average age and retroreflectivity levels for each county, there does not appear to be a noticeable geographic trend that suggests retroreflectivity varies greatly from region to region within Pennsylvania.

To gain a better understanding of the data, age versus retroreflectivity was plotted to determine if any correlation could be found between the two variables. For each plot, linear regression equations (lines of best fit) and R^2 (Coefficient of Determination) values were generated. The Coefficient of Determination (R^2) is a descriptive measure between 0 and 1 which represents the relative predictive power of a variable. An R^2 value of 1 implies that a model provides perfect predictions, while an R^2 value of 0 would indicate a poor model for prediction. For the linear regression lines we formed, a high R^2 value would indicate that age and retroreflectivity correlate very well and therefore, age can be used to determine retroreflectivity. Our models produced low R^2 values ranging from 0.10 to 0.30; therefore, our results indicate no direct correlation between age and retroreflectivity, which is similar to the previous studies and literature reviewed. Also, the linear regression equations for the various data sets produce very long service lives, which is unreasonable when compared to real life experience and warranty values.

These results of our study suggest that age alone cannot be used to predict retroreflectivity, as many other factors are involved. However, other studies have tested correlation between retroreflectivity and a number of other variables, with no direct relationships detected, and have shown that age is the single biggest factor affecting retroreflectivity over time. Given the high performance of signs in the 13 to 15 year old age range, we believe a minimum sign life of 15 years is acceptable, similar to other studies and states.

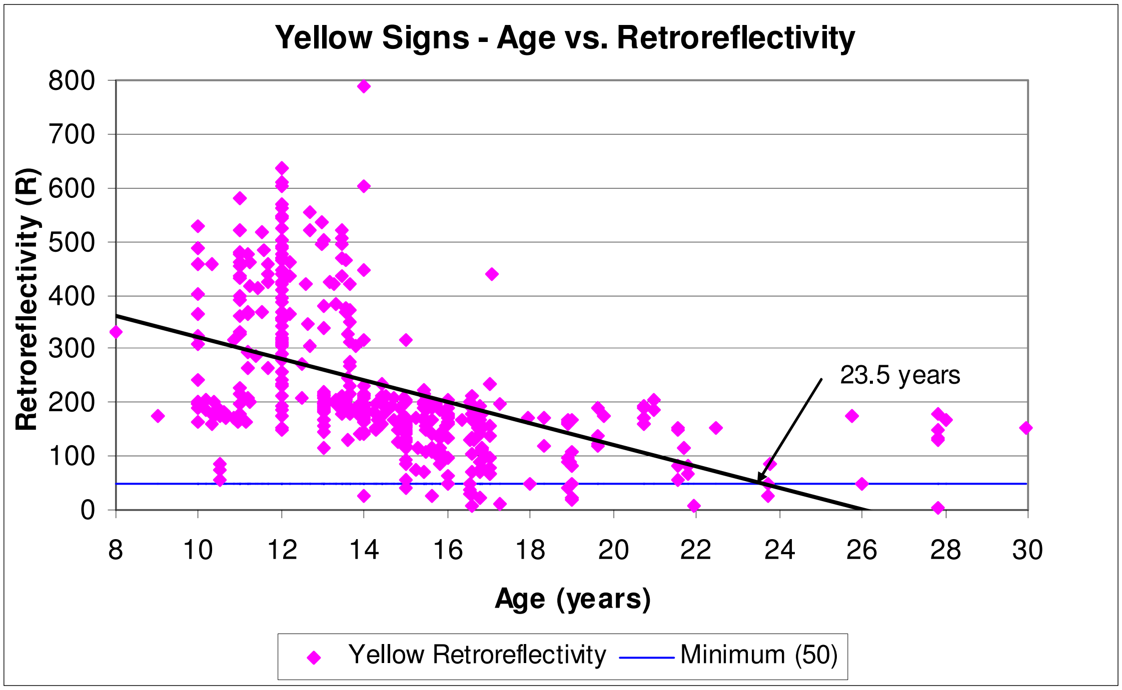
Figures 1 through 6 show age versus retroreflectivity for white, yellow, red and green signs (all counties combined), respectively. The Appendix includes individual plots for each color in each of the three counties, plus all three counties combined.

Figure 1: Age versus Retroreflectivity for White Signs (all counties combined)



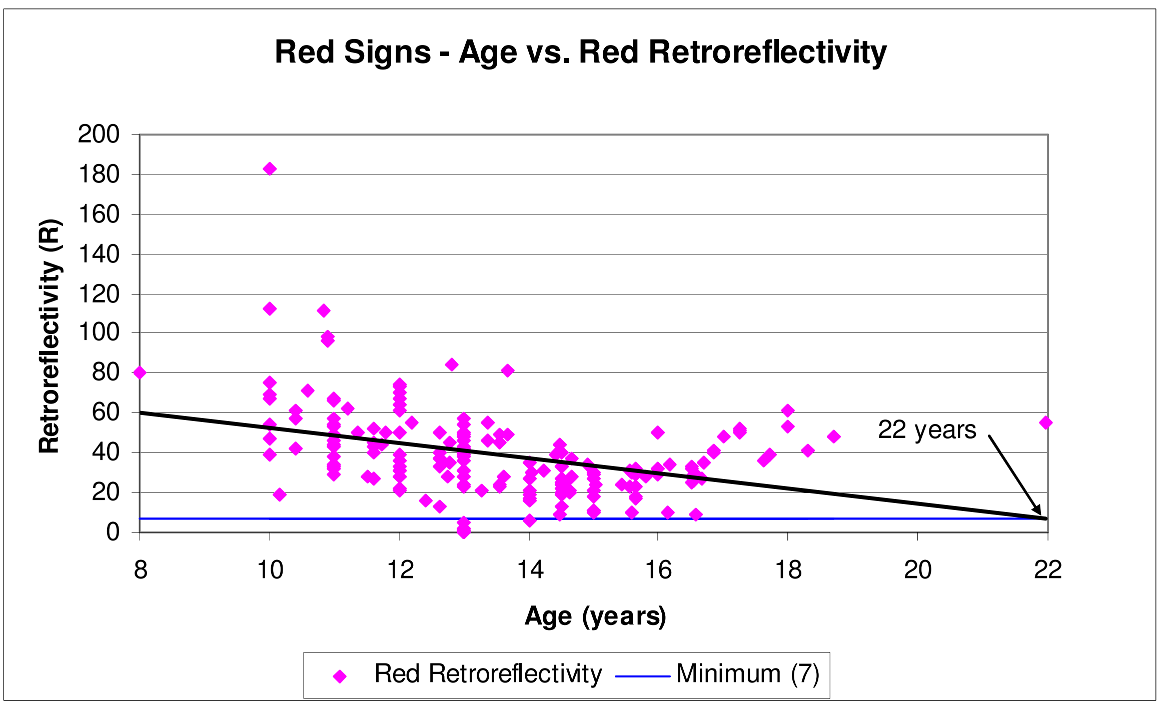
$y = -32.078x + 758.31$ $R^2 = 0.2527$

Figure 2: Age versus Retroreflectivity for Yellow Signs (all counties combined)



y = -20.24x + 523.53 R^2 = 0.2533

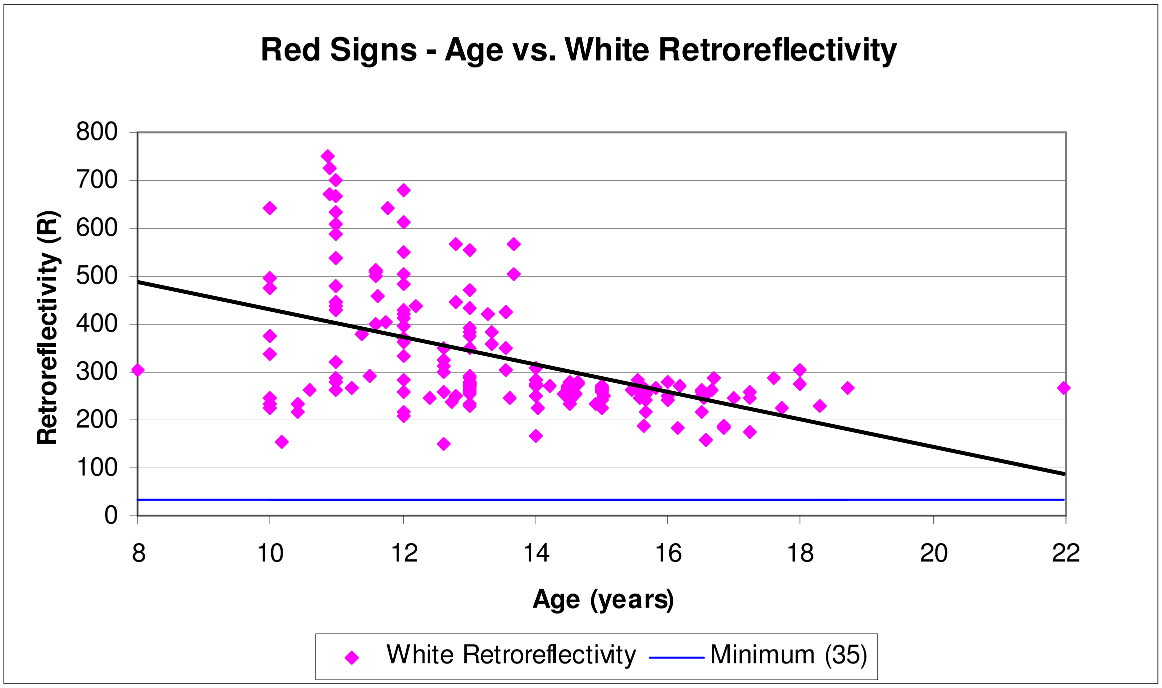
Figure 3: Age versus Retroreflectivity for Red Signs (Red) (all counties combined)



y = -

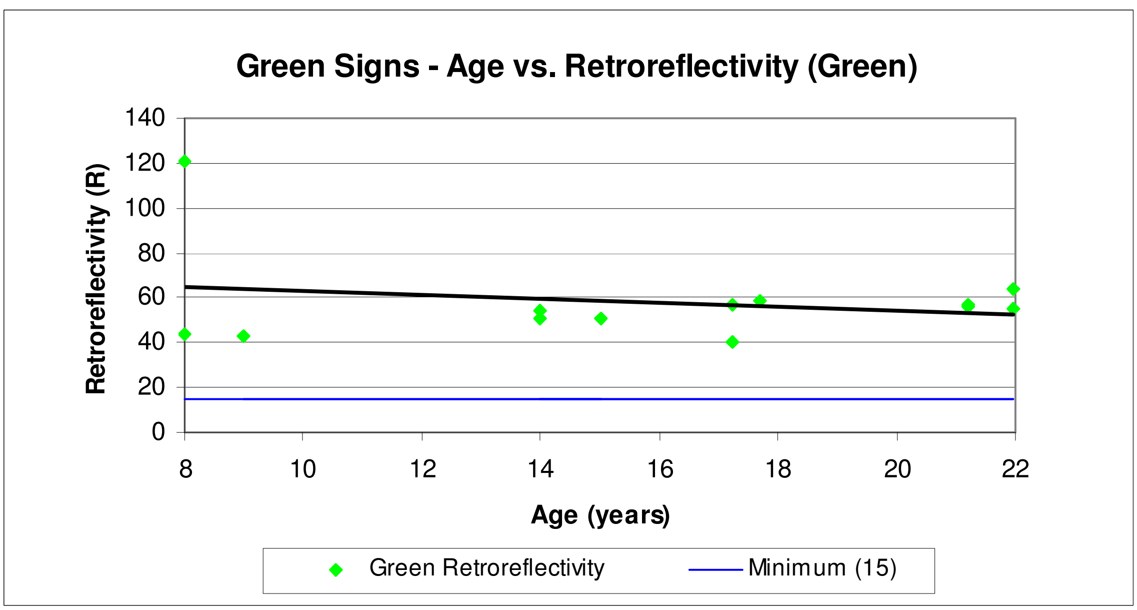
y = 4.0818x + 94.055 R^2 = 0.1537

Figure 4: Age versus Retroreflectivity for Red Signs (White) (all counties combined)



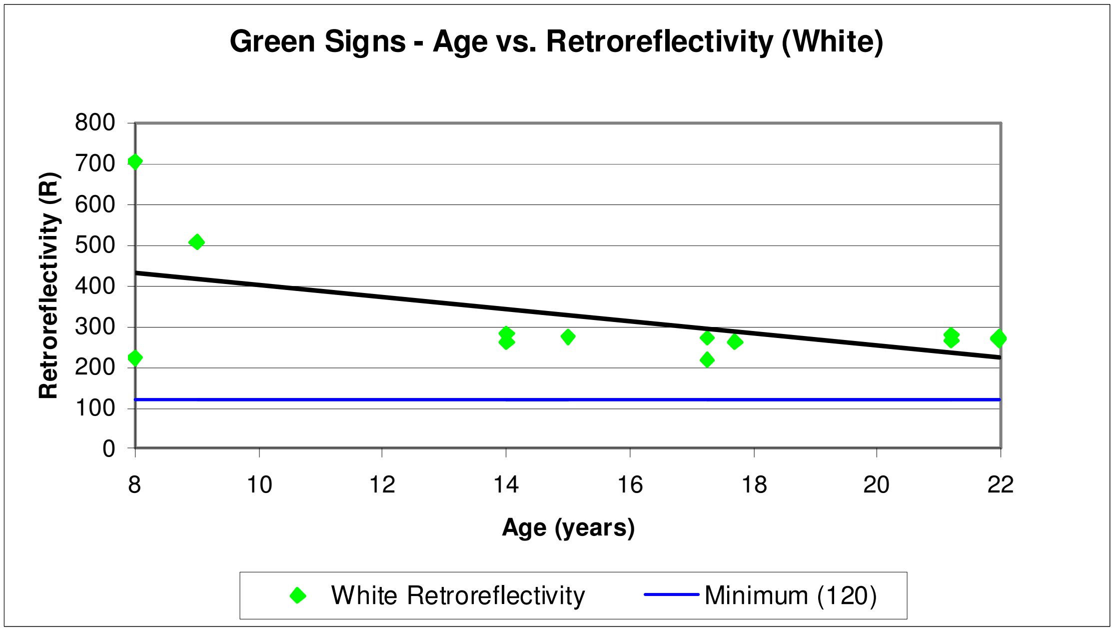
$y = -30.287x + 738.04$ $R^2 = 0.2643$

Figure 5: Age versus Retroreflectivity for Green Signs (Green) (all counties combined)



$y = -0.8512x + 71.165$ $R^2 = 0.0467$

Figure 6: Age versus Retroreflectivity for Green Signs (White) (all counties combined)



y = -0.8512x + 71.165 R^2 = 0.0467

Standard Normal Distribution Analysis:

From our research on other states' sign management methods and the previous literature review, we found that most agencies are using a service life beyond the manufacturer warranty of 10 years and that typically a service life of 15 years is used for Type III sheeting. Given that most of the signs measured for this study are an average age of 13 to 15 years old with average retroreflectivity levels well above the minimum requirements, it seems reasonable to expect over 15 years of life from Type III sheeting in Pennsylvania. To determine if the expected sign life could be confidently extended beyond 15 years, a standard normal distribution analysis was performed on the data for signs 16 to 18 years old, for white, yellow and red signs only. This age range was chosen for the analysis because very few of the sample signs in our study are older than 19 years. We did not conduct a standard normal distribution analysis on green signs because of the very small sample size. Of the 13 green signs we were able to collect data for, only 3 signs fall in the 16-18 year age range. Because the sample population is so small, the standard normal distribution model cannot be used with a high degree of confidence to predict the probability of these signs exceeding the minimum retroreflectivity requirements.

Using the mean retroreflectivity level and standard deviation for each analysis group (white, yellow and red signs, aged 16-18 years) and assuming standard normal distribution, we are able to predict the probability that a sign aged 16 to 18 years old will meet the minimum retroreflectivity requirements. The Standard Deviation (σ) is a measure of the variation from the mean for a set of data. A small standard deviation indicates that the data points are located close to the mean, whereas higher standard deviation values indicate a wider dispersion of data from the mean. Standard Deviation (σ) is calculated as follows:

$\sigma = \sqrt{1/N\,[(x_1-\mu)^2 + (x_2-\mu)^2 + (x_N-\mu)^2]}$, where: N = sample size
μ = mean

Using the sample size of each population we can also determine the tolerance of our calculated mean within a certain interval of confidence which is a way to determine the validity of the calculated mean. Tolerance (e) is a statistical interval, given a specific confidence level, in which a certain proportion of the population falls. The tolerance is calculated by first determining the Standard Error of the Mean (E) which is the standard deviation of the data divided by the square root of the sample population: $E = \sigma / \sqrt{N}$. The tolerance is equal to E multiplied by a coefficient specific to a given confidence level. For example, the true mean for various confidence levels can be calculated as follows:

$\mu = x \pm E$, with 68.3% confidence (tolerance, $e = E$)
$\mu = x \pm 1.96E$, with 95% confidence (tolerance, $e = 1.96E$)
$\mu = x \pm 3.00E$, with 99.7% confidence (tolerance, $e = 3E$)

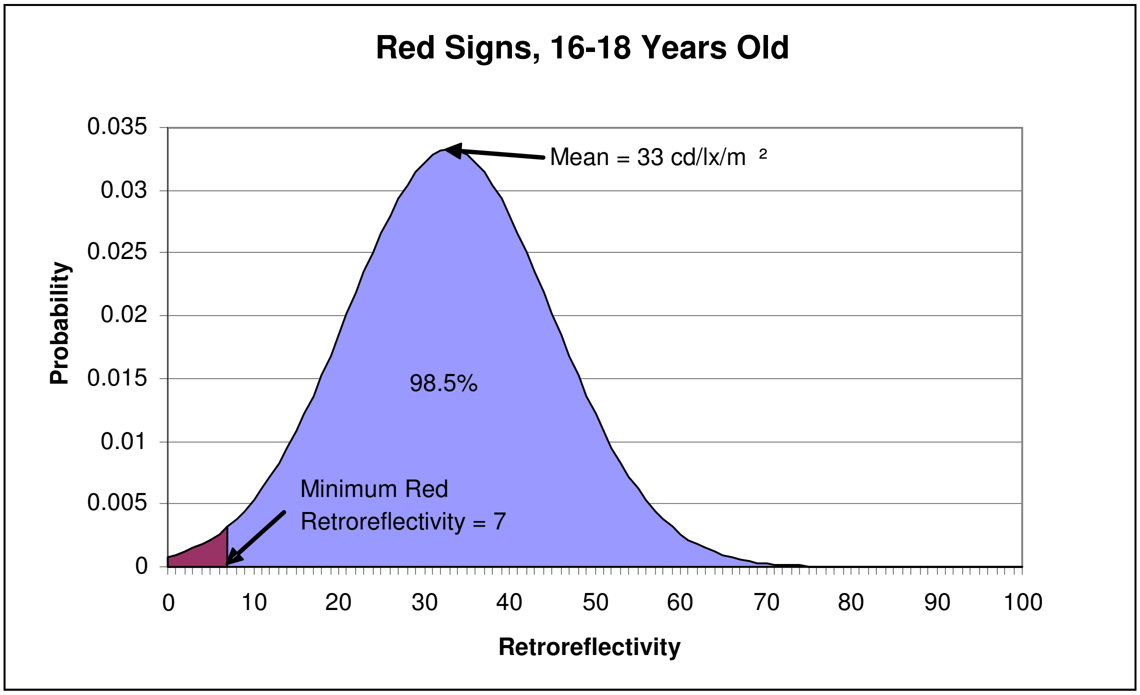
The results of the standard normal distribution analysis are shown beginning on the next page.

Red Signs, 16-18 years old

Sample Size = 40 signs
Calculated Mean Retroreflectivity = 33 cd/lx/m^2
Standard Deviation = 12.0
True Mean Retroreflectivity = 33 ± 3.72 with 95% confidence

For this data set, the true mean was calculated to be 33 ± 3.72 with 95% confidence which means that there is 95% chance that the true mean retroreflectivity is between 29.28 and 36.72 cd/lx/m^2. **Figure 7** shows that for this data set, there is a 98.5 % probability that 16-18 year old red signs will have retroreflectivity greater than the required minimum level of 7 cd/lx/m^2.

Figure 7: Probability of Red Signs, 16-18 Years Old, Exceeding Minimum Retroreflectivity

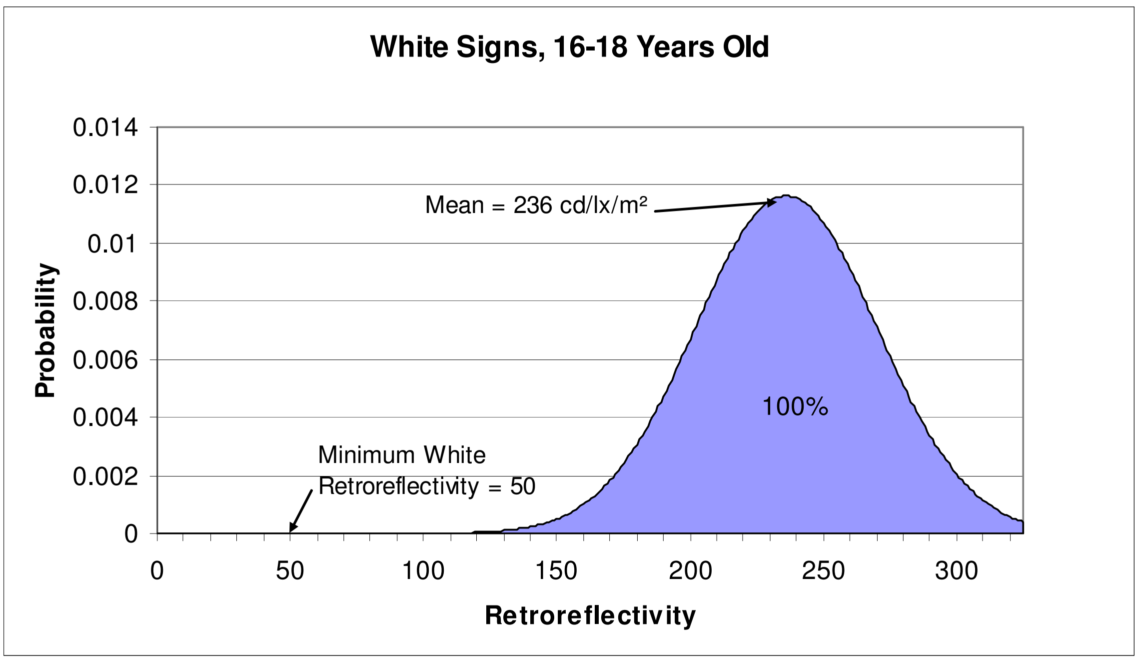


White Signs, 16-18 years old:

Sample Size = 116 signs
Calculated Mean Retroreflectivity = 236 cd/lx/m²
Standard Deviation = 34.3
True Mean Retroreflectivity = 236 ± 6.24 with 95% confidence

For this data set, the true mean was calculated to be 236 ± 6.24 with 95% confidence which means that there is 95% chance that the true mean retroreflectivity is between 229.76 and 242.24 cd/lx/m². **Figure 8** shows that from our data set, there is a 99.99% probability that 16-18 year old white signs will have retroreflectivity greater than the required minimum level of 50 cd/lx/m².

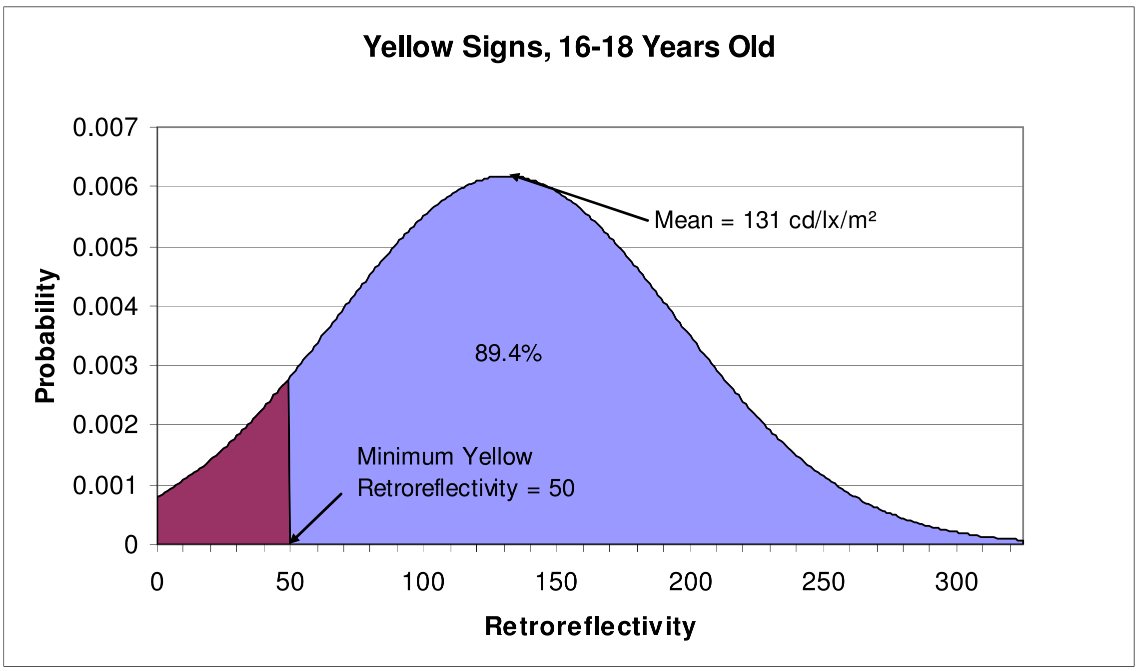
Figure 8: Probability of White Signs, 16-18 Years Old, Exceeding Minimum Retroreflectivity



Yellow Signs, 16-18 years old:
Sample Size = 81 signs
Calculated Mean Retroreflectivity = 131 cd/lx/m²
Standard Deviation = 64.6
True Mean = 131 ± 14.1 with 95% confidence

For this data set, the true mean was calculated to be 131 ± 14.1 with 95% confidence which means that there is 95% chance that the true mean retroreflectivity is between 116.90 and 145.10 cd/lx/m². **Figure 9** shows that from our data set, there is a 89.4% probability that 16-18 year old yellow signs will have retroreflectivity greater than the required minimum level of 50 cd/lx/m².

Figure 9: Probability of Yellow Signs, 16-18 Years Old, Exceeding Minimum Retroreflectivity



D. Conclusion

The overall data collection results for each color of sheeting are shown below in **Table 8**.

Table 8: Data Collection Summary

Color	Sample Size	Mean Age (years)	Mean R (cd/lx/m²)	Min R (cd/lx/m²)	% Non-Compliant
Yellow	441	14.5	230	50	0
White	368	13.9	313	50	4.8
Red	185	13.5	39/328	7/35	3.8
Green	13	15.9	58/316	15/120	0
Total	1,007	14.1	N/A	2.8	2.8

Based on the raw data and statistical analysis, we can see that sign sheeting retroreflectivity performs well above minimum standards well beyond the manufacturer's warranty. While we could not find direct correlation between age and retroreflectivity, the raw data shows that the expected sign life can confidently be recommended as 15 years for yellow, white and red signs. Despite the limited green sign data, we have a high degree of confidence in recommending a service life of 15 years for green signs as well. Using simple statistical analysis, we also determined that there is a high probability that signs of all colors aged 16 to 18 years old will continue to exceed minimum retroreflectivity levels.

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Retroreflectivity of Existing Signs in Pennsylvania
FINAL REPORT

APPENDICIES

Appendix 1: Table of States Responses & Data Reduction

Appendix 2: Manufacturer Information

A . 3M High Intensity Prismatic Reflective Sheeting Series 3930 with Pressure Sensitive Adhesive Product Bulletin 3930

B. Avery Denison T-6000 & W-6000 Series Product Data Sheet

STATES RESPONSES

Questions posed to the AASHTO TE Subcommittee members from all 50 states:

1) Are you using the expected sign life approach, blanket approach control signs approach or an assessment method?
2) If you are using the expected sign life approach - are you using the manufacturer's warranty (typically 10 years for Type III sheeting material) or other values?
3) If you are using other values, what research if any is that based on?
4) Are there any other criteria you consider critical in addition to age (e.g., orientation, type of sheeting, etc.)?

[grey box] = No Response

State	Name	Question 1 Answer	Question 2 Answer	Question 3 Answer	Question 4 Answer
Alabama	Stacey N. Glass, P.E.	Alabama has implemented the Nighttime Inspection method using calibration panels.			
Alaska	Kurtis J. Smith, P.E.	We are using a two phase approach: 1) an initial sign inventory process, including collection of a large sampling of in-service sign retroreflectivity, using hand-held retroreflectometers, and 2) the visual nighttime inspection as an ongoing assessment method.			No. Inspectors are collecting orientation and sheeting type information during the inventory, but we're not sure whether that will play a role in determining when a sign is replaced. The nighttime inspectors will utilize calibration signs for their assessment method.
Arizona	Mike Manthey, P.E.	For freeway signing we are using the expected sign life approach, and for non-freeway signs we will use an assessment method. Both of these will be in conjunction with our Sign Management System database.	Since we are using high end prismatic sheeting, we have not yet determined the sign life. That is something we will be tracking for a sample of signs in our Sign Management System.	Will be based on future research.	Our approach will be to upgrade all of our signs to the high end prismatic sheeting, and then track a sample amount of signs to determine expected sign life. Orientation may become a part of the analysis, but to be safe we may replace all signs when the orientation becomes a factor.
Arkansas	Eric Phillips				
Arkansas	Tony Sullivan	We are using the blanket repacement approach at specified intervals of 10 years.	Yes, the 10 year intervals are based on the manufacturer's warranty for Type III sheeting.		
California	Robert Copp	No, we have traditionally utilized, and continue to employ the Visual Nighttime Inspection assesment method.			
Colorado	Gabriela Vidal				
Connecticut	John F. Carey, P.E.				
Delaware	Donald D. Weber, P.E.	DelDOT uses a combination of night time inspections and the expected sign life approach. The night time inspections also use a handheld retroreflectometer for any signs that are questionable. With the expected sign life approach every sign is labeled with a sticker noting the date of installation.	Yes	N/A	No, although the south facing signs do degrade at a faster rate.
Washington DC	Soumya S. Dey				
Florida	Mark C. Wilson, P.E.				
Georgia	Keith Golden, P.E.				
Hawaii	Alvin Takeshita	We have not decided on the type of sign management approach that we will be implementing.			We believe type of sheeting is an important factor since the higher type sheeting will have retro levels with greater margins over the minimum required level.

STATES RESPONSES
Questions posed to the AASHTO TE Subcommittee members from all 50 states:

1) Are you using the expected sign life approach, blanket approach control signs approach or an assessment method?
2) If you are using the expected sign life approach - are you using the manufacturer's warranty (typically 10 years for Type III sheeting material) or other values?
3) If you are using other values, what research if any is that based on?
4) Are there any other criteria you consider critical in addition to age (e.g., orientation, type of sheeting, etc.)?

[grey box] = No Response

Idaho	Brent Jennings, P.E.	We have selected the visual assessment, nighttime inspection using calibration signs procedure.			We know that signs in the direct sunlight fade faster than others oriented a different direction, and that some colors fade faster than other colors. That has led to not using an expected sign life approach in our sign management system.
Illinois	Aaron Weatherholt				
Indiana	James Poturalski				
Indiana	Todd Shields	Combination of sign life and blanket replacement methods (typically sign life, but trying to get our sheet signs in a corridor on the same cycle)	18 years for Type III and above	We have done field studies looking at different colors in differing orientations. Type III sheeting exceeded the MUTCD minimum at 18 years. Type I will not, and is nearly phased out.	INDOT switched to minimum Type IV 2 years ago. The limited data we have with Type IV indicates we will likely extend our 18 year age in the future, as Type III are phased out.
Iowa	Timothy D. Crouch	We plan to use an assessment approach - visual inspection			Climate - snow belt vs. sun belt - sun angle is much less in the winter months in Iowa than it is in Arizona or Florida during the same time.
Kansas	Kenneth F. Hurst, P.E.				
Kentucky	Jeff Wolfe	In the short term we will be doing nighttime inspections. Routes will be reviewed every other year. At the same time, we are (1) developing a sign inventory, (2) developing a bar code system to track installation/fabrication/etc. for newly installed signs, and (3) created test decks for sign sheeting. As our inventory and sheeting data improves, we will ultimately get away from nighttime inspection and use replacement based on projected sign sheeting life.			
Louisiana	Peter Allain, P.E., PTOE	For years we have used the expected sign life method for sign management. We record the installation date on the back of the sign an then rpelace based on an expected life.	We asked several manufacturers for expected life values but were told they would not share that information. They suggested we use the warranty value, although we know from previous research that sheeting life extends well beyond these values.	We plan on reviewing a student paper exploring the use of AASHTO NTPEP data to estimate sign life (attached).	
Maine	Bruce A. Ibarguen, P.E.	We are using the expected sign life approach.	We are using the manufacturer's warranty - typically 10 years	N/A	Our program is only the regulatory and warning signs.
Massachusetts	Neil E. Boudreau	MassDOT currently replaces major directional signs on interstates and freeways under blanket sign replacements every 12 to 14 years. As guide signs are replaced, regulatory and warning signs are as well. MassDOT does not currently have a replacement program for secondary highways, but at this time they plan on basing future sign replacements on periodic nighttime inspections. They will begin this once the sign inventory system that is currently under development is in place.	The replacement cycle is based on historical experience in MA and adjoining states with high intensity (Type III) sheeting, which MassDOT has used since the late 1960's. However, as MasssDOT has been using high intensity prismatic sheeting (HIP Type VIII or better) the cycles has been extended to 16 to 18 years based on intial results observd with using HIP sheeting.		

STATES RESPONSES

Questions posed to the AASHTO TE Subcommittee members from all 50 states:

1) Are you using the expected sign life approach, blanket approach control signs approach or an assessment method?
2) If you are using the expected sign life approach - are you using the manufacturer's warranty (typically 10 years for Type III sheeting material) or other values?
3) If you are using other values, what research if any is that based on?
4) Are there any other criteria you consider critical in addition to age (e.g., orientation, type of sheeting, etc.)?

[grey box] = No Response

Michigan	Mark W. Bott	Michigan has utilized the blanket replacement method based on expected sign life in its corridor approach to replacment of signs.	Based on our field experience, it's MDOT's goal to replace signs every 15 years, but with strains on the traffic signing budget, the expected replaement cycle is 17 years for freeway signs and 20 years for non freeway signs	To ensure appropriate replacement cycle length, a control group of signs is being measured by retroreflectometers to generate expected life curves.	N/A
Minnesota	Susan M. Groth				
Mississippi	Robert "Wes" Dean	We are using the expected sign life method, coupled with blanket replacement. We don't have a certain age that we use policy –wise, but we are assuming 10-12 years for Type III HIP and 15 years for Type XI. We are basically following the manufacturer's warranties as far as the life. Recieved PP on this that we are presenting at SASHTO this month.			
Missouri	Eileen Rackers	Missouri was orignally planning to use expected sign life as our approach but have since decided to use an assessment method - visual nighttime sign inspections. The reason that we changed direction is that we were changing out entire routes in order to get the route on the same cycle for the next replacement, and in the process we believe too many good signs were being replaced that still had useful life. We are interested in your research as it would be helpful to have better data as to how long the sign sheeting is reflective instead of having to use the manufacturer's warranty. We believe it is longer than 10 years, but did not have anything to base that on.			
Montana	Duane Williams, P.E.				
Nebraska	Daniel J. Waddle, P.E.				
Nevada					
New Hampshire	William Lambert				
New Jersey	David Martin				
New Mexico	Vacant				
New York		We're generally going to use a corridor approach with a 12-15 year cycle.			
North Carollina	J. Kevin Lacey, P.E., CPM	NCDOT conducts nighttime sign reviews to look for signs showing poor or low retroreflectivity. Interstate routes are reviewed each year; primary routes are reviewed every other year; and, secondary routes are reviewed every three years. Signs in bad condition are replaced during the day. Immediate action is taken to replace red series signs, whereas yellow signs are replaced as soon as possible. Directional sign replacements are scheduled as needed.			
North Dakota	Shawn Kuntz, P.E.	Assessment method - nighttime visual inspection	In the past we used manufacturer's warranty for regulatory and warning signs. Our new method (visual nighttime inspection) requires all signs must be inspected annually and identified as being in need of replacement if they appear to be at or near the minimum values of the TEST signs observed.		
Ohio	Jim Roth	Blanket replacement method.	15 year replacement interval	Oklahoma research (1994 Report named FHWA/OK 95(02)	No.
Oklahoma	Harold Smart				
Oregon	Edward L. Fischer, P.E., PTOE				

STATES RESPONSES

Questions posed to the AASHTO TE Subcommittee members from all 50 states:

1) Are you using the expected sign life approach, blanket approach control signs approach or an assessment method?
2) If you are using the expected sign life approach - are you using the manufacturer's warranty (typically 10 years for Type III sheeting material) or other values?
3) If you are using other values, what research if any is that based on?
4) Are there any other criteria you consider critical in addition to age (e.g., orientation, type of sheeting, etc.)?

[gray box] = No Response

Puerto Rico	Carlos M. Contreras				
Rhode Island	Robert Rocchio, P.E.				
South Carolina	Richard B. Werts, P.E.				
South Dakota	Laurie Schultz	We have a proposed draft policy utilizing the Expected Sign Life Method.	Engineer Sheeting (Type I) - 7 years, High Intensity (Type II or III) - 12 years, High Int. Prismatic (Type IV, VI, VIII or X) - 15 years, Diamond Grade Prismatic (Type IX or XI) - 18 years	The replacement schedules are based on data from MNDOT test decks, warranties of sheeting manufacturers, and experience with existing signs and weather conditions.	
Tennessee	Michael L. Tugwell				
Texas	Margaret (Meg) A. Moore, P.E.				
Utah	Robert E. Hull, P.E.				
Vermont	Bruce Nyquist, P.E.	For smaller signs (<= 20 sq ft) we are using the expected sign life method, utilizing a cycle of 15 years based on a research study conducted by our Materials & Research section (see attached link in email). For larger signs, we are considering using a control group of signs to determine our replacement cycle. We have yet to finalize the method and specifics for accomplishing this task.			
Virginia	Raymond J. Khoury, P.E.	VDOT is moving forward with the "expected life" methodology in combination with spot audits of visual nighttime inspection as the proposed management methodology.	Following manufacturer's warranty may result in premature replacement of sign, thus VDOT's own testing and verification through sampling are being considered to establish the typical extended retrorefelectivity life span of the sheeting material. VDOT's initial assumption for expected life is a 15-year life cycle.	VDOT will be evaluating in-house sheeting samples after extended accelerated weathering (3+ years). The use of available manufacturer's sheeting degradation information.	Some of the criteria that may be utilized in the management plan could include: roadway classification and speed, sign type, sheeting type, life cycle, orientation, contrast ratio and road segment crash history.
Washington	Theodore Trepanier, P.E.				
West Virginia	Cindy Cramer, P.E.				
Wisconsin	Thomas N. Notbohm, P.E., PTOE	WisDOT is utlizing both the expected sign life method and blanket replacement method. The blanket replacement method is utilized on roadway construction/improvement projects where we normally include all sign replacements as part of the project.	For the expected sign life method, WisDOT utilizes a 12 year replacement cycle.	Currently, our 12 year replacement cycle is based on experience of utilizing the Type III sheeting. In order to make our policy more objective, WisDOT has established a control signs test deck at our central sign shop in Madison, which is also one of approved MUTCD assessment / management method. The goal of the test deck is to provide Engineering support to our replacement criteria. As time profresses, the 12 year criteria may change.	We are evaluating the ASTM Types III, IV, IX and XI on our signing test deck with different colors. We will begin evaluating the deterioration of colors and factor that into our sign replacement criteria also. All signs on our test evaluation deck face south to get the maximum sunlight and UV rays. Our replacement criteria at this time is based on south facing signs.
Wyoming	Joel Meena, P.E.	Assessment method. We do keep track of age and have a rigid performance measurement system.	We have been getting more than 10 years.	We use a statistical method as you described above for our performance measures.	Silk screened sign. We have found that screened signs mostly for STOP signs have half the life as other signs. The red inks do not last very long.

Pennsylvania Green Sign Data

Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

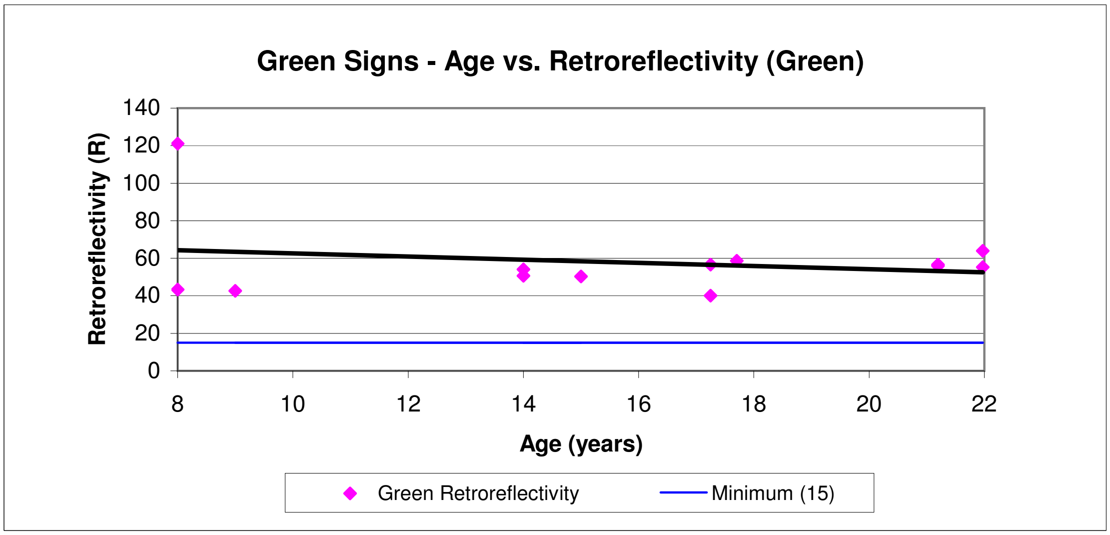
Green: R ≥ 15 cd/lx/m²
White: R ≥ 120 cd/lx/m² (Ground-mounted signs)

Sample Size: 13
PA Total Green: 21,269

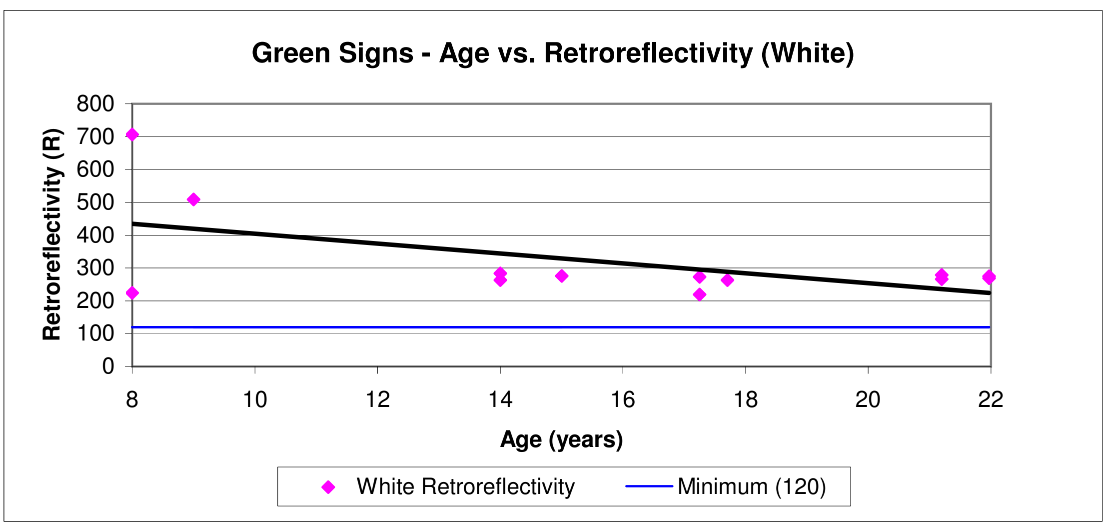
AGE INFO	
Mean Age:	15.9
Std Dev:	5.1
15th Percentile:	8.8
85th Percentile:	21.4

GREEN RETROREFLECTIVITY INFO	
Mean Green R:	57.6
Std Dev:	20.3
15th Percentile:	43.2
85th Percentile:	59.7

WHITE RETROREFLECTIVITY INFO	
Mean White R:	315.8
Std Dev:	136.9
15th Percentile:	255.3
85th Percentile:	328.4



y = -0.8512x + 71.165 $R^2 = 0.0467$



y = -17.443x + 586.52 $R^2 = 0.3247$

Pennsylvania Red Sign Data

Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Red: R ≥ 7 cd/lx/m² for all red signs
White: R ≥ 35 cd/lx/m² for all red signs
Contrast Ratio: W:R ≥ 3:1 for all red signs

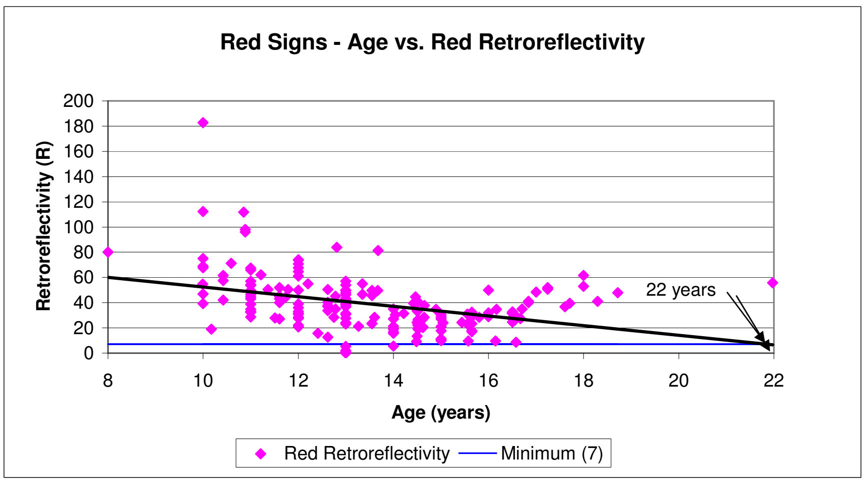
Sample Size: 185
PA Red Total: 107,648

AGE INFO	
Mean Age:	13.5
Std Dev:	2.2
15th Percentile:	11.0
85th Percentile:	15.7

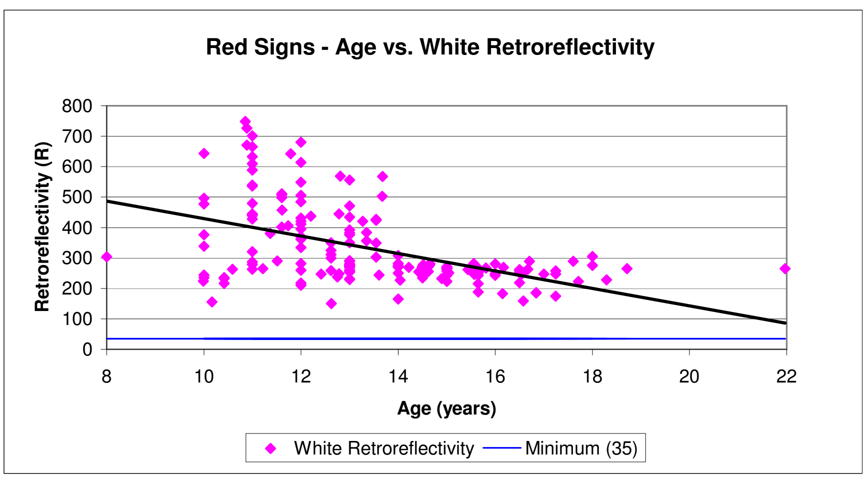
RED RETROREFLECTIVITY INFO	
Mean Red R:	38.8
Std Dev:	22.3
15th Percentile:	20.7
85th Percentile:	55.0

WHITE RETROREFLECTIVITY INFO	
Mean White R:	328.1
Std Dev:	126.0
15th Percentile:	242.5
85th Percentile:	462.8

CONTRAST RATIO INFO	
Mean:	16.1
Std Dev:	51.4
15th Percentile:	5.6
85th Percentile:	14.1



$y = -4.0818x + 94.055$ $R^2 = 0.1537$



$y = -30.287x + 738.04$ $R^2 = 0.2643$

RESULTS: 7 of 185 signs (3.8%) do not meet FHWA minimum requirements. 6 signs do not meet minimum requirments for red retroreflectivity (R ≥ 7) and one sign does not meet minimum requirements for contrast ratio (W:R ≥ 3:1)

Pennsylvania White Sign Data

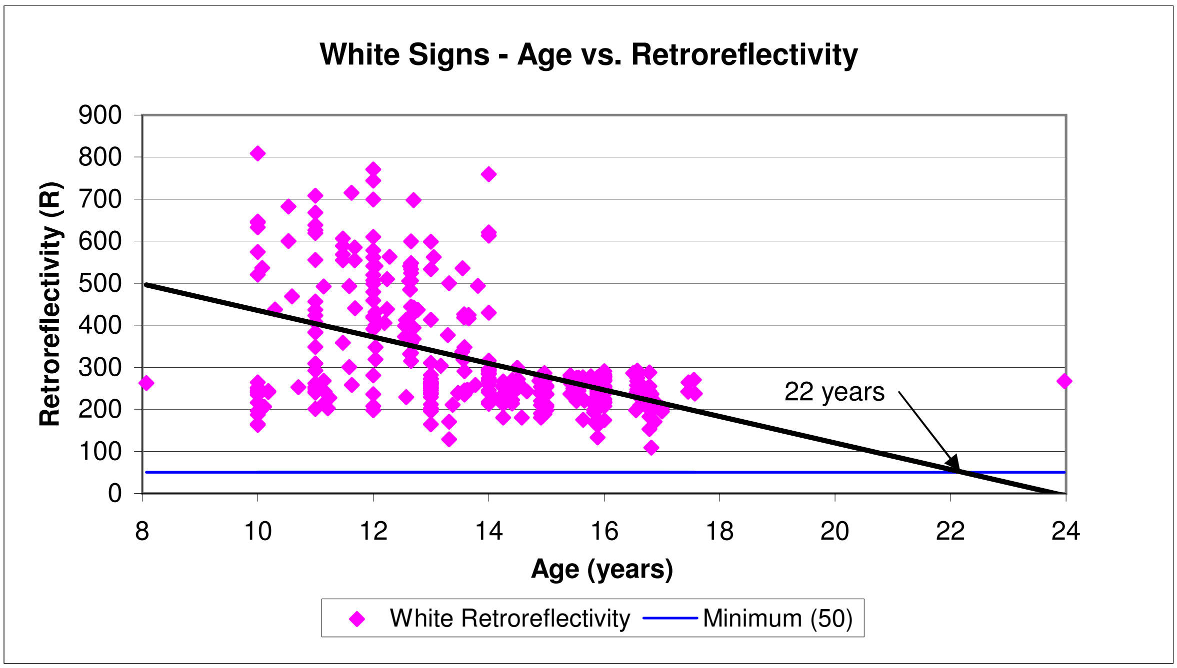
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

White: R ≥ 50 cd/lx/m² for all white signs

Sample Size: 368
PA White Total: 222,224

AGE INFO	
Mean Age:	13.9
Std Dev:	2.1
15th Percentile:	11.2
85th Percentile:	16.0

RETROREFLECTIVITY INFO	
Mean White R:	312.8
Std Dev:	135.1
15th Percentile:	214.1
85th Percentile:	479.1



y = -32.078x + 758.31 $R^2 = 0.2527$

RESULTS: All white signs meet FHWA minimum requirements for white retroreflectivity (W ≥ 50)

Pennsylvania Yellow Sign Data

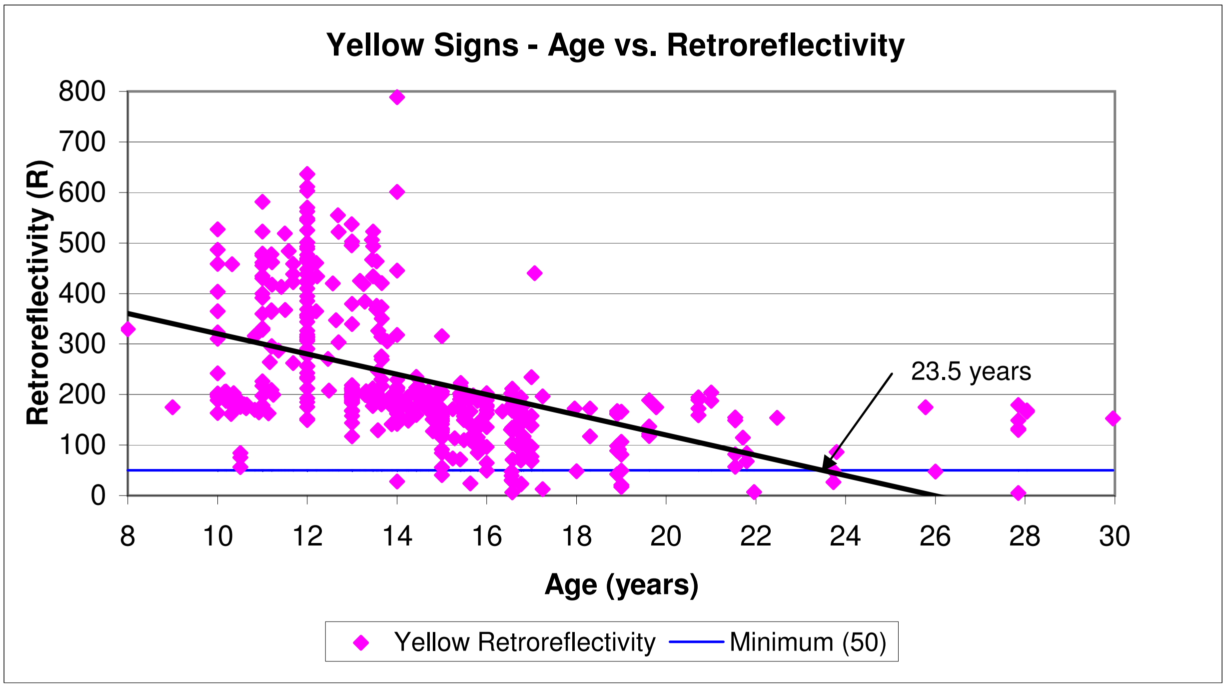
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Yellow : R ≥ 50 cd/lx/m² for all bold symbol signs and text/fine symbol signs ≥ 48"
R ≥ 75 cd/lx/m² for text/fine symbol signs ≤ 48"

Sample Size: 441
PA Yellow Total: 266,679

AGE INFO	
Mean Age:	14.5
Std Dev:	3.4
15th Percentile:	11.5
85th Percentile:	16.8

RETROREFLECTIVITY INFO	
Mean Yellow R:	229.7
Std Dev:	135.8
15th Percentile:	117.0
85th Percentile:	409.7



$y = -20.24x + 523.53$ $R^2 = 0.2533$

Lacakawanna County - Red Signs

Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Red: R ≥ 7 cd/lx/m² for all red signs
White: R ≥ 35 cd/lx/m² for all red signs
Contrast Ratio: W:R ≥ 3:1 for all red signs

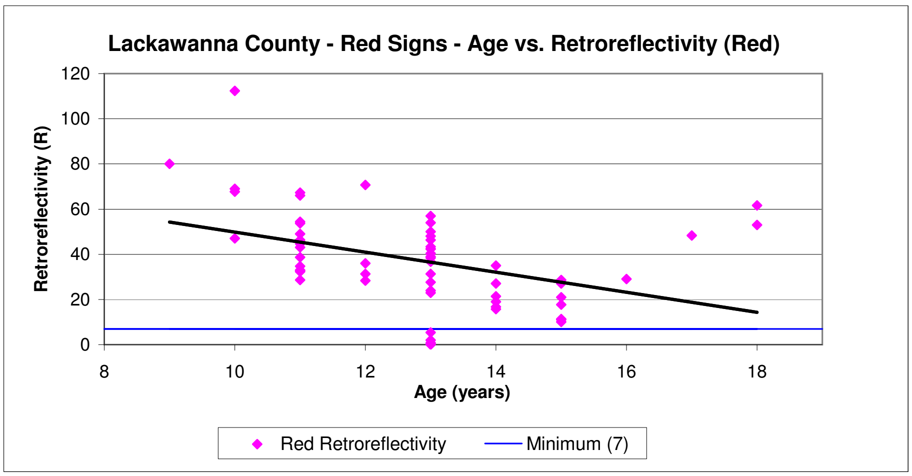
Sample Size: 61
PA Total Red: 107,648

AGE INFO	
Mean Age:	12.8
Std Dev:	1.9
15th Percentile:	11.0
85th Percentile:	15.0

RED RETROREFLECTIVITY INFO	
Mean Red R:	37.3
Std Dev:	21.2
15th Percentile:	16.7
85th Percentile:	54.3

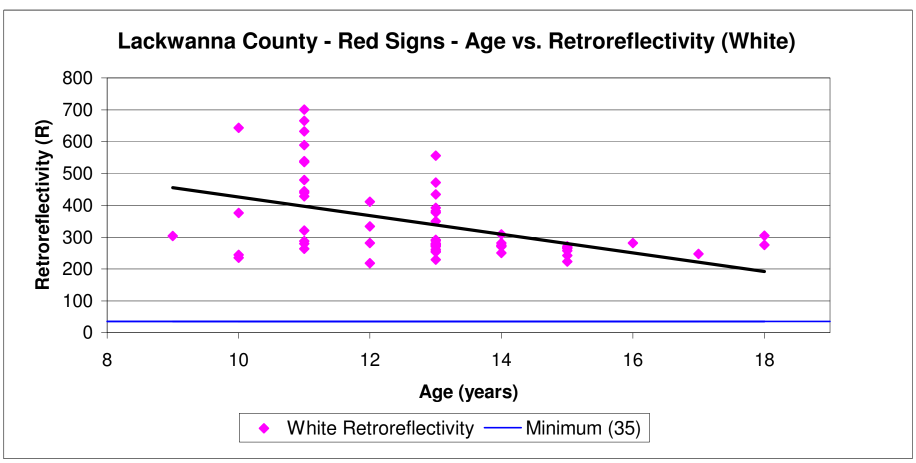
WHITE RETROREFLECTIVITY INFO	
Mean White R:	343.6
Std Dev:	122.7
15th Percentile:	256.3
85th Percentile:	471.0

CONTRAST RATIO INFO	
Mean:	29.3
Std Dev:	88.2
15th Percentile:	5.2
85th Percentile:	16.4



y = -4.4361x + 94.12
R^2 = 0.1597

5 of 61 (8.2%) signs failed to meet FHWA minimum requirements for red retroreflectivity (R ≥ 7)



y = -29.257x + 718.69
R^2 = 0.2075

All signs meet FHWA minimum requirements for white reflectivity (W ≥ 35)

Lacakawanna County - White Signs

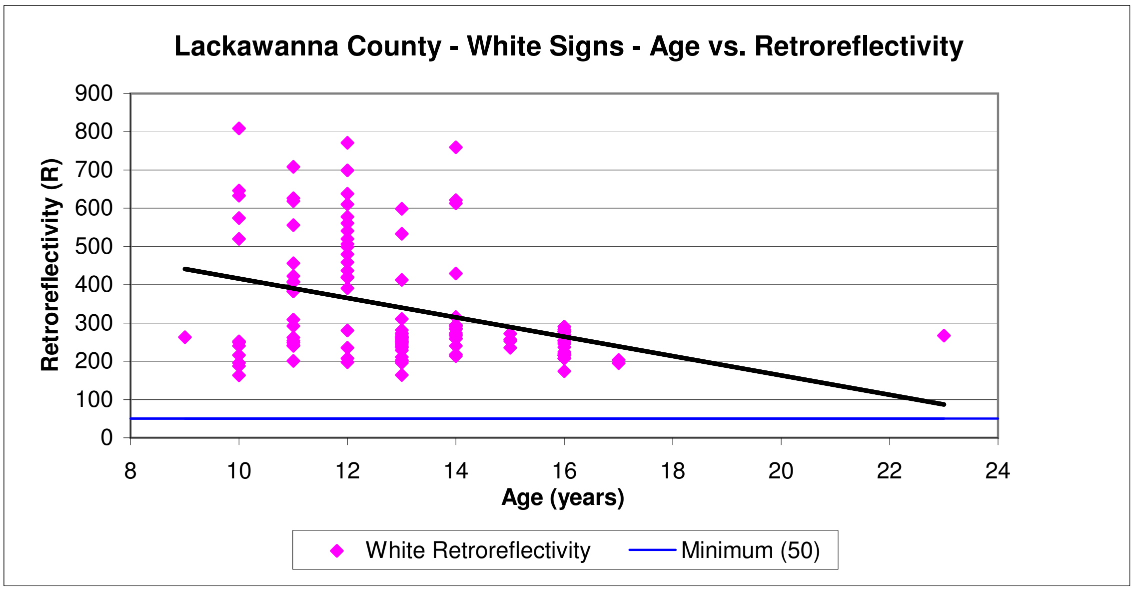
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

White: R ≥ 50 cd/lx/m² for all white signs

Sample Size: 125
PA Total White: 222,224

AGE INFO	
Mean Age:	13.1
Std Dev:	2.2
15th Percentile:	11.0
85th Percentile:	16.0

RETROREFLECTIVITY INFO	
Mean White R:	337.1
Std Dev:	153.5
15th Percentile:	216.0
85th Percentile:	536.2



$y = -25.329x + 669.44$
$R^2 = 0.1271$

All white signs meet minimum FHWA requirements.

Lackawanna County - Yellow Signs

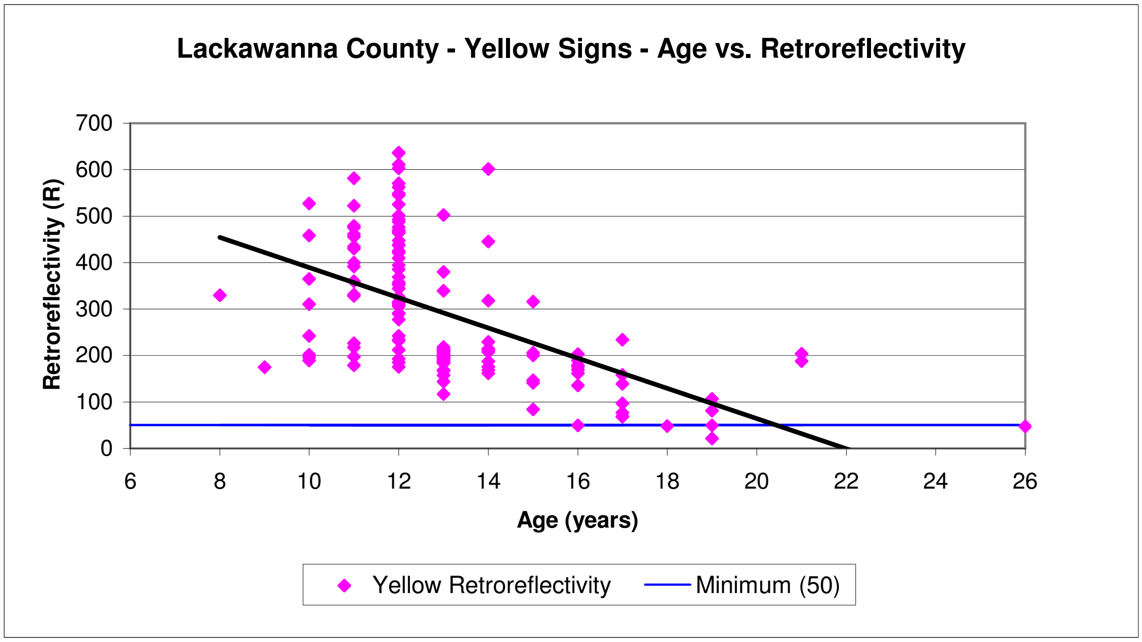
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Yellow : R ≥ 50 cd/lx/m² for all bold symbol signs and text/fine symbol signs ≥ 48"
R ≥ 75 cd/lx/m² for text/fine symbol signs ≤ 48"

Sample Size: 149
PA Total Yellow: 266,679

AGE INFO	
Mean Age:	13.1
Std Dev:	2.5
15th Percentile:	11.0
85th Percentile:	15.8

RETROREFLECTIVITY INFO	
Mean Yellow R:	287.4
Std Dev:	149.1
15th Percentile:	167.1
85th Percentile:	469.3



y = -32.518x + 714.51
R^2 = 0.2927

3 of 149 signs (2.0%) did not meet minimum FHWA requirements.

Lehigh County - Red Signs

Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Red: R ≥ 7 cd/lx/m² for all red signs
White: R ≥ 35 cd/lx/m² for all red signs
Contrast Ratio: W:R ≥ 3:1 for all red signs

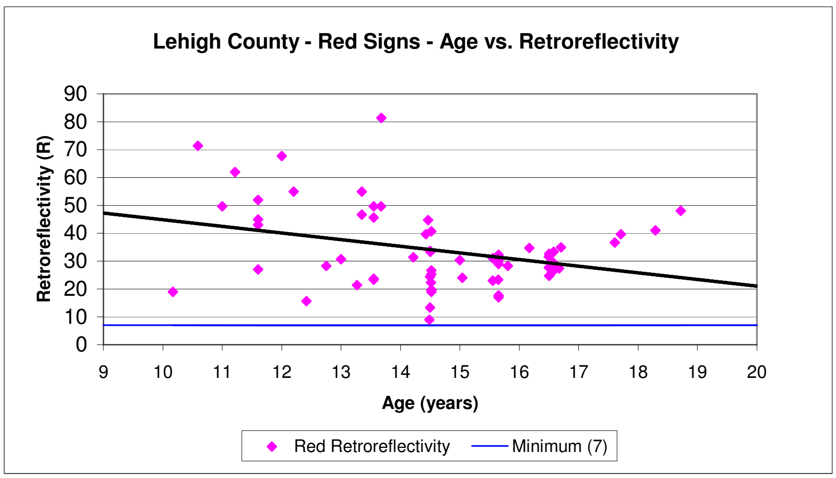
Sample Size: 66
PA Red Total: 107,648

AGE INFO	
Mean Age:	14.6
Std Dev:	1.9
15th Percentile:	12.4
85th Percentile:	16.5

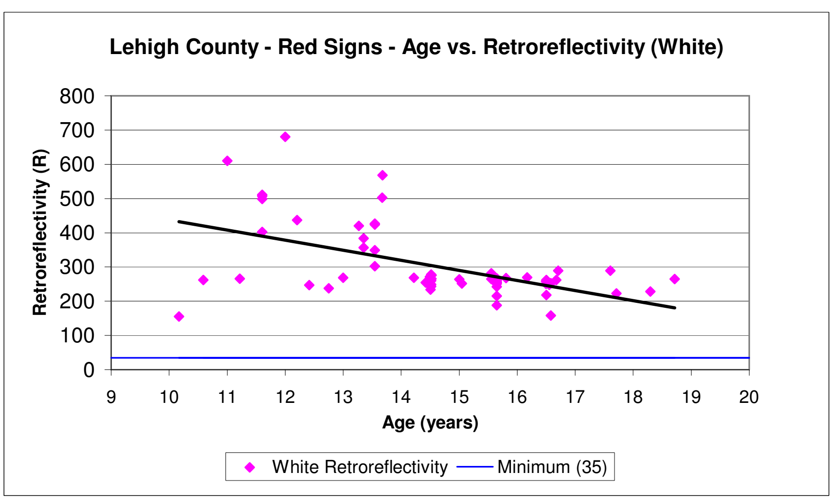
RED RETROREFLECTIVITY INFO	
Mean Red R:	34.0
Std Dev:	14.1
15th Percentile:	22.1
85th Percentile:	48.4

WHITE RETROREFLECTIVITY INFO	
Mean White R:	302.7
Std Dev:	105.1
15th Percentile:	243.1
85th Percentile:	421.2

CONTRAST RATIO INFO	
Mean:	9.9
Std Dev:	4.3
15th Percentile:	6.8
85th Percentile:	14.0



Y = -2.3829X + 68.67
R^2 = 0.1023



y = -29.413x + 731.21
R^2 = 0.2793

All signs meet FHWA minimum standards for red (R>7), white (W>35), and contrast ratio (>3:1)

Lehigh County - White Signs

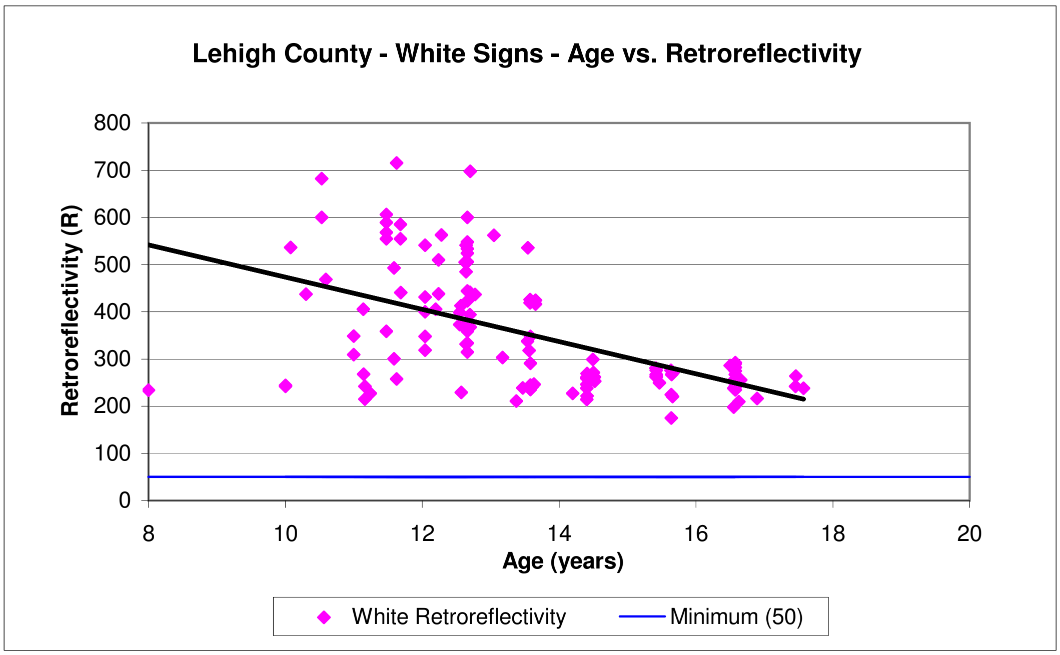
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

White: R ≥ 50 cd/lx/m² for all white signs

Sample Size: 122
PA White Total: 222,224

AGE INFO	
Mean Age:	13.5
Std Dev:	2.0
15th Percentile:	11.5
85th Percentile:	16.5

RETROREFLECTIVITY INFO	
Mean White R:	353.8
Std Dev:	129.3
15th Percentile:	237.8
85th Percentile:	532.2



Y = -35.978x = 840.1
R^2 = 0.3041

All signs well above minimum FHWA standards.

Lehigh County - Yellow Signs

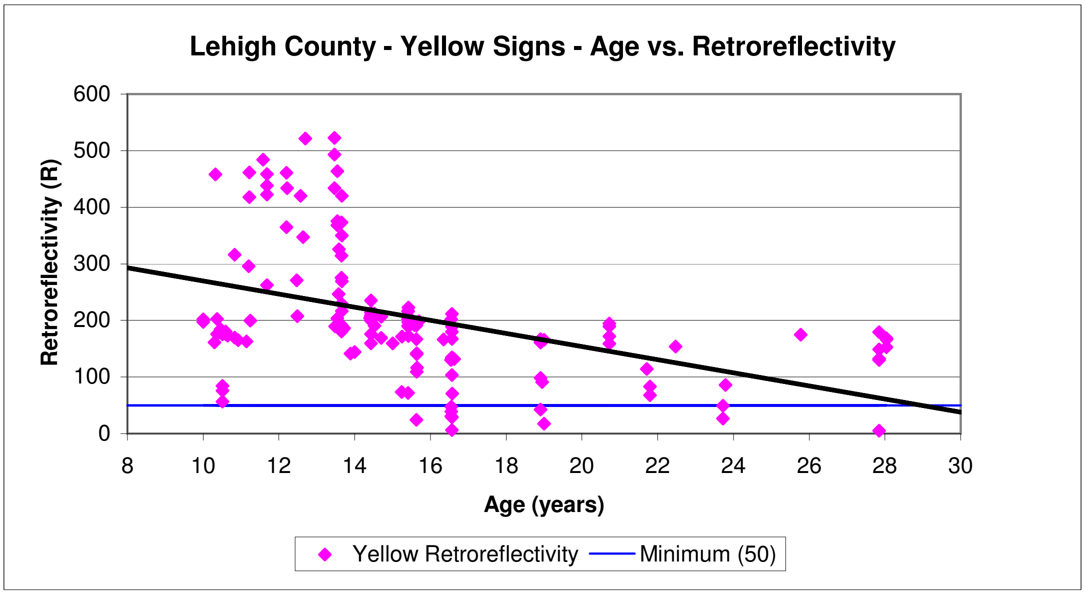
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Yellow : R ≥ 50 cd/lx/m² for all bold symbol signs and text/fine symbol signs ≥ 48"
R ≥ 75 cd/lx/m² for text/fine symbol signs ≤ 48"

Sample Size: 145
PA Yellow Total: 266,679

AGE INFO	
Mean Age:	15.6
Std Dev:	4.3
15th Percentile:	11.4
85th Percentile:	19.0

WHITE RETROREFLECTIVITY INFO	
Mean White R:	204.6
Std Dev:	115.2
15th Percentile:	101.5
85th Percentile:	334.5



y = -11.582x + 385.6
R^2 = 0.1903

11 of 146 (7.5%) did not meet FHWA minimum standards. These signs range in age from 16-28 years old.

Lancaster County - Red Signs

Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Red: R ≥ 7 cd/lx/m² for all red signs
White: R ≥ 35 cd/lx/m² for all red signs
Contrast Ratio: W:R ≥ 3:1 for all red signs

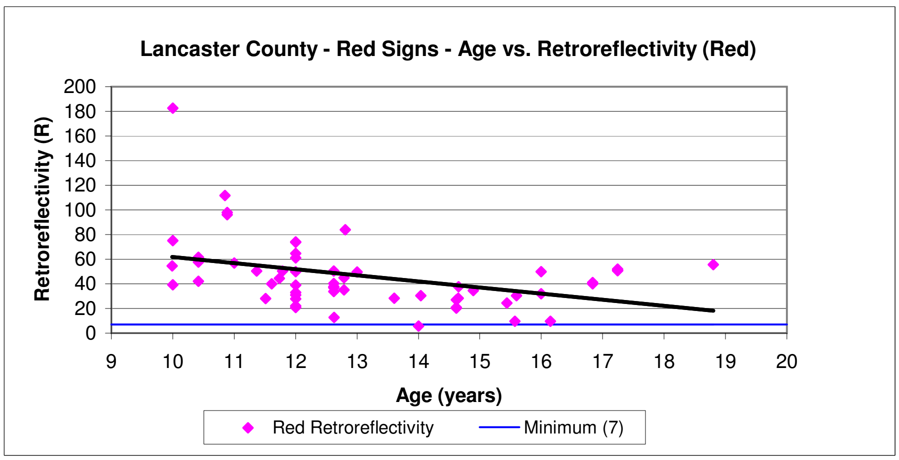
Sample Size: 58
PA Red Total: 107,648

AGE INFO	
Mean Age:	13.1
Std Dev:	2.2
15th Percentile:	10.9
85th Percentile:	15.8

RED RETROREFLECTIVITY INFO	
Mean Red R:	46.4
Std Dev:	28.2
15th Percentile:	25.8
85th Percentile:	63.0

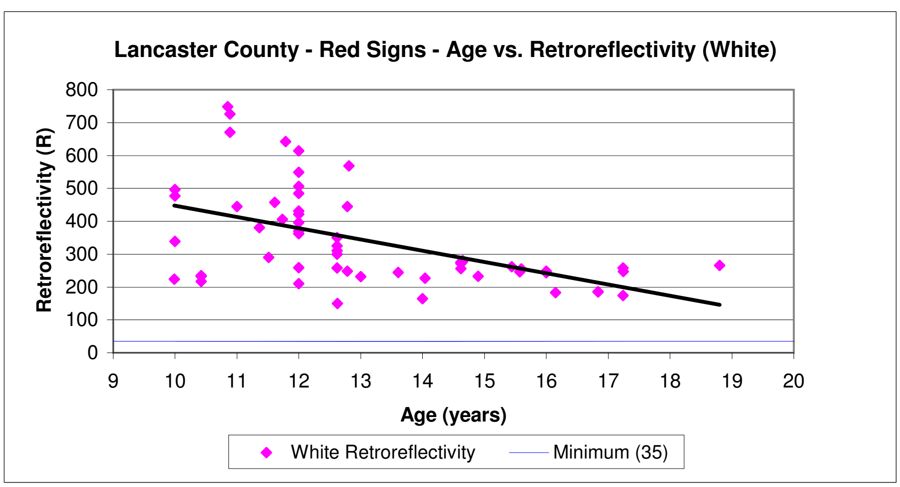
WHITE RETROREFLECTIVITY INFO	
Mean White R:	340.6
Std Dev:	147.0
15th Percentile:	225.5
85th Percentile:	490.0

CONTRAST RATIO INFO	
Mean W/R:	8.9
Std Dev:	15.7
15th Percentile:	23.5
85th Percentile:	55.0



y = -4.9806x + 111.7
R^2 = 0.1521

One sign is non-compliant for red (R>7) and one sign is non compliant for contrast ratio (>3:1)



y = -34.256x + 789.85
R^2 = 0.2651

All signs meet FHWA minimum standards for white retroreflectivity (W ≥ 35)

Lancaster County - White Signs

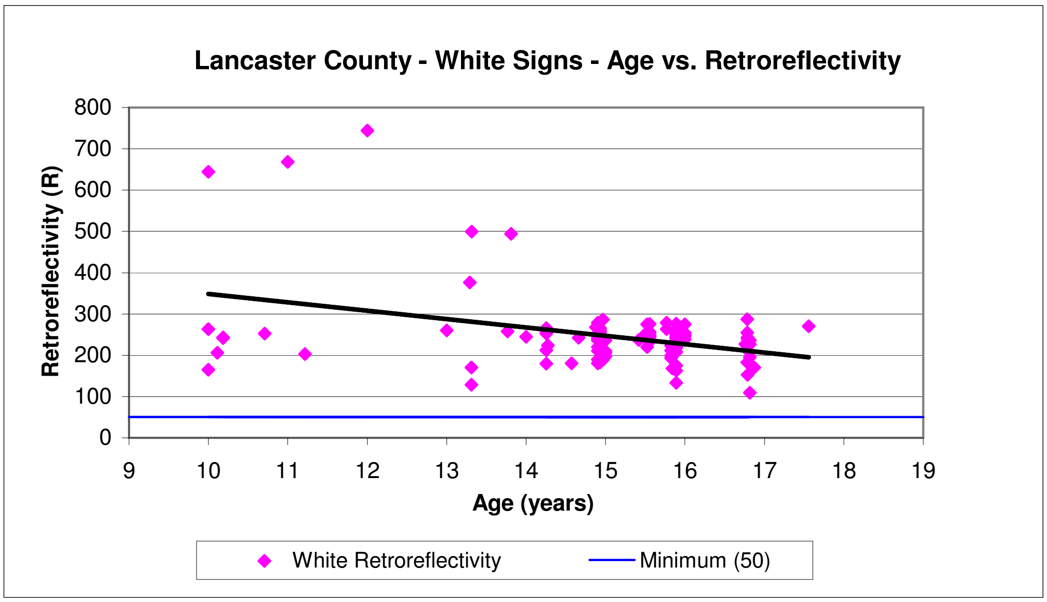
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

White: R ≥ 50 cd/lx/m² for all white signs

Sample Size: 121
PA White Total: 222,224

AGE INFO	
Mean Age:	15.1
Std Dev:	1.6
15th Percentile:	14.3
85th Percentile:	16.0

RETROREFLECTIVITY INFO	
Mean White R:	245.6
Std Dev:	86.7
15th Percentile:	190.0
85th Percentile:	266.0



y = -20.228x + 550.52
R^2 = 0.1453

All signs meet FHWA minimum standards (W>50).

Lancaster County - Yellow Signs

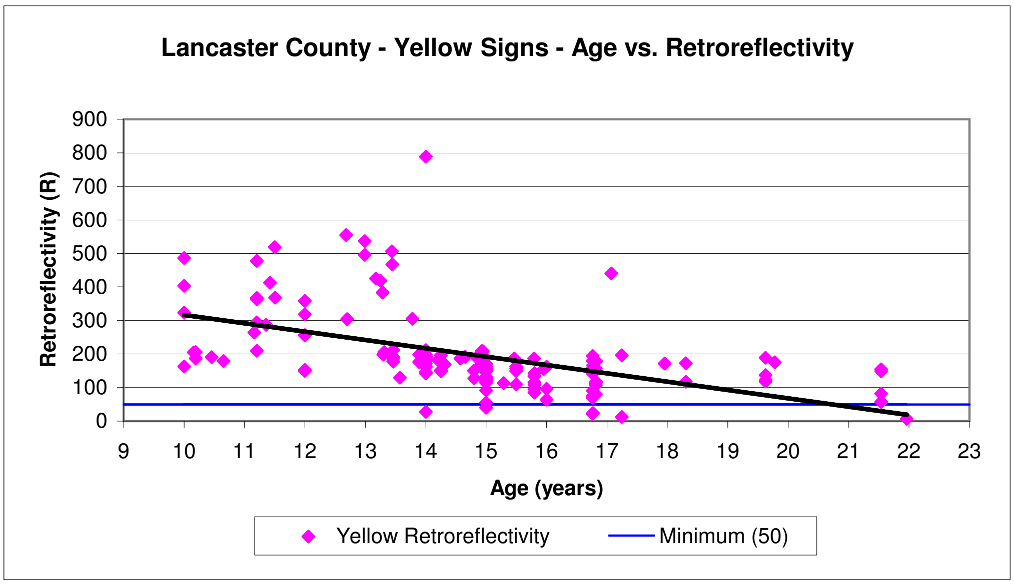
Minimum Maintained Traffic Sign Retroreflectivity Levels (Table A1, MUTCD):

Yellow : R ≥ 50 cd/lx/m² for all bold symbol signs and text/fine symbol signs ≥ 48"
R ≥ 75 cd/lx/m² for text/fine symbol signs ≤ 48"

Sample Size: 147
PA Yellow Total: 266,679

AGE INFO	
Mean Age:	14.8
Std Dev:	2.5
15th Percentile:	12.0
85th Percentile:	16.8

RETROREFLECTIVITY INFO	
Mean R:	196.5
Std Dev:	121.3
15th Percentile:	113.6
85th Percentile:	303.8



y = -24.839x + 564.6
R^2 = 0.2634

7 of the 147 (4.7%) signs were below FHWA minimum standards (Y>50 for all bold symbol signs and). The non compliant signs range in age from 14 to 22 years old.

High Intensity Prismatic Reflective Sheeting

Series 3930 with Pressure Sensitive Adhesive

Product Bulletin 3930 **August 2008**

Replaces PB 3930 dated Sept. 2006

Description

3M™ High Intensity Prismatic Reflective Sheeting Series 3930 is a non-metalized micro-prismatic lens reflective sheeting designed for production of reflective durable traffic control signs, work zone devices and delineators that are exposed vertically in service. Applied to properly prepared sign substrates, 3M high intensity prismatic sheeting provides long-term reflectivity and durability. Series 3930 sheeting is available in the following colors.

Color	Product Code
White	3930
Yellow	3931
Red	3932
Orange	3934
Blue	3935
Green	3937
Brown	3939

Photometrics

Daytime Color (x,y,Y)

The chromaticity coordinates and total luminance factor of the retroreflective sheeting conform to Table A.

Color Test

Conformance to standard chromaticity (x,y) and luminance factor (Y, %) requirements shall be determined by instrumental method in accordance with ASTM E 1164 on sheeting applied to smooth aluminum test panels cut from Alloy 6061-T6 or 5052-H38. The values shall be determined on a HunterLab ColorFlex 45/0 spectrophotometer. Computations shall be done for CIE Illuminant D65 and the 2° standard observer.[1]

[1]The instrumentally determined color values of retroreflective sheeting can vary significantly depending on the make and model of colorimetric spectrophotometer as well as the color and retroreflective optics of the sheeting (David M. Burns and Timothy J. Donahue, Measurement Issues in the Color Specification of Fluorescent-Retroreflective Materials for High Visibility Traffic Signing and Personal Safety Applications, Proceedings of SPIE: Fourth Oxford Conference on Spectroscopy, 4826, pp. 39-49, 2003). For the purposes of this document, the HunterLab ColorFlex 45/0 spectrophotometer shall be the referee instrument.

Table A - CIE Chromaticity Coordinate Limits* for new sheeting

	1		2		3		4		Limit Y (%)	
Color	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**	**Min.**	**Max**
White	.303	.300	.368	.366	.340	.393	.274	.329	40	-
Yellow	.498	.412	.557	.442	.479	.520	.438	.472	24	45
Red	.648	.351	.735	.265	.629	.281	.565	.346	3	12
Orange	.558	.352	.636	.364	.570	.429	.506	.404	14	30
Blue	.140	.035	.244	.210	.190	.255	.065	.216	1	10
Green	.026	.399	.166	.364	.286	.446	.207	.771	3	9
Brown	.430	.340	.610	.390	.550	.450	.430	.390	1	6

* The four pairs of chromaticity coordinates deteremine the acceptable color in terms of the CIE 1931 standard colormetric system measured with standard illuminant D65.

Coefficients of Retroreflection (R_A)

The values in Table B are minimum coefficients of retroreflection expressed in candelas per lux per square meter (cd/lux/m²).

Test for Coefficients of Retroreflection

Conformance to coefficient of retroreflection requirements shall be determined by instrumental method in accordance with ASTM E-810 "Test Method for Coefficient of Retroreflection of Retroreflective Sheeting" and per E-810 the values of 0° and 90° rotation are averaged to determine conformance to the R_A limits in Table B.

Table B - Minimum Coefficient of Retroreflection
R_A for new sheeting
(cd/lux/m²)

-4° Entrance Angle[2]

	Observation Angle[1] 0.2°	0.5°
White	560	200
Yellow	420	150
Red	84	30
Orange	210	75
Green	56	20
Blue	28	10
Brown	17	6

30° Entrance Angle[2]

	Observation Angle[1] 0.2°	0.5°
White	280	100
Yellow	210	75
Red	42	15
Orange	105	37
Green	28	10
Blue	14	5
Brown	8.4	3

[1]Observation (Divergence) Angle - The angle between the illumination axis and the observation axis.

[2]Entrance (Incidence) Angle - The angle from the illumination axis to the retroreflector axis. The retroreflector axis is an axis perpendicular to the retroreflective surface.

R_A for Screenprinted Colors and Overlay Films

For screenprinted transparent color areas on white sheeting, or white sheeting covered with 3M™ ElectroCut™ Film Series 1170 when processed according to 3M recommendations, the ratios of the R_A for the color to the R_A for the white shall be no less than 70% of the R_A listed for the integral color in Table B and the colors shall conform to Table A on page 1.

Adhesive

Series 3930 sheeting has a pressure-sensitive adhesive that is recommended for room temperature application. Room temperature application is defined as 65°F (18°C) or higher.

Test Methods of Adhesive and Film

Standard Test Panels

Unless otherwise specified, the reflective sheeting shall be applied according to the manufacturer's recommendations to smooth 0.063 inches (1.6mm) minimum thickness 6061-T6, 5052-H38 or equivalent aluminum panels that have been degreased and lightly acid etched. Lack of contamination of test panels must be confirmed by passing the water break test and tape snap test as described in 3M Information Folder 1.7.

Properties

Standard Conditioning: All mounted and unmounted test specimens shall be conditioned for 24 hours hours at 73°F +/- 2°F (23°C + 1°C) and 50% +/- 4% R.H. before testing.

1. Adhesion

Test Weight 1-3/4 lbs. (0.8 kg) Test Method - Apply 4 inches (10cm) of 1 inch x 6 inch (2.54x15cm) strip to panel and condition, face panel down and suspend test weight from free end. Requirement - Not more than 2 inches (5.0cm) of peel in five minutes.

2. Impact Resistance

Test Method - Apply sheeting to a standard panel 3 inch x 6 inch (7.6x15.2cm) and condition. Subject sheeting to a 50-inch pound (5.7Nm) impact in accordance with ASTM D-2794. Requirement - No separation from panel or cracking outside immediate impact area.

3. Shrinkage

Test Method - Following conditioning of 9 inch x 9 inch samples, remove liner, place specimen on flat surface with adhesive side up. Requirement - Shrinkage not greater than 1/32 inches (0.8mm) in 10 minutes or more than 1/8 inches (3.2mm) in 24 hours in any dimension.

4. Flexibility

Test Method - Following conditioning of 1 inch x 6 inch sample, remove liner and dust adhesive with talc. At standard conditions, holding the ends of the sample, bend in one second around 1/8 inch (3.2mm) mandrel with adhesive side facing mandrel. Requirement - No cracking, peeling or delamination.

5. Gloss

Test Method - Test in accordance with ASTM D523 using an 85° glossmeter. Requirement - Rating not less than 50.

Sign Fabrication Methods

Application

3M high intensity prismatic sheeting series 3930 incorporates a pressure sensitive adhesive and should be applied to the sign substrate at room temperature 65°F (18°C) or higher by any of the following methods:

Mechanical squeeze roll applicator - Reference 3M Information Folder 1.4 (Room temperature application)

Application to extrusions requires heat directed at the next-to-last edge roller. Cracking or edge lifting may occur if the top film is not sufficiently softened.

Hand squeeze roll applicator - Reference 3M Information Folder 1.6

Hand Application

Hand application is recommended for legend and copy only. Application of sheeting for complete signs or backgrounds must be done with a roll laminator, either mechanical or hand. See 3M Information Folder 1.5 for more details.

Hand applications will show some visual irregularities that are objectionable to aesthetically critical customers. These are more noticeable on darker colors. To obtain a close-up uniform appearance, a roll laminator must be used.

All direct applied copy and border MUST be cut at all metal joints and squeegeed at the joint.

Splices

Series 3930 sheeting should be butt spliced when more than one piece of sheeting is used on one piece of substrate. The sheeting pieces should not touch each other at the splice and a gap of up to 1/16 inch is acceptable. This is to prevent buckling as the sheeting expands in extreme temperature/humidity exposure. If the visual appearance of the splice is important or a slight gap is undesirable, the following procedures must be followed:

1. Overlap the sheeting at least one inch, with or without the liner attached.
2. Using a straight edge and a sharp utility knife, cut through both layers of reflective sheeting.
3. Peel back and remove cut remnants. If liner was left on, remove and roll down remaining sheeting.
4. Seal edge with thinned 3M™ Process Color 880I Clear using a fine artist paintbrush.

Double Faced Signs - Series 3930 sheeting on the first side must be protected by damage from the steel bottom roll of squeeze roll applicators with FR-2 sponge rubber and SCW 568.

Substrates

For traffic sign use, product application is limited to properly prepared aluminum (see 3M Information Folder 1.7). Extrusions can be wrapped or trimmed, and flat panel signs are to be carefully trimmed so that sheeting from adjacent panels do not touch on the assembled signs. Users are urged to carefully evaluate all other substrates for adhesion and sign durability. Series 3930 sheeting is designed primarily for application to flat substrates. Any use that requires a radius of curvature of less than five inches should also be supported by rivets or bolts. Plastic substrates are not recommended where cold shock performance is essential. Sign failures caused by the substrate or improper surface preparation are not the responsibility of 3M.

Screen Processing

Series 3930 sheeting may be screen processed into traffic signs before or after mounting on a sign substrate, using 3M Process Colors Series 880I (see Product Bulletin 880I) or Series 880N (see Product Bulletin 880N). Series 880I or 880N process colors can be screened at 60-100ºF (16-38ºC) at relative humidity of 20-50%. A PE 157 screen mesh with a fill pass is recommended. See Information Folder 1.8 for details. Use of other process colors series is not recommended. 3M assumes no responsibility for failure of sign face legends or backgrounds that have been processed with non-3M process colors or 3M process colors other than those listed above.

Care should be taken to avoid flexing Series 3930 sheeting before and especially after screening to eliminate the possibility of cracking from improper handling techniques.

Cutting and Matching

The sheeting may be hand cut or die cut one sheet at a time, and band sawed or guillotined in stacks.

Series 3930 sheeting can be hand cut from either side with a razor blade or other sharp hand tool. Like all reflective sheetings, when two or more pieces are used side by side on a sign, they must be matched to assure uniform day color and night appearance.

Cutting equipment such as guillotines and metal shears, that have pressure plates on the sheeting when cutting, may damage the optics. Padding the pressure plate and easing it down onto the sheets being cut will significantly reduce damage.

Maximum stack height for cutting Series 3930 sheeting is 1-1/2 inches or 50 sheets. Details on cutting can be found in 3M Information Folder 1.10.

Multi-piece signs should have all panels or pieces oriented identically for uniform appearance under all viewing conditions (arrow and the seal pattern in the same direction).

Edge sealing Series 3930 sheeting is generally not required. Following extended exposure, airborne dust particles may become trapped within the row of cut cells along the sheeting edge. This should have no adverse effect on sign performance. If the user chooses to edge seal, series 880I process color should be used.

Cleaning

Signs that require cleaning should be flushed with water, then washed with a detergent solution and bristle brush or sponge. Avoid pressure that may damage the sign face. Flush with water following washing. Do not use solvents to clean signs. See 3M Information Folder 1.10.

Storage and Packaging

Series 3930 sheeting should be stored in a cool, dry area, preferably at 65-75°F (18-24°C) and 30-50% relative humidity and should be applied within one year of purchase. Rolls should be stored horizontally in the shipping carton. Partially used rolls should be returned to the shipping carton or suspended horizontally from a rod or pipe through the core. Unprocessed sheets should be stored flat. Finished signs and applied blanks should be stored on edge. Screen processed signs must be protected with the adhesive liner or SCW 568 slipsheet paper. Place the glossy side of the slipsheeting against the sign face and pad the face with closed cell packaging foam. Double-faced signs must have the glossy side of the slipsheet against each face of the sign.

Unmounted screened faces must be stored flat and interleaved with SCW 568 slipsheet, glossy side against the sign face. Packages of finished sign faces must include sufficient nylon washers for mounting. Avoid banding, crating, or stacking signs. Package for shipment in accordance with commercially accepted standards to prevent movement and chafing. Store sign packages indoors on edge.

Panels or finished signs must remain dry during shipment and storage. If packaged signs become wet, unpack immediately and allow signs to dry.

See Information Folder 1.11 for instructions on packing for storage and shipment.

Installation

Nylon washers are recommended between the heads of all twist fasteners (such as screw heads, bolts, or nuts) and the sheeting to protect the sheeting from the twisting action of the bolt heads.

Health and Safety Information

Read all health hazard, precautionary and first aid statements found in the Material Safety Data Sheet, and/or product label of chemicals prior to handling or use.

General Performance Considerations

The durability of 3M high intensity prismatic reflective sheeting series 3930 will depend upon substrate selection and preparation, compliance with recommended application procedures, geographic area, exposure conditions, and maintenance.

Maximum durability of Series 3930 sheeting can be expected in applications subject to vertical exposure on stationary objects when processed and applied to properly prepared aluminum according to 3M recommendations provided in 3M Information Folder 1.7 on Sign Substrate Surface Preparation.

The user must determine the suitability of any nonmetallic sign backing for its intended use.

Applications to unprimed, excessively rough or non-weather-resistant surfaces, or exposure to severe or unusual conditions can shorten the performance of such applications. Signs in mountainous areas that are covered by snow for prolonged periods may also have reduced durability.

3M process colors, when used according to 3M recommendations, are generally expected to provide performance comparable to colored reflective sheeting, except for certain lighter colors, such as yellow, gold, or heavily toned colors or blends containing yellow or gold, whose durability depends on how much of each color is used.

Dilution of color and atmospheric conditions in certain geographic areas may result in reduced durability.

3M™ ElectroCut™ Film Series 1170 can be expected to perform satisfactorily for the life of the sign when direct applied to series 3930 sheeting.

Warranty

3M warrants that 3M™ High Intensity Prismatic Reflective Sheeting Series 3930 sold by 3M to be used as components for traffic control and guidance signs in the United States and Canada will remain effective for its intended use and meet the stated minimum values for coefficient of retroreflection for ten years, subject to the following provisions in:

Table C
Percentage of Table B Initial R_A Minimums Guaranteed Over 10 Year Warranty Period (Colors: white, yellow, red, green and blue)

Warranty Period	Minimum Percentage R_A Retained
1-7 Years	80%
8-10 Years	70%

R_A percentage retained above apply to all entrance and observation angles presented in Table B, and shall be measured per ASTM E 810.

All measurements shall be made after cleaning according to 3M recommendations. If a high intensity grade prismatic sign surface is processed and applied to sign blank materials in accordance with all 3M application and fabrication procedures provided in 3M's product bulletins, information folders, and technical memos (which will be furnished to the agency upon request), including the exclusive use of 3M matched component systems, process colors, clear coatings, electronic cuttable films, protective overlay films, and recommended applications equipment; and

If the sign deteriorates due to natural causes to the extent that: 1) the sign is ineffective for its intended purpose when viewed from a moving vehicle under normal day and night driving conditions by a driver with normal vision, or 2) the coefficient of retroreflection after cleaning is less than the minimums specified in Table C, 3M's sole responsibility and purchaser's and user's exclusive remedy shall be:

If the failure occurs within the first 7 years from the date of fabrication, 3M will, at its expense, restore the sign surface to its original effectiveness. If the failure occurs within the 8th through the 10th year from the date of fabrication, 3M will furnish the necessary amount of high intensity prismatic sheeting to restore the sign surface to its original effectiveness.

Warranty for 3934 Sheeting

3M warrants that 3M™ High Intensity Prismatic Reflective Sheeting 3934 Orange sold by 3M to be used as components for traffic control devices used in work zones in the United States and Canada will remain effective for its intended use and meet the stated minimum values for coefficient of retroreflection for three years, subject to the following provisions:

Minimum Coefficient of Retroreflection
Candelas per Foot Candle per Square Feet
Candelas per Lux per Square Meter
(0.2° observation and -4° entrance)*

Sheeting Color	Min. Coeff. of Retroreflection (Three Years)
Orange	80

*All measurements shall be made after sign cleaning according to 3M recommendations and in accordance with ASTM E 810 "Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting."

If a high intensity prismatic sign surface is processed and applied to sign blank materials in accordance with all 3M application and fabrication procedures found in 3M's product bulletins, information folders and technical memos (which will be furnished to the agency upon request), including the exclusive use of 3M matched component systems, process colors, clear coatings, electronic cuttable films, protective overlay films, and recommeneded application equipment; and

If the sign deteriorates due to natural causes to the extent that: 1) the sign is ineffective for its intended purpose when viewed from a moving vehicle under normal day and night driving conditions by drivers with normal vision, or 2) the coefficient for retroreflection is less than the minimum herin specified, 3M's sole responsibility and purchaser's and user's exclusive remedy shall be that 3M will provide pro-rata replacement of the 3M materials:

If failure occurs within the first year from the date of fabrication, 3M will at its expense, restore the sheeting surface to its original effectiveness. If failure occurs in the second year, two-thirds of the sheeting will be replaced. If failure occurs in the third year, one-third of the sheeting will be replaced.

Conditions

Such failure must be solely the result of design or manufacturing defects in the 3M high intensity prismatic reflective sheeting and not of outside causes such as: improper fabrication, handling, maintenance or installation; use of process colors, thinners, coatings, or overlay films and sheetings not made by 3M; use of application equipment not recommended by 3M; failure of sign substrate; exposure to chemicals, abrasion and other mechanical damage from fasteners used to mount the sign; sign burial; collisions, vandalism or malicious mischief.

3M reserves the right to determine the method of replacement. Replacement sheeting will carry the unexpired warranty of the sheeting it replaces. Claims made under this warranty will be honored only if the signs have been dated at the time of sheeting application, which constitutes the start of the warranty period. Claims made under this warranty will be honored only if 3M is notified of a failure within a reasonable time, reasonable information requested by 3M is provided, and 3M is permitted to verify the cause of the failure.

Limitation of Liability and Remedies

3M's liability under this warranty is limited to replacement or allowance as stated herein, and 3M assumes no liability for incidental or consequential damages such as lost profits, business or revenue in any way related to the product regardless of the legal theory on which the claim is based.

THIS WARRANTY IS MADE IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY, OF FITNESS FOR A PARTICULAR PURPOSE, ANY IMPLIED WARRANTY ARISING OUT OF A COURSE OF DEALING OR OF PERFORMANCE, CUSTOM OR USAGE OF TRADE.

Literature Reference

IF 1.3 Instructions for Squeeze Roll Applicator
IF 1.5 Hand Application Instructions
IF 1.6 Instructions for Hand Squeeze Roll Applicator
IF 1.7 Sign Base Materials
IF 1.8 Color Application Instructions
IF 1.10 Cutting, Matching, Premasking, and Prespacing Instructions
IF 1.11 Storage Maintenance, and Removal Instructions

"Standard Highway Signs, As Specified in the Manual on Uniform Traffic Control Devices",
U.S. Department of Transportation, Federal Highway Administration, 1979.

FOR INFORMATION OR ASSISTANCE CALL:
1-800-553-1380

IN CANADA CALL:
1-800-265-1840

Internet:
www.3M.com/tss

3M assumes no responsibility for any injury, loss or damage arising out of the use of a product that is not of our manufacture. Where reference is made in literature to a commercially available product, made by another manufacturer, it shall be the user's responsibility to ascertain the precautionary measures for its use outlined by the manufacturer.

Important Notice

All statements, technical information and recommendations contained herein are based on tests we believe to be reliable, but the accuracy or completeness thereof is not guaranteed, and the following is made in lieu of all warranties, or conditions express or implied. Seller's and manufacturer's only obligation shall be to replace such quantity of the product proved to be defective. Neither seller nor manufacturer shall be liable for any injury, loss or damage, direct, special or consequential, arising out of the use of or the inability to use the product. Before using, user shall determine the suitability of the product for his/her intended use, and user assumes all risk and liability whatsoever in connection therewith. Statements or recommendations not contained herein shall have no force or effect unless in an agreement signed by officers of seller and manufacturer.

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Electronic Only

Avery Dennison® T-6000 & W-6000 HIP Series

High Intensity Microprismatic Retroreflective Film

Issued: April 2011 Revision 1

Avery Dennison® T-6000 & W-6000 Series High Intensity Microprismatic (HIP) Retroreflective Film for permanent and temporary traffic signage, is a high-quality, durable, microprismatic retroreflective material with a pressure sensitive adhesive. Its unique microprismatic construction provides a high level of retroreflectivity for demanding traffic control situations.

T-6000 & W-6000 Series sheeting is an Omni-Directional microprismatic film that incorporates tiles of microprisms arranged in multiple orientations. This feature – "Smart at Every Angle" benefits agencies by providing confidence that all signs will perform with uniform visual reflectivity at all sign face orientations.

Performance:
ASTM D4956 Type III & IV,
CUAP Table 7
See Page 2 for complete list.

Orientation: Omni-Directional

Durability: 10 year
Vertical Exposure only

Face: High-Gloss Acrylic Retroreflective Film with Microprisms

Adhesive: Permanent Pressure Sensitive

Liner: Polypropylene Film

Features:

- Omni-Directional
- High Intensity Microprismatic Retroreflective Performance
- Field proven long term durability on safety devices worldwide
- Uniform daytime and nighttime visual appearance

Conversion:

☒ Screen Printing
☒ Thermal Transfer Printing
☒ Solvent Based Inkjet Printing
☒ Mild/Eco Solvent Inkjet Printing
☒ UV Inkjet Printing
☒ Thermal Die-Cut
☒ Flat Bed Sign-Cut
☒ Drum Roller Sign-Cut
☒ Steel Rule Sign-Cut

Product Availability*:

Traffic Products		
T-6500	White	
T-6501	Yellow	
T-6505	Blue	
T-6507	Green	
T-6508	Red	
T-6509	Brown	
Work Zone Products*		
W-6100	White	
W-6200	White	
W-6204	Orange	
W-6504	Orange	
W-6511	Fluorescent Yellow	
W-6513	Fluorescent Yellow-Green	
W-6142	Orange Pre-Striped Barricade	4" Left
W-6143		4" Right
W-6144		6" Left
W-6145		6" Right
W-6242		4" Left
W-6243		4" Right
W-6244		6" Left
W-6245		6" Right

*See Page 5 for Nomenclature.
**3 Year Durability

Applications:

☒ Rigid Permanent and Temporary Outdoor Signage
☒ Rigid Work Zone Devices
☒ Safety Devices that Require Robust Retroreflective Performance

Graphics and Reflective Solutions
250 Chester Street
Painesville, OH 44077

Avery Dennison® T-6000 & W-6000 HIP Series

High Intensity Microprismatic Retroreflective Film

Issued: April 2011 Revision 1

Retroreflectivity:

Table A:
Min. coefficients of retroreflection (R_A)[1] per ASTM D4956[2] Type III & IV

Observation Angle	Color	Entrance Angle - 4°	Entrance Angle + 30°
0.1°[3]	White	500	240
	Yellow	380	175
	Orange	200	94
	Blue	42	20
	Green	70	32
	Red	90	42
	Brown	25	12
	Fluorescent Yellow	300	140
	Fluorescent Yellow-Green	400	185
0.2°	White	360	170
	Yellow	270	135
	Orange	145	68
	Blue	30	14
	Green	50	25
	Red	65	30
	Brown	18	8.5
	Fluorescent Yellow	220	100
	Fluorescent Yellow-Green	290	135
0.5°	White	150	72
	Yellow	110	54
	Orange	60	28
	Blue	13	6.0
	Green	21	10
	Red	27	13
	Brown	7.5	3.5
	Fluorescent Yellow	90	40
	Fluorescent Yellow-Green	120	55

Table B:
Min. coefficients of retroreflection (R_A)[1] CUAP Table 7 (EN-12899 RA2)

α Observation Angle	Color	β1 (β2=0˚) Entrance Angle + 5°	+ 30°	+ 40°
12' (0.2°)	White	250	150	110
	Yellow	170	100	70
	Orange	100	60	29
	Blue	20	11	8
	Green	45	25	12
	Red	45	25	15
	Brown	12	8.5	5.0
20' (0.33°)	White	180	100	95
	Yellow	120	70	60
	Orange	65	40	20
	Blue	14	8.0	7.0
	Green	21	12	11
	Red	25	14	13
	Brown	8.0	5.0	3.0
2°	White	5.0	2.5	1.5
	Yellow	3.0	1.5	1
	Orange	1.5	1	--
	Blue	0.2	--	--
	Green	0.5	0.3	0.2
	Red	1	0.4	0.3
	Brown	0.2	--	--

HIP Series sheeting **exceeds** all values listed in **Table A** and **Table B.**

HIP Series sheeting also **exceeds** the current applicable requirements for the following specifications:

ASTM D4956	International
AASHTO M268	USA
CUAP	EU
GB/T 18833	China
N-CMT-5-03-001	Mexico
UNE 135340	Spain
NF XP98520	France
BSI 8408	UK
UNI 11122	Italy
JIS Z9117	Japan
SANS 1519-1	South Africa
AS/NZS 1906.1	Australia New Zealand
ABNT NBR 14644	Brazil
IRAM 3952	Argentina

Avery Dennison suggests you obtain the current requirements from your local agency and ensure product conformance with such requirements. Your Avery Dennison Representative can assist you in this regard.

R_A =
candelas per foot-candle per square foot (cd/fc/ft^2) OR Candelas per lux per square meter (cd/lx/m^2)

[2] Measured according to ASTM E810

[3] Note that 0.1° Observation angle is a "supplemental Requirement" in ASTM D4956. It represents long highway viewing distances of about 900 ft (275 Meters) and greater.

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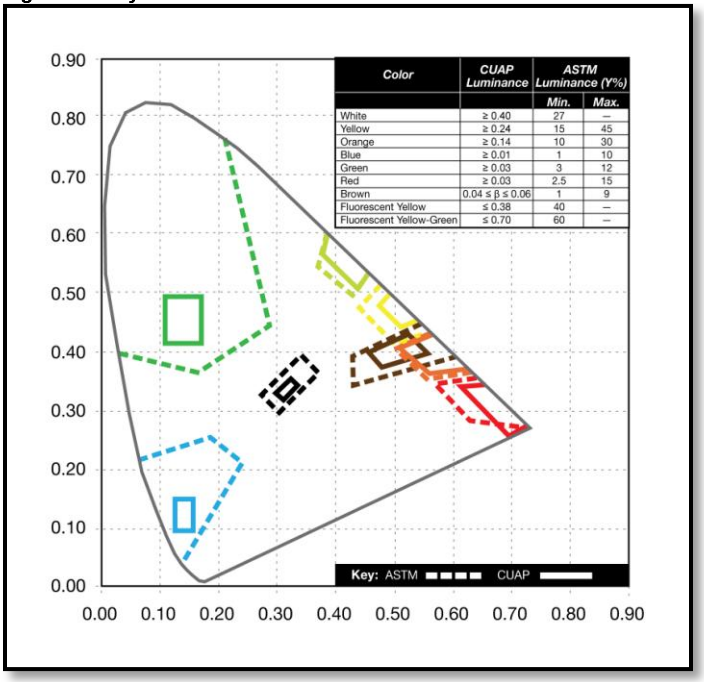
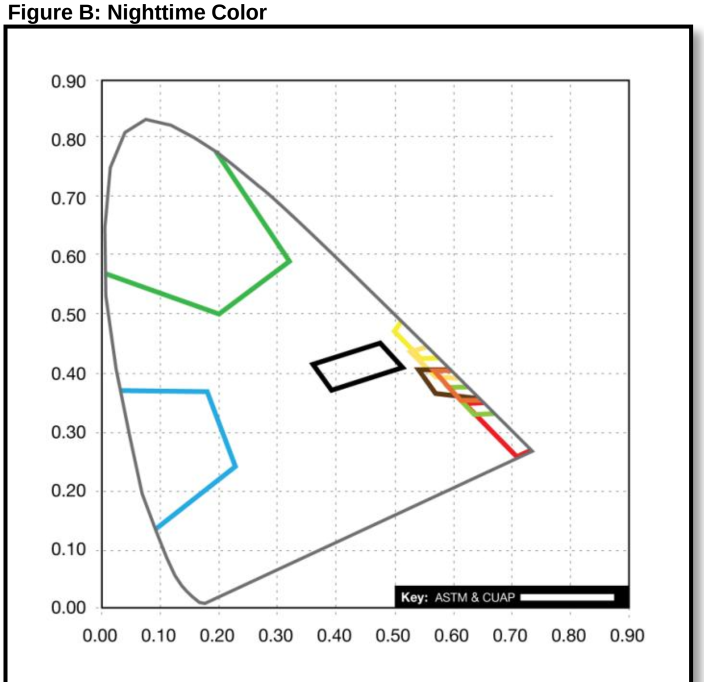
Colors and Specification Limits:

Figure A: Daytime Color



Color	CUAP Luminance	ASTM Luminance (Y%)	
		Min.	Max.
White	≥ 0.40	27	–
Yellow	≥ 0.24	15	45
Orange	≥ 0.14	10	30
Blue	≥ 0.01	1	10
Green	≥ 0.03	3	12
Red	≥ 0.03	2.5	15
Brown	0.04 ≤ β ≤ 0.06	1	9
Fluorescent Yellow	≤ 0.38	40	–
Fluorescent Yellow-Green	≤ 0.70	60	–

Figure B: Nighttime Color



HIP Series sheeting **meets** the current applicable daytime and nighttime color requirements for ASTM D4956 and CUAP as well as standards listed on Page 2.

Chromaticity Coordinate Limits

Figures A & B show the four pairs of chromaticity coordinates from ASTM D4956 and CUAP on the color grid.

Daytime Color

The four pairs of chromaticity coordinates in **Figure A** determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with Standard Illuminant D65 and CIE Publication no. 15 using CIE Standard Illuminant D65 and CIE 45/0 geometry. Luminance factor shall comply with table in **Figure A.**

Note: The saturation limit of green and blue may extend to the border of the CIE chromaticity locus for spectral colors

Nighttime Color

The four pairs of chromaticity coordinates in **Figure B** determine the acceptable color measured using CIE Illuminant A, observation angle of 0.33 degrees, entrance angle of +5 degrees, source and receiver apertures not to exceed 10 minutes of arc, and CIE 1930 (2 degree) standard observer per ASTM D4956.

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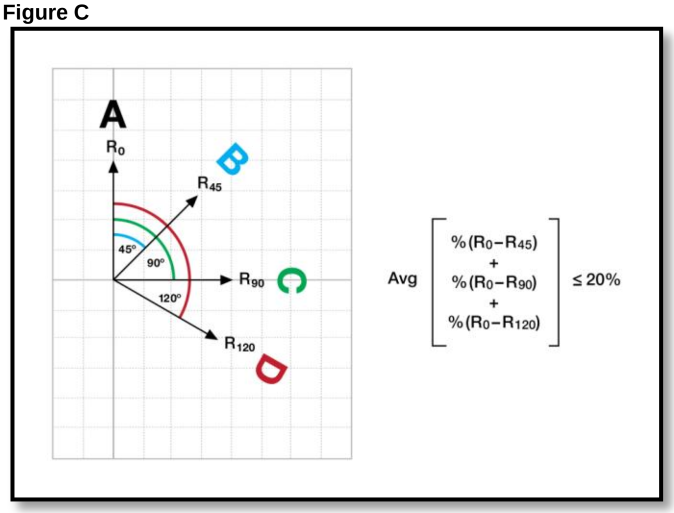
Sheeting Orientation:

The American Association of State Highway Transportation Officials (AASHTO) has recognized that some retroreflective films are rotationally (orientation) sensitive. Because this impacts sign luminance, AASHTO has defined a specification to measure orientation performance. **Figure C** shows how the orientation sensitivity is measured. In order for a film to be considered rotationally insensitive the average percent difference (shown in **Figure C**) must be less than or equal to 20%.

Figure C



When measured for orientation sensitivity as described in AASHTO M 268-10, all Avery Dennison sheeting, both beaded and prismatic, **pass** the specification as **rotationally insensitive**. Therefore no special identification marks or other features (such as a datum mark, or distinctive seal pattern) are required to denote optimum orientation for sheeting. Because the user can expect visual uniformity regardless of orientation, no costly and cumbersome fabrication techniques are required to orient sheets, cut sign legend or border tape during sign fabrication.

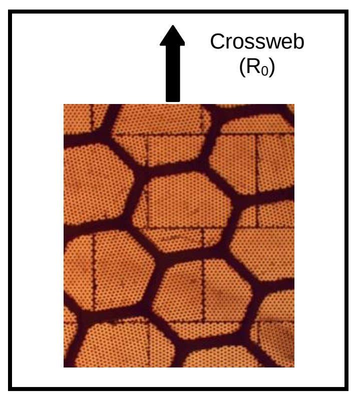
Specifying agencies and sign fabricators are cautioned that some retroreflective sheetings, even of the same ASTM "Type" may not provide consistent luminance for desired night visibility if the sheeting is not applied in the optimal, or in uniform orientation. Agencies and fabricators should be aware of this concern and discuss the potential effects of rotation on luminance of specific sheetings with their material supplier before beginning installation and/or fabrication.

HIP Series sheeting is Omni-Directional and **passes** the AASTHO specification as being **rotationally insensitive.**

Retroreflectivity R_A values taken per ASTM E810
0.5˚ Observation angle and
-4˚ or 5˚ Entrance angle

As a datum for laboratory measurements R_0 is identified in the crossweb direction. See **Figure D**

Figure D



Watermark: HIP Series contains the watermark seen in **Figure E.**

Figure E

HIP Lot #

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Avery Dennison® T-6000 & W-6000 HIP Series

High Intensity Microprismatic Retroreflective Film

Issued: April 2011 Revision 1

Nomenclature:

T – 6 5 0 0

- Initial Letter(s): Application/Durability
- 1st Number†: Series
- 2nd Number: Adhesive
- 3rd & 4th Numbers: Color

Initial Letter	Application	Durability*
T	Traffic/Permanent Sheeting	10 year
W	Work Zone Sheeting	3 year
WR	Work Zone Reboundable	3 year

***** See your local representative for complete details.

Series	6000

2nd Number	Substrate
1	Pressure Sensitive for Plastic Substrates
2	Pressure Sensitive for Wood Substrates
5	Pressure Sensitive for Aluminum Substrates

3rd & 4th Numbers	Color
00	White
01	Yellow
04	Orange
05	Blue
07	Green
08	Red
09	Brown
11	Fluorescent Yellow
13	Fluorescent Yellow-Green
14	Fluorescent Orange
42	4” LEFT Orange Pre-Striped Barricade
43	4” RIGHT Orange Pre-Striped Barricade
44	6” LEFT Orange Pre-Striped Barricade
45	6” RIGHT Orange Pre-Striped Barricade

† OmniCube is the exception and leads with the number 11

The following Warranty is limited to North America.

WARRANTY
Avery Dennison T-6000 & W-6000 prismatic retroreflective sheeting (“Product(s)”) are warranted to be free from defects in material and workmanship for one (1) year from date of purchase (or the period stated on the specific product information literature in effect at time of delivery, if longer). It is expressly agreed and understood that Avery Dennison's sole obligation and Purchaser's exclusive remedy under this warranty, under any other warranty, express or implied, or otherwise, shall be limited to repair or replacement of defective Product without charge at Avery Dennison's plant or at the location of Product (at Avery Dennison's election), or in the event replacement or repairs is not commercially practical, to Avery Dennison's issuing Purchaser a credit reasonable in light of the defect in the Product.

Avery Dennison further warrants that Avery Dennison® T-6000 & W-6000 prismatic retroreflective sheeting will retain its effectiveness as a component of traffic control and guidance signs, and will meet the stated minimum values for coefficient of retroreflection (“Performance Warranty”) as set forth in accordance with the following standards:

Warranty Period*	Minimum Percentage R_A Retained
1-7 years	80%
8-10 years	80%

* Performance Warranty Period for Work Zone products is one to three (1-3) years

Note: For transparent color screen printed areas using Avery Dennison supplied or approved inks or OL-2000 Overlay films on Avery Dennison® T-6500 white sheeting, values shall be a minimum of 70% of values in Table A

R_A percentage retained above apply to all entrance and observation angles in Table A, and shall be measured per ASTM E 810.

All measurements shall be made after cleaning according to Avery Dennison procedures.

PERFORMANCE WARRANTY
If within ten (**10**) years from the initial date of installation, the Product deteriorates due to natural causes to the extent that: 1) the Product fails to retain the minimum reflectivity values warranted for the ten (**10**) year period under the standard in force at the time of installation, or 2) the Product is ineffective for its intended purpose when viewed from a moving vehicle under normal daytime or nighttime driving conditions, Avery Dennison will furnish a replacement amount of like Product at no cost to enable the installed surface to be restored to its original effectiveness. If within seven (**7**) years of installation such deterioration occurs or the Product fails to retain the minimum seven (**7**) year reflectivity values, Avery Dennison will restore the installation surface to its original effectiveness at no cost for materials or labor.

CONDITIONS.
This warranty shall be effective only if all of the following conditions are met:

Fabrication and/or installation must occur within one (1) year from the date of purchase.

The failure must have resulted solely from a manufacturing defect or deterioration of the Product due to natural causes under the Performance Warranty. Without limiting the generality of the foregoing, there is no warranty for the failure of the sheeting due to improper sign fabrication, storage, handling, installation, maintenance, failure of the sign substrate, vandalism or mischief. Slight color fading, cracking, chalking, edge lifting, or slight reduction in gloss or reflectivity will not materially detract from appearance and does not constitute a breach of warranty.

Avery Dennison has published instructional bulletins pertaining to the storage, handling, and cleaning of Product, approved substrates, and application procedures (collectively, the “Procedures”). The Product must have been processed and applied to blank, clean material in accordance with the Procedures, as such may be amended from time to time. Avery Dennison reserves the right to reject any warranty claim where the fabricator or installer cannot satisfactorily prove or demonstrate that the Avery Dennison procedures were utilized. The date of installation, warranty registration, and claim procedures established by Avery Dennison must be followed, and failure to follow such procedures shall void this warranty. Replacement Product carries only the unexpired warranty portion of the Product it replaces. The Product must be properly stored and applied within the shelf-life as stated in the applicable Avery Dennison Product Data Sheet including adhesive and other material product data sheets.

Characteristics:

Property	*Value*	*Instructional Bulletins*
Shelf-Life	1 year from date of purchase when stored at the following conditions; 65°-75°F (18°-24°C) and 50% ± 5% R.H.	#8.00
Typical film Caliper	18 – 19 mils (457 – 483µ) Orange: 17 – 18 mils (432 – 457µ)	NA
Min. Application Temperature	65° F (18° C)	#8.10
Service Temperature	-10°F to +150°F (-23°C to + 65°C)	#8.00
Screen Printing	Long term durability of screen printing in combination with HIP series sheeting is warranted when used with approved inks and overlays. See Page 7.	#8.30 #8.55
Inkjet Printing	User assumes responsibility for fitness of use for this converting method. Long term durability of inkjet printing in combination with HIP series sheeting is not warranted.	#8.55
Thermal Transfer Printing	Long term durability of Thermal Transfer Printing in combination with any HIP series sheeting is warranted. Refer to Instructional Bulletin	#8.60

ADDITIONAL LIMITATIONS

Unintended Use: This warranty only applies to Product that is used by professional converters and installers for the defined end uses and in the combinations described in the applicable Avery Dennison Product Data Sheets and Instructional Bulletins. For any other use, the user is responsible for determining the suitability of the Product, and for any and all risk or liability associated with that use or application, and the user agrees to indemnify, defend and hold harmless Avery Dennison for any claims, losses, damages, judgments, expenses and/or expenses, including attorneys fees, resulting from such use or application. This warranty is expressly conditioned on the Product being processed by professional converters or installers in accordance with the Avery Dennison recommended written processing instructions, and being applied to properly prepared surfaces and cleaned and maintained in accordance with recommended Avery Dennison procedures. It is the converters, installers or other users responsibility to perform incoming raw material quality inspections, to assure proper surface preparation and that approved application procedures are followed, to retain converted samples, and to immediately cease using and notify Avery Dennison and/or its authorized agent or distributor of any Product, Materials and/or finished Product discovered to be (or reasonably capable of being discovered to be) defective.

Misuse and Force Majeure: Avery Dennison has no obligations or liability under this warranty with respect to Product that has been altered, modified, damaged, misused, abused, subject to accident, neglected or otherwise mishandled or improperly processed or installed. Product is not warranted against premature failure caused by chemical, environmental or mechanical means such as, but not limited to, vandalism, cleaning solutions, paints, solvents, moisture, temperature, mechanical washing equipment, engine fuel spills, engine exhaust, steam, organic solvents or other spilled chemicals pollutants, including industrial and volcanic ash. Damage from fire, structural failure, lightning, accidents, and other force majeure events are not covered by this warranty.

Third Party Product: Avery Dennison assumes no responsibility for any injury, loss or damage arising out of the use of a product that is not of our manufacture. Where installer or converter uses or reference is made to a commercially available product, made by another manufacturer, it shall be the responsibility of the user, installer or converter to ascertain the precautionary measures for its use outlined by the manufacturer.

The remedies provided under this warranty are exclusive. In no event shall Avery Dennison be responsible for any direct, indirect, incidental or consequential damages or specific relief whether foreseeable or not, caused by defects in such Product, whether such damage occurs or is discovered before or after replacement or credit, and whether or not such damage is caused by Avery Dennison's negligence. In no event shall Avery Dennison's liability hereunder exceed the remedies specifically set forth in this warranty. Avery Dennison's liability shall be limited, at Avery Dennison's option, to the purchase price, replacement of the defective Product and in some cases when authorized by Avery Dennison the repair and replacement of the defective Product.

THIS WARRANTY IS GIVEN IN LIEU OF ALL OTHERS. ANY AND ALL OTHER WARRANTIES, WHETHER EXPRESS OR IMPLIED, INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, ARE HEREBY DISCLAIMED. NO WAIVER, ALTERATION, ADDITION OR MODIFICATION OF THE FOREGOING CONDITIONS SHALL BE VALID UNLESS MADE IN WRITING AND MANUALLY SIGNED BY AN OFFICER OF AVERY DENNISON.

Converting Information:

The following Avery Dennison literature will provide information to the user for proper application, storage, and other requirements. Find the latest information on the Avery Dennison website, www.reflectives.averydennison.com. We encourage you to check our website periodically for updates.

Approved screen printing inks, overlays, thermal transfer ribbons:

Supplier	***Series***	***System***	***Instructional Bulletins***
Avery Dennison	4930 Inks	1 Part Solvent	#8.40
Avery Dennison	UVTS Nazdar	UV	#8.38
Avery Dennison	OL-2000	Acrylic Overlay	#8.01, #8.10, #8.25
Avery Dennison	OL-1000	Anti-Graffiti	#8.01, #8.10
Matan	DTS	Thermal Transfer	#8.60

Instructional Bulletins:

Film Care & Handling	#8.00
Substrate Requirements	#8.01
Application Techniques for PS Film	#8.10
Cutting Methods	#8.20
Computer Sign Cutting	#8.25
Screen Preparation	#8.30
Troubleshooting Printing & Processing	#8.34
UVTS Nazdar Inks	#8.38
4930 Series Inks	#8.40
Ink Recommendations Guide	#8.55
Matan Thermal Transfer Printing	#8.60

Substrates:

The application of Avery Dennison HIP Series sheeting is limited to properly prepared substrates which differ by product. For traffic products and W-6504, application is limited to properly prepared Aluminum. For products in the W-6100 line, application is limited to properly prepared plastic. For products in the W-6200 line, application is limited to properly prepared wood. Users are urged to carefully evaluate, under actual use conditions, any film application to other substrates. Failure of film caused by other substrates, materials, contamination, or improper surface preparation is not the responsibility of Avery Dennison. See Instruction Bulletin #8.01 for full details on substrate requirements.

DEFINITIONS

Durability: means that the Product in a finished graphic, panel or sign situated outdoors, subject to the limitations herein and Avery Dennison Product Data Sheets and Instructional Bulletins, and applied to recommended surfaces, will not deteriorate excessively such that the finished sign, panel or graphic is ineffective for its identification when viewed under normal conditions from the intended viewing distance.
Outdoor Durability: is based on normal middle European and central North American outdoor exposure conditions and application to recommended surfaces. Actual performance life will depend on a variety of factors, including but not limited to substrate preparation, exposure conditions and maintenance of the Product and finished graphic, panel or sign. In case the finished graphics, panel or sign is in areas of high temperatures or humidity, in industrially polluted areas or other areas with air laden particulate matter, and/or in high altitudes, Outdoor Durability may be reduced. Please see your local Avery Dennison representative for changes to warranties based on such localized conditions.
Vertical Exposure: means that the face of the finished graphic is ±10° from vertical.
Non-Vertical Exposure: means that the face of the finished graphic is greater than 10° from vertical and greater than 5° from horizontal. Retroreflective films are not warranted for this exposure.
Flat surfaces: means a two dimensional flat surface without protruding objects.
Weathering Effects: Some degradation of Product performance over time is considered normal wear. Slight color fading, chalking, edge lifting, or slight reduction in gloss or reflectivity due to normal wear exposure and other natural weathering, environmental or other conditions or damage caused by tornadoes, hurricanes, wind, excessive ice buildup or extraordinary frozen particulate conditions, large hail stones or other acts of God, do not constitute a breach of warranty or give rise to any liability by Avery Dennison.
Printing, Curing and Ink Defects: Ink contaminations, failures or other defects, or other failures due to improper printing conditions or settings including, but not limited to, unsuitable color calibration, incorrect ICC color profile or incompatible printing, do not constitute a breach of warranty. Product failure caused by ink over-saturation, excessive or under curing, failure of ink to render desired colors on Product, or other treatment or processing errors are not warranted.
Adhesion to Application Surfaces: This warranty does not cover the Product if the application surface is not properly prepared; nor does the warranty cover the Product or damage to the substrate because the layers of the substrate separate due to a lower bond between those layers than the bond between the Product and the top layer of the substrate, or surfaces which subsequently crack, peel, outgas, or become damaged beneath the Product

INDEPENDENT TESTING REQUIRED

All statements, technical information and recommendations about Avery Dennison products are based upon tests and information believed to be reliable but do not constitute a guarantee or warranty of any kind. All Avery Dennison products are sold with the understanding that Purchaser has independently determined the suitability of such products for its intended and other purposes.