

**Evaluation of Measuring Methods for
Traffic Sign Retroreflectivity
Final Report**

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16. Abstract This report documents the evaluation of measuring methods for traffic sign retroreflectivity project. The primary objective of this research initiative was to establish a retroreflectivity assessment protocol for sign sheeting in order to meet new federal requirements. While two methods, sign assessment or management, are allowable under the new ruling, this study will focus on assessment strategies. The MUTCD provides various options for assessment including visual nighttime inspection, measured sign retroreflectivity and expected sign life. For this study, retroreflectivity was measured as a function of time. ASTM Type 3 and Type 9 sheeting was evaluated. Data correlation was completed in consideration to the following variables: age, sheeting type, color, manufacturer, condition, type of roadway, orientation, offsets, and region. Some of these variables were not found to have a significant importance in determining life-cycle projections. Based on the results, the blanket replacement method in combination with measured sign retroreflectivity appears to be the most cost-effective methods for the State of Vermont.			
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1. EXECUTIVE SUMMARY

Traffic control devices (TCD), including signs, signals, and markings, provide an important means of communication for all roadway users. They are intended to promote driver safety by supplying advanced warning of upcoming regulatory, warning or guidance information. In addition to daylight hours, traffic control mechanisms must be capable of conveying information during inclement weather and evening hours when there may be little to no contribution from overhead lighting (*I*). Therefore, the appearance and proper recognition of traffic control devices are vital for the overall safety of the traveling public.

This study was conducted in order to establish a method for assessing sign sheeting retroreflectivity and generate recommendations for the cost-effective replacement of traffic signs in accordance with new MUTCD requirements. Field data collection efforts focused on evaluating the current condition of several sheeting types and color combinations including ASTM Type III and Type IX sheeting. These sheeting types were selected based upon the Agency's current practices. For ASTM Type III sheeting, four non-fluorescent sheeting colors were assessed as follows: green, red, yellow, and white. For ASTM Type IX sheeting, two fluorescent sheeting colors were examined: yellow, and yellow-green. The policy decision to consider only Type III or Type IX signs had a controlling effect on this study. Priority setting for replacement of other sign types is beyond the scope of this research.

All retroreflectivity measurements were taken in accordance with ASTM E 1709-08, "Standard Test Method for Measurement of Retroreflective Sign Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle." Several parameters were recorded including: date of data collection, location (district, county, town, route, and lane direction), type of sheeting, color, age, compass orientation of the sign, GPS coordinates, sheeting manufacturer, retroreflectivity and general condition of the sign (poor/fair/good/excellent). Photographs and visual observations were also documented.

The data was graphed during summer of 2008 to examine long term performance. Curves were generated in an attempt to predict the amount of time, or months of service, until values would likely fall below future minimum requirements using the best fit trend line. Corollary statistics were also performed to identify variables affecting long term performance including orientation, offset, wind exposure, and roadway type. A correlation between sign condition and retroreflectivity could not be established.

The absence of a correlation between sign condition and time means daytime inspections are not sufficient indicators of retroreflectivity unless it is paired with measured retroreflectivity measurements using a portable retroreflectometer. The only correlation identified was between the measured retroreflectivity and manufacturer. In all cases, the projected life expectancy for the Type III and Type IX sign sheeting exceeds 15 years. Blanket replacement on a 15 year cycle is supported by the results. This refers to the replacement of signs in an area/corridor or of a given type which eliminates the need to assess retroreflectivity or track the life of individual signs. With the use of the Agency's

sign inventory, the age of all traffic signs within the inventory are known and can be easily queried.

With limited long term data it is difficult to recommend an accurate expected sign life in excess of 15 years. Of all 618 traffic signs incorporated into the study, none were found to be below the future retroreflectivity requirements. After 7 to 12.5 and 5.4 to 6.4 years of service for Type III and Type IX sheeting, retroreflectivity readings are still considered acceptable. Given the best fit trend lines and predicted retroreflectivity over time, a modeled life cycle of 15 years is recommended for red sheeting and 15-20 years may be reasonable for white, green and yellow sheeting. However, additional long term data collection is highly recommended for both types of sign sheeting. The data developed in this study should provide an initial data set for a future supplement in approximately five to seven years when signs have experienced further deterioration.

2. INTRODUCTION

Traffic control devices (TCD), including signs, signals, and markings, provide an important means of communication for all roadway users. They are intended to promote driver safety by supplying advanced warning of upcoming regulatory, warning or guidance information. In addition to daylight hours, traffic control mechanisms must be capable of conveying information during inclement weather and evening hours when there may be little to no contribution from overhead lighting (1). Therefore, the appearance and proper recognition of traffic control devices are vital for the overall safety of the traveling public.

Since 1993, the Federal Highway Administration (FHWA) has researched various methods to measure and maintain retroreflectivity of various types of sign sheeting. Retroreflectivity, otherwise known as luminance, allows for nighttime visibility. Contrast between the sign lettering, sign background and natural setting most significantly influence daytime visibility. Like most traffic control devices, sign sheeting deteriorates over time due to a number of factors including natural events (sun exposure, dirt, wind, ice, etc), manmade contaminants (roadway treatment chemicals and emissions) and vehicular impacts (3). While the MUTCD addresses uniformity, design, placement, operation and maintenance, deterioration rates likely vary as a function of the referenced factors. In theory retroreflectivity, in direct correlation with sign sheeting, also decays over time reducing nighttime visibility. To alleviate accidents that may be due inadequate nighttime visibility, the MUTCD recently established minimum retroreflectivity standards to promote safety (4).

In concert with new minimum retroreflectivity sign sheeting requirements set forth by the MUTCD and VTrans Traffic Safety and Design Section, the primary objective of this research initiative was to examine three suggested methods of assessing and maintaining traffic sign retro-reflectivity. According to the FHWA guide Know Your Retro 2007, “Agencies have until January 2012, to establish and implement a sign assessment or management method to maintain minimum levels of sign retroreflectivity. The compliance date for retroreflectivity of regulatory, warning, and ground-mounted guide signs is January 2015. For overhead guide signs and street name signs, the compliance date is January 2018” (5). In addition to assessing various methods, recommendations pertaining to cost-effective and advantageous sign replacement have been provided.

3. BACKGROUND

Traffic signs are a critical safety feature for local roads and interstates, as they provide regulations, warnings, and guidance information for road users. In order to ensure that motorists receive all pertinent roadway information, traffic signs must be visible to the driver under varying driving conditions. In addition, “regulatory, warning, and guide signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night” (6). Three principle factors affecting recognition of traffic signs include contrast, color, and luminance. Perhaps the most critical factor that can affect visual performance, or how well a target can be seen by the eye, is the luminance of an

object as compared to the luminance of the background. The greater the contrast between the two objects, the easier an object is to identify. This is especially important for nighttime visibility as there is typically little to no ambient lighting reducing the overall contrast between traffic signs and surroundings. In order to ensure adequate visibility at night, retroreflective sheeting is utilized during sign fabrication (7,8).

In order to produce reflective properties, a light source, such as a headlight from a vehicle, interacts with the sign sheeting to reflect a portion of the incoming light rays back towards the driver. This is a quantifiable property known as retroreflectivity (9). Due to the irregularities of the surface, most light beams tend to scatter in all directions, allowing only a small amount of incoming light to reflect back toward the light source. During daylight hours, there is generally enough surrounding light to make up for the lack of a light source (i.e. headlights). During evening hours, however, where overhead lighting is minimal to nonexistent the only source of lighting is headlights. It is important to note that greater retroreflectivity results in an increase in traffic sign visibility and preview distances (10). Many studies have shown that this is especially important for older drivers which require “more light to see delineation and are slower to react” (10). Additionally, beginning at age 20, the amount of light required to see doubles every 13 years.

According AASHTO M 268-08, “Standard Specification for Retroreflective Sheeting for Traffic Control,” “Retroreflective sheeting shall consist of a white or colored sheeting having a smooth outer surface and that essentially has the property of a retroreflector over its entire surface. There are ten types and five classes of retroreflective sheeting. Types are determined by conformance to the retroreflectance, color and durability requirements. Type designation based on manufacturing technique provides a means for differentiating functional performance” (11). For example, Type III sheeting is considered a “high intensity” retroreflective sheeting that is “typically encapsulated glass-bead sheeting” (11). Type IX sheeting is regarded as, “A very-high intensity retroreflective sheeting having highest retroreflective characteristics at short road distances. This sheeting is typically an unmetallized microprismatic retroreflective element material” (11). Typical applications for both sheeting types include highway signing, construction-zone devices and delineators (11). Detailed descriptions of each type are located in Appendix A in Table A-1.

In accordance with the new federal requirement, minimum retroreflectivity requirements are based upon sheeting type and sign color. For ground-mounted signs with green sheeting and white lettering, the minimum requirement is 15 cd/lx/m^2 . Minimum retroreflectivity requirements for red sheeting with white lettering, such as stop signs, are 7 cd/lx/m^2 (5). A summary of the retroreflectivity requirements for all sheeting types and color combinations incorporated into the study are summarized in Table 1 below. Additional requirements for all sheeting types are provided in Table A-2 in Appendix A.

Table 1: Retroreflectivity Requirements.

Minimum FHWA Retroreflectivity Requirements for Sign Sheeting in cd/lx/m ²		
Sign Type	Sign Color	Min. Retro.
III	Red	7
III	Green	15 ⁽¹⁾
III	Yellow	50
III	White	50
IX	Yellow	50
IX	Yellow-Green	50

⁽¹⁾ For ground mounted signs

FHWA has described five suggested methods in publication FHWA-SA-07-020 entitled, “Know Your Retro 2007” to aid public agencies and officials having jurisdiction to use a method that is designed to maintain sign retroreflectivity at or above the minimum levels. The five methods are broken into two categories: assessment and management. The assessment methods include visual assessment and measured sign retroreflectivity (5). The most common and accurate way to evaluate the retroreflectivity of sign sheeting is through the use of a portable retroreflectometer, an apparatus capable of quantifying nighttime luminance under daylight conditions, in concert with ASTM E 1709-08, “Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle” (12). The three management methods are expected sign life, blanket replacement, and control signs. These methods suggest sign replacement based on predetermined factors such as retroreflectivity degradation classified by age and/or location. These methods replace signs as a group instead of on an individual basis. A more in-depth description of each method can be found in Table A-3 in Appendix A.

4. PROJECT SCOPE

The main objective of this research initiative was to establish and implement a sign assessment method and provide recommendations for the periodic replacement of traffic signs in a cost effective manner. The project scope was broken down into several components and included a cross-sectional sign sheeting evaluation and associated analysis. The four components of the project as originally stated within the project proposal are as follows:

1. Survey of States concerning sign sheeting and assessment methods.
2. Literature Review to determine what practices for evaluation of traffic signs exist in other states including research and operation activities. Advantages and disadvantages of the various methods were documented.

3. Cross-sectional retroreflectivity data collection of Type III and IX traffic signs. Retroreflectivity was evaluated with the use of a retroreflectometer capable of assessing varying types of sign sheeting and colors.
4. Corollary statistics were performed to determine key factors contributing to applicable decay rates. This information was used to assess sign sheeting replacement with consideration to possible contributing factors, such as sign orientation. Additionally, a decay analysis was performed to determine various life cycles.

A thorough literature search was performed in the summer of 2008 to examine traffic sign retroreflection and associated importance in the transportation field. The research focused on objectives, findings and/or conclusions regarding field studies and current sign sheeting management practices as well as existing standards and new regulation. In addition, publications relating sign sheeting and public safety were also examined. This information was used to guide data collection activities as described in the section below.

5. PROJECT DESCRIPTION

In an effort to establish a method for assessing sign sheeting retroreflectivity and generate recommendations for the cost-effective replacement of traffic signs in accordance with new MUTCD requirements, one assessment method and two management methods were examined, including the sign retro-reflectivity assessment method, blanket replacement and control signs. Field data collection efforts focused on evaluating the current condition of several sheeting types and color combinations including ASTM Type III and Type IX sheeting. These sheeting types were selected based upon the Agency's current practices. Per our project plans and special provisions, ASTM Type III sheeting is specified as the minimum sheeting type for the replacement of all traffic signs. In addition, it is general practice to specify the installation of ASTM Type IX fluorescent sheeting for pedestrian warning signs and documented dangerous locations such as sharp curves or hidden drives. For ASTM Type III sheeting, four non-fluorescent sheeting colors were assessed as follows: green, red, yellow, and white. For ASTM Type IX sheeting, two fluorescent sheeting colors were examined: yellow, and yellow-green. All sheeting types and colors examined are shown in Figure 1.



Type III Yellow



Type III Red



Type III White



Type III Green



Type IX Fluorescent Yellow-Green



Type IX Fluorescent Yellow

Figure 1: ASTM sheeting types and colors examined in the study.

Originally, the intent was to collect a minimum of 30 retroreflectivity readings per sheeting type and color at 5, 10 and 15 years of service. Locations for readings were expected to be selected from the Agency's Asset Management Program's "Signs Inventory." This inventory contains a large amount of information including inventory record number, sheeting type, sign type, background color, text legend color, location (district, county, town, route, lane position, and mile marker), MUTCD code, and age. Initially, a query was used to extract sheeting types of interest at the years of service referenced above. Each record within this query was numbered in ascending order from one through the total number of records. The sample population was selected through the use of a random number generator in Microsoft Excel. Unfortunately, this method did not yield anticipated results. For example, Type IX sheeting was introduced to the Agency roughly six years ago so the sampling pool could not satisfy the original method of choosing signs at 5, 10, and 15 years old. It was also difficult to find any Type III sheeting with a service life greater than 12.5 years. Finally, as stated above, Type III sign sheeting is a minimum requirement for most sign replacements. During the investigation, it was noted that there has been a wide use of Type IV sheeting as opposed to Type III sheeting between 2003 and 2009, however, only the minimum required Type III sheeting type was logged into the "Signs Inventory" database. Therefore, the original method of sampling using a minimum of 30 readings per sheeting type at 5, 10, and 15 years was abandoned.

A revised sampling method was derived to account for discrepancies within the "Signs Inventory" database. First, the State was divided into the Operation Division's 9 districts. Spreadsheets containing the location of all Type III and IX sheeting were generated for each district including the county, town and route. Signs were evaluated in conjunction with other ongoing research initiatives for economy and field inspection efficiency. For example, if concurrent research initiative was located in a particular town, the applicable spreadsheet would be examined to cross reference signs of interest along the route to access the site. Prior to leaving the office, signs would be selected at random and assessed along the way regardless of the age of the sign. A "FHWA Retroreflective Sheeting Identification Guide" published in 2005 was utilized to distinguish the type of sign sheeting and associated manufacturer (13). Signs with applicable sheeting types would be highlighted on the list to keep track of how many of each type and color were evaluated. When a Type IV or greater sheeting was encountered as opposed to a Type III, the sign's data was removed from the Type III dataset. In keeping with the original scope, a minimum of 90 signs per sheeting type and color were assessed.

5.1 Data Collection Techniques

All retroreflectivity readings were collected in accordance with ASTM E 1709-08, "Standard Test Method for Measurement of Retroreflective Sign Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle." Measurements gathered by this method "are related to the night time brightness of retroreflective traffic signs approximately facing the driver of a mid-sized automobile equipped with tungsten filament headlights at about 200 m distance" (12). All measurements were collected using a portable handheld sign retroreflectometer, "Model 922", manufactured by

RoadVista. This handheld sign retroreflectometer measures all types of retroreflective materials, requires only one reference standard, contains a built in GPS, and can store up to approximately 4,500 readings (14).

In accordance with the test method, the entrance and observation angles were set to -4° and 0.2° , respectively. Then the retroreflectometer was placed in contact with the sign within the area to be sampled. The trigger on the instrument was depressed to collect and record the associated reading. The retroreflectometer was then moved to another position on the sign and a second reading was recorded. As required by the test method, a minimum of four readings were collected and all results were averaged per each sign (12). In addition to assessing current retroreflective properties of each sign, several other parameters were recorded including: date of data collection, location (district, county, town, route, lane direction), type of sheeting, color, age, compass orientation of the sign, GPS coordinates, sheeting manufacturer, and general condition of the sign (poor/fair/good/excellent). Photographs and visual observations were also documented. All data was compiled into a dedicated spreadsheet. Following the data collection methods, corollary statistics were utilized to determine factors contributing to the rate of decay. In many cases, the signs were difficult to access due to the height of the sign. In this instance, an extension pole and ladder was used to ensure safe and accurate data collection. A photograph of standard data collection techniques is provided in Figure 1 below:



Figure 2: Retroreflectivity data collection.

A total of 618 traffic signs were evaluated over the summer of 2008. Table 2 provided below contains a summary of the final population analyzed within this study. A map with the locations of all project locations retained within the study shown as Figure B-1 is provided in Appendix B.

Table 2: Summary of Sample Population.

Sign Sheeting Sample Population Summary						
Sign Type	Sign Color	Number of Signs	Sign Age (Months)		Retroreflectivity Reading (average cd/lx/m ²)	
			Minimum	Maximum	Minimum	Maximum
III	Red	94	10	148	7.9	267.5
III	Green	105	8	150	24.6	656.5
III	Yellow	91	11	104	45.2	579.5
III	White	108	13	150	61.1	804.5
IX	Yellow	89	11	65	210.5	1025.3
IX	Yellow-Green	131	7	77	297.5	1008.8

In examining the characteristics of the sample population, it is interesting to note variation in the service ages with respect to the type of sheeting. The service ages of the Type III and Type IX sheeting ranges between 8.7 to 12.5 years and 5.4 to 6.4 years, respectively. In addition, the minimum retroreflectivity readings reflected in the table have yet to fall below future mandatory requirements. Therefore, the sample population may be insufficient for accurate prediction of the full service life of the various types of sign sheeting will need to be replaced. On the other hand, given the number of readings, the Agency can be fairly confident that these types of sign sheeting will not need to be replaced within the limits determined by this study. Finally, in comparison to Type III sheeting, Type XI signs display a greater initial retroreflectivity.

5.2 Explanatory Variables

Several variables potentially affecting retroreflectivity performance over time were examined within this study as described below:

Color – The six contrasts chosen for the study were based on the new federal requirements that were established and by VTrans personnel. There were four non-fluorescent Type III sheeting types chosen: white on green, white on red, black on white, and black on yellow. Two fluorescent Type IX sheeting types were chosen: black on yellow and black on yellow-green. These contrasts were not only the basis of the new FHWA final rule, 23 CFR Part 655 stating that agencies must maintain traffic signs to a minimum level of retroreflectivity, but are also the most common contrasts used for traffic signs nationwide according to the MUTCD, section 2A.08 (15).

Manufacturer – There are two primary sign sheeting manufacturers used within the state of Vermont. Every 2-4 years, a new sign contract for maintenance operations is awarded based on the low bidder. Generally either 3M or Avery Denison is awarded the contract.

For our research purposes we included both manufacturers. Federal aid construction projects may use any approved manufacturer's product.

Orientation – There has been some research that has concluded that extended sunlight exposure affects the retroreflectivity of sign sheeting. Ultraviolet light is known to degrade most polymeric compounds. For this reason, the orientation of each sign tested was recorded using a hand-held compass.

Offset – There are state standards requiring signs depending on the type to be placed at previously determined offsets (horizontal and vertical) to the roads' surface. Some signs are lower to the ground than others. There was some speculation that the lower the sign is to the ground, the more damaging effects to the sign face there would be. Therefore to determine this, the VTrans' design standards were utilized to determine the offsets of each sign tested.

Wind Exposure – Along with sun damage, there were concerns raised as to whether or not particles carried by wind would damage the sign face. For each sign tested, the same cardinal directions were used to determine wind directions.

Sign Type – There are ten types of ASTM retroreflective sheeting. Types are determined by conformance to the retroreflectance, color, and durability requirements listed within ASTM M 268. In Vermont, there is a requirement that states a minimum of Type III sheeting must be used statewide. Type IX signs are used in Vermont in cases where extra caution is necessary (i.e. sharp curves, hidden drives, and pedestrian crossings). Because Type III and Type IX signs are the majority of what is used in the state, these two types were used for evaluation in this study.

Type of Roadway – The signs evaluated for this study were located on several types of routes including, interstates, US and VT routes. The purpose of choosing various routes was to determine whether AADT affected the sign condition.

Physiographic Location – Vermont is divided into six physiographic regions based on the age and type of rock in the area, landscape (lowlands, hills, mountains), and climate. The six regions include Taconic Mountains, Champlain Valley, Vermont Valley, Green Mountains, Vermont Piedmont, and Northeastern Highlands. Each has specific characteristics that define the area as a region. For example, the Green Mountains region is considered the backbone of Vermont because of its' location in the state. A map defining the regions is shown in Figure B-2 and detailed summary containing a description of each region can be found in Appendix B. Due to the varying regions of Vermont, it was important to determine if the climates in these regions would have any affect on sheeting (16).

6. DATA ANALYSIS

As stated previously, the intent of this project was to perform a cross-sectional analysis of the retroreflectivity of sign sheeting types and colors of interest. This was to be

accomplished by plotting performance curves of retroreflectivity values over time for each sheeting type and color contrast and determining when values fell below the future minimum requirements. In addition, retroreflectivity values were binned by various potential explanatory variables for each sheeting type and color contrast to identify those affecting performance. For example, type III sheeting retroreflectivity results were binned by the manufacturer, either 3M or Avery-Dennison. Once binned, time-series plots were generated for each of the variables. Best fit trend lines of sign sheeting performance with respect to retroreflectivity were generated for each time-series plot. It is important to note that all data was included, therefore any potential outliers were not removed in the subsequent analyses.

Prior to examining all subsequent analysis, it is important to examine the range of the sample population as the intent of the study was to examine long term sign sheeting performance. However, as stated previously, Type IX sheeting has been utilized by the Agency for approximately 6 years. This was not a sufficient amount of time to examine long term performance conclusively. In addition, the installation of Type III sheeting is a minimum requirement and subsequently Type IV was widely used between 2003 through 2009 creating a gap in the data set. A summary of the number of signs expressed by service lives is provided in Table 3 below:

Table 3: Range of the Sample Population.

Sample Population Summary by Months of Service						
Age in Months	Type III				Type IX	
	Red	Green	Yellow	White	Yellow	Yellow-Green
0-12	1	4	1	0	1	7
13-24	0	20	6	28	41	27
25-36	20	33	6	22	31	26
37-48	16	17	30	26	2	15
49-60	28	14	12	27	6	45
61-72	25	3	27	3	8	10
73-84	1	5	3	1	0	1
85-96	2	6	0	0	0	0
97-108	0	1	6	0	0	0
109-120	0	0	0	0	0	0
121-132	0	1	0	0	0	0
133-144	1	0	0	0	0	0
145-156	0	1	0	1	0	0

As shown within Table 3, the majority of the sample population is comprised of sign sheeting with services ages between 13 to 72 months, or 1 to 6 years. Given the large number of sample population for each type of sheeting and color contrast, predicted performance derived from this subset is considered statistically significant within the reference timeframe. However, the number of records beyond 6 years of service appears to be insufficient with respect to assessing long term performance. Although Type III was introduced into the state of Vermont as early as the late 1980's the use was minimal and typically used at high impact areas such as curves. During this time span from the late 1980's to May 2004, Type I and Type II signs were still allowed to be used for all

sign types statewide. In May 2004, the use of Type III signs became mandatory. Therefore the population of signs of this type became much larger than that of Type I and Type II after this date.

6.1 Sign Sheeting Performance

As stated above, time series plots were generated from the cross-sectional data collected during summer of 2008 to examine long term performance. Given the large sample population, any potential outliers were not removed as these were anticipated to have little influence on any subsequent results. Once graphed, performance curves were generated utilizing Microsoft Excel in an attempt to predict the amount of time, or months of service, until values would likely fall below future minimum requirements using the best fit trend line

6.1.1 Type III Sheeting

Figure 3 below displays a graphical time-series plots of Type III sign sheeting retroreflectivity over time with respect to color regardless of manufacturer or other variables. Performance curves along with the R^2 values, or goodness of fit, are displayed on the graphs.

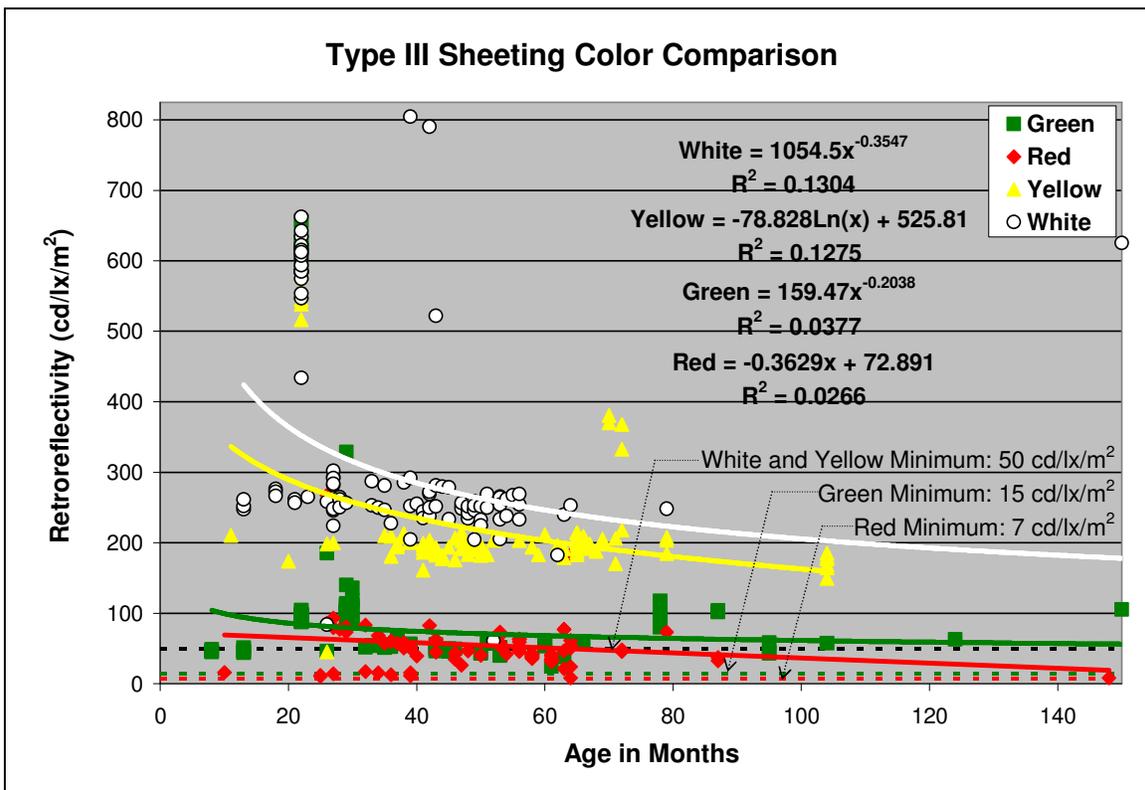


Figure 3: Type III sheeting performance comparison.

As shown in the Figure above, white sign sheeting was shown to display the highest retroreflectivity over time in comparison to all other Type III colors incorporated into the

study. Conversely red sheeting was found to exhibit the lowest retroreflectivity. While the majority of the readings are fairly consistent for a particular color of sheeting, some readings appear to be significantly higher than the majority of the sample population. This may be due to the manufacturer as discussed below. While there are fewer within the sample population, signs produced by Avery-Dennison were found to display much higher readings as compared to signs manufactured by 3M. However, these were not removed from this data set in an effort to accurately depict true retroreflectivity values. Non-linear best fit trend lines were established for all Type III sheeting colors with the exception of red sheeting. All were found to decay over time. R^2 values are low indicating a large spread between the best fit trend line and actual data. However, this was anticipated as potential outliers were not removed.

6.1.2 Type IX Sheeting

Figure 4 below displays a graphical time-series plots of Type III sign sheeting retroreflectivity over time with respect to color regardless of manufacturer or other variables. Performance curves along with the R^2 values are displayed on the graphs.

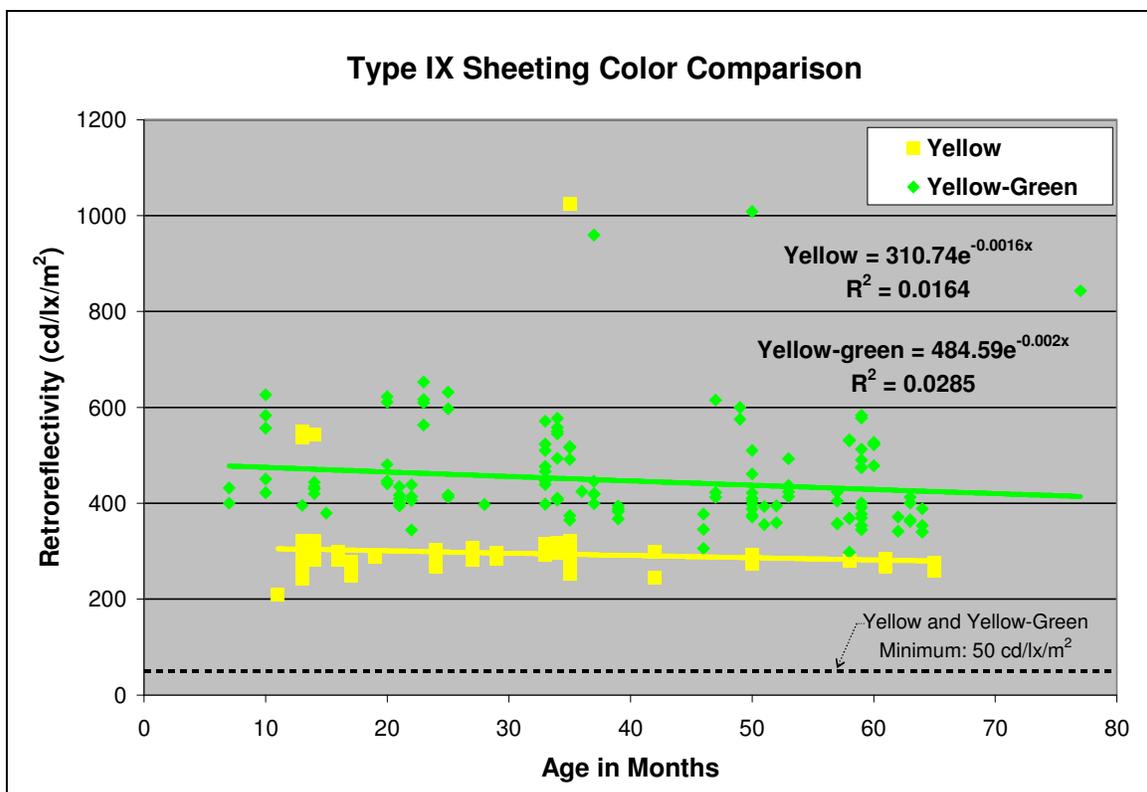


Figure 4: Type IX sheeting performance comparison.

Yellow-green Type IX sheeting was found to display higher retroreflectivity as compared to yellow sheeting with an average retroreflectivity of 457 and 303 cd/lx/m², respectively. It is important to note that all of the yellow Type IX sheeting incorporated into the study was manufactured by Manufacturer B whereas 27% of the yellow-green population was

manufactured by Manufacturer A. In examining the consistency of the two colors, yellow sheeting appears to be more consistent over time as compared to yellow-green sheeting. This however is likely due to differences between the two manufacturers. Non-linear decay curves were generated for both colors of sheeting and although the R² values are low, the trend lines are still believed to be fairly accurate with respect to performance over time. Most importantly, both colors are well above the minimum future retroreflectivity requirements of 50 cd/lx/m² following 5.4 to 6.4 years of service.

6.1.3 Predicted Replacement Cycles

In an effort to predict replacement cycles, the best fit trend lines as described and shown above were utilized to calculate the number of years sign retroreflectivity would be at or above future retroreflectivity requirements. Limited correlation was found to exist. Results are summarized in Table 4.

Table 4: Predicted Replacement Cycle Summary.

Type:	Color:	Decay Eq.:	R ² :	Minimum Intensity Requirement:	Years to reach min requirement:
III	Red	$Y = -0.3629X + 72.891$	0.0266	7	15
III	Green	$Y = 159.47X^{-0.2038}$	0.0377	15	9083
III	Yellow	$Y = -78.828\text{LN}(X) + 525.81$	0.1275	50	35
III	White	$Y = 1054.5X^{-0.3547}$	0.1304	50	450
IX	Yellow	$Y = 310.74\text{EXP}^{-0.0016X}$	0.0164	50	95
IX	Yellow-Green	$Y = 484.59\text{EXP}^{-0.002X}$	0.0285	50	95

With the exception of Type III red and possibly yellow sheeting, all other predicted life cycles appear to over predict a reasonable duration of service life. This is likely due to limited long term data as the result of recently introduced sheeting types and associated specification changes. Therefore, a second round of data collection for all signs is recommended in five years. However, after 8.7 to 12.5 years of service for Type III sheeting and 5.4 and 6.4 years of service for Type IX sheeting, readings have yet to fall below future minimum requirements as described within Table 4. Finally, Type IX yellow sheeting appears to outperform Type III yellow sheeting with respect to the predicted number of years prior to falling below future minimum retroreflectivity requirements.

6.2 Variables Affecting Sheeting Performance

As stated previously, sign sheeting was theorized to deteriorate over time due to exposure to natural constituents, including sun exposure, dirt and wind, manmade contaminants such as emissions and pollutants and vehicular impacts. Therefore additional sign characteristics including orientation, offset and wind direction were recorded and analyzed. This was accomplished by sorting the sample population for each sheeting

type and color by the variable of interest and then plotting the age of the individual sign by the associated retroreflectivity reading. Once again, no potential outliers were removed. Prior to initiating this process, correlation matrixes were generated in Minitab to aid in the identification of explanatory variables. Unfortunately, this method did not identify any strong correlations. This is likely due to the size of the sample population. As variables are binned for each characteristic, the size of the sample population continues to decrease resulting in increased variability.

6.2.1 Sheeting Type Comparison

Figure 5 below displays a graphical time-series plots of sign sheeting retroreflectivity over time with respect to sheeting type. Only yellow sheeting produced by 3M was considered for comparative purposes. As stated previously, Type III sheeting is considered to be “high intensity” while Type IX sheeting is regarded at a “very-high intensity retroreflective sheeting having highest retroreflective characteristics at short road distances.”

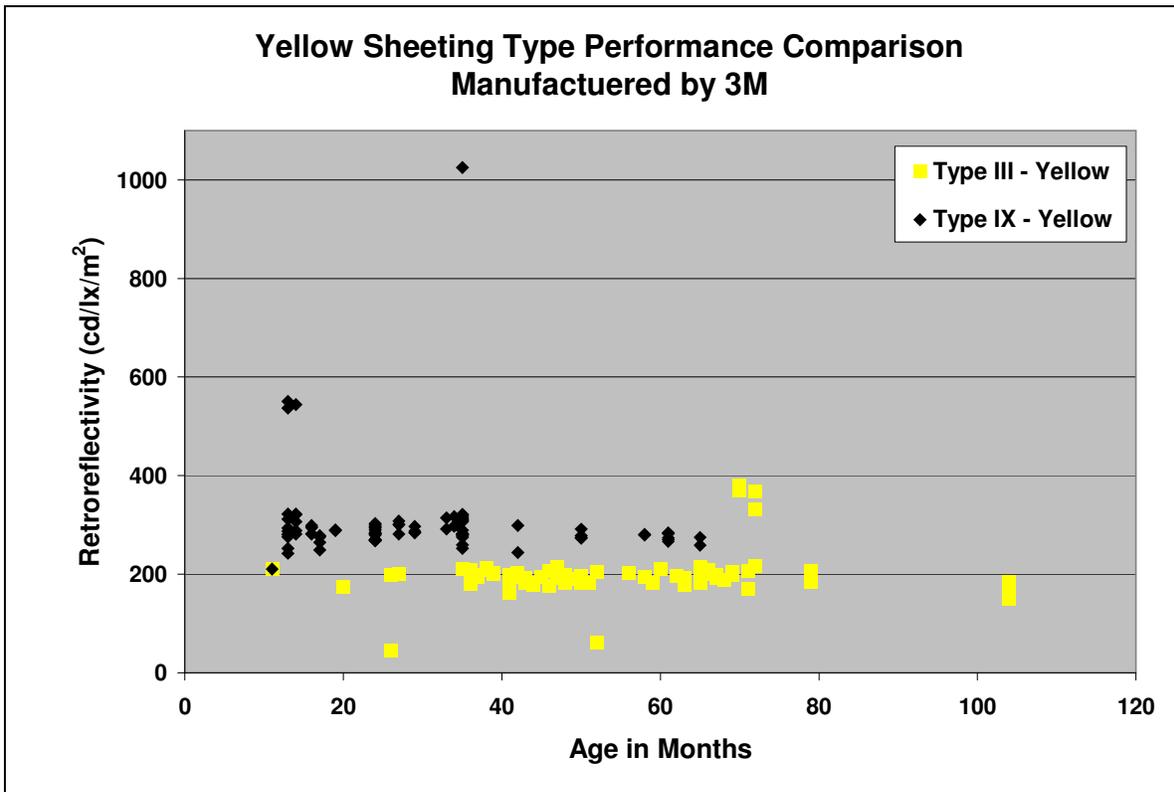


Figure 5: Type IX vs. Type III yellow age comparison.

On average Type IX sheeting was found to produce higher retroreflectivity readings as compared to Type III. Initial retroreflectivity values gathered from the yellow Type III and Type IV control signs manufactured by 3M resulted in readings of 361 cd/lx/m² and 200 cd/lx/m², respectively. Overall, Type IX sheeting displayed an average of 303.19 cd/lx/m² over time whereas Type III had an average of 198.29 cd/lx/m². It is interesting

to note that some readings appear to be significantly higher or lower than the majority of the sample population. This is somewhat counterintuitive given continued improvements in the manufacturing process with respect to consistency. However, this may be attributed to additional factors as discussed below. Clearly the Type IX sheeting displays a nonlinear rate of decay. However, long term performance of the Type III sheeting appears to be relatively consistent.

6.2.2 Manufacturer Comparison

Figures 6 through 8 below display graphical time-series plots of sign sheeting retroreflectivity over time with respect to the two manufacturers. Given the smaller sample population size of Manufacturer A, only a comparison between Type III green and white sheeting and Type IX yellow-green sheeting is provided below.

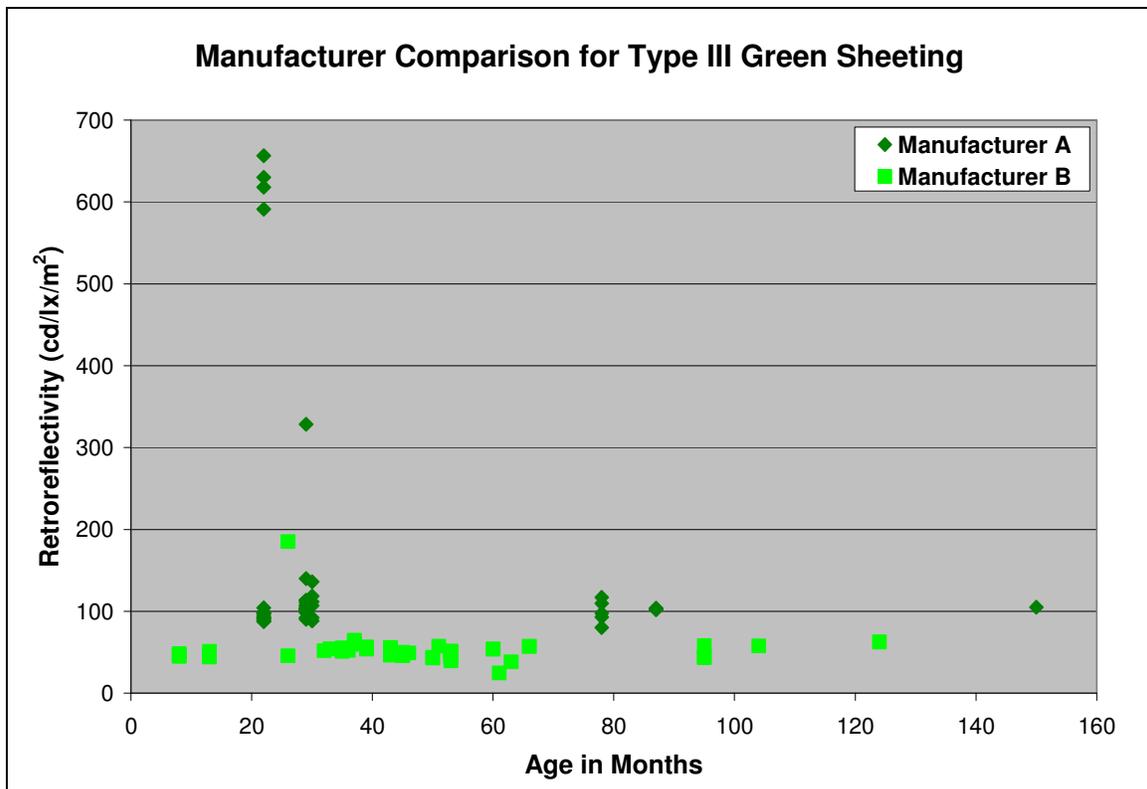


Figure 6: Type III green sign sheeting comparison by manufacturer.

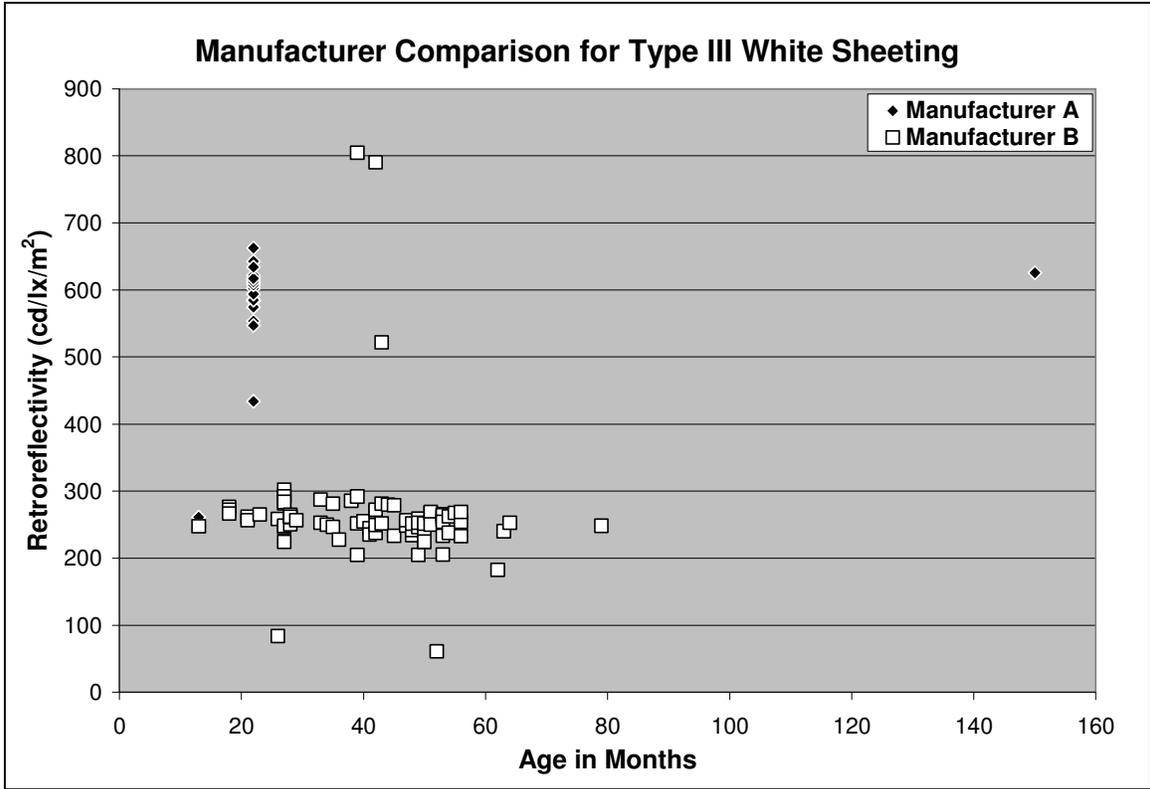


Figure 7: Type III white sign sheeting comparison by manufacturer.

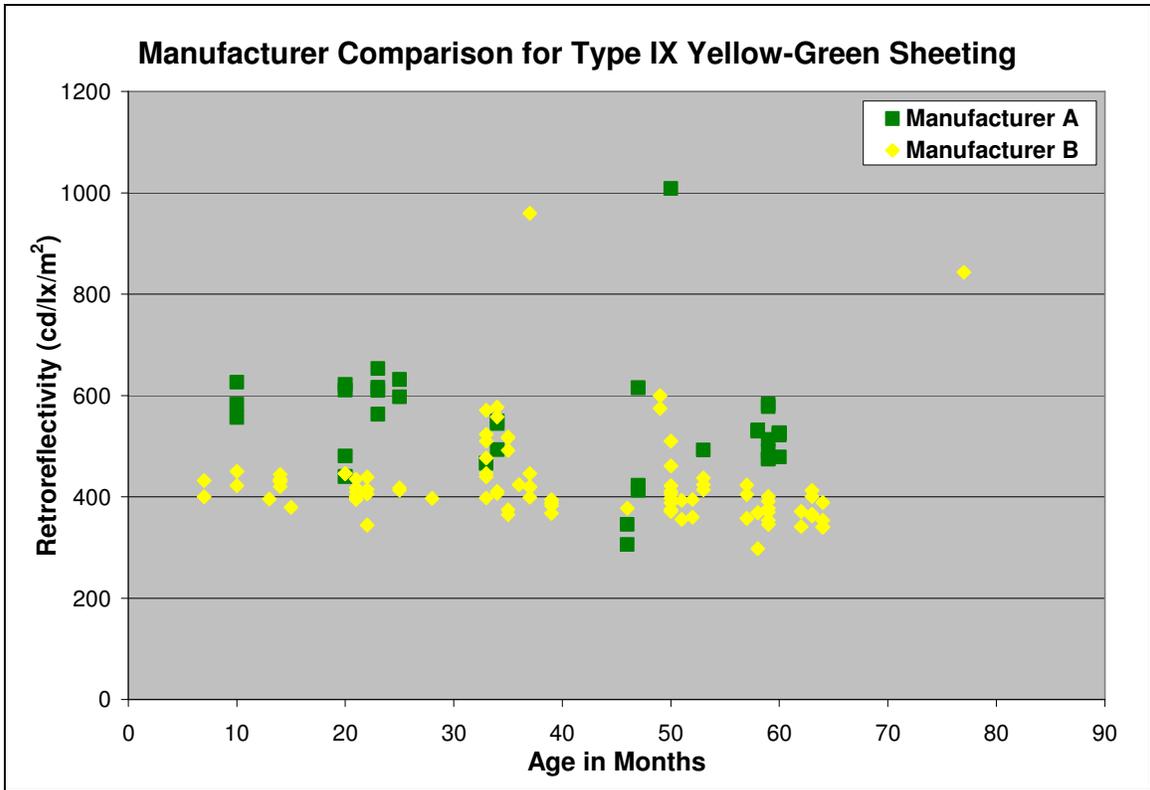


Figure 8: Type IX yellow-green sign sheeting comparison by manufacturer.

In general Manufacturer A sign sheeting was found to display higher retroreflectivity readings as compared to Manufacturer B. This is more evident in the Type III sheeting sample population. Type III green sheeting produced by Manufacturer A accounts for roughly 46% of the respective population, the greatest percentage of all other sheeting types and colors. In almost all cases, Manufacturer A signs outperform Manufacturer B sheeting. However, the cluster of Manufacturer A signs with retroreflectivity values greater than 590 cd/lx/m² may not be representative. In examining the data set, these four signs are located within 0.08 miles of one another and replaced during the same timeframe. Therefore they may have been from the same lot. Only 20% of the Type III white sheeting is comprised of signs manufactured by Manufacturer A. However, of the limited sample size, Manufacturer A signs were found to display greater retroreflectivity. Of the 22 Manufacturer A signs, 19 of them at 22 months of service are all located within 0.48 miles along Route 7. Once again these signs may all be from the same lot or manufactured at the same time. 27% of the Type IX yellow-green sheeting is composed of signs produced by Manufacturer A. In this case, both data sets display fairly consistent downward trend over time. Once again, Manufacturer A signs were found to display slightly higher retroreflectivity values.

6.2.3 Overall Orientation Comparison

Figure 9 provided below displays a graphical time-series plot of sign sheeting retroreflectivity over time with respect to either northerly or southerly orientation. Simply stated, all signs that faced a northerly direction, including northwest, north, and northeast indicated that the sign face was oriented in the direction of the northern pole while southerly facing signs including southwest, south, and southeast indicated that the sign faced in the direction of the southern pole. It was hypothesized that southern facing signs would be subjected to a greater amount and intensity of sunlight throughout the day resulting in accelerated decay from ultraviolet radiation. For comparative purposes, only Type III green sheeting produced by Manufacturer B was examined.

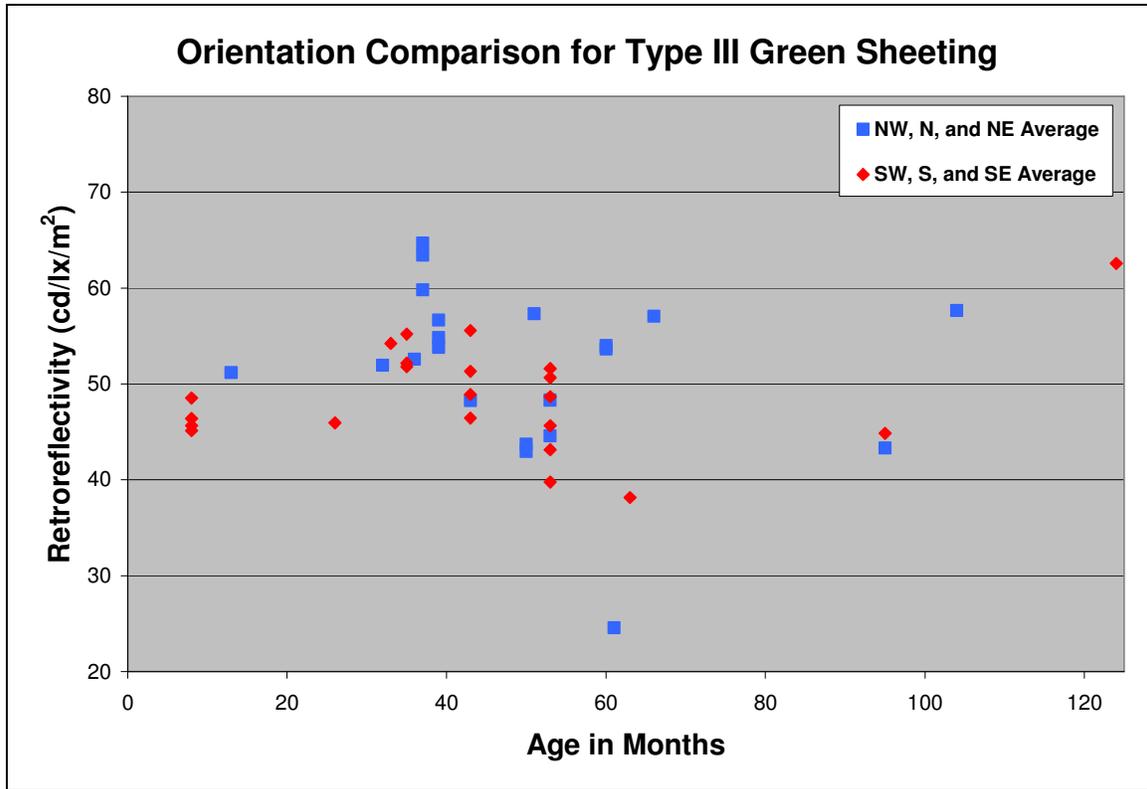


Figure 9: Northerly vs. southerly sign orientation for Type III green sheeting.

One can see in Figure 9 that the northerly facing signs retained a slightly higher retroreflectivity over time as compared to southern signs. However, given the small sample population of 8 and 14 southerly and northerly oriented signs, respectively, the difference in performance does not appear to be significant. Additional data collection is warranted to assess the affect of prolonged sunlight on sign sheeting. At this time there is not enough evidence to establish that orientation should be considered for sign replacement strategies. However, ultraviolet radiation is known factor affecting the degradation of signs. At a annual National Transportation Product Evaluation Program (NTPEP) conference, general feedback from state departments of transportation indicated that fading pigments and subsequent decrease in contrast between the sign sheeting and lettering may decrease more rapidly as compared to retroreflectivity.

6.2.4 Overall Sheeting Condition

It has been said that looks can be deceiving. This study illustrated this point quite clearly through daytime data collection. Figures 10 through 13 shows 4 signs included in the study. Each photograph lists the condition rating, age, and retroreflectivity reading. Figures 10 depicts a sign that is 56 months old and was rated in poor condition having many scrapes, dents, and delaminated sheeting. This sign however has an average retroreflectivity rating of 53 cd/lx/m². Comparatively, the sign in Figure 11, is 64 months old, considered by be in poor condition, and has a significantly lower retroreflectivity of 8 cd/lx/m².

Signs that are considered to be in excellent condition can be deceiving as well. Figure 12 is of a sign that is 25 months old, in excellent condition (free of defects), and had an average retroreflectivity value of 10 cd/lx/m², a considerably low reading especially for a “young” sign. Comparatively the sign shown in Figure 13 is a sign that is 64 months old, in excellent condition with an average retroreflectivity value is 77 cd/lx/m². It is apparent from Figures 10 through 13 that daytime inspections are not sufficient indicators of retroreflectivity unless it is paired with measured retroreflectivity measurements using a portable retroreflectometer. Due to the cost and subjectivity of nighttime inspections this may not be the safest or most cost efficient option for many states. To illustrate this point further, a plot comparing retroreflectivity and age by conditional rating is supplied in Figure 14. For consistency and ease comparison, only Type III red sheeting is shown.



Figure 10



Figure 11



Figure 12



Figure 13

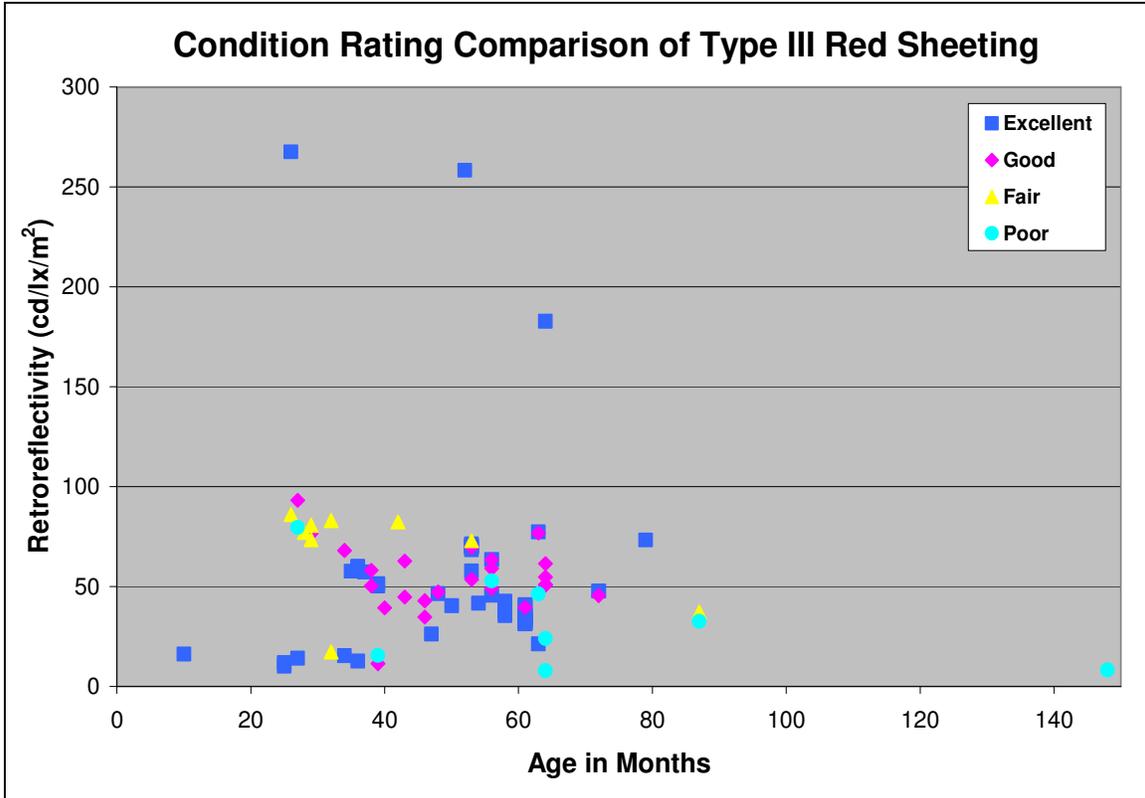


Figure 14: Overall condition rating by month for Type III red sheeting.

As seen in the graph all of the condition averages are very similar, which indicates again that visual inspections is not an accurate inspection method to determine proper sign replacement intervals. Many signs considered to be in “excellent condition” were found to low retroreflectivity values. Even a few signs assessed as “poor” displayed moderately high retroreflectivity reading. It should be noted that the ratings are highly subjective. For this examination, criteria for conditional rating were established prior to implementing field data collection. However even with pre-established criteria, visual assessments will vary from person to person.

6.2.5 Wind Comparison

Figure 15 provided below displays a graphical time-series plot of sign sheeting retroreflectivity over time with respect wind exposure. Typically wind blows from southwest to northeast. Therefore signs facing to the northeast to easterly direction are exposed to a greater amount of wind and associated debris. Therefore, these signs were expected to decay more quickly overtime. For comparative purposes, only Type III green sheeting produced by 3M was examined.

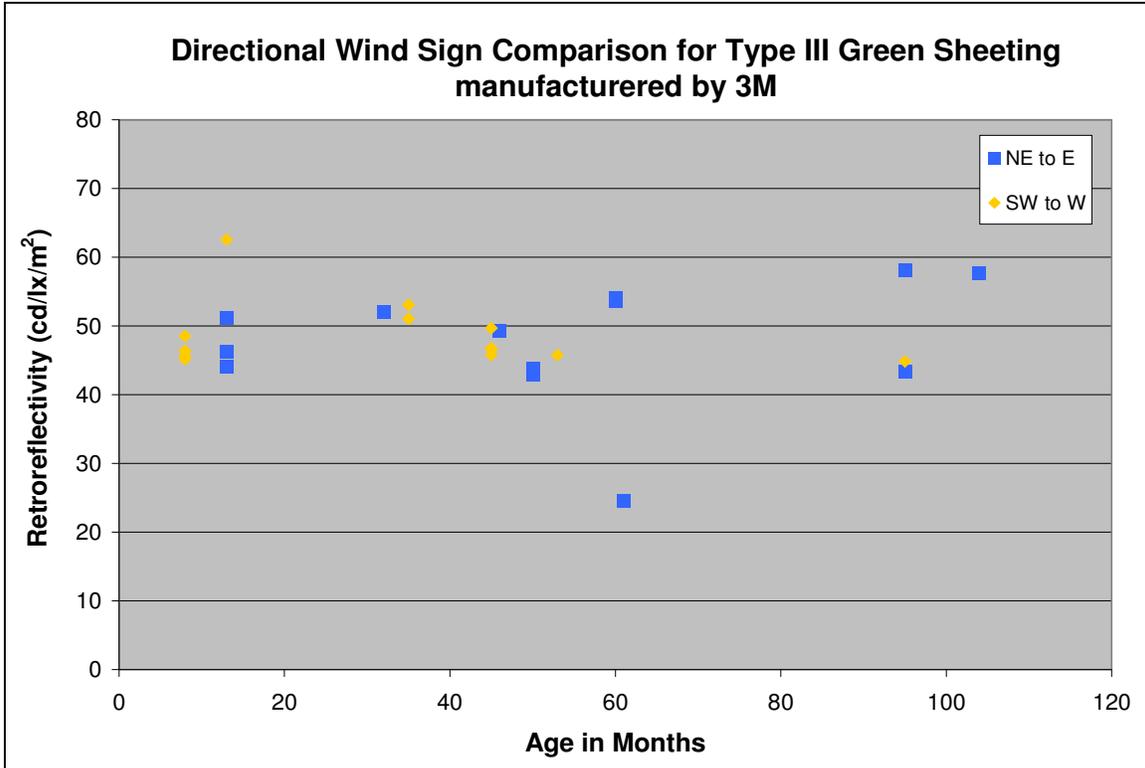


Figure 15: Wind exposure comparison for Type III green sheeting.

As shown within the graph above, there does not appear to be a large difference in performance between signs facing northeast to east and southwest to west. However, given the small sample population of 13 to 12 signs for each referenced orientation respectively, the pool is considered too small to be statistically significant. In addition, increased decay due to excessive wind exposure is largely time based and unfortunately, there is little long term data. Therefore, a more extensive long term study is recommended to draw any definitive conclusions. For short term performance, wind exposure does not have a large influence on sign sheeting performance.

7. CONTROL SIGNS

One of the management methods, known as control signs, was assessed as part of this study. The use of control signs is to provide an agency with the ability to maintain sign retroreflectivity without having to assess individual signs. This method includes using a control sample of signs that represent all signs in an agency's inventory. All samples are monitored and associated signs are replaced based on their performance.

For this effort, manufacturers provided several types of sheeting including Type III, Type IV, Type IX and Type XI. Colors in association with measured sign sheeting were assessed including, sign sheeting white, yellow, green, red, fluorescent yellow-green and fluorescent yellow. Two samples per sheeting type and color were used. All samples were cut into small rectangular sections and placed onto the back of recycled aluminum

The signs have been evaluated annually. Subsequent results are summarized in Table 5 below:

Table 5: Control Sign Retroreflectivity Summary.

Control Signs - Retroreflectivity (mcd/m²/lx)					
NORTH A - Facing North			SOUTH A - Facing South		
Type 3	8/14/2008	8/13/2009	Type 3	8/14/2008	8/13/2009
White	262	259	White	259	271
Green	50	64	Green	46	47
Red	59	71	Red	56	70
Yellow	203	203	Yellow	197	214
Type 4	8/14/2008	8/13/2009	Type 4	8/14/2008	8/13/2009
White	550	482	White	529	505
Green	73	93	Green	69	94
Red	116	116	Red	107	130
Yellow	381	370	Yellow	377	418
Type 9	8/14/2008	8/13/2009	Type 9	8/14/2008	8/13/2009
YG	397	359	YG	378	403
NORTH B - Facing North			SOUTH B - Facing South		
Type 9	8/14/2008	8/13/2009	Type 9	8/14/2008	8/13/2009
White	402	428	White	410	432
Green	50	76	Green	53	71
Red	126	141	Red	124	145
Yellow	370	364	Yellow	353	389
Type 11	8/14/2008	8/13/2009	Type 11	8/14/2008	8/13/2009
White	720	670	White	687	781
Green	103	107	Green	104	118
Red	178	183	Red	181	192
Yellow	585	503	Yellow	581	561
Type 9	8/14/2008	8/13/2009	Type 9	8/14/2008	8/13/2009
Yellow	277	289	Yellow	270	305

As shown in the Table 5, one year of data is clearly not enough to determine at what rate each sheeting type decays. Some samples show that the sheeting's retroreflectivity values are increasing and some are decreasing. At this time, these results are inconclusive and the samples will be continued to be tested on an annual basis.

8. SURVEY

As part of the project scope, a nationwide survey was conducted to obtain a consensus of how other state transportation departments are tackling the new requirements as shown below. In short, 18 of 50 states responded, a fairly high response rate. Three of the

eighteen states are conducting or proposing studies to establish the most cost-effective method of sign replacement. These studies include developing a sign maintenance program in Texas beginning September 2009, setting up a mini test deck to evaluate control signs to predict life expectancy in Wisconsin, and researching various methods in Oregon to choose an appropriate method. The majority of the states currently replace signs based on age using blanket replacement in cycles (eight states) or condition using visual inspections (eight states). Tennessee did replace interstate signs on a twelve year cycle but ended several years ago due to budget constraints. Maine was the only state that did not have a statewide policy, sign replacement is the responsibility of each region. Twelve of the states have chosen their method of replacement. Many states are exploring using a combination of methods including blanket replacement, nighttime inspections, and life expectancy. The primary factors for choosing a method(s) were feasibility and simplicity. Sixteen states have some type of inventory or are trying to establish one and fourteen states expect the inventory to aid in the future replacement process. The survey questions and results are displayed in Appendix D.

9. SHEETING COSTS

Periodically, the State distributes a “Request for Proposal” or RFP for specified types of sign sheeting. Interested manufacturers and suppliers respond with bid prices of sheeting per square foot. Typically, a sign sheeting supplier is awarded based on the lowest bid. Once awarded under a contract, respective sign sheeting may be purchased for any Agency project including knock-down requests, specific sign replacement projects or any other roadway rehabilitation projects that includes sign replacement. Table 6 supplies a summary of contract prices that have been in effect from 1999 through 2009. Low bid was the basis of award in all cases.

Table 6: Sign Sheeting Bid Price Summary.

Sheeting Cost Comparison				
Sheeting Type:	Years		Manufacturer:	Cost (sq ft):
	To:	From:		
Type III	1999	2003	3M	\$1.75
Type IV	2003	2007	3M	\$1.23
Type IV	2007	2009	3M	\$1.23
Type IX	1999	2003	3M	\$4.90
Type IX	2003	2007	3M	\$4.39
Type IX	2007	2009	Avery-Dennison	\$4.50

As stated previously, the cost for Type IV sign sheeting produced by 3M is lower than the cost for Type III as shown in the table. It is also interesting to note that Type IX sheeting costs approximately 3.6 times that of Type III sheeting. While this may seem like a large difference in cost, it minimally increases the overall cost for the traffic sign. According to FHWA, “the estimated of an 18-in by 23-in Chevron sign with Type III sheeting is about \$335. This estimate was based on a unit price of 1.20/ft² for sheeting. Applying an estimated cost of \$4.00/ft² of fluorescent color microprismatic sheeting brings the total sign cost to \$343, a cost increase of only 2.4%” (17). Given additional

safety benefits of Type IX sheeting including a longer viewing distance and increased visibility along with a longer projected sign life, continued placement of Type IX sheeting along sharp horizontal curves and other areas of concern is highly recommended.

10. RECOMMENDATIONS

Data analysis did not confirm any variables affecting long term performance when considering orientation, offset, wind exposure or roadway type with the exception of the manufacturer. In light of this finding expected sign life or blanket replacement is recommended. With respect to expected sign life, signs older than the expected sign life should be replaced. Given that the Agency maintains a sign inventory, the age of all traffic signs within the inventory are known and can be easily queried to identify those older than the expected sign life. Blanket replacement refers to the replacement of signs in an area/corridor or of a given type at specified intervals which eliminates the need to assess retroreflectivity or track the life of individual signs. This replacement interval should be based upon expected sign life for the shortest-life materials used on the affected signs unless a more complex system is devised to address category and type.

With limited long term data it is difficult to recommend an accurate expected sign life. Of all 618 traffic signs incorporated into the study, none were found to be below the future retroreflectivity requirements. After 7 to 12.5 and 5.4 to 6.4 years of service for Type III and Type IX sheeting, retroreflectivity readings are still considered acceptable. Given the best fit trend lines and predicted retroreflectivity over time, a replacement cycle of 15 years is recommended for red sheeting and 15-20 years for white, green and yellow sheeting. A recommended replacement cycle for Type IX sheeting is not feasible at this time given the current data pool. It is easy to suspect that replacement cycles for Type IX sheeting would be greater than those of Type III sheeting given short term performance. However, additional long term data collection is highly recommended for both types of sign sheeting.

11. SUMMARY

The main objective of this research initiative was to establish and implement a sign assessment method and provide recommendations for the periodic replacement of traffic signs in a cost effective manner in concert with future minimum sign sheeting retroreflectivity requirements set forth by the MUTCD. This was accomplished by examining one assessment method and two management methods including the sign retro-reflectivity assessment method, blanket replacement and control signs. Field data collection efforts focused evaluating the current condition of several sheeting types and color combinations including ASTM Type III and Type IX sheeting. These sheeting types were selected based upon the Agency's current practices. ASTM Type III sheeting is specified as the minimum sheeting type for the replacement of all traffic signs. In addition, it is general practice to specify the installation of ASTM Type IX fluorescent sheeting for a pedestrian warning signs and documented dangerous locations such as sharp curves or hidden drives. For ASTM Type III sheeting, four non-fluorescent

sheeting colors were assessed as follows: green, red, yellow, and white. For ASTM Type IX sheeting, two fluorescent sheeting colors were examined: yellow, and yellow-green.

All retroreflectivity readings were collected randomly in accordance with ASTM E 1709-08, "Standard Test Method for Measurement of Retroreflective Sign Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle." A total of 618 traffic signs were evaluated over the summer of 2008. Several potential explanatory variables were examined including condition, manufacturer, wind direction, orientation, color, type, physiographic location, type of roadway, AADT, and offsets (vertical and horizontal). Although the intent was to perform a cross-sectional study documenting sheeting retroreflectivity over a 15 year service life, given policy changes and introduction of new sheeting types, this was not feasible. For example, due to a specification change implemented on March 1st 2003, a minimum sheeting grade of Type III was required for most signs. Prior to this date, Type I and II was widely used. Type IX fluorescent sheeting utilized for a pedestrian warning signs and documented high crash locations such as sharp curves or hidden drives was not introduced until 2002. Therefore we were unable to collect any long term data.

As data analysis did not identify variables affecting long term performance including orientation, offset, wind exposure or roadway type with the exception of the manufacturer, expected sign life or blanket replacement is recommended. With limited long term data it is difficult to recommend an accurate expected sign life. Of all 618 traffic signs incorporated into the study, none were found to be below the future retroreflectivity requirements. Given the best fit trend lines and predicted retroreflectivity over time, a replacement cycle of 15 years is recommended for red sheeting and 15-20 years for white, green and yellow sheeting. A recommended replacement cycle for Type IX sheeting is not feasible at this time given the current data pool. It is easy to suspect that replacement cycles for Type IX sheeting would be greater than those of Type III sheeting given short term performance. However, additional long term data collection is highly recommended for both types of sign sheeting. Control sign sheeting data collection will be performed annually and be used to supplement the findings in this report.

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Appendix A

Table A-1: AASHTO M268-08 & ASTM D 4956-07 - Description of Sheeting Types.

AASHTO M268 Sign Sheeting Type Descriptions	
Type	Description
I	A medium-intensity retroreflective sheeting referred to as "engineering grade" and typically enclosed lens glass-bead sheeting. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
II	A medium-high-intensity retroreflective sheeting sometimes referred to as "super engineer grade" and typically enclosed lens glass-bead sheeting. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
III	A high-intensity retroreflective sheeting that is typically encapsulated glass-bead retroreflective material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
IV	A high-intensity retroreflective sheeting. This sheeting is typically an unmetallized microprismatic retroreflective element material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
V	A super-high-intensity retroreflective sheeting. This sheeting is metalized microprismatic retroreflective element material. This material is typically used for delineators.
VI	An elastomeric high-intensity retroreflective sheeting without adhesive. This sheeting is typically a vinyl microprismatic retroreflective material. This sheeting is typically used for orange temporary roll-up warning signs, traffic cone collars, and post bands.
VII	A super-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at long and medium road distances. This sheeting is typically an unmetallized microprismatic retroreflective element material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
VIII	A super-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at long and medium road distances. This sheeting is typically an unmetallized microprismatic retroreflective element material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
IX	A very-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at short road distances. This sheeting is typically unmetallized microprismatic retroreflective element material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.
X	A super-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at medium road distances. This sheeting is typically unmetallized microprismatic retroreflective element material. Typical applications for this material are permanent highway signing, construction zone devices, and delineators.

Table A-2: Minimum Retroreflectivity Value Table.

Minimum Maintained Retroreflectivity Levels					
Sign Color	Sheeting Type (ASTM D4956-04) (1)				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			Ground-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/m² 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 1200 mm (48 in) and for all sizes of bold symbol signs

(3) For text and fine symbol signs measuring less than 1200 mm (48 in)

(4) Minimum Sign Color Ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)

* This sheeting type should not be used for this color for this application.

Table A-3: FHWA Proposed Assessment and Management Methods Table.

FHWA Methods	
Assessment Methods	Description
Visual Assessment	Fours suggestions to utilize this method are: nighttime inspection, calibrated sign comparison, comparison panels procedure, and consistent parameters procedure.
Measured Sign Retroreflectivity	The retroreflectivity of a sign is measured and directly compared to the minimum level using the Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer (ASTM E1709).
Management Methods	Description
Expected Sign Life	All signs are replaced based on expected sign life which is determined by sign retroreflectivity degradation.
Blanket Replacement	All signs in an area or of a given type are to be replaced at specified intervals, eliminating the need to assess retroreflectivity or track the life of individual signs.
Control Signs	Replacement of signs in the field is based on the performance of a sample of control signs.

FHWA Suggested Methods for Maintaining Sign Retroreflectivity Summary

Assessment Methods:

1. Visual Assessment

1. Please note that one or more procedures (b, c, and/or d) are recommended to be used to support the Nighttime Inspection.

- a.) **Nighttime Inspection:** On-the-fly nighttime assessments are made by an inspector. The following recommendations provide guidance for proper inspection techniques:
- Develop guidelines and procedures for inspectors to use in conducting the nighttime inspections and train inspectors in the use of these procedures.
 - Conduct inspections at normal speeds from the travel lane.
 - Conduct inspections using low-beam headlights and minimize interior vehicle lighting.
 - Evaluate signs at typical viewing distances, giving the driver adequate timing to provide an appropriate response.
- b.) **Calibration Signs Procedure:** An inspector views a “calibration sign” prior to conducting the nighttime inspection. The signs should have known retroreflectivity levels at or above the minimum levels and be set up where the inspector can view them in a manner similar to nighttime field inspections. The visual appearance of the sign should allow the inspector to establish the evaluation threshold for that night’s inspection activities. The following factors provide additional information for using this procedure:
- Signs are needed for each color.
 - Signs are viewed at typical viewing distances using the inspection vehicle.
 - Signs need to be properly stored between inspections to insure their retroreflectivity does not deteriorate over time.
 - Retroreflectivity of these signs should be verified periodically.
- c.) **Comparison Panels Procedure:** Panels will be utilized to assess signs that have marginal retroreflectivity. The panels shall be fabricated at retroreflectivity levels at or above the minimum levels. When the inspector identifies a sign that has marginal retroreflectivity, a comparison panel is attached to the sign so that the inspector can view the variances between the two.
- d.) **Consistent Parameters Procedure:** Nighttime inspections can be conducted under the following similar factors that were used to develop the minimum retroreflectivity levels:
- Use a sport utility vehicle or pick-up truck to perform the inspection.
 - Use a model year 2000 or newer for the inspection.
 - Use an inspector who is at least 60 years old.

2. Measured Sign Retroreflectivity

2. This method will utilize ASTM E1709, the Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer to measure the retroreflectivity of a sign and directly compare it to the minimum level appropriate for any given sign.

Management Methods:

1. Expected Sign Life

3. Individual signs are replaced before reaching the end of their projected service life, which is the time anticipated for the retroreflective material to degrade to the appropriate minimum level.
4. Based on sign sheeting warranties, weathering deck results, measurements of field signs, or other criteria.
5. A system must be developed and used to track sign age. Various approaches can be used including: sign labels marking the year of fabrication or installation or sign management systems.

2. Blanket Replacement

- All signs in an area or of a given type will be replaced at specified time intervals based on the relevant expected sign life. This typically requires that all of the designated signs within a replacement area or of a sign type be replaced, even if a sign was recently installed.

3. Control Signs

- A control sample of signs is used to represent all of an Agency's signs. The signs will be monitored and replacement of field signs will be based on performance of the control group.
- Recommendations:
 - a. Agencies should develop a sampling plan to determine the appropriate number and type of control signs needed to represent the overall total.
 - b. Control signs may be actual signs in the field or signs in a maintenance year (for convenience).
 - c. The retroreflectivity of the control signs should be monitored using an assessment method.

Appendix B

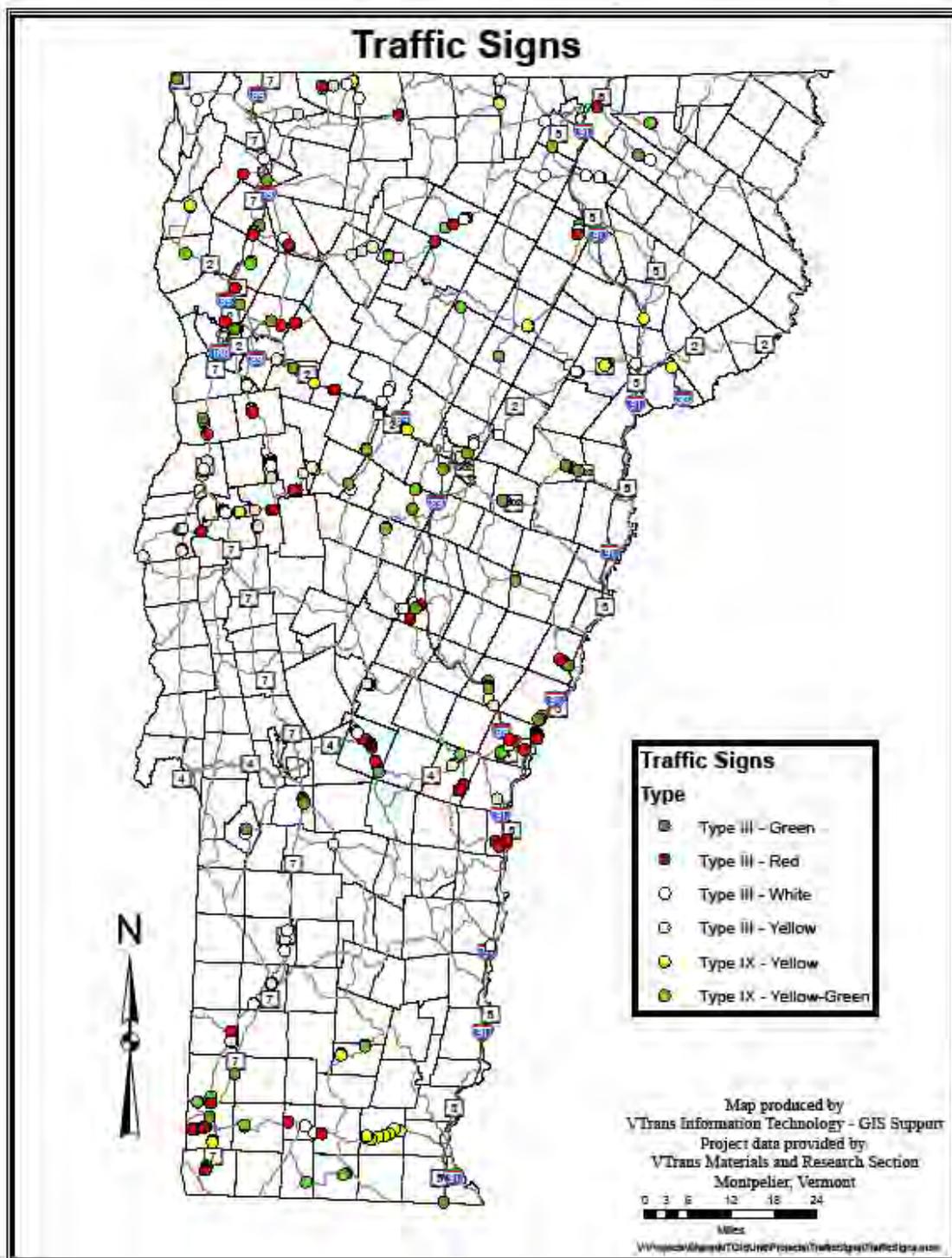


Figure B-1: All signs tested.

Six Physiographic Regions of Vermont

Vermont Lowlands

Located on the western side of the state, the lowlands extend from the Brandon area to the Poultney River near the Canadian border. Lying between the Adirondack Mountains to the west in New York and the Green Mountains on the east, the region has a low elevation. This paired with the moderate temperatures around Lake Champlain, this region is the mildest region in the state, receiving the least precipitation. The milder climate and fertile soil permits the region to thrive in agricultural endeavors.

The Green Mountains

Part of the Appalachian Mountain chain, the Green Mountains are known as the backbone of Vermont. Scientists have found evidence that the mountains in this region which extend the length of the state, varying in width from 20 to 35 miles are some of the oldest on the planet, having formed over 400 million years ago. The climate in this region is harsher than the other regions in the state. The temperatures in the region are often much lower and there is a large amount of precipitation.

The Taconic Mountains

Located in the Southwestern corner of Vermont, this region is full of peaks rising above 3,000 feet. The climate in the region is similar to that of the Green Mountain region.

The Valley of Vermont

Sandwiched between the two mountain regions within the state, the smallest region in the state is very similar to the Vermont Lowlands region. It is considered by many as an extension of the Lowlands region because it exhibits the same climate and agricultural characteristics.

The Vermont Piedmont

To the east of the Green Mountain region, the Piedmont region made up of several rolling hills and valleys, is the largest region in the state. The region contains some of the Monadnock Mountain chain and also is abundant with lakes and ponds.

The Northeast Highlands

Located in the Northeast corner of the state in Essex County, this region is very similar in nature to that of the White Mountains in New Hampshire. This area has an abundance of swamps and bogs due to the poor water drainage qualities throughout the region caused by sand and loose rock deposits left by the glaciers that once covered Vermont thousands of years ago.

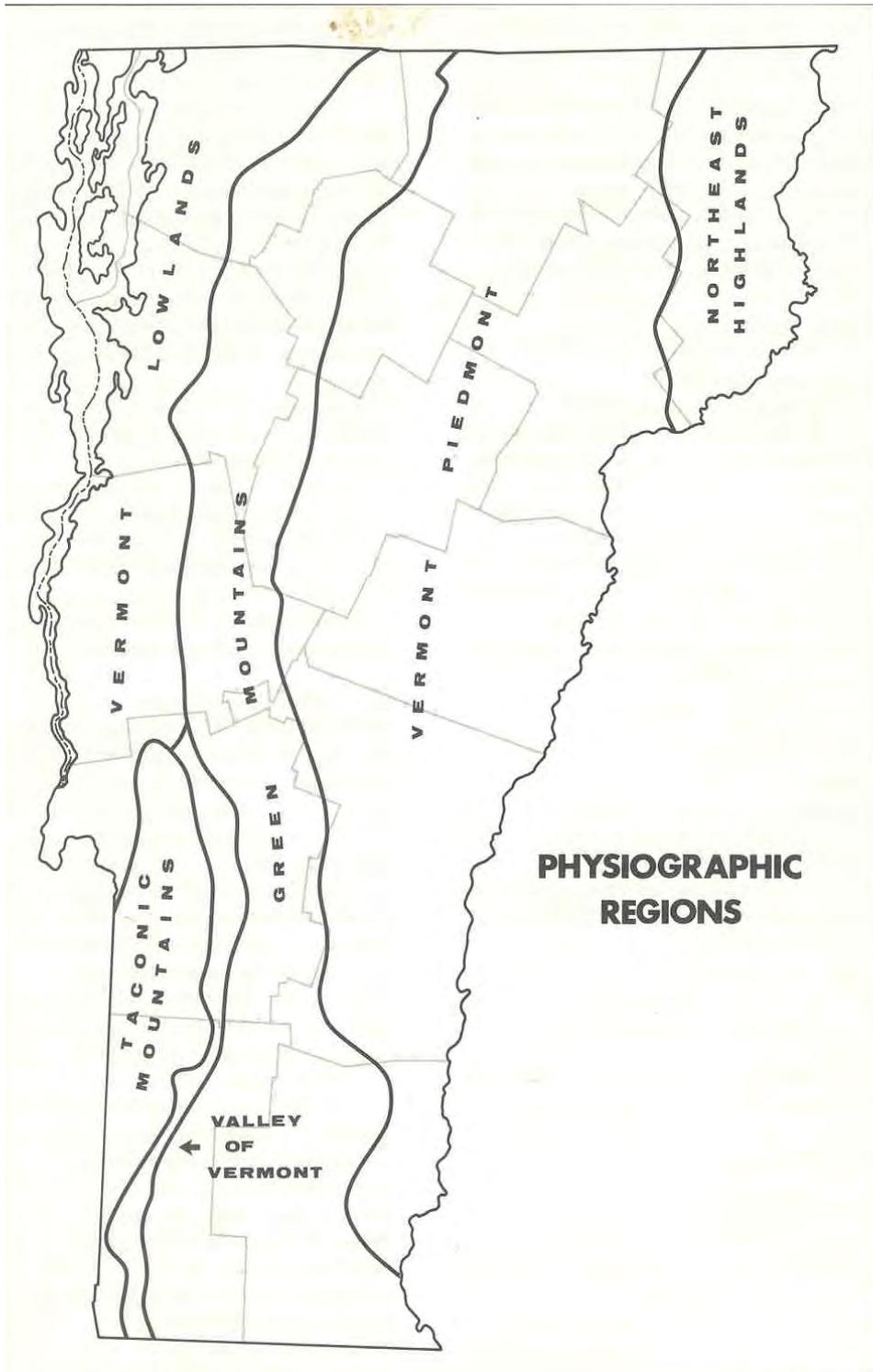


Figure B-2: Physiographical regions of Vermont (16).

Appendix C

Table C-1: Life Expectancy Table.

Type 3					
Graph	Line	Trend Type Selection	Equation	R ²	Life Expectancy (years)
Overall Color	Green	Linear	$y = -0.8538x + 135.16$	0.0359	11.73
Overall Color	Green	Log	$Y = -37.804\ln(x) + 234.66$	0.0366	27.82
Overall Color	Green	Exp	$y = 93.821e^{-0.0047x}$	0.0393	32.51
Overall Color	Red	Linear	$y = -0.3629x + 72.891$	0.0266	15.13
Overall Color	Red	Log	$Y = -13.737\ln(x) + 107.55$	0.016	125.81
Overall Color	Red	Exp	$y = 58.998e^{-0.0053x}$	0.0224	33.52
Overall Color	Yellow	Linear	$y = -1.23999x + 284.39$	0.0771	15.75
Overall Color	Yellow	Log	$Y = -78.828\ln(x) + 525.81$	0.1275	34.85
Overall Color	Yellow	Exp	$y = 240.53e^{-0.003x}$	0.0323	43.63
Overall Color	White	Linear	$y = -2.1282x + 408.64$	0.0586	14.04
Overall Color	White	Log	$y = -130.27\ln(x) + 790.7$	0.1288	24.56
Overall Color	White	Exp	$y = 374.32e^{-0.0059x}$	0.0618	28.43
Manufacturer Green	A	Linear	$y = -0.0838x + 59.788$	0.0038	534.46
Manufacturer Green	A	Log	$Y = -0.6662\ln(x) + 58.342$	0.001	18 Octillion
Manufacturer Green	A	Exp	$y = 54.315e^{-0.0009x}$	0.0045	119.14
Manufacturer Green	B	Linear	$y = -0.9291x + 182.62$	0.0292	180.41
Manufacturer Green	B	Log	$Y = -4.0872\ln(x) + 161.64$	0.0019	3.8 Quadrillion
Manufacturer Green	B	Exp	$y = 135.29e^{-0.0032x}$	0.0027	57.28
Offset - 3M	6ft x 6ft	Linear	$y = -4.3938x + 63.058$	0.3362	10.94

Green					
Offset - 3M Green	6ft x 6ft	Log	$y = -13.057\ln(x) + 62.663$	0.2234	38.49
Offset - 3M Green	6ft x 6ft	Exp	$y = 73.139e^{-.1281x}$	0.3821	12.37
Offset - 3M Green	30ft x 7ft	Linear	$y = 1.5798x + 41.903$	0.1734	-17.03
Offset - 3M Green	30ft x 7ft	Log	$y = 10.791\ln(x) + 32.492$	0.1198	0.2
Offset - 3M Green	30ft x 7ft	Exp	$y = 43.242e^{.028x}$	0.1477	-37.81
N vs. S - 3M Green	North	Linear	$y = -1.419x + 62.458$	0.0508	33.45
N vs. S - 3M Green	North	Log	$y = -5.389\ln(x) + 63.315$	0.0321	7828.18
N vs. S - 3M Green	North	Exp	$y = 60.39e^{-0.0236x}$	0.0562	59.02
N vs. S - 3M Green	South	Linear	$y = -0.9124x + 50.382$	0.224	38.78
N vs. S - 3M Green	South	Log	$Y = -2.1695\ln(x) + 49.156$	0.115	6,877,183.50
N vs. S - 3M Green	South	Exp	$y = 50.483e^{-0.0203x}$	0.2187	59.78
Type 9					
Graph	Line	Trend Type	Equation	R²	Life Expectancy (years)
3M YG vs. Y	YG	Linear	$y = -9.5203x + 454.88$	0.2624	42.53
3M YG vs. Y	YG	Log	$Y = -17.867\ln(x) + 441.15$	0.116	3,218,931,927
3M YG vs. Y	YG	Exp	$y = 457e^{-0.0239x}$	0.2842	92.58
3M YG vs. Y	Y	Linear	$y = 5.5979x + 256.84$	0.0789	-36.95
3M YG vs. Y	Y	Log	$y = 27.131\ln(x) + 246.68$	0.2325	0.0007
3M YG vs. Y	Y	Exp	$y = 250.48e^{0.0258x}$	0.1122	-62.46

Table C-2: Correlation Table of Important Variables in Determining Sign Sheeting Replacement.

Results			
Type	Color	Variable	Correlation
3	Green	Time	Y
		Color	Y
		Condition	Y
		Manufacturer	Y
		Offsets	Y
		Orientation	N
		Type A or B	N
		AADT	N
		Wind	N
3	Red	Time	Y
		Color	Y
		Condition	Y
		Manufacturer	Y
		Offsets	N/A
		Orientation	N
		Type A or B	N/A
		AADT	N/A
		Wind	N/A
3	Yellow	Time	Y
		Color	Y
		Condition	Y
		Manufacturer	Y
		Offsets	N/A
		Orientation	N
		Type A or B	N/A
		AADT	N/A
		Wind	N/A
3	White	Time	Y
		Color	Y
		Condition	Y
		Manufacturer	Y
		Offsets	N/A
		Orientation	N
		Type A or B	N/A
		AADT	N/A
		Wind	N/A
9	YG	Time	Y
		Color	Y
		Condition	Y

		Manufacturer	Y
		Offsets	N/A
		Orientation	N
		Type A or B	N/A
		AADT	N/A
		Wind	N/A
9	Yellow	Time	Y
		Color	Y
		Condition	Y
		Manufacturer	Y
		Offsets	N/A
		Orientation	N
		Type A or B	N/A
		AADT	N/A
		Wind	N/A

Appendix D

Survey Questions

1. What are your current procedures for sign replacement? (before the FHWA minimum requirements and replacement methods came out)
2. Has your state chosen a method of replacement to conform to the new FHWA requirement?
3. If yes, what method was chosen? Is it one of the FHWA suggested methods, combination of methods or something different?
4. What were or are the factors in choosing a method for sign replacement in your state?
5. If a study is underway what methodology procedures are being used?
6. What date do you project for choosing a method?
7. Does your state currently have a sign inventory as part of your asset management program?
8. If so, will you be utilizing this as part of your replacement strategy?

Table D-1: State Survey Results.

Survey Responses								
State	State							
	1	2	3	4	5	6	7	8
AZ	Replace on a cycle (2010 - \$4million per year)	Yes.	Combination of replacement cycles and inventory.	Funding and simplicity.	No.	N/A	Currently working on the inventory. Expected to finish this summer.	Yes.
CA	Visual nighttime inspection.	Yes.	Expect no changes in current method.	Maintain current method.	No.	N/A	Maintained on a district basis in 12 different offices.	Looking into how to establish and maintain an inventory.
DE	Blanket replacement and as projects are implemented.	Yes.	Blanket replacement, Nighttime visual inspection, sign retroreflectivity.	Blanket replacement when funding is available. Nighttime used to spot check.	No.	Currently active.	Yes for overhead and I-beam mounted signs, not for ground mounted signs.	Yes, currently used for forecasting replacement costs.
IL	Route sign inspections, based on condition	Yes.	Blanket replacement, based on county or route every 15 years.	Cost.	No.	N/A	Yes but maintaining the inventory is difficult due to reduced	Yes, planning on implementing a different inventory

							staff.	program.
LA	Ground mounted signs = 10 years. Overhead signs = 15 years.	Yes.	Manage signs by age only.	Some service life data is available but more is needed from manufacturers. Considering using expected service life curves.	N/A	N/A	No but are planning to establish one. Currently the value of an inventory does not justify the cost.	N/A.
ME	Each region is responsible for the assessment and replacement of signs.	Yes.	Life-cycle method. Awaiting decisions from other New England states.	Life cycle method seems most appropriate.	No.	N/A	Inventory is out of date and is not electronic. Hoping to use MATS in the future.	Hopefully. Also considering inclusion of replacement in repaving projects.
MN	Replacing Type III signs with Type IX since March 1999 on a 12 year cycle. In August 2005 switched to DG3 sheeting.	Yes.	Expected sign life on a projected time frame of 15 years for prismatic sheeting types. Also a NTPEP test deck is located here and is tested annually.	Past experience in combination with determining the most cost effective method of sign replacement.	No.	N/A	Implementing the SignCAD SignTRACK inventory system for all signs on state highways. It is anticipated that this will take several years to update.	Possibly.

MS	District offices maintain signs on a 7-10 year cycle on all state roadways except the Interstate system which is maintained by Traffic Engineering on a 10 year cycle. An inventory is in place and aids in determining how many signs to replace annually.	Yes.	Life expectancy and blanket replacement methods.	The inventory has been in place for five years and have been using this method since then.	No.	N/A	Yes and are presently in discussions on how to update the system and possibly migrate to a new database structure.	Yes.
MO	Annual sign log inspections were performed, looking at every sign on the entire system. The inspections alternated between day inspection one year and night inspections the next. Not successful due to subjectiveness of the inspectors.	Yes.	3 Major Steps: 1) Setting a sheeting type. Upgraded to Type IV for permanent sheeting and Type VII for work zones. 2) Develop inventory. 3) Adopt a management method based on replacement cycle of 10	Requiring the higher sheeting type will automatically raise the initial retroreflectivity values well above the minimums. The inventory will help in managing what signs to replace and when. As the inventory is populated, it is expected that a true life expectancy will alter the current	No.	N/A	Yes as mentioned previously.	Yes and random annual nighttime inspections will also be performed to validate the replacement plan based on the inventory.

			years.	replacement cycles over time.				
NE	Nighttime inspection for retroreflectivity, faded signs, and when damaged.	Yes.	Current nighttime inspection and some retroreflectivity measurements.	Policy has been in place for several years. Seems logical to keep this going.	No.	N/A	No, but discussed it several times.	N/A.
NC	Daytime and nighttime visual inspections.	No.	Currently in an evaluation process of the most effective and efficient methods to comply.	Leading method is visual inspection coupled with using retroreflectivity readings for borderline signs.	Y/N - Preliminary stages will require central research on expected sign life and a survey of field personnel.	TBD	No.	N/A.

NY	Ground mounted signs were replaced on 12 year cycles but due to limited funding cycles have moved to 15 to 16 years. Annual sign contracts exist to address corridors and specific signs.	No.	In reviewing process. Expect a combination of methods (corridor replacement, life cycle, and nighttime inspection, test deck) will be chosen.	Using retroreflectometers for measured sign retroreflectivity will not be an option due to costs.	No.	TBD - Before Summer 2009.	No - Currently in process of developing an inventory using Cartegraph. Estimate 750,000 signs on the state system. A number of regions have developed systems using dBase, Access, Excel, etc.	Yes.
OR	Combination, including: nighttime inspection, complaints and/or damage, construction projects, and funding.	No.	Hoping that the maintenance group will form a task group to evaluate the situation and make a recommendation. Research has proposed a study to evaluate alternatives and associated	Cost, equipment and staff needed, time involved, effectiveness, consistency between districts, time to implement, and whether existing procedures will comply.	Not yet.	None yet.	Software has been available to all districts for 15 years but usage is not mandatory. Over the last 2 years, a "basic inventory" has been produced at a statewide	Hoping to make this the starting block for their replacement strategy. Retroreflectivity values and condition are documented in the basic inventory.

			costs.				level.	
TN	Originally, interstate signs were replaced on a 12 year cycle and all others were random by county. This ended several years ago due to budget constraints.	No.	Currently reviewing how to comply with the new requirements.	Most likely a combination of retroreflectivity readings and cycle replacements based on the costs.	No.	N/A	The existing inventory is several years old. A new contract to collect data is about to start. Looking at the cost of retroreflectivity readings as part of the process to see if it is something that would fit into budgeting.	If it fits within the budget.
TX	All signs are inspected twice a year for position, damage, legibility, structural distress, general condition. One inspection is at night, using two people.	No.	Leaning toward nighttime inspection with calibrated signs.	Cost, feasibility, current practice.	Yes, project 0-6408 Develop a Statewide Sign Maint. Program is underway and hopefully will begin in September 2009.	2012	No, but some of the smaller maintenance sections have created spreadsheet based inventories.	N/A.

VA	Visual inspections (day and night), conducted by 5 regional offices.	No.	Looking at visual inspections with measured readings for signs that are questionable.	Expected sign life and blanket replacement is not reliable due to large inventory and inaccurate documentation. Control signs are too labor intensive. Visual inspections will be chosen and those signs that are suspected to be below the minimums will be continually measured for retroreflectivity.	No.	None yet.	Not a full inventory is in place. All overhead signs were done as part of a structural inspection program. 5 regional offices have functionally complete inventories. Working to develop using video graphic tools for interstate signs.	Unsure, but most likely.
WV	Overhead signs = 12 to 15 yrs by contract and statewide maintenance handles these signs if damaged. All other signs are	Yes.	Replacement based on age.	Due to large inventory of signs, this method is most cost effective for the state.	No.	N/A.	Some districts use various inventory methods. For roadways renovated by contract, plans are used as	Spoken with 3M about using their sign asset mgmt. software. This would be used for the district shops initially

	handled by district sign shops with varying strategies.						the inventory.	and if proven successful spread statewide.
WI	Signs replaced on a 12 year cycle but is difficult to maintain due to funding and manpower.	Yes.	Blanket replacement and control signs.	Practical methods and easy implementation.	Yes - control signs.	In place.	Yes - Cartegraph Sign View, started in 1999 now totally 302,000 signs.	Yes - critical to replacement strategy.