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AN ANALYSIS OF TRAFFIC SIGN PERFORMANCE FOR THE ESTABLISHMENT  
OF A MAINTENANCE PLAN

by

Wesley Bill Boggs

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

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UTAH STATE UNIVERSITY  
Logan, Utah

2012

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## ABSTRACT

An Analysis of Traffic Sign Performance for the Establishment of a Maintenance Plan

by

Wesley Bill Boggs, Master of Science

Utah State University, 2012

Major Professor: Dr. Kevin Heaslip  
Department: Civil and Environmental Engineering

Since the establishment of the first minimum retroreflectivity levels in 1993, agencies and researchers have focused on determining the service life of different sheeting type and color combinations. While deterioration curves and measured retroreflectivity are viable methods for maintaining retroreflectivity compliance, they do not ensure the ability of the traffic sign to convey its intended message. Retroreflectivity efficiency only ensures visibility but does not properly describe the legibility of the sign. Therefore, while agencies across the nation are developing and implementing traffic sign maintenance plans, the emphasis should not be solely placed on visibility.

In order to evaluate the performance of UDOT's traffic signs, a sample sign population was collected across all four of UDOT's maintenance regions. Analysis on this sample set not only determined the current rate of compliance, but it also identified several issues seen throughout the population. Signs under UDOT's jurisdiction are four times more likely to have substantial damage to the sign face than to fail to meet the

minimum retroreflectivity levels. Analysis was conducted on determining contributing factors damage rates and it was determined that precipitation, elevation, seasonal temperature swing, and exposure of the sign all contributed to higher rates of damage. Additional analysis was conducted on determining the service life of different type and sheeting combinations. Hindered by the lack of known installation information, the analysis only identified service life as a significant contributor to sheeting deterioration.

Since the majority of new sign installations are prismatic sheeting, the recommended maintenance plan needs to reflect the performance characteristics of this sheeting while continuing to manage the existing sign population. With the combination of UDOT's current sign knowledge and the sheeting deterioration and damage analysis conducted in this thesis, the feasibility of the five preapproved FHWA methods is discussed. This report concludes with the recommendation of a visual nighttime inspection method due to this method's ability to assess both the visibility and legibility of traffic signs. This will ensure that UDOT maintains compliance with the retroreflectivity mandate, while improving safety for motorists.

(150 pages)

## PUBLIC ABSTRACT

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For a variety of reasons both within and outside the control of transportation agencies, there is a higher frequency of fatalities during nighttime hours than during daytime hours. In an effort to enhance visual cues for nighttime motorists, the Federal Highway Administration (FHWA) established the minimum maintained retroreflectivity levels. This retroreflective mandate required agencies or public officials that have jurisdiction over a traffic sign population to implement maintenance methods that would ensure signs were performing at or above the minimum levels. Retroreflectivity is a unique type of reflection that distinguishes itself by reflecting light back in the direction of the light source. The retroreflective process produces an illuminated sign, and the efficiency of this process is measured in candelas per lux per square meter ( $\text{cd/lx/m}^2$ ). While ensuring adequate brightness, via retroreflectivity, enables a sign to stand out from the surrounding environment, it does not guarantee message conveyance. In order for a

message to be conveyed and provide for an adequate reaction time, traffic signs need to be highly visible and legible.

The Utah Department of Transportation (UDOT) initiated this research as a response to the retroreflectivity mandate. In order to take full advantage of this research, UDOT wanted to reevaluate how they manage their traffic sign assets. To evaluate the current performance and identify any current issues, a collection effort was launched. Analysis was conducted to determine the contributing factors to rapid sheeting deterioration and increased damage rates. With the knowledge from the collection effort and the analysis on traffic sign performance, the feasibility of the different FHWA methods is discussed.

This research will provide plan recommendations that are tailored to UDOT's specific sign needs. These recommendations will allow UDOT to maintain compliance with the retroreflectivity mandate, while ensuring their traffic sign assets retain high visibility and legibility. By efficiently managing their traffic signs assets, UDOT can limit the financial and personnel strains of the retroreflectivity mandate, while improving motorist safety.

## DEDICATION

To my Mallory for the weekdays, my Keurig for the weeknights, and alcohol for the short weekends.



## ACKNOWLEDGMENTS

This research was made possible through funding from the Utah Department of Transportation. Special thanks to the several professionals at UDOT who played key roles as members of the Technical Advisory Committee and project team. The contributing members of the Utah State University research group were:

- Devin Squire - USU Graduate Student
- Travis Evans - USU Graduate Student
- Tomas Lindheimer - USU Graduate Student
- Kevin Gardiner - USU Undergraduate Student
- Mike Langford - USU Undergraduate Student

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Wesley Bill Boggs

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## CHAPTER 1

### INTRODUCTION

With the newly accepted revisions to the 2009 Manual on Uniform Traffic Control Devices (MUTCD), the Utah Department of Transportation (UDOT) has a two year window to implement a traffic sign maintenance plan that will ensure future compliance with the retroreflectivity mandate. The retroreflectivity mandate within the MUTCD states that “public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels” (1). UDOT initiated this research as a response to the release of the second revision of 2009 MUTCD. Included within this revision to the MUTCD was the elimination of the existing target dates for replacement of underperforming traffic signs and the subsequent addition of the following provision, “Implementation and continued use of an assessment or management method that is designed to maintain regulatory and warning sign retroreflectivity at or above the established minimum levels” (1). Elimination of the original target dates coupled with the additional two years till required plan implementation provides UDOT with adequate time to develop a traffic sign maintenance plan that is tailored to UDOT’s specific traffic sign needs.

Motivation for this research is derived from the Federal Highway Administration’s (FHWA) primary mission to improve safety on the nation’s roadways. According to the National Safety Council even though only a quarter of all travel occurs at night, about half of traffic fatalities occur during nighttime hours (2). A percentage of these nighttime fatalities can be attributed to intoxication and fatigue, but these factors



are not controlled by agencies. In order to address the limited visual cues present during nighttime driving, FHWA established the minimum maintained retroreflectivity levels which would ensure adequate levels retroreflectivity on signs throughout the nation's roadways. Many agencies across the nation have voiced concern about meeting the new retroreflectivity mandates, due to current budget constraints and an already stretched labor force. For larger agencies, like UDOT, that maintain tens of thousands of traffic signs efficient maintenance methods need to be implemented that are tailored to that agencies specific signage needs in order to avoid budgetary waste.

While enhancing the retroreflectivity of traffic signs is beneficial to all motorists, it is particularly important to older drivers. The vision of a motorist declines as they age. Starting at age 20, the amount of light needed by a motorist to see doubles every 13 years. By the year 2020, one-fifth of the population in the United States will be over the age of 65 (2). Increasing the visibility of traffic signs not only improves safety for all motorists, but it allows elderly motorists to retain their mobility and independence.

### **1.1 Research Question**

The major question on which this research focuses is: *“Given UDOT’s current knowledge of its traffic sign population, what method(s) would allow for continuous compliance with the minimum retroreflectivity standard, while ensuring the legibility and visibility of its traffic sign assets?”* In order to properly address this question a subset of traffic signs must be assessed to identify current issues and any inadequacies that exist throughout the sign population. The attributes that will be recorded during a collection

effort need to be sufficient enough to assess the feasibility of adopting any of the preapproved FHWA maintenance methods. Not focusing on a specific method allows for flexible plan development, which can be adapted to overcome various inadequacies and issues discovered during a collection effort. Even though the FHWA has placed an emphasis on maintaining the visibility of traffic a sign, via its retroreflectivity, without adequate legibility a traffic sign loses purpose. Therefore, the goal of UDOT's traffic sign maintenance plan should be to ensure the visibility and legibility of the traffic sign assets under their jurisdiction.

## **1.2 Research Problem and General Approach**

In order to recommend a FHWA approved retroreflectivity maintenance method that is specific to UDOT's traffic sign needs, it is the intent of this research to attempt to answer the following questions:

- How are UDOT's traffic signs currently performing with respects to the minimum retroreflectivity mandate?
- Is there an increase in damage amongst subsets sign populations that share similar weather and location conditions?
- What are the effects on traffic sign maintenance of using prismatic sheeting?
- What FHWA maintenance methods are feasible for implementation by UDOT at this current time?

In order to determine the current rate of compliance with the retroreflectivity mandate a collection effort is needed to assess the performance of UDOT's traffic signs. UDOT manages an estimated 95,000 signs across four maintenance regions. By conducting a data collection effort prior to plan implementation not only will UDOT know its current compliance with the minimum retroreflectivity mandate, but various issues can be identified that may influence the selection of a maintenance method.

During a preliminary collection effort, it was determined that signs under UDOT's jurisdiction are frequently damaged during service life. Therefore, damage needs to be categorized and assigned a severity. Since the location will be known for signs recorded during a collection effort, analysis will be conducted to determine the contributing factors of increased damage rates. This analysis will lean heavily on weather observation and location data from a variety of sources. In order to interpolate climate data for individual signs, geographic information systems software will be utilized. Since limited research has been conducted on the damage rates of traffic signs, analyzing the performance of traffic signs by geographic condition and location might prove beneficial to larger agencies.

Multi-layered prismatic sheeting is a relatively new product being utilized in traffic sign construction. Prismatic sheeting is more efficient than beaded sheeting, which may lead to a shift in the emphasis of traffic sign maintenance. UDOT is beginning to replace underperforming traffic signs with prismatic ones due to their higher retroreflective performance. The superior performance of prismatic sheeting comes at a cost. Not only is this sheeting type more expensive, it also requires that the sign be

oriented in the proper position to achieve optimal retroreflectivity. In addition, multi-layered signs have been observed to have less durability compared to single-layer signs. As UDOT begins to replace underperforming single-layer signs with more vulnerable multi-layered signs, ensuring the legibility of a sign might become the primary focus of traffic sign maintenance. Since the majority of current research was conducted on beaded sheeting the affects that prismatic sheeting has on plan development have not been identified.

With the information gained from a collection effort, the feasibility of the preapproved FHWA maintenance methods can be assessed to determine which one best meets UDOT's specific needs. The frequency of damage, installation dates and sheeting type variety will all contribute to the determination of the best maintenance method for UDOT. By the conclusion of this research, recommendations will be made to UDOT that identify the maintenance method(s) that can improve retroreflective compliance, while fixing issues identified during a collection effort.

### **1.3 Anticipated Contributions**

Development and implementation of a traffic sign maintenance plan is required by June 13, 2014. The FHWA has preapproved five methods for achieving compliance with the retroreflectivity mandate and it is up to UDOT to determine which method(s) to implement. This research will assess the current performance of UDOT's traffic sign population, identify current issues and inadequacies, and recommend the most suitable method for UDOT. This research is the initial step in the reevaluation of how UDOT

maintains its traffic sign assets and establishes a foundation from which future researchers can build upon. As UDOTs knowledge of its traffic signs assets improves overtime this foundation should be adjusted to take advantage of the most current information.

#### **1.4 Research Outline**

This report highlights research performed on traffic signs under UDOT's jurisdiction. Chapter 2 provides a comprehensive literature review of previous research and current knowledge of traffic sign management and performance. Included in this review is discussion on the principles of retroreflectivity, establishment of the minimum retroreflectivity levels, research on the deterioration rates, traffic sign damage rates, and recommended management methods for retroreflectivity maintenance. Chapter 3 discusses the collection of the traffic sign dataset and will identify current issues within the traffic sign population. Chapter 4 presents analysis on the contributing factors of traffic sign damage and preliminary deterioration analysis of multi-layered sheeting. Chapter 5 discusses the feasibility of preapproved FHWA maintenance methods for UDOT and make recommendations on plan implementation. Chapter 6 discusses the conclusions of this research and how they affected the recommendation of a traffic sign maintenance plan for UDOT, as well as provide areas for future research.

## CHAPTER 2

### LITERATURE REVIEW

#### **2.1 Purpose**

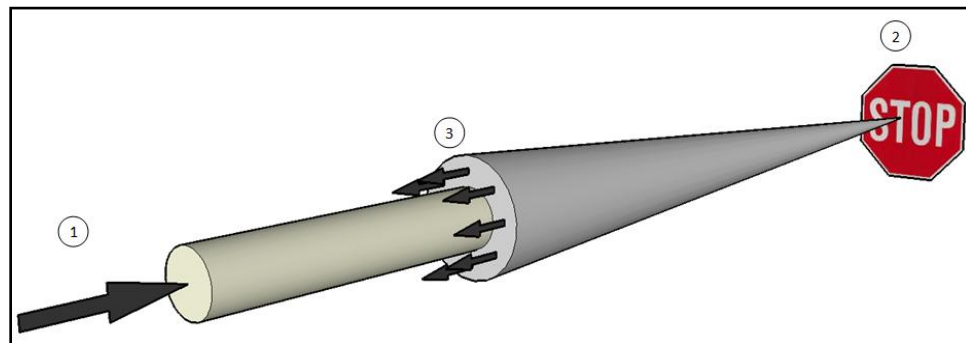
This literature review establishes a knowledge base on retroreflectivity principles and previous research conducted on traffic sign performance. This review will be divided into four sections in order to educate the reader and identify areas of inadequate knowledge. The first section is an in-depth discussion on the principles of retroreflectivity and different performance characteristics of current traffic sign sheeting. Secondly, a brief history of the establishment of the minimum maintained retroreflectivity levels and the need for formalized documentation of agency maintenance practices is presented. The third section presents previous research on the deterioration of traffic sign sheeting and traffic sign damage frequency. Lastly, the recommended FHWA assessment and management methods are presented. After reading this literature review, the reader will understand the motivation for this research and be provided with the knowledge to adequately understand the scope of this research.

#### **2.2 Principles of Retroreflectivity**

Retroreflectivity is a unique type of reflection that distinguishes itself by reflecting and focusing light back in the direction of the light source. Traffic sign sheeting is constructed of retroreflective elements that are specifically designed to reflect light from vehicle headlights conically back towards the vehicle. The retroreflective elements typically utilized for this process are spherical lenses (glass

beads) or prismatic (cube-corner prisms), with prismatic sheeting being the more efficient of the two.

Retroreflectivity is formally defined as the coefficient of retroreflection ( $R_A$ ) and has units of candelas per lux per square meter ( $\text{cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2}$ ). The luminous intensity of light emitted from the headlights is measured in candelas (cd). This intensity of light applied to the surface of the sign is defined as illuminance and is measured in lux (lx). The light that is returned to the vehicle is defined as luminance with units of candelas per square meter ( $\text{cd}\cdot\text{m}^{-2}$ ) (3). Figure 2.1, illustrates the retroreflectivity process where Point 1 represents a beam of light emitted from the headlights, Point 2 is the area that is illuminated by the emitted light, and Point 3 is retroreflected light which is redirected in the direction of the vehicle. In order to emphasize the conical spread of retroreflected light, the illustration only shows a very narrow beam of light emitted from the vehicle. In order to perceive the brightness of the sign, motorists must be within the conical spread of retroreflected light, which is defined as the cone of retroreflectivity. As the motorist drifts away from the center of the cone of retroreflection the perceived brightness of the



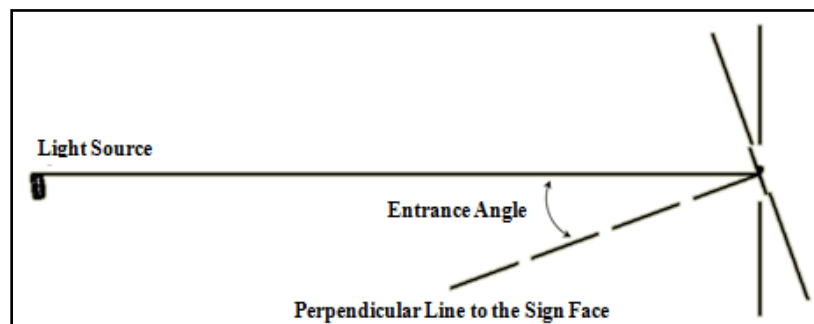
**FIGURE 2.1 Illustration of retroreflection process**

sign diminishes. These basic properties are the same for all retroreflective materials, where these materials retroreflectivity of a traffic sign is defined as the ratio of the amount of light coming out of the retroreflective sheeting (luminance) to the amount of light emitted from the light source (illuminance). Larger measured values of retroreflectivity indicate a more efficient retroreflection process, and assuming the signs are exposed to the same light intensity it produces a visually brighter sign.

### 2.2.1 Retroreflectivity Angularity

The retroreflectance of traffic sign sheeting is always described in context of its angularity. The angularity of a traffic sign refers to the range of angles at which the sign will retain its retroreflectivity and is described by its entrance and observation angles (3). The entrance angle, illustrated in Figure 2.2, is the angle between a line perpendicular to the sign face and a second line drawn from the light source to the sign face.

The entrance angle is a function of the location of the vehicle and sign, therefore it changes as this distance between the vehicle and sign changes. Retroreflectometers typically have settings to measure retroreflectivity at entrance angles of -4 degrees and +30 degrees. An entrance angle of -4 degrees is intended for a traffic sign at the edge of



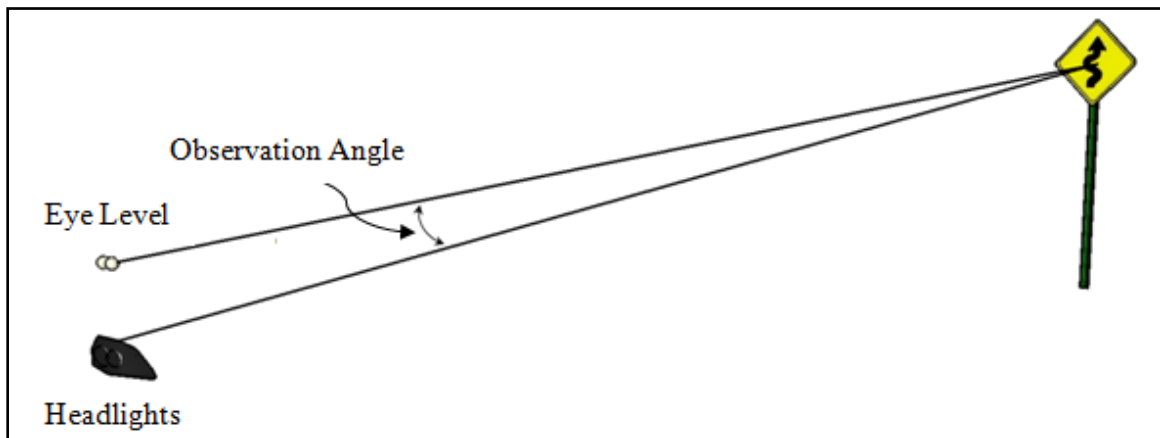
**FIGURE 2.2 Entrance angle illustration**



the roadway, whereas an entrance angle of +30 degrees represents the widest reasonable angle between a sign and a motorist for whom the sign is intended for (4). Non-negligible changes in retroreflectivity are not seen until the entrance angle exceeds 20 degrees in either direction.

In order to obtain the maximum retroreflectivity, and limit specular glare it is important to ensure that traffic signs are properly aligned. Traffic signs are recommended to be aligned slightly more than perpendicular to the roadway, with manufacturers recommending a 93 degree alignment (4). Doing so will limit specular glare which, under direct sunlight, causes a rainbowing effect across the sign and decreases its legibility.

Contrasting from the insensitivity of the entrance angle research has determined that minor changes in the observation angle can have substantial effects on the retroreflectivity of a sign. The observation angle is defined as the angle between the eye level of the motorist and the headlight height with its apex located on the sign face, as shown in Figure 2.3. According to the American Association of State Highway and



**FIGURE 2.3 Observation angle illustration**

Transportation Officials (AASHTO), the average passenger car has a headlight height of 2 feet with a corresponding motorist eye level of 3.5 feet . As previously described, retroreflective sheeting reflects light back in the direction of the headlights, but due to the conical spread of light the motorist is able to see the illuminated traffic sign. Since the distance between the eye level of the motorist and the headlights varies depending on vehicle types the observation angle needs to encompass all vehicle types while maintaining the narrowest cone possible for optimal brightness. As the motorist's eye level is raised, the distance from the center of the cone of retroreflectance is increased causing a slight increase in the observation angle and decrease in the perceived brightness of the sign. Since the distance between the motorist eye level and the headlight height is fix for a particular vehicle, as the distance between the vehicle is halved the angle of observation is doubled (5). Therefore, the perceived brightness of the traffic sign diminishes as motorists approach the sign. For these reasons observation angles are generally measured at +0.2 degrees or +0.5 degrees which equates to sign sight distances of 500 feet and 200 feet, respectively (6).

### 2.2.2 Retroreflective Sheeting Types

Due to the variety of retroreflective sheeting available for traffic signs, it became imperative to develop a standardized classification for sheeting performance. The American Society for Testing Materials (ASTM) established standard specifications for retroreflective sheeting within ASTM D4956-11a (6). Currently, ASTM has nine different types of retroreflective sheeting whose recommended applications are

summarized in Table 2.1. Higher sheeting types do not necessarily imply higher performance, rather a difference in sheeting performance characteristics.

Type I – A retroreflective sheeting referred to as “engineering grade” and is an enclosed lens glass-bead sheeting (6). Has a seven year sheeting life, but is known for its durability both in handling and damage resistance. There is not distinctive watermark to distinguish between manufacturers.

Type II – A retroreflective sheeting referred to as “super engineering grade” that is an enclosed lens glass-bead sheeting (6). Via utilization of larger glass-beads, this sheeting achieves twice the retroreflectivity of Type I. Typically has a service life of 10 years and manufacturers can be identified by watermarks within the sheeting.

Type III – A retroreflective sheeting referred to as “high-intensity” that is typically manufactured as an encapsulated glass-bead or unmetalized microprismatic sheeting (6). Type III can be identified by the honeycomb looking lattice, which varies slightly for manufacturer identification. The cost is typically twice that of Type I sheeting, but it produces retroreflectivity measurements four times higher than Type I. It has an expected service life of 10 years.

**TABLE 2.1 Applications of retroreflective sheeting by type (6)**

Type	Applications	Intensity Rating
I	Permanent highway signing, construction zone devices, and delineators	Medium
II	Permanent highway signing, construction zone devices, and delineators	Medium-high
III	Permanent highway signing, construction zone devices, and delineators	High
IV	Permanent highway signing, construction zone devices, and delineators	High
V	Delineators	Super high
VI	Temporary roll-up signs, warning signs, traffic cones collars, and post bands	High
VIII	Permanent highway signing, construction zone devices, and delineators	Super high
IX	Permanent highway signing, construction zone devices, and delineators	Very high
XI	Permanent highway signing, construction zone devices, and delineators	Super high

Type V - A retroreflective sheeting referred to as "super high-intensity" that is typically a metalized microprismatic retroreflective element material (6). Its primary application is on delineators and raised pavement markers. The service life is five years and it cost five and a half times as much as Type I.

Type VI - An elastomeric retroreflective sheeting without adhesive. This sheeting is typically a vinyl microprismatic retroreflective material (6). This sheeting is composed of a flexible vinyl cloth allowing it to be utilized on clothing and roll-up traffic signs. It cost six times as much as Type I sheeting and has a service life of two years.

Type VIII, Type IX, Type XI - A retroreflective sheeting typically manufactured as an unmetalized cube corner microprismatic retroreflective element material (6). Type VIII, IX, XI produce retroreflectivity measurements that are nine, five, and seven and half greater than Type I, respectively. The cost for Type VIII and Type IX is five times as much as Type I and Type XI is six and a half times as much as Type I. Service lives vary from 10 to 12 years depending on the manufacturer.

Due to the fact that sheeting classifications change over time it should be noted that the following reclassifications are applicable as of November of 2011: all retroreflective sheeting material previously classified as a Type VII or Type X have been reclassified to Type VIII (6). The minimum coefficient of retroreflection to be considered as one type or another are summarized in Table 2.2. A minus sign denotes that there is currently no specific minimum for that color and type combination. In addition to the presented information ASTM D4956-11a includes information about sheeting weathering and accelerated weathering for different observation and entrance angle combinations.

TABLE 2.2 Minimum retroreflectivity for sheeting type classification (6)

Type	Sheeting Color									
	White	Yellow	Orange	Green	Red	Blue	Brown	Fluorescent		
								Yellow-Green	Yellow	Orange
I	70	50	25	9	14	4	1	-	-	-
II	140	100	60	30	30	10	5	-	-	-
III	250	170	100	45	45	20	12	-	-	-
IV	360	270	145	50	65	30	18	290	220	105
VI	500	350	125	60	70	45	-	400	300	200
VIII	700	525	265	70	105	32	21	560	420	210
IX	380	285	145	38	76	17	-	300	230	115
XI	580	435	200	58	87	26	17	460	350	175

† Values for 0.2° observation angle and a -4° entrance angle

### 2.3 Establishment of the Minimum Retroreflectivity Levels

In 1992, Congress mandated that the Secretary of Transportation revise the language within the MUTCD to include “a standard for minimum levels of retroreflectivity that would be applicable to all roadways open to public travel” (7). In order to directly address the Congressional mandate, the FHWA conducted several studies, which were summarized in 1993 and lead to the establishment of the first minimum retroreflectivity levels (8). These initial minimum levels were derived from analyses based on the Computer Analysis of Retroreflectance of Traffic Sign (CARTS) model (9). The initial minimum retroreflectivity levels were divided up into four tables depending on the color of the sign and were applicable to both post-mounted and overhead signs. The four tables were: white, yellow and orange, green, and red signs. In addition, the initial mandate also established a minimum contrast ration of 4:1 for white on red and white on green signs (10).

After the 1993 minimum retroreflectivity levels were published, reviewers of the work began to question many of the modeling assumptions. Most of the comments centered on the assumption of the driver being located directly above the headlight, which represented a motorcycle rather than a passenger vehicle. The CARTS model was adjusted to accommodate the effects of dual headlights on the observation angle (11). In 1997, new specifications were passed for headlights by the Federal Motor Vehicle Safety Standards. This addressed issues with the luminous intensity of headlights directed towards overhead signs. The FHWA sponsored additional research for minimum retroreflectivity levels for overhead and street-name signs and established the current minimum levels for both post-mounted and overhead guide signs (12). Final adjustments to the minimum retroreflectivity levels resulted from research conducted in 2003, in which consistent testing parameters for driver age, vehicle type, headlights, and retroreflective sheeting types were taken into account (13).

Section 2A.08 of the 2009 Edition of the MUTCD establishes the minimum retroreflectivity levels, displayed in Table 2.3, which must be maintained by public agencies or officials that have jurisdiction over traffic signs. In addition to establishing minimum retroreflectivity levels, the MUTCD introduced the follow standard “Public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels” (1). Incorporated with the above standard were three target compliance dates. By January 22, 2012 an agency must implement an assessment or management method that is designed to maintain traffic sign retroreflectivity at, or above, the established minimum levels. By

January 22, 2015, signs that have been identified as failing, including regulatory, warning, and post mounted guide signs must be replaced. Finally, by January 22, 2018, the additional replacements for street signs and overhead guide signs are required (1).

On August 31, 2011, a Notice of Proposed Amendments was published in the Federal Register, proposing to revise Table I-2 in the Introduction of the 2009 MUTCD. On May 14, 2012, the proposed amendment was accepted by FHWA and eliminated the majority of compliance dates for traffic sign retroreflectivity. The only remaining compliance date requires agencies to implement an assessment or management method for maintaining only regulatory and warning sign retroreflectivity above the minimum levels. Implementation and continued use of a retroreflectivity maintenance method is required by June 13, 2014 (15). The MUTCD provides five different methods for maintaining retroreflectivity compliance, which are separated into two different categories: assessment or management. The assessment methods include visual nighttime inspection and measured sign retroreflectivity, whereas the management methods include expected sign life, blanket replacement, and control signs (1). Within the five different compliance methods inefficiencies exist because agencies are reliant upon manufactures warranties for establishing replacement rates or inventory intervals for the traffic signs under their jurisdiction. In order to decrease these inefficiencies, agencies have sought to create degradation curves to fine tune sign replacement and effectively allocate agency funding for traffic sign management.

**TABLE 2.3 Minimum maintained retroreflectivity levels (1)**

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				–
<sup>1</sup> The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m <sup>2</sup> measured at an observation angle of 0.2° and an entrance angle of -4.0°.					
<sup>2</sup> For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs					
<sup>3</sup> For text and fine symbol signs measuring less than 48 inches					
<sup>4</sup> Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)					
<sup>*</sup> This sheeting type shall not be used for this application.					
Bold Symbol Signs					
<ul style="list-style-type: none"> <li>• W1-1,2 – Turn and Curve</li> <li>• W1-3,4 – Reverse Turn and Curve</li> <li>• W1-5 – Winding Road</li> <li>• W1-6,7 – Large Arrow</li> <li>• W1-8 – Chevron</li> <li>• W1-10 – Intersection in Curve</li> <li>• W1-11 – Hairpin Curve</li> <li>• W1-15 – 270 Degree Loop</li> <li>• W2-1 – Cross Road</li> <li>• W2-2,3 – Side Road</li> <li>• W2-4,5 – T and Y Intersection</li> <li>• W2-6 – Circular Intersection</li> <li>• W2-7,8 – Double Side Roads</li> </ul>		<ul style="list-style-type: none"> <li>• W3-1 – Stop Ahead</li> <li>• W3-2 – Yield Ahead</li> <li>• W3-3 – Signal Ahead</li> <li>• W4-1 – Merge</li> <li>• W4-2 – Lane Ends</li> <li>• W4-3 – Added Lane</li> <li>• W4-5 – Entering Roadway Merge</li> <li>• W4-6 – Entering Roadway Added Lane</li> <li>• W6-1,2 – Divided Highway Begins and Ends</li> <li>• W6-3 – Two-Way Traffic</li> <li>• W10-1,2,3,4,11,12 – Grade Crossing Advance Warning</li> </ul>		<ul style="list-style-type: none"> <li>• W11-2 – Pedestrian Crossing</li> <li>• W11-3,4,16-22 – Large Animals</li> <li>• W11-5 – Farm Equipment</li> <li>• W11-6 – Snowmobile Crossing</li> <li>• W11-7 – Equestrian Crossing</li> <li>• W11-8 – Fire Station</li> <li>• W11-10 – Truck Crossing</li> <li>• W12-1 – Double Arrow</li> <li>• W16-5P,6P,7P – Pointing Arrow Plaques</li> <li>• W20-7 – Flagger</li> <li>• W21-1 – Worker</li> </ul>	
Fine Symbol Signs (symbol signs not listed as bold symbol signs)					
Special Cases					
<ul style="list-style-type: none"> <li>• W3-1 – Stop Ahead: Red retroreflectivity ≥ 7</li> <li>• W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35</li> <li>• W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7</li> <li>• W3-5 – Speed Reduction: White retroreflectivity ≥ 50</li> <li>• 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.</li> </ul>					

## 2.4 Deterioration and Damage Rate Studies

While the FHWA has outlined general guidelines for various methods of complying with the minimum retroreflectivity mandate, specific management strategies are left to the agencies to develop. These assessment and management strategies rely upon the ability to accurately predict how retroreflective sheeting will deteriorate over its service life. Sign deterioration studies are commonly conducted under either controlled or



uncontrolled conditions. Controlled conditions study the deterioration of traffic signs that are separated from the roadway and are commonly contained in an experimental sign retroreflectivity measurement facility (15). Uncontrolled signs are in-service signs that are exposed to traffic, damage, as well as natural weathering.

#### 2.4.1 Controlled Conditions Deterioration Studies

AASHTO established the National Transportation Product Evaluation Program (NTPEP) in 1994 to eliminate duplication of testing and auditing by states and manufacturers for products that are used on transportation infrastructure (16). In order for new sheeting material to be used in the United States, the manufacturer must submit it to NTPEP for testing. In accordance with ASTM D4956-11 and ASTM G7/G&M-11, standards sheeting types are oriented at a 45 degree angle and facing the equator. Sheeting types tested at this orientation have been shown to deteriorate twice as fast compared to vertically mounted samples (17). The NTPEP only collects data on sheeting materials for three years but, due to the orientation and setting of the samples, it effectively represents six years of deterioration. The weathered samples are compared against a control sample that has been stored in a protective environment. Controlled deterioration studies have less variability in their results because they only experience natural weathering and are examined by manufacturer representatives prior to testing to ensure quality. Even with only natural weather the results of controlled condition deterioration are inconclusive. As shown in Table 2.4, the difference in initial and final retroreflectivity varies by both test deck facility and sample within a test deck facility. In some cases, sheeting performance had increased overtime, whereas in other cases the file

sample that was not exposed to natural weathering experienced a higher degree of deterioration than the exposed samples.

It is possible that some of the counterintuitive results could be eliminated by increasing the sample size of the control sign population. Even the best testing facilities are subject to human error in measurement recording and this is evident in the Virginia samples. It is apparent that the point instrument was improperly rotated when the initial measurements were taken. Due to the rotational sensitivity of prismatic sheeting types, any use of a point instrument for portable retroreflector readings can produce inaccurate readings if testing procedures are not followed.

**TABLE 2.4 NTPEP analysis on 3M diamond grade white sheeting (18)**

		Portable Reflectometer Reading (cd/lx/m <sup>2</sup> )					
	Specimen	Initial	6 Month	1 Year	2 Year	3 Year	Δ
AZ <sup>a</sup>	Sample A	905	906	884	901.5	857	48
	Sample B	910	926	931	940.5	922	-12
	File Sample	939	944	928	940	927	12
VA <sup>a</sup>	Sample A	663	884	891	902	890	-
	Sample B	689	895	901	899	894	-
	File Sample	736	-	895	914	934	-
MN <sup>b</sup>	Sample A	876	867	876	794	825	51
	Sample B	891	889	870	834	787	104
	File Sample	911	901	901	892	843	68
LA <sup>b</sup>	Sample A	800	809	777	759	734	66
	Sample B	820	807	779	755	716	104
	File Sample	806	813	818	819	790	16

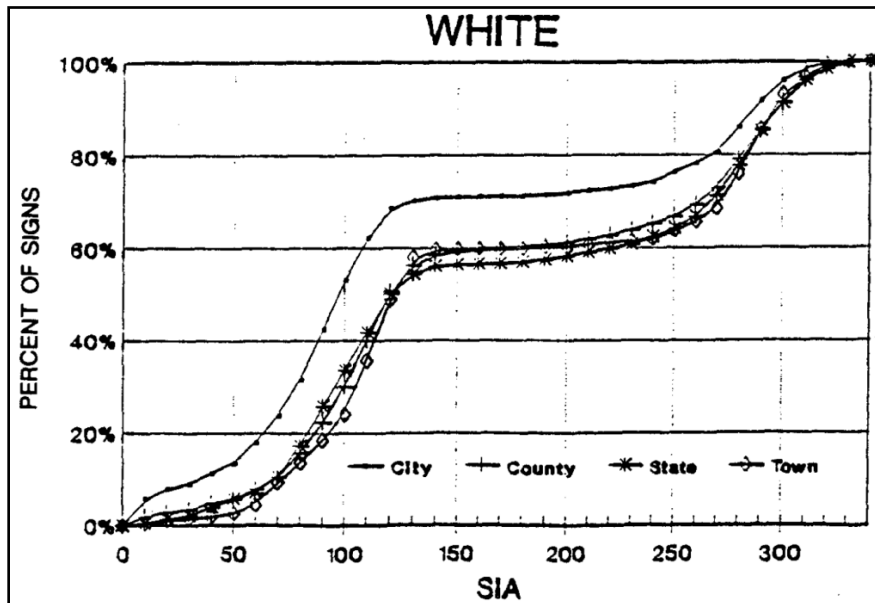
<sup>a</sup> Portable retroreflector was a point instrument at a rotation of 0°.

<sup>b</sup> Portable retroreflector was an annular instrument.

#### 2.4.2 Uncontrolled Conditions Deterioration Studies

The first project looking into retroreflectivity performance of in-service sign sheeting was completed in 1992. For the project, over 8,000 signs were collected and analyzed from 26 states to assess the practicality of the proposed minimum retroreflectivity levels (3). The primary goals of the project were to determine: overall retroreflective conditions of traffic signs across the nation, estimate the size of the underperforming sign population, and estimate the economic cost of establishing the minimum retroreflectivity levels on state and local agencies. The performance of traffic signs was organized by color and summarized via frequency diagrams as shown in Figure 2.4. An additional hindrance to the performance forecasting value of this project was the limited number of known installation dates. At the time only one jurisdiction had an inventory that included installation dates for the traffic signs under their jurisdiction. At the conclusion of the project it was determined that a sign's  $R_A$ , referred to as specific intensity per unit area (SIA) within the report, deteriorated no significant factors that contributed to rapid deterioration could be determined. The report did conclude that, for white on red signs, the measured  $R_A$  increased overtime the cause for which was theorized to be the fading of the silk screen which exposed more the retroreflective material to the light source (3).

In 2001, a research group for the Oregon Department of Transportation (ODOT) conducted a study with the specific goal of determining the relationship between retroreflective performance and the service life of traffic signs. At the completion of the collection effort the sample sign population consisted of 157 Type III signs distributed

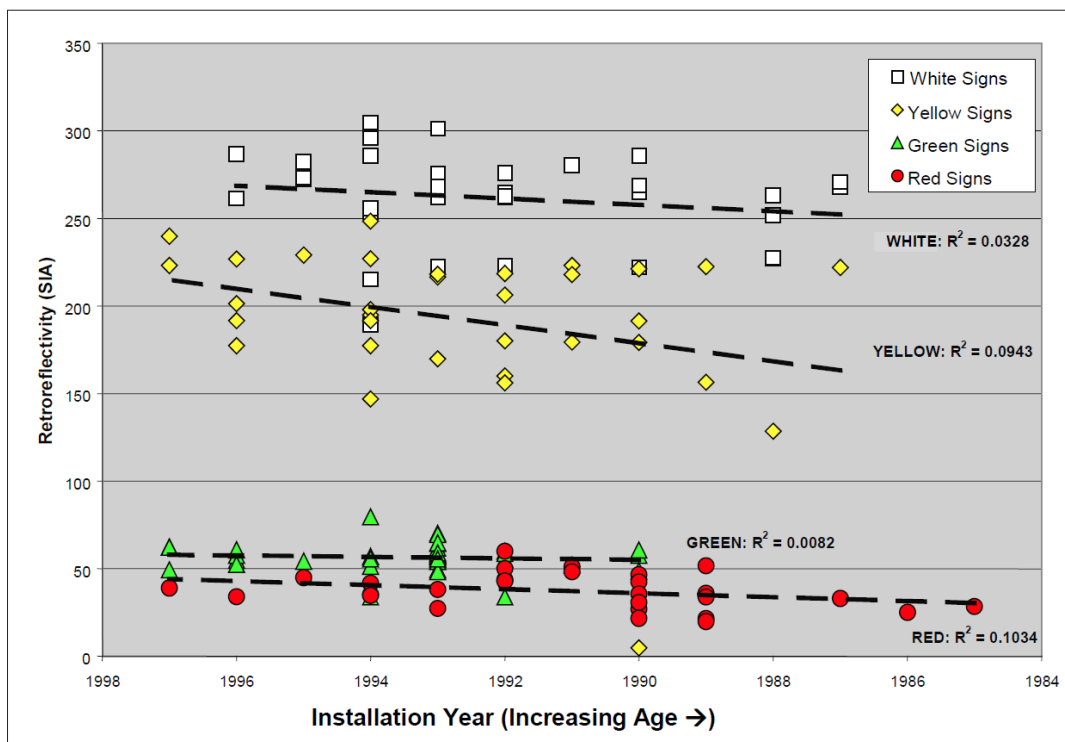


**FIGURE 2.4** Frequency graph for white sheeting (3)

across four sheeting colors (19). At the conclusion of the analysis, the projected trend lines demonstrated a low correlation between retroreflective performance and the age of the traffic sign, as shown in Figure 2.5.

The researchers cited two major factors that contributed to the weak relationships: the age range of the traffic signs and the reliability of observed installation dates. Since most manufacturer warranties for ASTM Type III sheeting are around 10 years, the idea that the age range was not big enough to provide an accurate depiction of sheeting deterioration is invalid. The accuracy of installation dates is crucial to any deterioration study and could easily distort the true deterioration of traffic sign sheeting.

The major issue with this research was the practice of washing the traffic sign prior to take retroreflectivity measurements. Doing so enables the sign to produce higher measured values, but these do not reflect the true in-service performance.



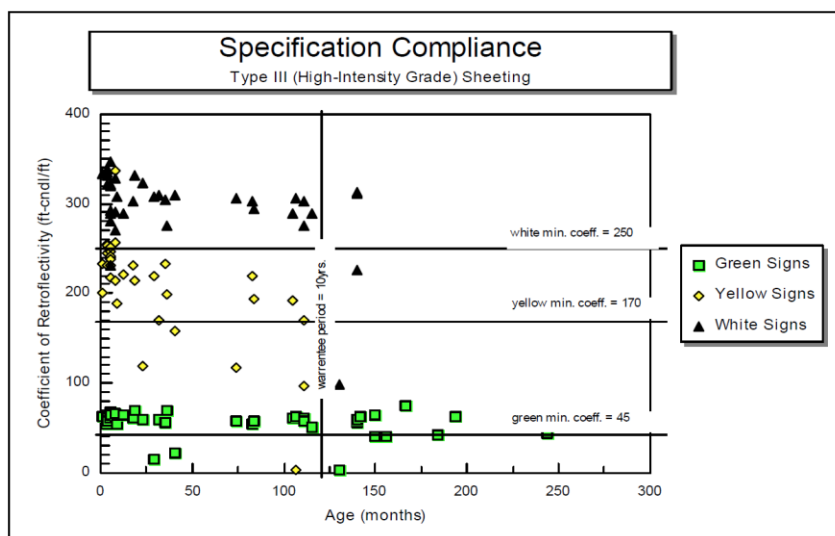
**FIGURE 2.5 ODOT retroreflective performance trend lines (19)**

Retroreflectivity measurements are very sensitive to the presence of water and not allowing for adequate drying time can drastically affect the values returned from a retroreflectometer.

In 2002, researchers from Louisiana State University conducted a study on furthering the evaluation of contributing factors to rapid sheeting deterioration for the Louisiana Department of Transportation and Development (DOTD). At the conclusion of the data collection effort, 237 signs were surveyed with an equal distribution between Type I and Type III (20). Similar to the ODOT project, measurements were taken on cleaned traffic signs but, unlike the ODOT project, additional measurements were recorded prior to cleaning the traffic signs. Along with the age of the sign, the distance to

the edge of pavement, and the orientation of the sign face were also recorded. Figure 2.6 displays the retroreflective performance of the three colors measured during this research. The unwashed sign performance closely mirrored the cleaned measurements in the ODOT project. Yellow sheeting deteriorated at a faster rate than white, while green sheeting had nearly not observed deterioration rate. Using the three recorded sign attributes along with sheeting color, 12 performance equations were developed to forecast sheeting deterioration. Prior to this study, there was anecdotal evidence that the orientation of the sign face was a significant factor in sheeting deterioration. For the sample population surveyed by the research team, the F-test on the data determined that orientation and distance from the edge of pavement were not statistically significant (20).

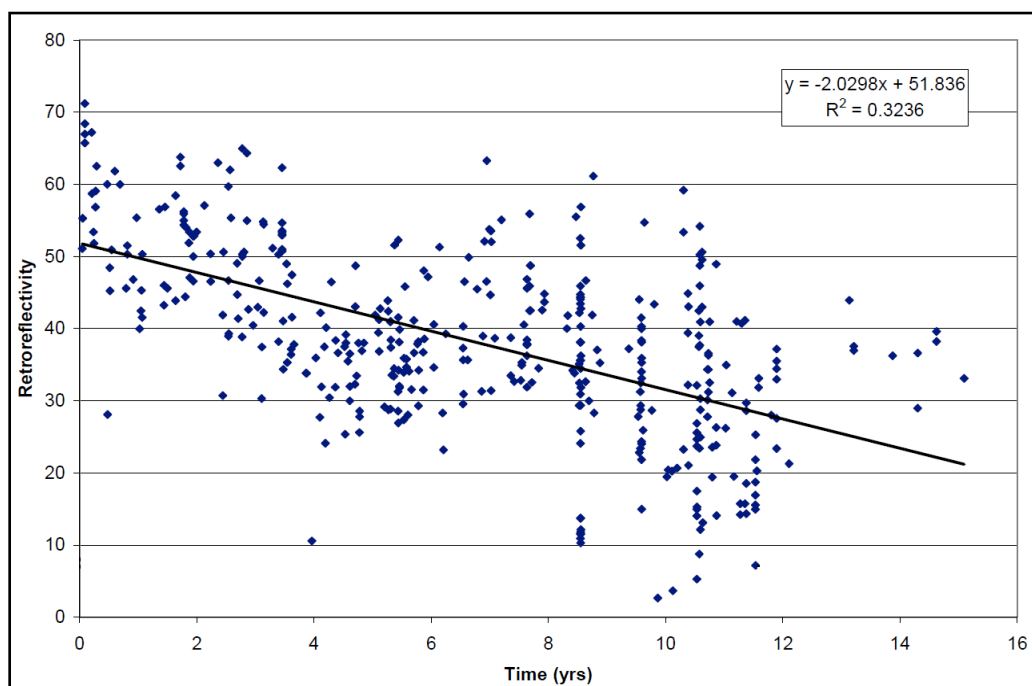
In 2002, the Indiana Department of Transportation (INDOT) conducted a study to assess traffic sign performance on roadways under INDOT jurisdiction. The study focused on ASTM Type III sheeting for red, white, and yellow signs. The report



**FIGURE 2.6 DOTD Type III deterioration trends (20)**

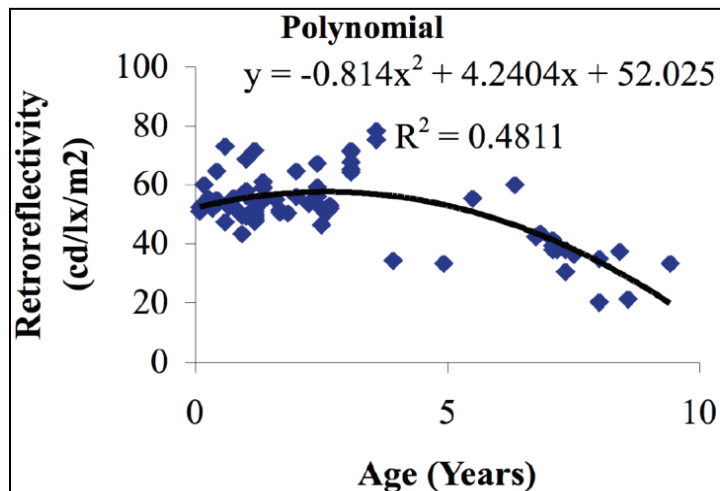
conducted analysis on 1,341 in-service traffic signs (21).

Although developing a deterioration model was not the primary focus of the study, analysis was carried out for the three different sheeting colors. The results for white sheeting matched those of the previous studies conducted by ODOT and DOTD, with a very slight decrease in retroreflectivity over time. For yellow colored sheeting, the deterioration trend line was steeper which again matched the data from the ODOT and DOTD reports. Where the INDOT report differs is the recorded deterioration rate for white on red sheeting over time. Contrary to the ODOT and FHWA study, the INDOT report displays a steep deterioration trend line for white on red sheeting, shown in Figure 2.7. This report did agree with the insignificance of sheeting deterioration due to the orientation of the signs face.



**FIGURE 2.7 INDOT Type III red deterioration (21)**

While trying to design an efficient nighttime inspection procedure for the North Carolina Department of Transportation (NCDOT), researchers reviewed data to try and determine any potential correlations between sign age and retroreflective deterioration (22). At the conclusion of the collection effort, 1,029 traffic signs of all four major colors were collected, with 60 percent of them being Type I sheeting. A general regression analysis was performed on the different sheeting colors and results were plotted by measured retroreflectivity versus the sign age. Linear, Logarithmic, Polynomial, Power, and Exponential curves were then fitted for each of the data sets. The best coefficient of determination,  $R^2 = 0.48$ , was observed on Type III sheeting using a polynomial curve fit, displayed in Figure 2.8. Due to the low degree of correlation for all of the sheeting types and colors, the researchers decided to extract the data from previous deterioration studies and plot new curves. This new data set included data from the FHWA (23), ODOT (19), DOTD (20), and INDOT (21) deterioration studies. Even with the increased sample population size, correlation between retroreflectivity and sign age was still consistently



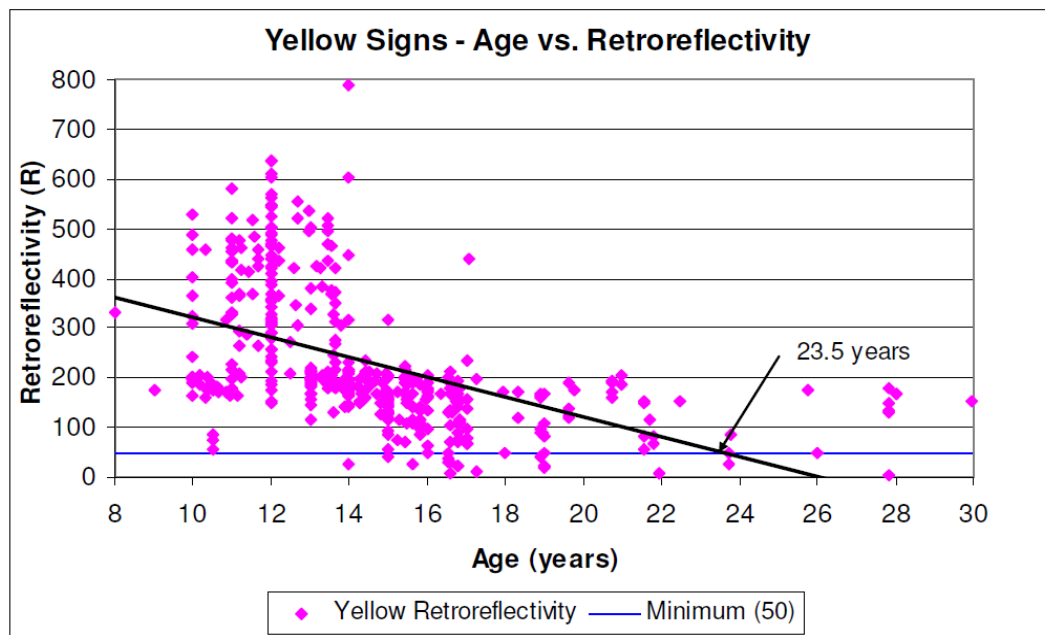
**FIGURE 2.8** NCDOT polynomial deterioration for Type III red sheeting (22)



low for all types and colors. Extrapolating the expected service life of a sign from these curves produced service lives ranging from 17 to 80+ years. In addition, green sheeting tended to increase in retroreflectivity with age, which is counterintuitive.

The most recent deterioration analysis was completed for the Pennsylvania Department of Transportation (PennDOT). By the completion of the collection effort, 1,000 traffic signs were measured that had experienced a minimum of ten years of service (24). The service life analysis was limited to Type III sheeting. The deterioration trend for Type III yellow sheeting is shown in Figure 2.9. Although the linear trend of age and retroreflectivity had a weak coefficient of determination,  $R^2 = 0.25$ , the researchers were confident that, for Type III sheeting of all colors, an expected life of 15 years could be expected.

The majority of deterioration trends were able to determine that signs do deteriorate over time but were unable to determine any significant contributing factors to the deterioration of retroreflective sheeting other than the age of the sheeting. Knowing the expected service life of a sheeting color and type combination would allow agencies to budget for expected sign replacements. The majority of the deterioration trend had  $R^2$  that were less than 0.25, which shows that factors other than age contribute to sheeting deterioration. Additionally, the majority of deterioration trend analysis has been conducted on Type I and Type III sheeting. UDOT continues to implement more prismatic sheeting into the sign population ensuring the visibility of the sign will become less vital. Most prismatic sheeting has retroreflectivity efficiencies that are 10 times greater than the minimum levels. Assessing the legibility of traffic signs will become more important than



**FIGURE 2.9 PennDOT Type III yellow deterioration (24)**

its visibility and more of an emphasis will need to be placed on damage rates.

#### 2.4.3 Traffic Sign Damage Studies

There has been limited previous research into the damage rates of traffic signs managed by an agency. Several studies have focused on the determination of the service life of traffic signs, but did not focus on the rate of sign damage. In 1991, a FHWA report stated that rural areas had a high frequency of vandalism damage (23). Another report by McGee and Paniati, while not discussing damage rates, concluded that the effects of damage on traffic signs should not be ignored (5). The report recommended that signs be visually inspected in order to ensure legibility and visibility but was silent on the issue of the frequency of inspection. This conclusion was reinforced by a report for the North Carolina Department of Transportation in 2002 (25). From 2005 to 2010 researchers at

North Carolina State University completed several reports that discussed observed damage rates of NCDOT traffic signs (22) (26). A total of 1,057 traffic signs were measured by the completion of the collection effort. Damage was organized into three categories: human caused, nature and non deliberate human damage. Of note is that the majority of the sign population was made up of Type I and Type III sheeting with little evaluation of the damage sensitive prismatic sheeting. Within the sample, dominated by Type I and Type III sheeting, researchers found that approximately four percent of all annual sign replacements were the direct result of damage (26). By identifying locations where increased damage rates are expected, agencies can begin to fine-tune assessment intervals and to develop mitigation strategies in the continuing effort to increase motorist safety. With the continued implementation of prismatic sheeting in UDOT's sign population, maintaining the nighttime legibility of traffic signs is expected to become more important than simply ensuring its visibility.

## **2.5 Recommended Methods for Maintaining Retroreflectivity**

Coupled with the minimum retroreflectivity levels established in the MUTCD there were five recommended methods for maintaining sheeting retroreflectivity. These five recommended methods are categorized into two groups: assessment and management (1). The difference being that assessment strategies evaluate the performance of individual traffic signs and management methods group signs by like attributes and manage them by expected group performance. The recommended methods provided in the MUTCD guidance section are:

- I. Visual Nighttime Inspection
- II. Measured Sign Retroreflectivity
- III. Expected Sign Life
- IV. Blanket Replacement
- V. Control Signs

Where methods I and II are assessment methods and III, IV, and V are management methods. Implementation of a single, combination or a different method (that has documentation proving its validity) would achieve compliance with the MUTCD standard for maintaining retroreflectivity. The standard states that “public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels” (I). The support for the above standard states that as long as a method is being used an agency would be considered compliant even if individual signs do not meet the minimum retroreflectivity levels (I). Regardless of what method is selected by the agency, the proper identification of sheeting types is critical for accuracy and completeness. Therefore, FHWA has provided a traffic sign retroreflectivity identification guide, which aides in determining sheeting types produced from a variety of manufacturers, shown in Figure 2.10.

#### 2.5.1 Visual Nighttime Inspection Method

Visual nighttime inspection involves the assessment of the retroreflectivity of an in-service traffic sign by a trained sign inspector. Visual nighttime inspection has been demonstrated to be the most likely means for identifying a variety of nighttime visibility

problems associated with traffic signs. Agencies using this assessment method should develop a training procedure for inspectors and establish guidelines for their individual agency to manage the performance of signs. This training should facilitate the ability of an inspector to discern between signs that meet minimum retroreflectivity levels and those that are near or below standards (10). What makes visual inspection so advantageous to agencies is the ability to assess the retroreflectance of a traffic sign while identifying other issues with nighttime visibility. FHWA has approved three procedures for the visual inspection method: the calibration signs, comparison panel, and consistent parameters procedure. No matter the visual inspection method the following general guidelines should be followed: inspection must take place at night, at normal travel way speeds, in the right most travel lane, while using low-beam headlights (10) (28).

#### *2.5.1.1 Calibration Sign Procedure*

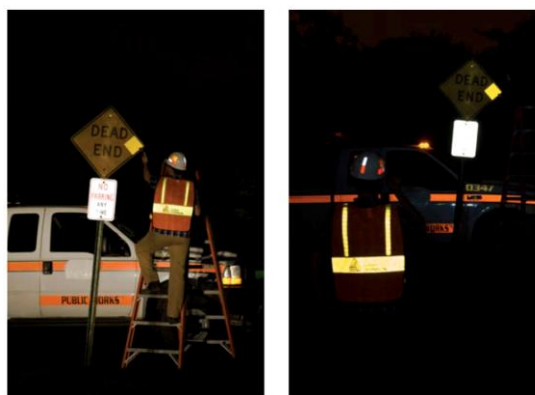
Calibration sign procedure involves inspectors viewing full scale traffic signs that are close to the minimum required retroreflectivity level to “calibrate” their eyes for that night’s inspection. Due to the observation angles that typically govern traffic signs (+0.2 degrees and +0.5 degrees), they should be viewed at a sight distance ranging from 200 ft to 500 ft (29). The calibration process should take place in the same vehicle used for nighttime inspection. The calibration signs can either be permanently mounted at a maintenance station or can be stored in between inspections to reduce the deterioration of the sheeting. Currently, minimum retroreflectivity kits produced by manufacturers are available for a quarter of the price of portable retroreflectometers (30).

2011 Traffic Sign Retroreflective Sheeting Identification Guide								
<p style="text-align: right;">U.S. Department of Transportation Federal Highway Administration</p> <p>This document is intended to help identify sign sheeting materials for rigid signs and their common specification designations. It is not a qualified product list. FHWA does not endorse or approve sign sheeting materials. Many other sheeting materials not listed here are available for delineation and construction/work zone uses.</p>								
Retroreflective Sheeting Materials Made with Glass Beads								
Example of Sheeting (Shown to scale)								
ASTM D4956-04	I	II	II	III	III	III	III	III
ASTM D4956-09	I	II	II	III	III	III	III	III
AASHTO M268-10	(1)	(1)	(1)	A	A	A	A	A
Manufacturer	Several companies	Avery Dennison®	Nippon Carbide	3M™	ATSM, Inc.	Avery Dennison®	Nippon Carbide	Orcal
Brand Name	Engineer Grade	Super Engr Grade	Super Engr Grade	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity
Series	Several	T-2000	15000	2800 3800	ATSM HI	T-5500	N500	5800
NOTES:	(2)	(3) (4)	(4)	(3) (4)	(4)	(4)	(4)	(4)
<p>(1) – Sheeting material does not meet minimum AASHTO classification criteria.                  (2) – Glass Bead Engineer Grade sheeting is uniform without any patterns or identifying marks. Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.                  (3) – Material no longer sold in the United States as of the date of this publication.                  (4) – Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new legends on green overhead signs.</p>								
Retroreflective Sheeting Materials Made with Prisms								
Example of Sheeting (Shown to scale)								
D4956-04	(5)	III, IV	III, IV, X	(5)	(5) / X	(5)	VIII	VII, VIII, X
D4956-09	I	III, IV	III, IV	IV	IV / VIII	VIII	VIII	VIII
M268-10	(6)	B	B	B	B	B	B	(9)
Manufacturer	3M™	Avery Dennison®	3M™	Reflexite®	Nippon Carbide	3M™	Avery Dennison®	3M™
Brand Name	Engr Grade Prismatic	High Intensity Prismatic	High Intensity Prismatic	High Intensity Prismatic	Crystal Grade	Reflective Sheeting	MVP Prismatic	Diamond Grade™ LDP
Series	3430	T-6500	3930	IC400	94000 / 92000	3940	T-7500	3970
NOTES:	(7)				(8)			(10)
Example of Sheeting (Shown to scale)						NOTE: The watermarks have been enhanced in this ID Guide. They are shown to scale but are not as visible on actual sheeting materials. It helps to view the sheeting materials at different angles to see the watermarks. The spacing of the watermarks varies and therefore watermarks may not be present on small pieces of sheeting.		
D4956-04	IX	IX	(5)	(5)	(5)			
D4956-09	IX	IX	IX	XI	XI			
M268-10	B	B	B	D	D			
Manufacturer	3M™	Avery Dennison®	Nippon Carbide	3M™	Avery Dennison®			
Brand Name	Diamond Grade™ VIP	OmniView™	Crystal Grade	Diamond Grade™ DG3	OmniCube™			
Series	3990	T-9500	95000	4000	T-11500			
NOTES:								
<p>(5) – Material was either unavailable in 2005 (previous version of this Guide) or unassigned in the 2004 version of ASTM D4956.                  (6) – Sheeting material does not meet minimum AASHTO classification criteria.                  (7) – Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.                  (8) – These two materials (94000 and 92000) are visually indistinguishable from one another.                  (9) – Material has been discontinued prior to AASHTO M268-10.                  (10) – Material no longer sold in the United States as of the date of this publication.</p>								

FIGURE 2.10 FHWA sheeting identification guide (27)

### 2.5.1.2 Comparison Panel Procedure

Comparison panel procedure require that inspectors clamp small sheeting panels on traffic signs that appear to perform below minimum retroreflective levels and determine if the sign is as bright as the panel. Typical dimensions for comparison panels are 6” by 6” sheeting samples (31). Unlike the calibration sign procedure, inspection crews do not need to calibrate their eyes prior to beginning the inspection. Instead they identify signs that appear to be near the minimum retroreflectivity levels and clamp the panel to the sign. Using a flashlight of adequate brightness an inspector assesses the sign’s retroreflectance and determines if it exceeds the panel, as shown in Figure 2.11. Signs that appear less bright than the panel should be scheduled for replacement, as is the case in Figure 2.11. As the inspection continues, the inspectors effectively calibrate their eyes throughout the night as they determine what the performance of a marginal traffic sign is. Because inspectors will need to exit the vehicle and clamp the comparison panels to the traffic sign, this visual inspection method would be more time consuming than the calibration sign procedure.



**FIGURE 2.11 Example of comparison panel procedure (31)**

### *2.5.1.3 Consistent Parameters Procedure*

Utilizing the consistent parameters procedure requires visual inspection of traffic signs to be conducted under conditions that are similar to those used in the development of the minimum retroreflective levels. This requires a sport utility vehicle or pick-up truck model year 2000 or newer. The inspector must be an individual age 60 or older. Inspectors then travel along the roadway at normal driving speeds and reject signs that are not legible for the 60 year old inspector (28). Due to the required inspector age, many agencies would have to hire senior citizens to assist in the inspection process. This requirement diminishes the feasibility of this method for most agencies.

### *2.5.1.4 Visual Inspection Accuracy*

The major concern of visual nighttime inspections is the subjective nature of the retroreflectivity performance. Nighttime inspections must maintain consistent testing procedures, while attempting to compare a qualitative visual assessment with the quantitative minimum retroreflectivity standards. The accuracy of nighttime inspection is dependent upon the amount of training the individual has received.

Inspectors in Washington State who only received limited training could correctly classify regulatory and warning signs with accuracies of 75 and 74 percent, respectively (32). Researchers at North Carolina State University (NCSU) shadowed NCDOT inspectors during the annual visual nighttime inspection and concluded that, for Type I sheeting of all background colors, inspectors could accurately detect failed signs 64 percent of the time (26). Depending on the inspection crew, correct detection for all traffic sign types varied between divisions ranging from 54 percent to 83 percent.



Furthermore, NCSU determined that individual inspectors who received detailed training could increase the accuracy of regulatory signs up to 82 percent (22). There is limited data available for inspector accuracy when it comes to Type III sheeting because the majority of infield signs have not degraded near the minimum retroreflective levels.

In order to evaluate the effects of inspector age on the accuracy of visual inspection, Purdue University briefly trained college students as sign inspectors (33). A total number of 1,743 traffic signs were first assessed using nighttime inspection and then later by the measured retroreflectivity method. The results of the study are summarized in Table 2.5. Type I error is defined as signs that inspectors failed but were later measured as passing signs and type II error is defined as signs that pass visual inspection but fail when the retroreflectivity was measured.

A contributing factor that should be considered in the accuracy of visual inspection is difference in retroreflective performance by sheeting type. The minimum values to be classified as a newer prismatic sheeting are six times greater than the minimum retroreflectivity levels. A Type IX would have to lose 86 percent of its

**TABLE 2.5 Purdue University inspector accuracy summary (33)**

Sign Group	Signs Surveyed	Type I Error	Type II Error	Percent Correct
White on Red	681	9	56	90.5%
Black on White	505	1	65	86.9%
Bold Black on Yellow	390	6	44	87.2%
Fine Black on Yellow	162	5	21	84.0%
All Other Colors	4	0	3	25.0%
$\Sigma=$	1,742	21	189	87.9%

retroreflectivity before it fell below the minimum levels. This means that, as agencies begin to implement more efficient prismatic sheeting into their sign population, underperforming traffic signs will become easier to identify.

An additional factor that might discourage agencies from implementing a visual nighttime inspection is accruing overtime pay for sign inspectors. There are several ways to avoid this scenario one being to hiring seasonal interns and train them as sign inspectors. As stated above in the Purdue University report, college age inspectors can correctly detect failing traffic signs with a high degree of accuracy (33).

Although FHWA provided a guidance statement for visual nighttime inspection in Paragraph 6 of Section 2A.08 of the MUTCD as:

The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels should be replaced. (1)

Many agencies failed to recognize the support statement for this guidance in Paragraph 5 of Section 2A.08 which provides a reference to the 2007 Edition of FHWA's "Maintaining Traffic Sign Retroreflectivity" document that provides addition information on all of the recommended assessment and management methods (28). Within this document FHWA divided visual assessment into the three aforementioned methods. Therefore, if an agency wants to utilize a different form of visual inspection, like daytime inspection, they must provide an engineering study that proves the validity of the method.

#### 2.5.2 Measured Sign Retroreflectivity Method

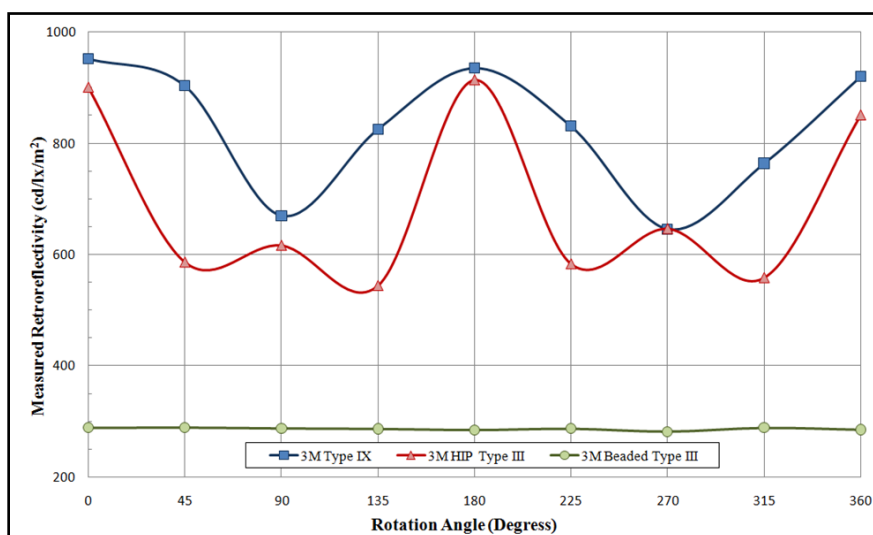
The other assessment method stated by FHWA in the MUTCD is measured sign retroreflectivity, which requires the agency to have access to a portable

retroreflectometer. The retroreflectometer returns numerical values that can be directly compared to the minimum retroreflectivity levels. This eliminates the greater part of the subjectivity presented by visual inspection. Following ASTM E1709-09 standards, four measurements are required for each retroreflective sheeting present on the sign. In order to describe the overall performance of the traffic sign, the four measurements are averaged (29). Collecting retroreflectivity measurements for every sign within an agency's jurisdiction requires the dedication of people-hours and therefore is cost prohibitive. Collection rates vary, depending on the number of attributes that are being measured, from 10 to 25 signs per hour (32) (34).

There are two types of retroreflectometers and, due to the geometric differences of the receiver aperture, the recorded measurements can significantly vary. Both types of retroreflectometer produce valid measurements, but values should not be compared between different retroreflectometers. For sign sheeting that is considered rotationally insensitive, both retroreflectometers produce similar values. The measured retroreflectivity of prismatic sheeting, which is rotationally sensitive, can significantly vary depending on the type of retroreflectometer. Since annual retroreflectometers essentially take the average of several points, they are less than sensitive to the orientation of the retroreflectometer. The measured value produced by point retroreflectometers can vary up to five percent for every five degrees of rotation from optimal (29). Therefore, the type of retroreflectometer combined with the rotation of the retroreflective sheeting or retroreflectometer can drastically affect the measured retroreflectivity of the traffic sign.

During the sample sign survey conducted for UDOT it was noted that there was high variance in values recorded from route identification signs, which share the same installation data and orientation. The inspection crew was using a Delta RetroSign Model 4500 retroreflectometer which is a point instrument (34). After careful inspection of the sheeting on the multiple signs present on the same support and installation date, it was determined that the sheeting upon the sign face was not optimally oriented. Repeating the techniques using by Carlson and Hawkins, but using a point retroreflectometer on different types of 3M sheeting used by UDOT produced Figure 2.12. Three types of ASTM sheeting were analyzed one spherical beaded, Type III, and two microprismatic Type III HIP (ASTM Type IV) and ASTM Type IX. The retroreflectometer started in its original “up” position and rotated clockwise in 45-degree intervals from 0 to 360 degrees. Four sections of the sign were measure and averaged to produce the lines in Figure 2.12. As expected, the insensitive beaded ASTM Type III shows negligible sensitivity to the rotation of the retroreflectometer. Conversely, the prismatic sheeting’s retroreflectivity decreases an average of 30 percent when rotated 90 degrees.

Research has determined that the rotational sensitivity of prismatic sheeting is only significant at a sight distance of 100 feet. At further distances the degradation in retroreflectivity shown in Figure 2.12 becomes negligible (17). This means that, from a visual assessment of the sign, the rotation is negligible but this is not true for the measured retroreflectivity. Any method that depends upon retroreflective measurements is susceptible to these rotational readings. There are two causes of rotational sensitivity in retroreflective measurement readings: instrument rotation and sign rotation. Further



**FIGURE 2.12 Rotational sensitivity of point retroreflectometer (34)**

complicating the measured sign retroreflectivity method is the bias and uncertainty in retroreflectometer measurements. In a study performed by Purdue University, 22 stop signs were measured under controlled laboratory conditions (35). The report focused on ASTM Type I and Type III sheeting that were measured by four different operators and three different retroreflectometers. In addition to the 22 stop signs, 87 in-service regulatory and warning traffic signs were measured. The goal of this report was to determine the bias and uncertainty in retroreflectivity readings when recorded by different operators and retroreflectometers. The coefficient of variation for each traffic sign was calculated for comparison between signs of different colors and sheeting types. The study concluded that the coefficient of variation for an individual sign was between 4 and 14 percent (35). The study concluded, that even under controlled conditions, there is nontrivial bias and uncertainty in retroreflectometer measurements.

### 2.5.3 Management Methods

Management methods try to predict how the retroreflectivity of signs that have similar color, sheeting type, or geographic conditions degrade over time. Management methods offer a semi hands-off approach to managing retroreflective compliance, which may prove advantageous to agencies that currently maintain comprehensive sign inventories. The three preapproved FHWA management methods are expected service life, blanket replacement and control signs.

#### *2.5.3.1 Expected Service Life Method*

For the expected life method, signs are replaced before the retroreflectivity degrades below the minimum levels. The expected service life can be based on manufacturers' warranties, measurements of infield control signs, retroreflective deterioration forecasting, and other various sources. What makes this method unique is its focus on managing signs based on installation date information. Installation dates can appear either on the sign itself and/or be recorded in a centralized agency database. Examples of installation stickers utilized by other agencies are shown in Figure 2.13.

The expected life of a sign can vary depending on the manufacturer, sheeting type and color, geographical location and various other attributes. Therefore, most agencies that implement this method will be reliant upon manufacturer's warranty periods until further research is completed on traffic sign sheeting deterioration. Until more accurate deterioration forecasting is completed, agencies will have to accept some level of error for the replacement of signs that both exceed and fail minimum levels. Although greatly

dependent on the manufacturer, typical warranty life for Type I, III, and IX signs are seven, ten, and twelve years, respectively (10).

Commonly, manufacturers establish the warranties to cover the sheeting for 80 percent of its initial  $R_A$  value. Looking at newly installed from the sample survey, white ASTM Type IX and XI have average  $R_A$  measurements of 564 and 745  $\text{cd/lx/m}^2$ , respectively. After these initial values deteriorated by 80 percent they would still have  $R_A$  measurements twice as large as the minimum retroreflectivity levels. By developing deterioration models, an agency can begin to look past a sign's warranty, and adjust replacement intervals to reduce sign waste.



FIGURE 2.13 Examples of installation stickers

### *2.5.3.2 Blanket Replacement Method*

The blanket replacement method is a modification of the expected life method which is executed either by geographical area, corridor, or sheeting type and color instead of by installation dates. Ideally, blanket replacement can be implemented most effectively with a combination of both geographic and sign sheeting criteria. Because this method requires no physical labeling of signs nor the need to record installation dates, it can be simple for an agency to implement. An agency only needs to keep track of the last blanket replacement (10).

The concerns that arise in the blanket replacement method are the high variance in expected sign deterioration levels. Similar to the expected life method if relevant data is not known about sign deterioration by region and sheeting type within the jurisdiction of agency, inefficiencies will arise. Within these inefficiencies is the waste that can occur if traffic signs are replaced in between scheduled replacement periods. These relatively new signs could be taken out of service before the retroreflectivity of the sign nears minimum levels if they are not carefully inventoried. One method to reduce traffic sign waste is to use newly installed signs that were replaced in the previous blanket replacement as the signs that replace damaged or knocked down traffic signs.

### *2.5.3.3 Control Signs Method*

Control sign method determines the life of the sign using control traffic signs placed within a maintenance yard or a sample set of in-service traffic signs. The subset of signs within the maintenance yard or the field needs to be representative of signs, sheeting type and color, within the region (10). Retroreflectivity is monitored via a



retroreflectometer to determine the performance of the sample population. For individual sheeting types and colors, as the measurements near the minimum level, signs should be replaced. The sample set of signs must be representative of signs in the region, in order to properly manage the signs in that region. Determining that a sign can out last the manufactures warranty by just a couple of years can save agencies signing materials and resources. Questions that arise during the implementation of this method are the required sample size for the control sample population, the number of control sample sites, and the frequency of retroreflective measurements. These questions are all left for the agency to decide and justify.

Researchers at NCSU produced a study on the construction and operation of an experimental sign retroreflectivity measurement facility (ESRMF). Under the estimations in the project the construction of an ESRMF would be \$82,000. This does not include the cost of a retroreflectometer for measuring  $R_A$ . The operation and maintenance of a ESRMF was approximated at \$20,000 per year (15).

## **2.6 Conclusion**

The above section described the basic principles of retroreflectivity, the establishment of minimum retroreflectivity levels, retroreflectivity deterioration and traffic sign damage, and the methods defined by FHWA for maintaining traffic sign retroreflectivity. Currently, forecasting retroreflectivity deterioration is difficult due to the amount of contributing factors. Traffic sign sheeting is known to deteriorate over time, but defining traffic sign attributes that significantly contribute to rapid deterioration

has proven problematic. Because of this, agencies must select a traffic sign management method that takes full advantage of their current known traffic sign information. Selection of an assessment or management method should take in to account efficiency of traffic sign assessment and accuracy of underperforming traffic sign detection. In Section 2A.06 of the MUTCD the support statements states:

The basic requirements of a sign are that it be legible to those for whom it is intended and that it be understandable in time to permit a proper response. Desirable attributes include high visibility during day and night and high legibility. (1)

While FHWA has recently place an emphasis on maintaining retroreflectivity as a means to increase nighttime driver safety, ensuring efficient retroreflectivity only guarantees the visibility of a traffic sign. The goal of a traffic sign maintenance plan should be to provide traffic signs that are both visible and legible to motorist, in the most cost efficient manner possible.

In order to determine current signage issues for the population under UDOT's jurisdiction, a collection effort was conducted to assess the performance of traffic signs across UDOT's maintenance regions. Previous studies have identified attributes that may contribute to rapid deterioration. During the data collection effort the offset, mount height, orientation and measured retroreflectivity will be collected. During the literature review a gap was identified in the current assessment of damage frequency on traffic signs under an agency's jurisdiction. Damage types were categorized and assigned severities depending on the degradation of the legibility and visibility of the traffic sign. Via utilization of geographic information systems contributing factors to higher rates of

sign damage will be analyzed to determine segments of the sign population that are more prone to damage. By performing this analysis a traffic sign maintenance plan that is catered to UDOT's specific signage needs can be developed to improve motorists safety, while achieving compliance with the retroreflectivity standard.

## CHAPTER 3

### DATA COLLECTION AND METHODOLOGY

#### **3.1 Introduction**

In order to assess the performance of traffic signs under UDOT's jurisdiction, a collection effort was launched. The attributes collected during the effort were sufficient enough to assess the feasibility of adopting any of the preapproved FHWA maintenance methods. Not focusing on a specific method allowed for flexible plan development, which could be adapted to overcome various inadequacies and issues discovered during the collection effort. Since UDOT maintains an estimated 95,000 traffic signs along 6,929 miles of roadway it is imperative that the sample sign population reflect the environments across all four of UDOT's maintenance regions. Collecting this data will provide insight into the current rate of compliance, damage frequency, and physical issues prevalent within UDOT's traffic sign population. While this research is a direct response to the retroreflectivity mandate, properly maintaining and managing traffic signs requires ensuring a variety of characteristics one of which is retroreflectivity. Therefore, an appropriately developed traffic sign maintenance plan needs to encompass both the legibility and visibility of a traffic sign. Within this section is a description of the collection methodology, assessment of current traffic sign performance, and a discussion of limitations in method selection from discovered inadequacies and issues within the subset sign population.

### 3.2 Traffic Sign Collection

For 2011-12 a traffic sign collection effort was launched to assess the current performance of traffic signs under UDOT's jurisdiction. Several different collection methods were utilized during the collection effort to ensure a variety of signs were assessed. During a preliminary collection two issues were identified: low sign variance along routes and the variety of observed traffic sign damage.

Collecting traffic sign along a route's entirety would result in a sample sign population that consisted mostly of white and yellow traffic signs. While this is representative of the expected sign population, it excludes red and green signs. Red signs have the highest priority because they are placed at locations to avoid collisions, whereas green signs often have the largest sheeting area and are therefore the most expensive signs within an agency. Since the purpose of this collection effort is to assess the performance of different types and colors of traffic sign sheeting, emphasis was placed on collecting an equal distribution of traffic signs by color. Junctions were selected across the state due to the diversity and density of sheeting color that is present. This cut down on the travel and equipment setup time during the collection effort. In an effort to spread data away from junctions, one sign color was collected for every 15 miles of travel in between junctions. This resulted in a sample set that had color diversity and was representative of signs located at junctions and along routes. The only exception to this collection methodology was traffic signs with installation dates. During the collection effort, regardless of color or location, any traffic sign that had an installation date present was collected. The reasoning behind this was the importance of known installation dates

to deterioration analysis on retroreflective sheeting. Figure 3.1 displays the location of traffic signs recorded during the collection effort across UDOT's maintenance regions.

It quickly became apparent that traffic signs under UDOT's jurisdiction experience a wide variety of traffic sign damage. Simply identifying that a traffic sign was damaged would provide inadequate information about the sign's performance. Therefore, damage was classified into the following types: bending, peeling, vandalism, cracking and other. Examples of each damage type are illustrated in Figure 3.2. During the collection effort, the severity of damage was also categorized. Damage in any form that diminished the legibility or visibility of the traffic signs intended message was designated as major damage, whereas damage that had negligible impact was minor damage. Due to the similarities that exist between different damage types, signs were later grouped into the following damage categories: aging, environmental and vandalism.

Aging traffic signs are signs that exhibited cracking across the retroreflective sheeting or peeling of the legend. This type of damage was most prevalent on UDOT's legacy Type I sheeting. Although the exact installation dates for these signs are not known, this type of damage is common on signs that have exceeded the manufacturer's warranty.

Environmental damage includes bending due to wind or snow thrown from snow plows, damages attributed to vehicle knockdowns and damaged caused by tree sap, tree rubbing, etc. The majority of environmental damage is considered inevitable, with the exception of bending which can be mitigated via back bracing. Under close inspection a significant amount of signs appeared to be damaged during the transportation and

installation of the sign. The presence of multiple cuts that penetrated one or more layers of the sheeting was identified as being environmental damage since the damage was not deliberate.

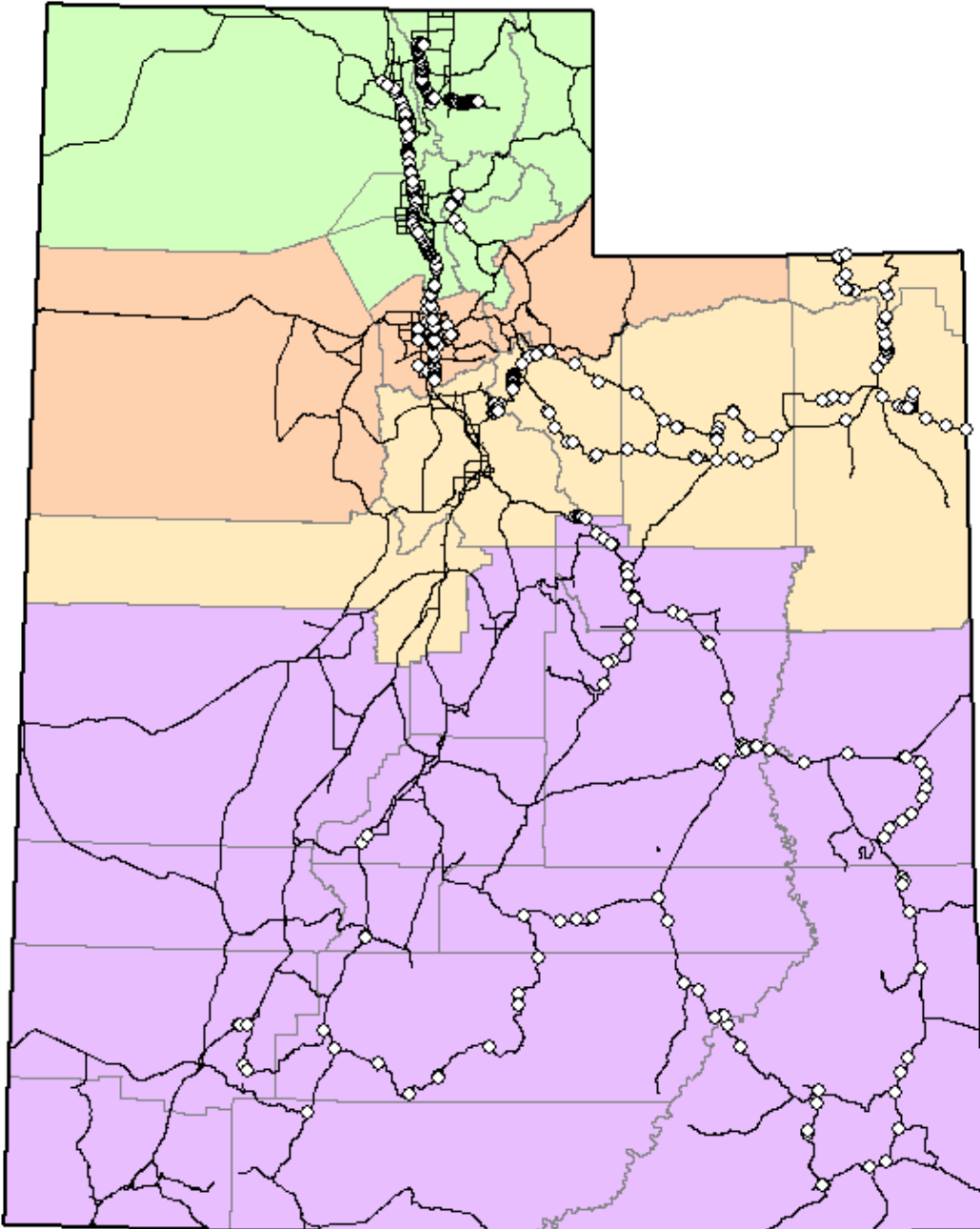
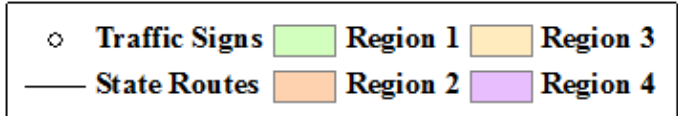
Vandalism damage is defined as any deliberate damage to the face of a traffic sign. Paintball impacts, bullet holes, eggs, bumper stickers, and spray paint were all categorized as vandalism damage. This type of damage was found more frequent in Utah's rural canyon areas and is considered the most detrimental form of damage due to the difficulty to assess how it affects the visibility and legibility of a sign at night.

In order to assist in deterioration analysis, various placement attributes were recorded for each traffic signs. These included: offset, mount height, and the orientation of the sign face. Combining this information with the measured retroreflectivity and observed damage severity would prove vital to analysis on traffic sign performance. All attributes were collected on a portable data logger that also recorded the elevation and GPS coordinates of the signs location.

### **3.3 Traffic Sign Performance**

In order to provide an adequate sample size, a total of 1,716 signs were recorded by the completion of the collection effort. The 1,716 traffic signs are just 1.8 percent of the estimated 95,000 signs under UDOT's jurisdiction. At the conclusion of the sample survey, five different ASTM sheeting types were observed in UDOT's sign population. The different sheeting types were ASTM Type I, III, IV, IX, and XI. The majority of

### UTAH DEPARTMENT OF TRANSPORTATION Maintenance Regions



**FIGURE 3.1** Location of sample sign population





A. Bending Damage

B. Peeling Damage



C. Vandalism



D. Cracking Damage



E. Other Damage Types

**FIGURE 3.2** Damage types

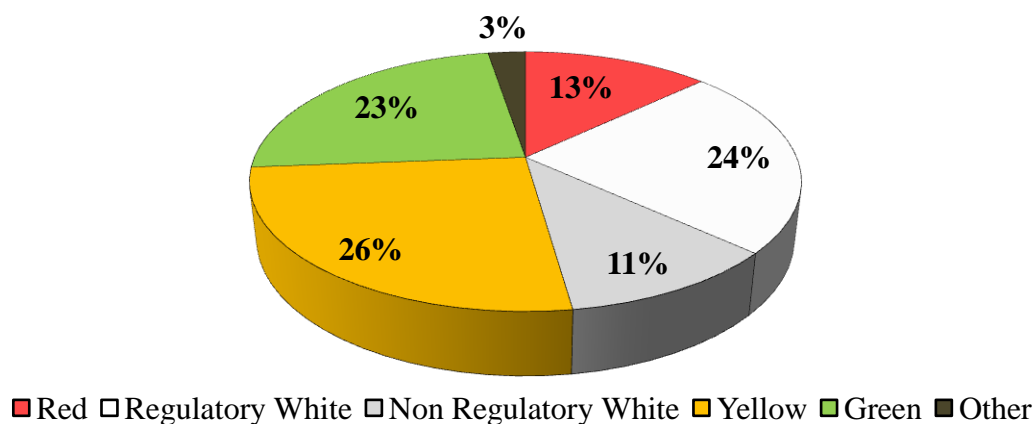
**TABLE 3.1 Summary of data collection signs**

Region	Red				White					Yellow				Green				Other	Total		
	III	III HIP	IX	XI	I	III	III HIP	IX	XI	I	III	III HIP	IX	XI	I	III	III HIP	IX		XI	
One	31	2	4	3	53	140	21	13	14	17	95	10	23	12	4	118	15	19	1	29	624
Two	24	13	14	1	0	10	36	20	19	1	16	8	10	10	0	21	8	14	12	12	249
Three	7	4	1	3	20	73	3	1	13	10	50	2	11	16	4	46	21	13	7	4	309
Four	88	12	4	13	13	99	17	11	19	7	80	33	26	10	7	58	4	18	15	0	534
Total	150	31	23	20	86	322	77	45	65	35	241	53	70	48	15	243	48	64	35	45	1,716

signs were manufactured by 3M Corporation, with some exceptions being produced by Avery Dennison. Table 3.1 displays a summary of traffic signs by color, type and UDOT maintenance region. Signs under the other column consist of fluorescent yellow and blue traffic signs. For consistency with UDOT's maintenance terminology, ASTM Type IV is referred to as Type III HIP for the entirety of this research.

The distribution of traffic sign by color is shown in Figure 3.3. With non-regulatory white signs being state route markers (M1-4, M1-5) and the accompanying directional arrows and regulatory white being all other white signs. During this collection effort no white on brown, black on orange, or black on fluorescent orange were recorded. Organizing the signs by maintenance region and sheeting type produces Figure 3.4. The majority of UDOT's traffic sign population currently consists of Type III retroreflective sheeting. Type I, UDOT's legacy signs, are currently being phased out due to low retroreflectivity performance and sheeting age. The majority of new installations are Type III HIP, Type IX and Type XI, which are all prismatic sheeting.

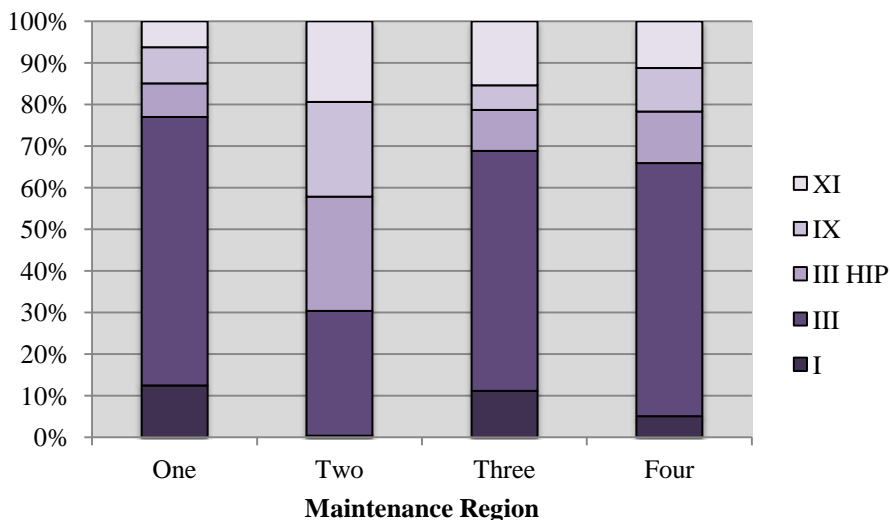
Overall, the vast majority of traffic signs under UDOT's jurisdiction are exceeding the minimum retroreflectivity levels. As is expected the only major underperforming sign population was the legacy Type I sheeting, which is currently



**FIGURE 3.3 Sample survey signs by color**

being phased out due to its poor retroreflectivity efficiency. Even though the majority of signs maintained by UDOT are not Type I, a significant population is still present.

The estimated Type I population is over 7,500, with 68 percent of this subset population failing to meet the minimum retroreflectivity levels. At the conclusion of the sample survey, it was determined that an estimated 6,643 traffic signs would fail to meet the minimum levels. The descriptive statistics for each sheeting type and color combination is shown in Table 3.2. The larger coefficients of variation (CV) for Type I and Type III sheeting are the result of excessive damage and deterioration. Even though 93 percent of the sample sign population was exceeding the minimum retroreflectivity levels, a wide variance in measured retroreflectivity was observed. Since each sheeting type and color combination has a substantially different means the coefficient of variation (CV) was utilized to provide a way to compare measured variations. As UDOT continues the current practice of removing Type I sheeting from its population, its rate of



**FIGURE 3.4 Distribution of sheeting type by maintenance region**

compliance with the retroreflectivity mandate is expected to increase since 93 of the 120 observed failures occurred on Type I sheeting. A more detailed discussion on the performance of different types of observed sheeting is provided in the Appendix A of this report. By the completion of the sample survey, several inadequacies and issues were discovered within UDOT's traffic sign population including: limited installation information, improper installation of rotationally sensitive sheeting, decline in legend to background contrast ratio on red signs, and high rate of major damage.

### **3.4 Identified Sample Sign Population Inadequacies and Issues**

#### **3.4.1 Limited Installation Information**

During the collection effort, it quickly became apparent that any attempts to forecast sheeting deterioration for traffic signs maintained by UDOT was hindered by the lack of known installation dates. At the completion of the collection effort, only 17

percent of signs had known dates of installation. The majority of these installation dates were milepost which UDOT had a record of installation dates. Looking at traffic signs that had installation stickers, the total number of known installation dates reduces to 150

**TABLE 3.2 Descriptive statistics of sheeting type and color combinations**

Sheeting Type		Sheeting Color				
		Red	White	Yellow	Green	Blue
Type I	Min	-	0	0	0	-
	Max	-	116	75	14	-
	Mean	-	36	23	4	-
	STDV	-	39	26	5	-
	CV	-	108%	110%	114%	-
Type III	Min	2	91	5	6	8
	Max	95	346	287	67	41
	Mean	41	275	188	47	17
	STDV	21	35	61	10	8
	CV	52%	13%	33%	21%	50%
Type III HIP	Min	15	270	318	47	-
	Max	225	878	608	148	-
	Mean	122	642	421	100	-
	STDV	53	139	67	21	-
	CV	43%	22%	16%	21%	-
Type IX	Min	58	236	208	3	23
	Max	142	579	584	82	52
	Mean	86	436	390	55	38
	STDV	23	97	101	15	10
	CV	26%	22%	26%	27%	25%
Type XI	Min	39	472	406	55	-
	Max	204	1,045	743	148	-
	Mean	130	709	584	99	-
	STDV	47	127	83	21	-
	CV	36%	18%	14%	21%	-

Standard Deviation (STDV), Coefficient of Variation (CV)

signs or just less than nine percent. Installation dates are vital for determining the factors that contribute to sheeting deterioration. Even though UDOT has policies in place that require installation stickers to be placed on new signs, compliance with this policy was not consistently adopted by the stations and contractors. Without known installation information, deterioration analysis is impossible since there is no way of knowing how old the sign is.

#### 3.4.2 Improper Installation of Rotationally Sensitive Sheeting

In the midst of the collection effort a wide a variation in measured retroreflectivity was observed on prismatic sheeting that shared the same support and date of installation. Investigating this phenomenon further resulted in the determination that the sheeting on the traffic sign was installed in the non optimal orientation. As discussed in Section 2.5.2 of this report depending on the retroreflectometer and the sheeting type, the measured retroreflectivity may be up to 36 percent less than the true value at its proper orientation. While improperly orienting the sheeting only visual effects the signs retroreflectivity at distances of less than 100 feet, it can cause issues in attempting to forecast deterioration of retroreflective sheeting. Figure 3.5, displays examples of Type III HIP sheeting that is improperly oriented. The striping watermark should be placed in the vertical direction for optimal retroreflective efficiency. Measured retroreflectivity on both properly and improperly oriented sheeting produces large variations in measure retroreflective as seen in the prismatic sheeting population in Table 3.2. This increases the difficulties of forecasting UDOT's newest sheeting, which will have most of the known installation information in the near future.

### 3.4.3 Decline in Legend to Background Contrast Ratio

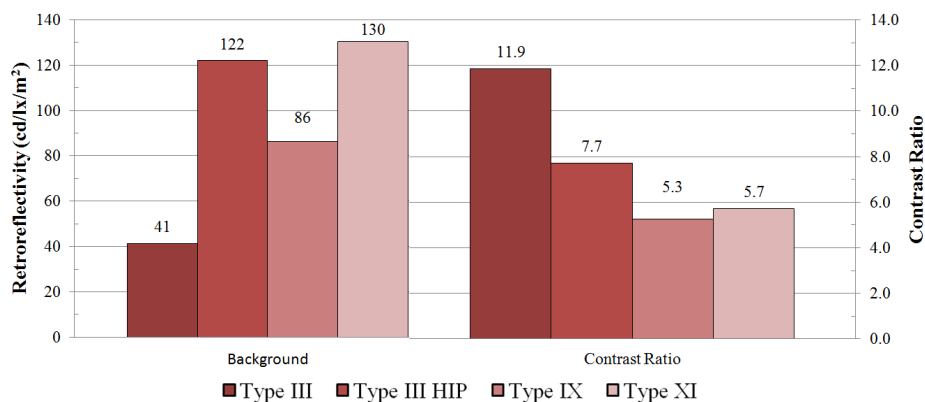
After further analysis on traffic sign performance an interesting trend was discovered that is a particular concern for red signs. A required characteristic of red regulatory signs is that they must maintain a legend to background ratio of at least 3:1. Retroreflective measurements taken on in-service prismatic sheeting types show that the increase in retroreflectivity efficiency in the background has not been matched by the legend, thereby decreasing the contrast ratio of the traffic sign. Figure 3.6, shows the relationship between measured retroreflectivity of the background and the resulting contrast ratio for the various sheeting types utilized by UDOT. As shown in the figure above as higher prismatic types are used on red signs there is a significant reduction in the average contrast ratio. This could lead to a higher rate of failure for newer prismatic sheeting signs far before they reach the minimum levels for the background and legend.

### 3.4.4 Observed Damage Frequency

During the collection effort, it was observed that traffic signs exhibited a wide variety and severity of damaged to the face of the sign. Seven percent of the sample sign



**FIGURE 3.5 Improperly oriented Type III HIP sheeting**



**FIGURE 3.6 Red sign background and contrast ratio relationships**

population did not meet the minimum retroreflectivity levels, while 28 percent had damaged present on the sign face that diminished the legibility of its message. Table 3.3 displays the number of sign failures by major damage category. Above and below refers to the minimum retroreflectivity level recorded via a portable retroreflectometer. The damage categories have different relationships with the retroreflective performance of the traffic signs. As shown in the previous figure, aging damage is indicative of lower performance but this does not hold true for the other types of damage. Environmental and vandalism typically passed the minimum retroreflectivity levels with failure rates of 12 and six percent, respectively. Environmental and vandalism damage accounted for over

**TABLE 3.3 Retroreflective performance of damaged signs**

Retroreflective Performance	Damage Category				Total
	Aging	Environmental	Vandalism	None	
Above	109	122	150	1,215	1,596
Below	79	17	10	14	120
Total	188	139	160	1,229	1,716



61 percent of all damaged traffic signs. As defined in the MUTCD, the basic requirements of a sign are, “that it be legible to those for whom it is intended and that it be understandable in time to permit a proper response” (1).

Therefore, the effects that damage has on the legibility of a traffic sign should be managed at the same importance as retroreflectivity is maintained. Simply ensuring that a traffic sign will have adequate brightness during nighttime conditions does not guarantee message conveyance. As shown in Figure 3.7, the S3-1 has a measured retroreflectivity of  $138 \text{ cd/lx/m}^2$ , but the paintball damage across the legend has effectively rendered the sign useless to motorists.



**FIGURE 3.7 Illegible traffic sign caused by vandalism damage**

### 3.5 Conclusion

In order to develop a traffic sign maintenance plan that ensures both the legibility and visibility of traffic signs maintained by UDOT, a data collection effort was launched. By its completion, 1,716 traffic signs were record along with various traffic sign attributes that would allow flexibility during the development of a traffic sign

maintenance plan. During the collection effort, several inadequacies and issues were identified that narrowed down the feasible maintenance methods.

The current sign population has inadequate installation information that all but eliminates the expected service life method. An inconsistent installation practice for prismatic sheeting types has produced various sheeting orientations throughout the sign population. The different orientations drastically affect the record measured retroreflectivity value of the sign, which adds subjectivity to the measured retroreflectivity method. Additionally, the blanket replacement method is reliant upon a replacement interval. Not being able to accurately predict when a sign will fall beneath the minimum levels means that conservative replacement intervals must be established based on the manufacturer's warranty.

During the sample survey, a trend was noticed in the contrast ratios present on red signs. For prismatic sheeting types, it was observed that a small contrast ratio was the result of a relatively bright background. Construction practices should be updated to ensure that newly installed prismatic red signs maintain the required contrast ratio. Currently UDOT is 93 percent compliant with the retroreflectivity mandate and this compliance is expected to increase as more Type I signs are removed from the sign population. As UDOT continues to implement more prismatic sheeting into the sign population, maintaining the legibility of a traffic sign is expected to become more important than simply insuring its visibility. Therefore, a traffic sign maintenance plan must be able to assess both the visibility and legibility of a traffic sign in order to improve motorist safety.

## CHAPTER 4

### DATA ANALYSIS

#### **4.1 Introduction**

Within the section of the thesis, analysis was conducted which attempts to determine factors that contribute to rapid sheeting damage and deterioration. Determining these factors will provide guidance in plan selection and implementation. By understand the current performance of UDOT's traffic sign assets UDOT can establish a proactive approach to managing and maintaining its traffic sign assets.

##### 4.1.1 Weather Observation and Location Data

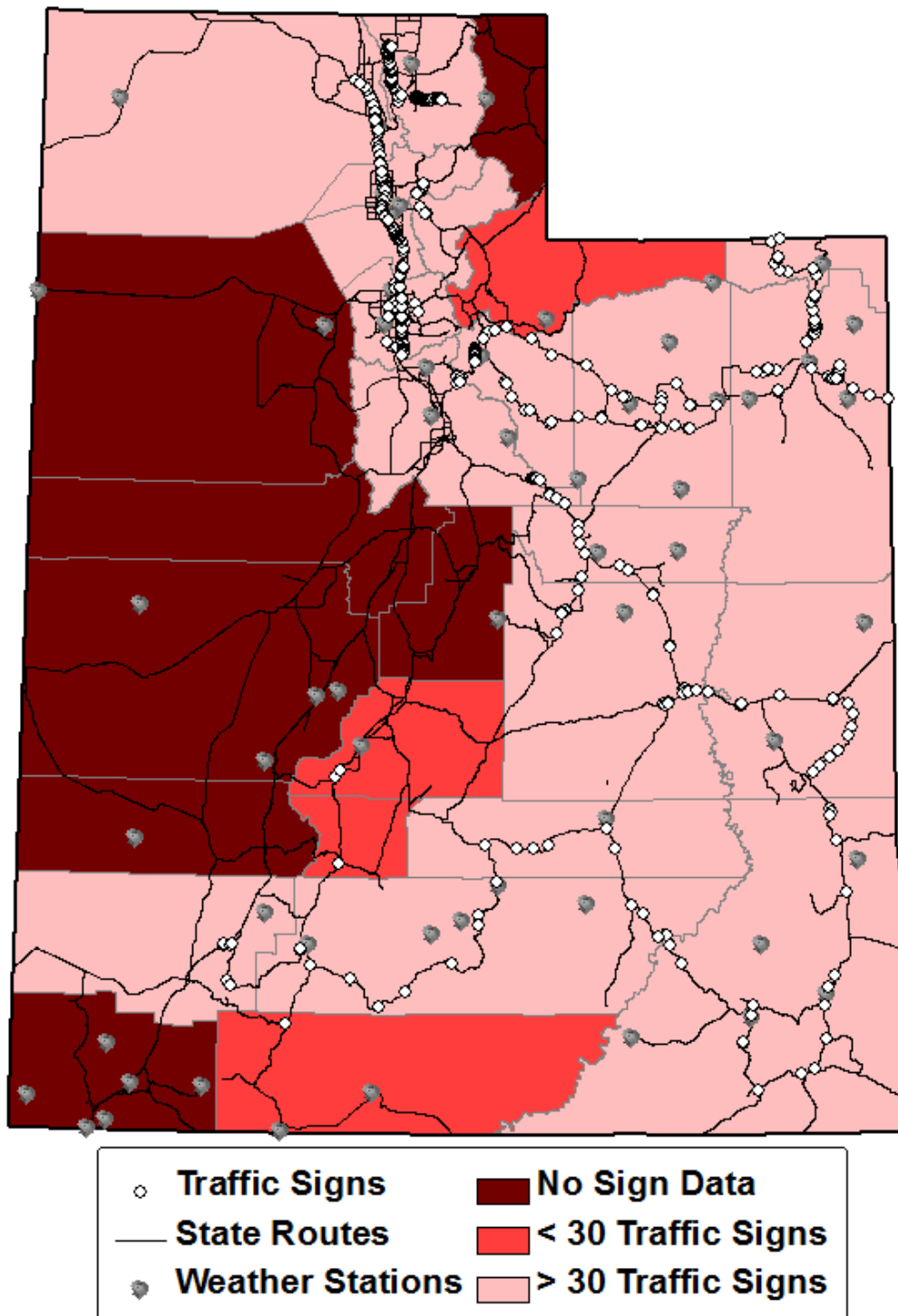
Weather observation and location data was collected from several sources in order to ensure completeness and accuracy. The average annual precipitation data was obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping system (36). PRISM data sets are recognized world-wide as the highest quality spatial climate data sets currently available. For the analysis in this report, the thirty year average (1981-2010) data set was used.

The seasonal temperature swing data was collected via MesoWest databases using two types of weather stations (37). The weather stations were a combination of National Weather Service (NWS) and Bureau of Land Management remote automated weather stations (RAWS). Hourly temperature data was downloaded for the last 10 years in order to represent temperatures seen by a sign during its service life. In order to represent the temperature range seen by a sign, seasonal highs and lows were averaged. For the

summer months, the temperatures during the hottest 12 hour period for each day were averaged. For the winter months, the coldest 12 hour period was averaged. The difference between the summer and winter 12 hour averages was defined as seasonal temperature swing. Figure 4.1, shows the location of the NWS and RAWS weather stations along with the location of traffic signs recorded during the collection effort.

The MesoWest weather station databases also recorded hourly wind speeds and wind gust speeds. Since the majority of the weather stations recorded similar average wind speeds, this variable was considered negligible. Average wind gust speed was determined by taking the average gust recorded by the station over the last 10-years.

Location data was organized into two categories: elevation and exposure. Both the elevation and exposure information were recorded during the collection effort. The elevation of each traffic sign was recorded by the portable data logger. The exposure of a sign was based on the environment that that surrounded the sign and was categorized into four different groups: canyon, mountain, rural, and urban. Routes that transitioned from rural to mountainous areas were classified as having canyon exposure. The only distinction between mountain and rural areas is that mountain areas had elevations greater than 6,000 ft. Urban exposure was latter defined by the US Bureau of Census (BOC) urbanized area boundaries data set (38). The BOC defines urban areas as having populations greater than 50,000. Traffic signs that were located within these urban boundaries were classified as having urban exposure.



**FIGURE 4.1** Locations of traffic signs and NWS/RAWS weather stations

#### 4.1.2 Damage Sign Analysis

The analysis portion of this thesis is divided into two sections. Because the damage categories are affected by different weather and location factors. The first section discusses the rates of aging and environmental damage with respects to average annual precipitation, elevation, seasonal temperature swing, and wind gust speed. The second section will discuss the effects of exposure on all categories of traffic sign damage.

##### *4.1.2.1 Average Annual Precipitation*

Measurements for average annual precipitation for each individual sign was extracted from the average annual precipitation PRISM raster data using ArcGIS. The results of this extraction are summarized in Table 4.1. As shown in Table 4.1 and in Figure 4.2, the majority of Utah's climate is classified as desert to semi-arid coupled with alpine mountains. From this data, it is apparent that the average annual precipitation plays a role in damage rate of traffic signs. Both damage and failure rates increased with an increase in average annual precipitation. Aging damage was three times as likely for traffic signs that experience more than 16 inches of rainfall.

##### *4.1.2.2 Elevation*

The elevation of individual traffic signs was recorded during the data collection effort via a portable data logger. The effects of elevation on traffic sign damage rates are summarized in Table 4.2. The GTOPO30 digital elevation model from the United States Geological Survey's EROS Data Center assisted in the creation of Figure 4.3 (38).

Similar to the damage rates observed with average annual precipitation, there is an observed increase in damage rates with elevation.

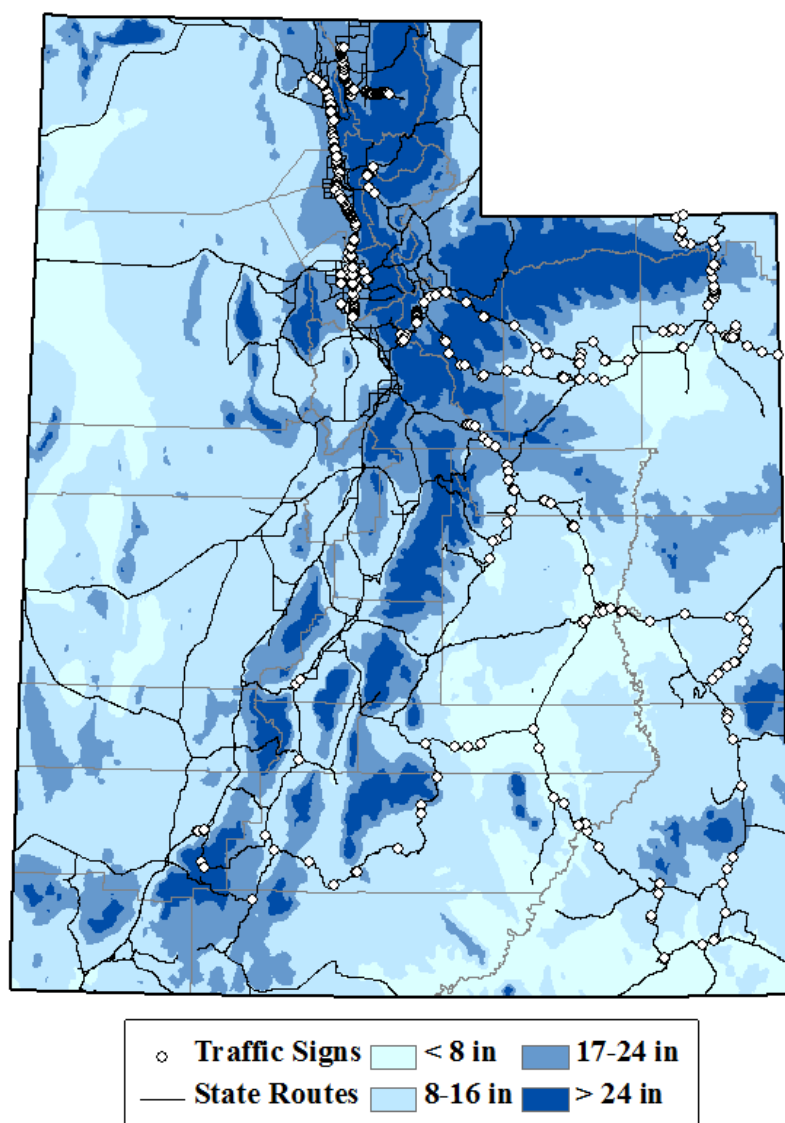
With the increase in elevation comes an increase in UV radiation and snow frequency. The increase in UV radiation can lead to rapid fading of darker background sheeting colors, which caused a decrease in overall contrast of the sign. This is a particular concern for white on red signs since they must maintain a minimum retroreflectivity level and legend to background contrast ratio. As shown in both Figure 4.2 and Figure 4.3, in Utah an increase in elevation typically equates to an increase in precipitation. Only 35 percent of the signs were located in areas that had greater than 16 inches of precipitation and at an elevation of at least 6,000 ft. Therefore, even though there is a correlation between precipitation and elevation, the majority of signs do not have both high precipitation and elevation. As snow plows clear roadways a significant amount of snow and roadway debris is thrown against the face of the traffic sign. This causes environmental damage to signs in areas that do not frequently have high wind and gust speeds.

#### *4.1.2.3 Seasonal Temperature Swing*

To account for expected highs and lows in annual temperature, temperature data was collected from weather stations across the state of Utah. For the summer months, the 12 highest hourly temperatures for each day were averaged, whereas for the winter months, the 12 lowest were averaged. By taking the difference of these measurements for the last 10-years, seasonal temperature swings focused on signs that experience a wide range in temperature. As summarized in Table 4.3, the majority of the sign population

**TABLE 4.1 Damage by average annual precipitation**

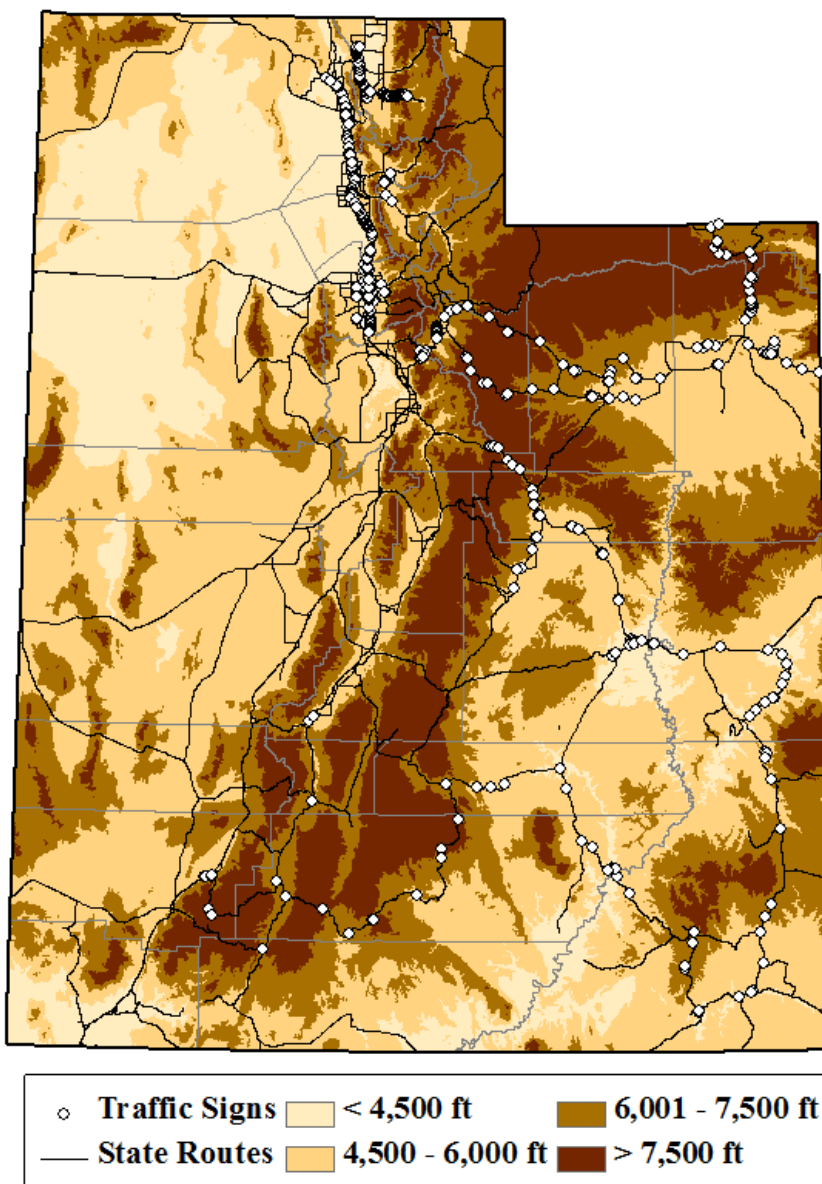
Precipitation (in)	# of Traffic Signs	Damage Category		% Damage	% Fail
		Aging	Environmental		
< 8	165	8	9	10.3%	6.7%
8-16	610	55	48	16.9%	5.9%
16-24	786	103	68	21.8%	7.5%
> 24	155	22	14	23.2%	9.0%

**FIGURE 4.2 Average annual precipitation map**



**TABLE 4.2 Damage rates by elevation**

Elevation (ft)	# of Traffic Signs	Damage Category		% Damage	% Fail
		Aging	Environmental		
< 4,500	527	45	34	15.0%	3.8%
4,500-6,000	836	95	67	19.4%	8.3%
6,001-7,500	258	31	30	23.6%	8.9%
> 7,500	95	17	8	26.3%	8.4%

**FIGURE 4.3 Elevation map**

experience seasonal temperature swings from 50 to 64 degrees. Sign locations that had lower seasonal temperature swings experienced a lower rate of damage. In order to produce Figure 4.4, the seasonal temperature swing data for areas in between weather stations was interpolated using ArcGIS. Values for individual traffic signs were determined by extracting values from that raster file created by the interpolation process.

Through observation made by researchers during the collection effort, aging damage was affected by the sheeting type of the traffic sign. For UDOT's Type I sheeting, aging damage commonly resulted in cracking across the sign face that penetrated down to the aluminum backing. On the oldest Type I signs, the retroreflective beading became very powdery and could be easily removed. The presence of aging damage on Type I sheeting proved to be a valid indicator that the traffic sign would not meet the minimum retroreflectivity levels. At the completion of collection effort, over 87 percent of aging damaged Type I traffic signs were performing below the minimum retroreflectivity levels. This did not hold true for multi-layer sheeting types. Of the observed 83 Type III signs with aging damage, 95 percent were performing above the minimum standards. Even though the vast majority of these signs retained enough retroreflectivity efficiency, other issues began to present themselves. Once a multi-layer sign is cut, cracked, or punctured it allows water to begin to collect within the layers of the sign sheeting. Over several seasons, the aging damage worsens via the freeze-thaw cycle causing the damage to fan out across the face of the sign. Not only does this begin to expose the retroreflective under layer to the elements, it also diminishes the contrast required for adequate legibility and visibility.

#### *4.1.2.4 Wind Speeds and Wind Gust Speeds*

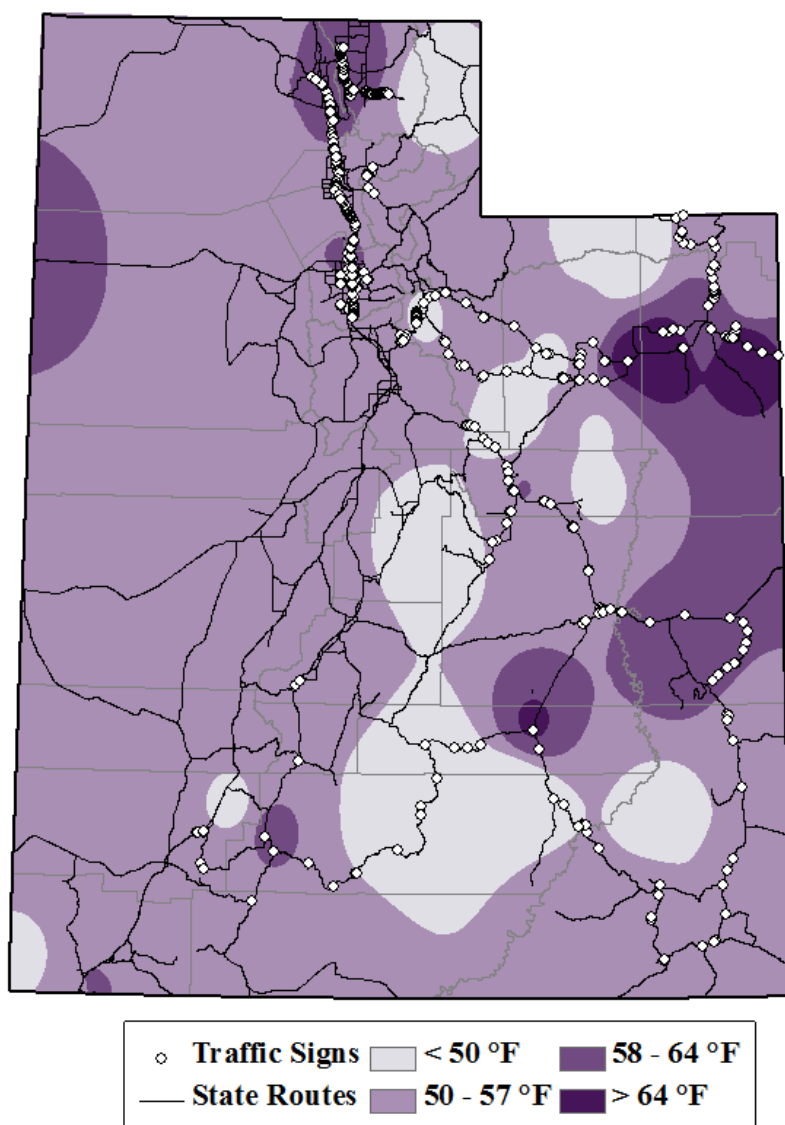
In order to determine if wind speed and wind gust speed was a contributing factor to increased damage rates, data was analyzed from the MesoWest database. Of the different contributing factors analyzed in this report, this is the only one that had a counterintuitive damage rate trend. As wind gust speed increased there was a decreased in the rate of damage. After further inspection, it was determined that UDOT has installed a significant amount of back bracing on traffic signs with average wind gust speeds above 20 miles per hour. For areas that averaged wind gust speeds greater than 25 mile per hour, over 64 percent of traffic signs had back bracing. Continuation of this maintenance practice will reduce the number of signs that are bent from both wind and snow plow spray.

#### *4.1.2.5 Exposure*

The affect that vandalism damage has on the legibility of a traffic sign depends greatly on the type of vandalism. Paintball and egg damage limits the available amount of light that can be retroreflected, but during the day it has little effect on the overall legibility of the sign. Compared to bullet holes, bumper stickers, and spray paint that can be seen during both day and nighttime conditions. In order to determine areas that exhibited high rates of vandalism damage, the traffic signs were organized into different exposure categories. Urban areas were determined by 2010 BOC urbanized area

**TABLE 4.3 Damage rates by seasonal temperature swing**

STS (°F)	# of Traffic Signs	Damage Category		% Damage	% Fail
		Aging	Environmental		
<50	152	12	5	11.2%	2.0%
50-57	880	84	77	18.3%	6.8%
57-64	630	83	52	21.4%	8.3%
>64	54	9	5	25.9%	9.3%

**FIGURE 4.4 Seasonal temperature swing map**

boundaries data. Using ArcGIS, traffic signs that intersected these areas were defined as having urban exposure. The remaining traffic signs were designated as having canyon, mountain, or rural exposures. Because vandalism damage is solely the result of humans it was excluded from the previous analysis section.

During a preliminary collection, it was quickly observed by the researchers that the damage rate for rural signs was greater than urban signs. Therefore, exposure was added to the collection attributes for each traffic sign. By the completion of the collection effort, this trend held true for signs across the state of Utah. As shown in Table 4.4, canyon areas had the highest rate of damage, while the urban sign population had the lowest observed damage rate.

Organizing the signs by exposure illustrates how much higher the rate of damage is compared to the minimum retroreflectivity failure rate. For all exposures, the damage rate was at least three times greater than the rate of failure. Canyon exposure had the lowest percentage of aging damage signs coupled with the highest rate of vandalized signs.

**TABLE 4.4 Damage rates by exposure**

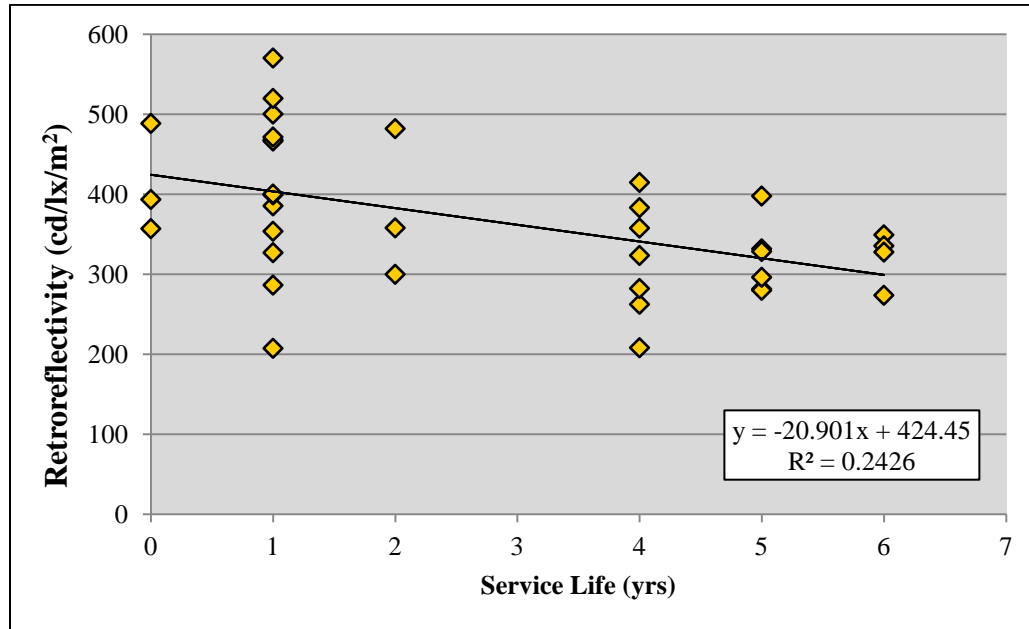
Exposure	# of Traffic Signs	Damage Category			% Damage	% Fail
		Aging	Environmental	Vandalism		
Canyon	197	20	19	35	37.6%	7.1%
Mountain	262	36	30	20	32.8%	9.5%
Rural	778	81	56	83	28.3%	6.4%
Urban	479	51	34	22	22.3%	6.5%

## 4.2 Preliminary Deterioration Analysis

During the collection effort different attributes were recorded to assess their potential effects on the deterioration of retroreflective sheeting. These attributes were the installation date, offset distance, mount height and orientation of the sign face. Post collection the offset distance and mount height were combined to create the effective distance of the sign. Since this analysis wanted to determine the contributing factors of traffic sign sheeting deterioration, all signs with major damage were excluded. This resulted in a deterioration population of 1,229 traffic signs. Other damaged signs that were the result of fading were included in the deterioration population.

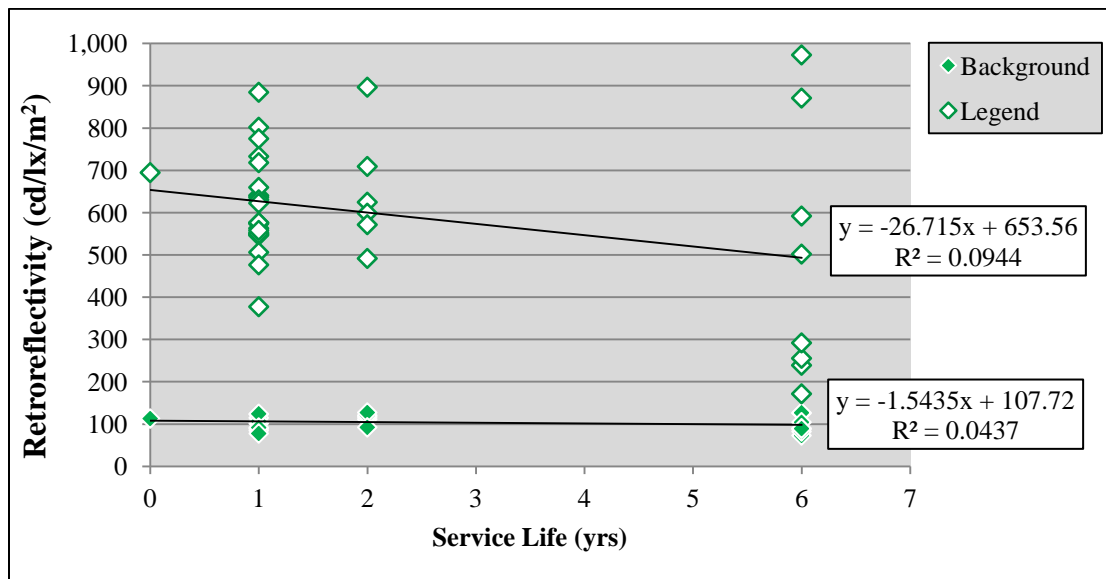
### 4.2.1 Sheeting Age

As previously mentioned within this report installation dates were not frequently observed on in-service traffic signs. It is common knowledge that retroreflective sheeting deteriorates over time, but little is known about what contributes to this deterioration. Figure 4.5, shows Type IX yellow traffic signs with known service life and its corresponding measured retroreflectivity. The linear regression shows that there is a downward trend in measured retroreflectivity, but values for certain years exhibit a wide degree of variance. The expected service life for this sheeting type and color combination would be 18 years. The darker guide signs experienced a minor downward trend of retroreflectivity performance as the sheeting aged. The relatively flat deterioration trend line for Type XI green may be the result of the green overlay fading over time and exposing more of the retroreflective material to the light source. Figure 4.6 shows the



**FIGURE 4.5 ASTM Type IX yellow deterioration**

measured retroreflectivity of the legend and background for Type XI green signs. During the collection effort the sheeting type for the legend was not recorded, because it was assumed to be the same as the background. It quickly became apparent that this assumption was wrong. Within Figure 4.6, it is evident that Type III, IX and XI white was utilized for the legend on the Type IX green traffic signs. This makes determining the deterioration of the contrast ratio very difficult for this color. From the data collected during the collection effort it is clear that over time retroreflective sheeting deteriorates. But as shown in the figures above traffic signs that have the same installation year display a large variance in measured retroreflectivity. In an attempt to determine what causes this variation in retroreflective performance additional analysis was conducted on the sign placement attributes.



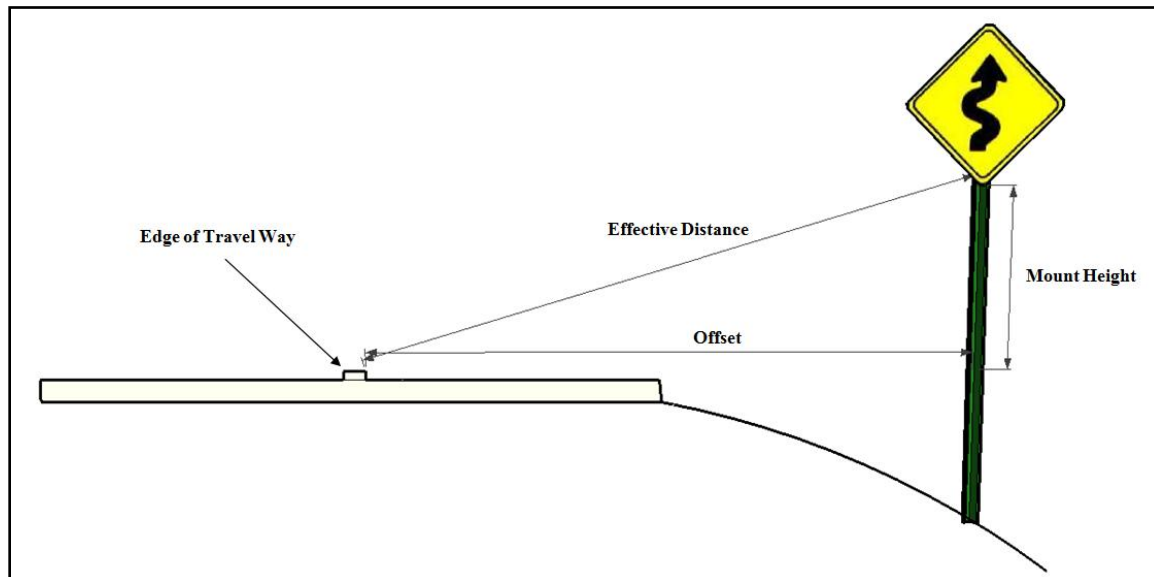
**FIGURE 4.6 ASTM Type XI green background deterioration**

#### 4.2.2 Sign Placement Attributes

During the sample survey three placement attributes were recorded for each traffic sign: orientation, offset and mount height. At the completion of the sample survey the offset and mount height were combined to determine the effective distance of the traffic sign. Figure 4.7, illustrates the different sign placement attributes. The first section analyzes the effects of effective distance and service life, while the second discusses the effects of the orientation of the sign face. Analysis was conducted on the effects that effective distance had on the portion of the sign population that had known installation. Linear regressions performed on undamaged signs with known installation dates are summarized in Table 4.5.

Values that are shown in grey were found to have no significant variables contributing to retroreflectivity deterioration. The best fits were for Type IX green and





**FIGURE 4.7 Illustration of sign placement attributes**

yellow sheeting, which only took into consideration the age of the sheeting. For green Type III HIP sheeting it was determined that the effective distance was significant for retroreflective performance, but the years of service was not. Even the bolded values in Table 4.5 do not provide accurate estimates of the deterioration of retroreflectivity and should not be used to estimate the service life of that sheeting type and color combination. Once UDOT increases the number of known installation dates, these equation could be improved upon. Currently this preliminary analysis only highlights a few significant variables that contribute to retroreflective deterioration. Due to the small sample size of signs with known installation dates determining the significance of sign face orientation was unfeasible. Therefore, orientation analysis was conducted on all recorded traffic signs. During the collection effort the true north-based azimuths, shown in Table 4.6 were used for orientation entry.

**TABLE 4.5 Linear regression analysis**

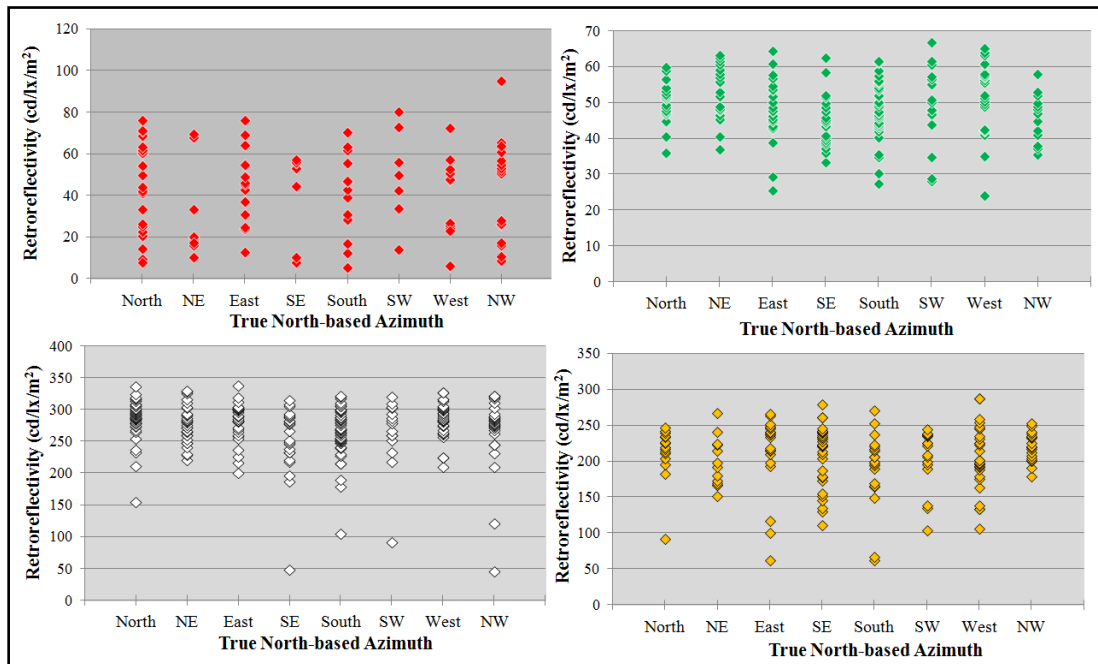
Coefficients (t Stat)	White		Yellow		Green	
	IX	XI	IX	III	III HIP	IX
Effective Distance	-0.33 (-0.53)	-1.46 (-1.86)	-	0.017 (1.35)	<b>0.19 (2.33)</b>	-
Years of Service	-11.42 (-0.53)	41.15 (0.61)	<b>-20.9 (-3.3)</b>	0.16 (0.164)	<b>-0.43 (-0.14)</b>	<b>-2.26 (-2.62)</b>
Sample Size	20	20	<b>36</b>	104	<b>24</b>	<b>17</b>
R <sup>2</sup>	0.09	0.19	<b>0.24</b>	0.02	<b>0.21</b>	<b>0.31</b>

One of the possible reasons for the poor fits for the regression equations was that the majority of known installation dates were observed on prismatic sheeting. Since prismatic sheeting are rotationally sensitive, and were commonly found orientated in its non-optimal orientation this causes a wide range of measured retroreflective variation for signs installed in the same year. In order to avoid rotational sensitivity, for the orientation analysis only Type III signs were analyzed. The measured retroreflectivity of Type III sheeting plotted against its orientation is shown in Figure 4.6.

The top half of the figure displays the darker red and green sheeting colors. Compared to the green retroreflective sheeting, the measure retroreflectivity of red signs varied greatly. Comparing the coefficient of variations (CV) the standard deviation for red Type III sheeting is 52 percent of the mean, compared to a CV of 21 percent for green Type III. Type III white had similar grouping, with the exception of a few outliers, with

**TABLE 4.6 True north-based azimuths**

North	337.5° - 22.5°	South	157.5° - 202.5°
Northeast (NE)	22.5° - 67.5°	Southwest (SW)	202.5° - 247.5°
East	67.5° - 112.5°	West	247.5° - 292.5°
Southeast (SE)	112.5° - 157.5°	Northwest (NW)	292.5° - 337.5°



**FIGURE 4.8 Orientation sensitivity of ASTM Type III sheeting**

over 66 percent of measurements between 265 and 325 cd/lx/m<sup>2</sup>. Contrasting to the CV of white Type III which was 13 percent of the mean, Type III yellow CV was 33 percent of the mean. A slight sensitivity towards southern facing signs was observed for yellow signs, but is far from being significant.

From analysis conducted on the detrimental effects of orientation on retroreflective performance it was concluded that the orientation of a sign was negligible. Since knowledge of know installation dates was limited the analysis was conducted without knowing the service life of the sheeting. As the number of known installation dates increases the effects of orientation, mount height, offset and effective distance might become more defined. With this current knowledge of UDOT maintained traffic signs the only contributing factor to retroreflectivity deterioration was the service life of

the sign. Although the service life was not significant for all sheeting type and color combination, it was the most significant attribute that contributed to sheeting deterioration.

### **4.3 Conclusion**

In order for an agency to efficiently implement a traffic sign maintenance plan, current issues within its signage population must be recognized. By the completion of the collection effort it was observed that the majority of UDOT's signs were performing about the minimum levels. Even though UDOT's signs were performing above the minimum levels the observed rate of damage was a concern to UDOT officials. Therefore, analysis was conducted into determining the contributing factors of increased damage rates. Even with the vast majority of UDOT's traffic sign population outperforming the minimum levels, determining the contributing factors to rapid sheeting deterioration would assist in estimating a traffic sign service life. Even though the sign population with known installation dates was undersized, a deterioration effort was attempted to determine the significance of different sign attributes on the deterioration of sign sheeting.

The major contributing factors that resulted in increased damage rates were average annual precipitation, elevation, seasonal temperature swing, and the exposure of the sign. By determining the contributing climate and location factors that lead to increased damage rates, agencies can identify routes that need more frequent assessment of sign legibility and visibility and can explore damage mitigation strategies. Although an

attempt was made in determining sign attributes that contribute to rapid sheeting deterioration the analysis was hindered by inadequate installation information. Once signage with known installation data has aged this analysis should be revisited to determine if any factors significantly contribute to the deterioration process.

## CHAPTER 5

### MAINTENANCE PLAN DEVELOPMENT

#### **5.1 Introduction**

This section discusses the development of a traffic sign maintenance plan for UDOT. Included within this section is a discussion about the feasibility of the five preapproved FHWA methods and maintenance plan recommendations. UDOT's maintenance plan should be adjusted to reflect the agency's current knowledge of its traffic sign assets. As newer technologies present themselves UDOT should adapt its maintenance plan to ensure that the process is as efficient as possible.

#### **5.2 Feasibility of FHWA Retroreflectivity Maintenance Methods**

This section discusses the feasibility and estimated cost of implementing the five approved FHWA methods in the MUTCD for managing UDOT's traffic sign population. Due to the similarities of the three management methods they will be discussed together in this section.

##### 5.2.1 Visual Nighttime Inspection

What makes visual inspection so advantageous to agencies is the ability to assess the retroreflectance of a traffic sign while identify other issues with nighttime visibility. Uniformity, damage, placement and obstruction can all detract from the ability of a sign to convey its message efficiently. FHWA has approved three procedures for the visual

inspection method. These procedures are the calibration signs, comparison panels and consistent parameters procedures. No matter the visual inspection method the following general guidelines should be followed: inspection must take place at night, at normal travel way speeds, in the right most travel lane, while using low-beam headlights (12). Since inclement weather can diminish the amount of available light to be retroreflected, it is recommend that collection only take place during the summer months.

Currently Avery Dennison offers a minimum reflectivity standard (MRS) kit which includes a full set of calibration signs and comparison panels. The MRS kit cost \$3,000 dollars and includes eight 24" x 24" calibration signs and 12 6" x 6" comparison panels (31). Purchasing a single MRS kit provides equipment for both the calibration and comparison sign methods. Studies have shown that inspector's age is negligible in visually assessing traffic signs that do not exceed the minimum levels (33). Therefore, inspection crews could be made-up of temporary interns, which would reduce the need for overtime pay of current maintenance staff. Due to the infeasibility of hiring 60-year old inspectors, the consistent parameters method is not considered feasible for UDOT to implement.

As with any assessment method the majority of the cost of implementation comes from the in-field collection of traffic sign performance. To ensure that visual inspection of traffic signs is conducted at night, assessment can only begin 30 minutes after the sun has set and must end 30 minutes before the sign rises. Using data collected by the United States Naval Observatory during the summer months there is an average of nine hours of darkness each day (39). Therefore, visual inspection can be done for a maximum eight

hours each night. Determining the amount of time need to complete a statewide inventory depends on the number of signs that need to be inspected. Table 5.1 displays the time necessary to complete a statewide visual inspection, which varies based on the number of traffic signs that need to be inspected.

Travel time is the main cost contributor in the visual inspection method. UDOT maintains 5,949 miles of highway and 977 miles of interstate highway. Since signs performance can only be assessed in the direction of travel, roadways will have to be driven twice, which equates to 13,852 miles. At a speed of 45 mph the required travel time for each inspection interval would be 308 hours. The calibration sign method requires no infield equipment setup and has an estimated collection rate of one sign per minute. Since the comparison panel method requires an inspector setting up a ladder in order to clamp the panel to the sign it has an estimated collection rate of three minutes per assessed sign. The combination method assumed that 50 percent of signs were inspected by the calibration sign method and the other half by comparison panel method. Since either visual inspection method ensures both the legibility and the visibility of traffic signs they are considered feasible for implementation by UDOT.

**TABLE 5.1 Estimated time required for visual inspection**

# of Signs Requiring Inspection	# of Signs Assessed	Visual Inspection Method		
		Calibration Signs (hrs)	Comparison Panels (hrs)	Combination (hrs)
1:1	95,000	1,891	5,058	3,474
1:10	9,500	466	783	624
1:20	4,750	387	545	466
1:30	3,167	361	466	413



### 5.2.2 Measured Sign Retroreflectivity

UDOT has previous experience with measure sign retroreflectivity from both the sample survey conducted by USU and a sign inventory completed in 2002. The main benefit of performing measured sign retroreflectivity is that measurements from the retroreflectometer can be easily compared to the minimum levels with limited subjectivity. Taking measurements on traffic signs ensures that UDOT will get the maximum service life out of each individual signs. An additional benefit of this method is that it does not require a comprehensive inventory of traffic signs. In fact this method could be used to establish an inventory and baseline retroreflectivity measurements.

Currently, UDOT owns four retroreflectometers that could be utilized in a measured sign retroreflectivity method and could all be service for \$1,200. If additional retroreflectometers are needed current prices range from \$1,500 per month for renting to \$10,000 for purchase. Extension poles can also be purchased to enable taking measurements on traffic signs without utilizing a ladder for \$1,500 (40) (41). Measurement of retroreflective sheeting using a portable retroreflectometer must be done in accordance to ASTM E1709 – 09, which requires a minimum of four measurements be taken per retroreflective sheeting present on the sign (29). This ASTM provides no guidance on where measurements should be taken. These measurements are then averaged to calculate the retroreflectivity of the traffic sign.

This brings up the question of how many measurements are required to provide a representative retroreflectivity. In addition to damage, the size of the traffic sign should play a role in determining the number of required retroreflective measurements. Four

measurements provide a better assessment of a rural stop signs retroreflectivity compared to an interstate guide sign. Taking into account the rotational sensitivity of sheeting and the bias and uncertainty of retroreflectometer measurements further increases the subjectivity of this method.

Depending on sign density and number of sign attributes that are being measured collection rates vary from 10 to 25 signs per hour (32) (34). UDOT currently maintains an estimated 95,000 traffic signs which would require a minimum of 3,800 person-hours to collect. Even if UDOT increased the number of measurements per retroreflectivity sheeting the increase in person-hours would be minimum due to the fact that the majority of time is spent traveling in between signs.

The collection rate during the sample survey was 15 signs per hour, but this could be increased by reducing the number of sign attributes that needed to be recorded. Table 5.2, displays the expected time required for a statewide measured retroreflectivity effort. Measured sign retroreflectivity provides a numerical value that can be directly compared to the minimum retroreflectivity levels. The increase in person-hours required by this method is supposed to result in measured retroreflectivity values with limited subjectivity. Measured retroreflectivity can only ensure the visibility of the sheeting that it measures and can never guarantee the legibility of the sign. Factors like sheeting orientation, location of measurements and number of measurements increase the subjectivity of this method. Due to the cost of this method and the uncertainty in it ensuring both the legibility and visibility of a traffic sign this method is not recommended.

**TABLE 5.2 Estimated time for measured sign retroreflectivity method**

Collection Rate (signs/hr)	Collection Time (hrs)
10	9,500
15	6,333
20	4,750
25	3,800

### 5.2.3 Management Methods

There are three management methods recommended within the MUTCD: expected service life, blanket replacement and control sign methods. Since 2008, UDOT has mandated that all signs placed into the field have an installation sticker on both the front and back of the sign. Compliance with this policy was not consistently adopted by the stations and contractors installing signs for UDOT and by the completion of the sample survey only 17 percent of the traffic signs had observed installation dates. Table 5.3, shows known installation dates by sheeting type from the sample survey. UDOT currently maintains a recorded of installation dates for milepost sign, but the vast majority of in place traffic signs have unknown installation dates. With the majority of traffic signs having unknown installation dates managing UDOT's statewide sign assets by the expected service life method is unfeasible.

Since the majority of UDOT signs have unknown installation dates implementing a blanket replacement method seems practical. Depending on the replacement interval UDOT would divide the state into different regions and replace all the signs in that region. This method would require no installation record keeping and would be simplistic

**TABLE 5.3 Known installation dates by type and year**

Type	Installation Year								Total
	2003	2004	2005	2006	2007	2009	2010	2011	
III	20	22	63	2	2	0	0	0	109
IIIHIP	7	0	15	0	6	2	2	0	32
IX	0	0	7	10	12	6	37	8	80
XI	0	0	8	0	0	19	44	2	73
Total	27	22	93	12	20	27	83	10	294

to implement and budget for. By replacing every traffic sign throughout its jurisdiction UDOT could start anew and fix various issues with its current sign population. But this comes at a cost since the vast majority of UDOT traffic signs are performing well above the minimum levels. The cost of replacing a sign varies with the size of the sign. For this blanket replacement analysis an average sign cost of \$350 was used. Although this price might be higher than typically replacement cost, it is averaging the sheeting area of larger interstate signs with smaller rural road traffic signs. Table 5.4 displays the expected annual cost for each replacement interval. The replacement intervals correspond with the anticipated sheeting life for the different types of sheeting.

**TABLE 5.4 Estimated cost of blanket replacement method**

Replacement Intervals	Type III, IV	Type IX	Type XI
	High Intensity Prismatic Series 3930	Diamond Grade VIP Series 3990	Diamond Grade GD3 Series 4000
10	\$3,325,000	\$4,001,875	\$3,973,375
12	\$2,770,833	\$3,334,896	\$3,311,146
15	\$2,216,667	\$2,667,917	\$2,648,917
20	-	\$2,000,938	\$1,986,688

The control sign method would require that UDOT establishes a comprehensive traffic sign inventory. UDOT could either select sample populations of in-service traffic signs or construct an ESRMF that contains a representative sample of traffic signs. If in-service signs are used as the control signs than this method would represent an efficient blanket replacement. Traffic signs would be replaced once the control signs for that color and type combination preformed below the minimum levels. The main difficulty is establishing corridors that have traffic signs that are representative of the region, both in color and sheeting type. An annual operation cost of \$20,000 per year would be expected to measured and record the retroreflectivity of the sample population. If UDOT constructed an ESRMF the estimated cost of construction would be \$82,000 with an annual operation and maintenance cost of \$20,000 (15). Using in-service field signs would reduce the upfront cost of constructing an ESRMF, but requires additional travel time for retroreflective measurements. Constructing an ESRMF would ensure that traffic signs are not lost to vehicle knockdowns, but they are also not exposed to damage and other real world factors that degrade sheeting overtime.

### **5.3 Maintenance Plan Recommendations**

In order to improve motorist safety on roadways under UDOT's jurisdiction traffic signs need to maintain high visibility and legibility. As discussed in the previous section, while the approved management methods are capable of ensuring visibility, a sign needs to be assessed on an individual basis to evaluate its legibility. Therefore none of the management methods are recommended for statewide implementation by UDOT.

The remaining two assessment methods are visual nighttime inspection and measured sign retroreflectivity.

FHWA describes measured retroreflectivity as an objective method since retroreflective measurements are simple averaged and compared to the minimum values. At first glance this seems to hold true, but several characteristics present in UDOT's sign population add subjectivity to this simplistic process. Sign sizes vary depending on several roadway characteristics. Therefore, the number of measurements taken on a sign should increase with size. Coupled with the number of measurements is the location of these measurements. The retroreflective value of a sign is highly subjective to the location and number of measurements. Further complicating these issues is the rotational sensitivity of prismatic sheeting.

Currently the majority of UDOT's new traffic signs are constructed with higher performing prismatic sheeting. In addition to the higher performance prismatic sheeting is rotational sensitive to the orientation of the retroreflectometer. This sensitivity has been discussed in literature with respects to the orientation of the retroreflectometer, but during the data collection effort inconsistent construction practices were discovered. In order to reduce sheeting waste it is not uncommon to construct a sign with its sheeting oriented at a suboptimal orientation. An example being the construction of diamond shaped warning signs, which are produced as squares then rotated later. Visually the reduction in performance is negligible for distances further than 100 ft, but it produces inaccurate retroreflective measurements. This diminishes the reliability of the measured values and will make it increasingly difficult to forecast sheeting deterioration in the future.

Taking into account the inherent subjectivity of the measured retroreflectivity method created by the number, location and rotational sensitivity of measurements decreases the implementation value of this method. Coupled with this uncertainty is the labor intensity required by this method. Continuous monitoring of retroreflective values would require a labor force that UDOT could not maintain within its current maintenance crews. Therefore, since the end results are subjective and the method is cost prohibitive it is not recommended for statewide implementation.

The most cost efficient and effective way for UDOT to ensure that traffic signs have adequate visibility and legibility is to visually assess the performance of individual signs at night. Although visual nighttime inspection is subjective in its assessment of retroreflective performance it is the only preapproved method that can examine the legibility of a traffic sign to nighttime motorist. Literature has concluded that inspectors age is not significant if the inspectors receive adequate training. Trained inspectors can be expected to have accuracies of 80 percent in determining underperforming signs. This inspection accuracy is expected to rise as more prismatic signs are installed within UDOT's signage population. Due to the efficiency of the prismatic sheeting lower performing traffic signs will become easier to identify.

As previously discussed three different visual assessment methods have been preapproved by FHWA. Due to the inspector age requirement the consistent parameters method is considered infeasible. The remaining visual nighttime inspection methods are calibration sign procedure and comparison panels. These methods require that an agency either construct or purchase signs or panels that at or near the minimum retroreflectivity

levels. Avery Dennison current provides a minimum reflectivity kit which provides equipment for performing both the calibration sign and comparison panel methods for \$3,000 (31). If it is difficult for UDOT to access low performing sheeting for the construction of these sign and panels then it is recommended that UDOT purchase a minimum reflectivity kit. Purchasing one kit would provide adequate equipment for two inspection crews. In order to reduce the strain on UDOT's current work force it is recommended that seasonal interns be hired and trained for the visual inspection of traffic signs. Once these crews are trained and have a basic understanding of the retroreflective process and the importance of maintaining both visibility and legibility of a traffic sign the follow inspection procedures should be followed.

#### 5.3.1 Recommended Inspection Procedures

The recommended procedure for both the calibration signs and comparison panels method are fairly similar and will be described together. Both methods require that inspections take place under proper darkness, therefore all nighttime inspection must wait half an hour past sunset prior to beginning. All inspections should be conducted at travel way speeds using the low beams on the vehicle. Due to the moisture sensitivity of retroreflective sheeting visual inspections should not be conducted during inclement weather conditions. Signs should be recorded for visual obstructions, low performance or severe damage.

The crew utilizing the calibration signs should set up the calibration signs a minimum of 300 ft, preferably 500 ft from the front of the inspection vehicle. With the low beams of the vehicle the inspectors will calibrate their eyes to the calibration signs to



establish a visual bench mark of underperforming signs. This process should last a minimum of two minutes to allow for adequate calibration of the inspectors eyes. Once the calibration time has passed the inspectors can begin the visual inspection. The passenger will be inspecting signs both for adequate visibility and legibility. If a traffic signs appears to be performing under the minimum levels or damaged severe enough to significantly diminish the intended message it should be scheduled for replacement. Using a customized data dictionary in a Trimble data logger or a custom mobile app the crew will pull over and take a GPS point next to the sign support. Included with the GPS point will be various attributes that will assist in the replacement of the sign including MUTCD code, sheeting type, size, damage, installation date and photograph. The inspection would continue throughout the night ensuring that both directions of the state routes are inspected. At the conclusion of the inspection the data will be sent to UDOT staff that will inspect the data to ensure its completeness and accuracy.

The process for the comparison panel procedure is very similar. Once the sun has been set for half an hour the inspection can begin. Once the inspectors identify a sign believed to be below the minimum levels they will stop the vehicle. Using a ladder one inspector clamps the appropriate comparison panel to the sign face. While the other inspector, standing a minimum of 25 ft from the support of the sign, illuminates the sign with a flashlight. If the comparison panel appears to be brighter than the sign then the sign is scheduled for replacement. Using the same customized data dictionary or mobile app the GPS location and sign attribute information is recorded and sent to UDOT personnel.

During either inspection method signs should be assessed for visibility and legibility. Therefore, signs should be recorded for visual obstructions, poor retroreflective performance, and extensive damage to the sign face. By associating the signs location along with its various attributes UDOT can link its sign assets to an ArcGIS map. This map would be used to prioritize replacements and adjust future inspection intervals.

### 5.3.2 Recommended Inspection Interval

At the implementation of the statewide visual inspection the inspection interval should be set at five years for all roadways under UDOT's jurisdiction. Regardless of the frequency of the inspection interval there will always be a subset of UDOT's traffic sign population that does not meet the visibility and legibility standards. By establishing a five year inspection interval this would enable UDOT to assess the performance of its traffic sign population, identify the location and quantity of underperforming signs, and provide adequate time to replace the identified signs. The first year would be spent conducting the nighttime inspections. The remaining four years would be spent on replacing the identified underperforming traffic signs. By conducting inspections every five years this should ensure that signs identified in a previous inspection have had adequate time to be replaced and are not re-inspected. Additionally UDOT would know that every five years they would have a subset sign population that needed to be replaced. Depending on the size and location of these signs UDOT could contract out the sign construction or construct the signs using their sign shop. By following this inspection interval it would eliminate replacement inconsistencies and become easy to budget for.

After a few inspection intervals have passed it may become clear that visual nighttime inspection is not the optimal method for certain roadways under UDOT's jurisdiction. Areas that experience frequent vandalism damage might be better served by a blanket replace rather than a visual inspection. Whereas, urban populations might only need to be assessed every ten years rather than every five. Therefore, it is important to remember that the way UDOT maintains its traffic sign performance should always reflect its current knowledge of its traffic sign assets.

### 5.3.3 Traffic Sign Inventory

Currently UDOT is conducting a statewide inventory of its transportation assets via mobile LIDAR collection. Traffic signs will be included and this inventory will become the foundation of UDOT's traffic sign maintenance plan. While this inventory will not be as accurate as a manual collection it will provide beneficial information that will assist in the evaluation of the traffic sign maintenance plan. How UDOT will maintain its traffic sign assets depends on the current knowledge of the sign population's performance. Although this inventory is not completed, the information for signs will be a GPS location, photograph, and a qualitative performance assessment. The main benefit of this initial inventory is establishing a population size. UDOT currently estimates that it manages 95,000 signs. This inventory will provide a more accurate sign population, as well as provide the number of regulatory, warning, and guide signs along each state route. This information is beneficial, but if it is not maintained then UDOT will not see the full return on its inventory investment. Since it is not financially practical for UDOT to

conduct a LiDAR inventory every few years, it is essential that UDOT develop procedures that will maintain this inventory.

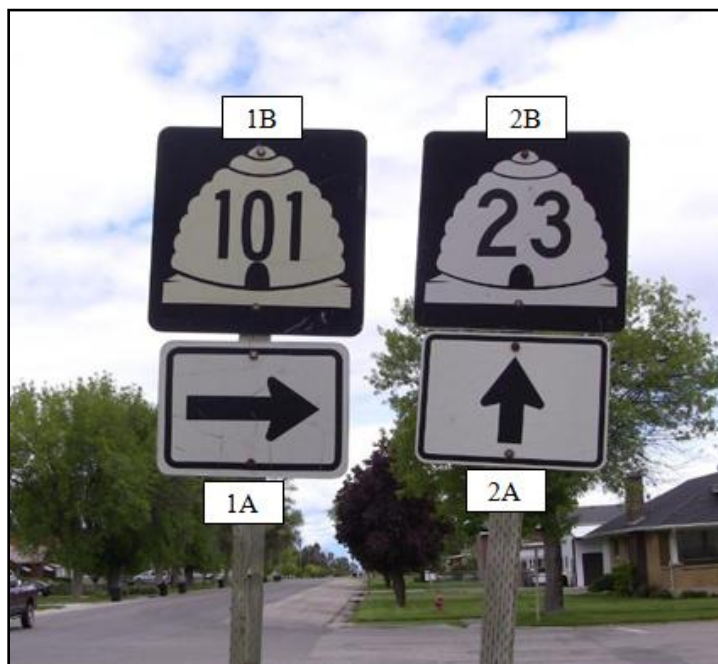
By following the aforementioned visual inspection procedure UDOT would be able to ensure that all sign replacements are recorded and leave a digital sign history. Maintaining a traffic sign inventory is a difficult process and would require accurate relays of information across all four of UDOT's maintenance regions. There are three major steps that would ensure that UDOT's traffic sign inventory reflects the current population.

The first step in maintaining a traffic sign inventory is identifying the sign in the field to the sign within the data base. Knowing the GPS location of a sign provides you with sufficient accuracy for the majority of traffic signs. Signs that will need additional information to clarify the exact sign would include signs pairs that are located across the street from each other, and supports that have multiple signs. For the sign pairs recording a direction of travel would be sufficient to distinguish between the two signs. For the signs that share a support a naming convention would need to be implemented similar to the one shown in Figure 5.1. The addition of a entry field in the data logger for sign placement and direction of travel would help ensure that the proper sign is recorded during the inspection and replacement process. If this procedure is followed it would eliminate the need to have physical bar codes for each sign or sign support.

The second step in maintaining a traffic sign inventory is ensuring that the fabrication of the replacement sign can happen in an efficient manner. In order to facilitate for this the traffic sign database should include the dimensions of the sign currently in place. This

might not be recorded during the initial inventory but should be recorded for subsequent replacement signs. Doing this would allow for more accurate cost estimates to be made for the replacement interval. In addition to the dimensions of the sign the sheeting type should be recorded to ensure that the replacement sign has the same performance characteristics of the sign it is replacing.

The third and final step for maintaining the traffic sign inventory would be ensuring that the installation dates for traffic signs are known on all new replacements. By inspecting traffic signs every five years this would provide a large replacement population. Therefore, for signs produced by a contractor the installation month and year could be stamped into the back of the sign. Even if the sign was produced in the second year and erected in the field on the fourth year of the installation interval it would ensure



**FIGURE 5.1 Naming convention of signs with multiple supports**

that every sign going into place would have a date of manufacture, which would be relatively close to the date of installation. Having the date of installation on every infield traffic sign would provide insight into areas that have shorter life cycles. For signs replaced in between inspection intervals UDOT should continue its current procedure of placing installation stickers.

The goal of having a traffic sign inventory is to provide UDOT with accurate information about the traffic signs that they manage. By knowing the exact amount of signs UDOT can help justify the allocation of funding for sign replacement projects. In addition to knowing the number of signs they manage UDOT would know the location and sheeting type for every sign under their jurisdiction. This would provide a foundation for UDOT to effectively manage their sign population and begin to establish sign life cycles for various environments in Utah. By only recording the date of installation, date of inspection, and the date of replacement it would limit the dedication of person-hours to traffic sign management within the database. By connecting the traffic sign database to the GIS map it would provide a spatial method for analyzing traffic sign performance. In addition it is recommended that traffic sign replacement and database management take place at the state level rather than the region level. This would produce a uniform database for UDOT, while eliminating any duplication.

#### **5.4 Conclusion**

After the completion of the collection effort and subsequent analysis of traffic sign performance it is recommended that UDOT implement a visual nighttime inspection

procedure to maintain its traffic sign population. Of the five preapproved FHWA maintenance methods visual nighttime inspection is the only one that can ensure both the legibility and visibility of UDOT's traffic sign assets. It is initially recommended that the inspection interval be set at five years. This would provide UDOT with adequate time and resources to determine which signs are failing and replace those identified signs. The first inspection interval is expected to result in a large number of replacements, due to the fact that UDOT has never assessed the performance of its signs on a statewide basis before. Subsequent inspections should result in smaller failure population and would be less intrusive on agency resources. Via the visual nighttime inspection method UDOT would be able to maintain the current sign inventory and avoid the cost of having to periodically reestablish its traffic sign inventory.

Because of the flexibility provided by FHWA on the replacement requirements of underperforming traffic signs two different recommended scenario are provided. By the completion of the collection effort 78 percent of all underperforming traffic signs were Type I sheeting. Replacing UDOT's Type I population would bring the rate of compliance up to 98 percent. The current estimated Type I population is 7,529, which under an estimated replacement cost of \$250 a sign equates to \$1.8 million. Since there are no specific replacement dates these signs could be replaced over a period of time, justified by UDOT's available resources.

The distinction between the two recommended scenarios is when or even if a minor blanket replacement of Type I sheeting takes place. In the first scenario the Type I blanket replacement takes place prior to the start of a visual assessment. The blanket

replacement would be divided up over the coming years to limit the financial burden on the UDOT's sign maintenance budget. Once the blanket replacement is completed then visual nighttime inspection would start. This would provide UDOT time to establish a training program for visual inspectors. The second scenario would start visually assessing traffic signs and replace the Type I population as they were identified as failing. This scenario would begin identifying underperforming traffic signs of all types and colors and replacements would be prioritized as UDOT officials see fit. It is not recommended to conduct a blanket replacement in conjunction with a visual nighttime inspection because signs would be identified as needing replacement by both methods and may lead to confusion. The FHWA leaves the inspection interval for visual nighttime inspection up to UDOT to determine and is recommended to start initially at five years. The inspection interval should be adjusted to match observed damage frequencies in different areas across the state. By provide five years in between inspection intervals this would provide UDOT with adequate time to replace signs that were identified as failing during the previous inspection.



## CHAPTER 6

### CONCLUSION AND FUTURE WORK

#### **6.1 Conclusion**

The Utah Department of Transportation initiated this research as a response to the release of the 2009 MUTCD, which established minimum maintained retroreflectivity levels for traffic signs. Since its establishment, the retroreflectivity mandate has been revised to only require a management plan for regulatory and warning signs. Even though guide and street name sign performance assessment has no specific compliance date, it is recommended that UDOT included these signs as their resources permit.

By reviewing current literature, this research identified that previous research relating to traffic sign performance has been largely theoretical and has yielded few conclusive results. The retroreflective performance of traffic signs is known to deteriorate with age, but within this deterioration there is a wide range of variation in measured retroreflectivity. It has been theorized that the orientation of the sign face or the distance from the edge of pavement increase the rate of deterioration, but these theories have not been backed up by research. Thus far, the only significant contributing factor to the deterioration of traffic sign performance is the service life of the sign. Therefore, UDOT is faced with selecting an assessment or management method that is based on the individual assessment of traffic sign performance or the management of sign population by like attributes.

In order to determine the current performance of traffic signs under UDOT's jurisdiction, data was collected by researchers at Utah State University. At the conclusion of this effort, several issues within UDOT's traffic sign population were identified. Only seven percent of measured traffic signs had retroreflective measurements that were below the minimum levels. With an estimated compliance rate of 93 percent for its traffic signs it was concluded that UDOT's traffic signs had adequate brightness to ensure safety for motorists during nighttime conditions. Even with the high rate of compliance additional information gained from the collection effort limited the feasibility of several of the preapproved FHWA maintenance methods.

The measured retroreflectivity of prismatic sheeting is sensitive to the rotation of the sheeting on the sign face. Current signage construction practices do not always ensure that sheeting is placed at its optimal orientation. This is commonly done in order to eliminate waste during the construction process. At rotations of 45 degrees from proper, measured retroreflectivity is reduced by up to 36 percent for modern prismatic sheeting types. Coupled with the rotation sensitivity of prismatic sheeting is the location and required number of measurements to properly portray the overall visibility of a traffic sign. Current ASTM standards do not indicate where measurements should be taken and only specify that a minimum of four measurements per retroreflective sheeting is required. Depending on damage, the size of the sign, the location and number of measurements the measured retroreflectivity of a sign can vary greatly. The FHWA presents measured retroreflectivity as a labor intensive method that has limited subjectivity, but questions about the number and location of measurements, and the

rotational sensitivity of prismatic sheeting greatly increase the subjectivity of this method. For these reasons, measured retroreflectivity is not recommended.

Currently, UDOT does not maintain a traffic sign inventory and has limited knowledge of known installation dates for its current traffic sign population. This eliminates the feasibility of two of the three retroreflectivity management methods. Both expected service life and control sign methods require knowledge of the signage population. At the conclusion of the sample survey, only 17 percent of traffic signs had known installation dates, therefore managing signs based on their installation date is infeasible. The majority of UDOT's sign population consists of four sheeting types, one beaded and three prismatic. In order to utilize the controls sign method, a representative sample of signage within a region or geographic area needs to be assembled. Due to the variety of sheeting types currently present within UDOT's sign population, assembling and measuring a control population becomes cumbersome. Not to mention the uncertainty of control signs reflecting the performance of the overall sign population. For these reasons maintaining traffic sign retroreflectivity via the control sign method is not recommended. Blanket replacement is the only remaining management method that does not require knowledge of the current sign population. Although blanket replacement would allow UDOT to correct several issues within its current sign population, a structured replacement schedule is inefficient and wasteful for statewide implementation.

There has been limited previous research into the damage rates of traffic signs managed by an agency. By the conclusion of the collection effort, the observed damage rate of UDOT signs was four times greater than the rate of retroreflective failure. In order

to determine contributing factors to increased damage rates, weather observation and location data was collected. It was determined that average annual precipitation, elevation, seasonal temperature swing and the exposure of the sign contributed to the rate of damage. Due to the observed rate of damage, the feasibility of any management method becomes questionable. Additionally, utilizing any management method for managing traffic signs allows for the existence of damage and underperforming traffic signs to exist for decades within the sign population.

With the establishment of the minimum retroreflectivity levels agencies became fixated with achieving compliance. This sponsored several studies focused on determining the deterioration trends of different sheeting type and color combinations. While deterioration trends provide estimates on the expected retroreflectivity of a traffic sign they do not address the legibility of the traffic sign. Ensuring that a traffic sign is visible does not guarantee the legibility of its intended message. With the observed frequency of damage present on UDOT's traffic signs, it is imperative that the performance of an individual traffic sign is assessed to ensure adequate reaction time for motorists traveling the roadway. Therefore, it is recommended that, UDOT implement a visual nighttime inspection method for maintaining compliance with the minimum levels. By visually assessing the performance of individual traffic signs UDOT can efficiently assess both visibility and legibility. Based on the availability of retroreflective sheeting that is at or near the minimum levels UDOT is recommended conduct either a calibration sign or comparison panel visual inspection procedure.

Using knowledge from the damage analysis portion of this report, UDOT can identify regions that are expected to experience a higher rate of damage and adjust the inspection intervals respectively. With the continued implementation of prismatic sheeting in UDOT's sign population, maintaining the nighttime legibility of traffic signs is expected to become more important than simply ensuring its visibility. Therefore, during the visual inspection process signs need to be assessed for both legibility and visibility.

Implementing a visual nighttime inspection method for the traffic sign maintenance plan would ensure that UDOT meets the MUTCD requirement for developing and implementing a method for traffic sign retroreflectivity compliance. As of May 14, 2012, this plan only needs to maintain the retroreflectivity on regulatory and warning traffic signs. Nevertheless, it is recommended that UDOT's visual inspection include guide, overhead and street name signs since these signs are on routes that inspectors would already be inspecting. Compliance with the minimum retroreflectivity levels is defined with the Support statement in Paragraph 3 of Section 2A.08 of the MUTCD:

Compliance is achieved by having a method in place and using the method to maintain the minimum levels. Provided that an assessment or management method is being used, an agency or official having jurisdiction would be in compliance even if there are some individual signs that do not meet the minimum retroreflectivity levels at a particular point in time. (42)

UDOT's traffic sign maintenance plan should be a living document that reflects the current knowledge of the traffic sign population. As the subset of signs with known installation dates begins to age, additional analysis should be conducted on sheeting

deterioration and expected service life. For areas that frequently experience higher rates of vandalism damage it might be more efficient to implement a five year blanket replacement instead of visually inspecting signs. The introduction of new technologies can drastically change the way UDOT manages its traffic signs. No matter the method the end goal of UDOT's traffic sign maintenance plan should always be to ensure the legibility and visibility of traffic signs under UDOT's jurisdiction.

## **6.2 Future Work**

Management of an agency's traffic sign assets is a dynamic process that should reflect the agency's current knowledge of its traffic sign assets. As new technologies are released or different assessment or management methods become financially feasible, the plan should be amended to improve the efficiency of the sign performance maintenance. This research has identified other areas where future research will be vital in order to create an efficient and effective traffic sign maintenance plan. These include:

- Continued research in to the determination of contributing factors of rapid deterioration of retroreflective sheeting, focusing primarily on prismatic sheeting.
- Utilization of mobile applications for the establishment and maintenance of a living traffic sign inventory.
- Additional validation in identifying areas of increased damage rates via weather observation and location data.

- Improving current measured retroreflectivity standards by determining the number measurements needed to describe a signs visibility.
- Analysis on the safety impact of placing higher performing sheeting.

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41. TAPCO. (2012) GR3 Rental Program. [Online]. [http://www.tapconet.com/store/product/ae0cac9a-3bee-4457-9959-7495c93cb91a/GR3\\_IDRental\\_IDProgram.aspx](http://www.tapconet.com/store/product/ae0cac9a-3bee-4457-9959-7495c93cb91a/GR3_IDRental_IDProgram.aspx).
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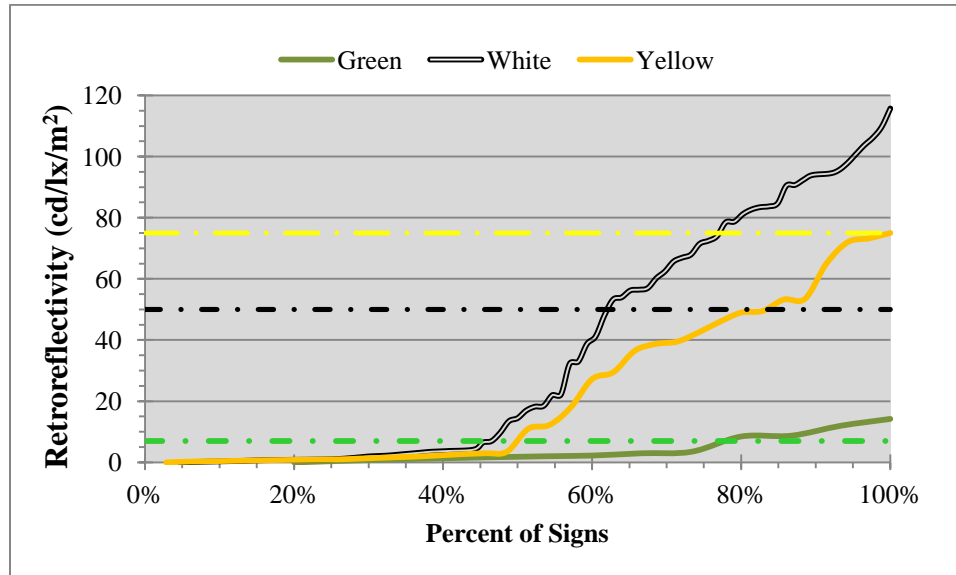
APPENDICES

APPENDIX A. DETAILED TRAFFIC SIGN PERFORMANCE

Displayed within this appendix is the detailed performance of each sheeting type and color combination that were observed during the collection effort. The first section discusses the performance of UDOT's legacy Type I sheeting. The second section discusses the performance of Type III sheeting within UDOT's population. The final section discusses the performance of prismatic Type III HIP, IX and XI sheeting under UDOT's jurisdiction.

### **A.1 Type I Sheeting Performance**

At the completion of the survey, a total of 136 Type I traffic signs were observed. While UDOT currently does not place new Type I signs, there is still a considerable population of these legacy signs still in-service. Figure A.1, is a frequency graph of Type I sheeting by color. The horizontal lines are the minimum retroreflectivity levels for green, white and yellow starting from the bottom on up. As shown in the figure below, the majority of Type I sheeting is performing below the minimum retroreflectivity levels as was expected. Type I signs accounted for 78 percent of observed failures during the collection effort. Type I sheeting simply cannot perform above the minimum levels for an extended period of time. Therefore, as is current in UDOT practice, Type I sheeting is no longer recommended for traffic sign construction.



**FIGURE A.1 Type I sheeting performance frequency graph**

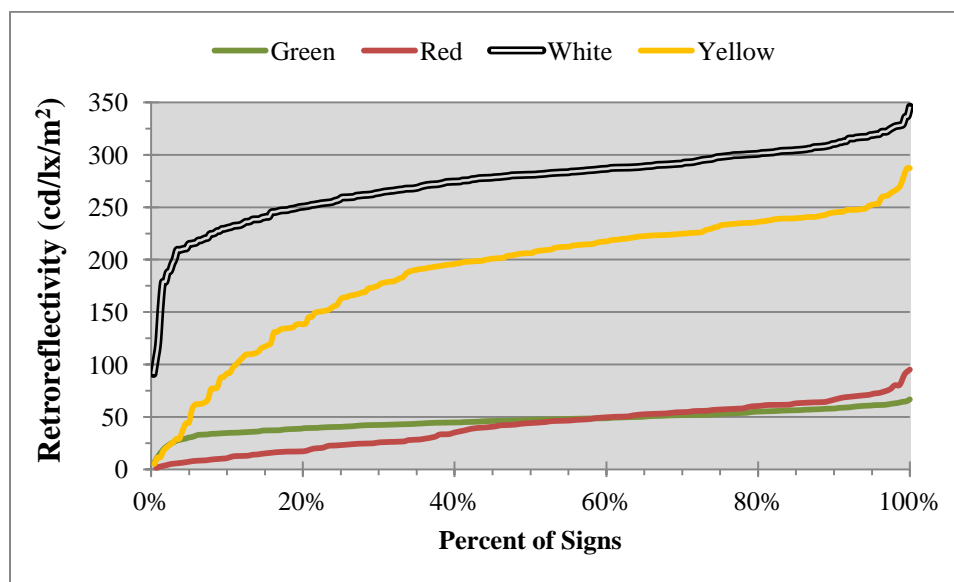
During the collection effort a simply way to determine whether or not a Type I sign was above or below the minimum levels was the presence of cracking damage. Over 60 percent of the Type I signs sampled exhibited this cracking damage. Of the signs with cracking damage present, 86 percent were found to be below the minimum requirements for the relevant sheeting color. This demonstrates the potential accuracy of visual assessment, if the inspectors know what to look for. No Type I red signs were observed during the collection effort.

### **A.2 Type III Sheeting Performance**

Out of all of the observed sheeting types during the collection effort, Type III sheeting was most commonly used, with 955 observed signs. The vast majority of Type III sheeting exceeded the minimum retroreflectivity level with only a three percent failure rate. The majority of underperforming signs were the result of excessive damage that



produced one or more dead spot measurements. Figure A.2, displays the performance frequency graph for Type III sheeting. The steep slopes produced by the lower performing signs are the direct result of damage or signs exceeded their warranty life. The curve is more gradual for yellow sheeting due to the high rate of damage observed on that sheeting color.

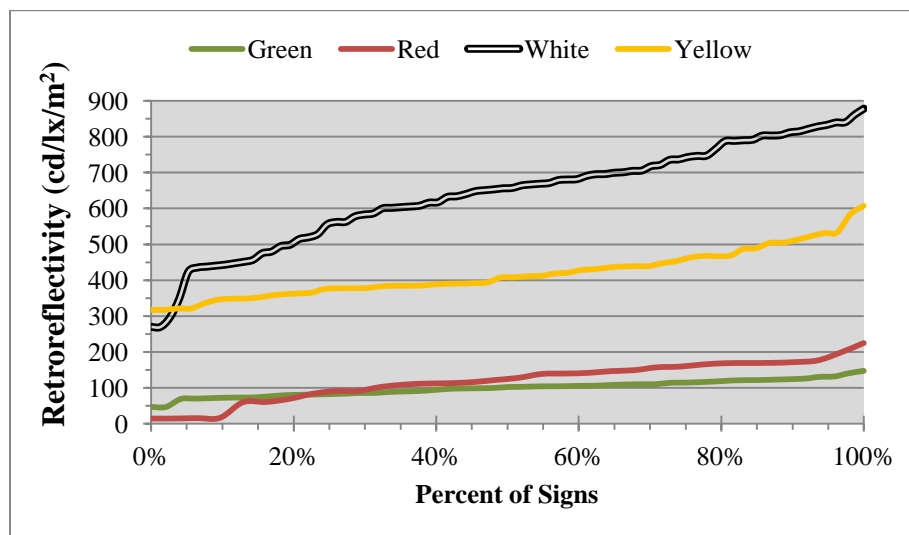


**FIGURE A.2 Type III sheeting performance frequency graph**

### **A.3 Prismatic Sheeting Performance**

This section discusses the performance of prismatic Type III HIP, IX and XI sheeting under UDOT's jurisdiction. Due to the similarities in performance these sheeting types have been grouped together for discussion in this report. All types of prismatic sheeting are rotationally sensitive and need to be placed at the proper orientation to achieve optimal performance.

By the completion of the data collection effort, 209 Type III HIP signs were observed. Even with the presence of damage, Type III HIP easily exceeded the minimum levels. A failure rate of less than half a percent was observed and on average Type III HIP signs exceeded the minimum level by an order of magnitude of greater than 10. Unlike the previous beaded sheeting types, Type III HIP is rotationally sensitive. At rotations of 45 degrees from the proper “up” position, Type III HIP retroreflectivity reduces by up to 36 percent. Figure A.3, displays the performance frequency graph for Type III HIP sheeting. The observed failure was on a stop sign that failure to retain the required 3:1 background to legend contrast ratio.

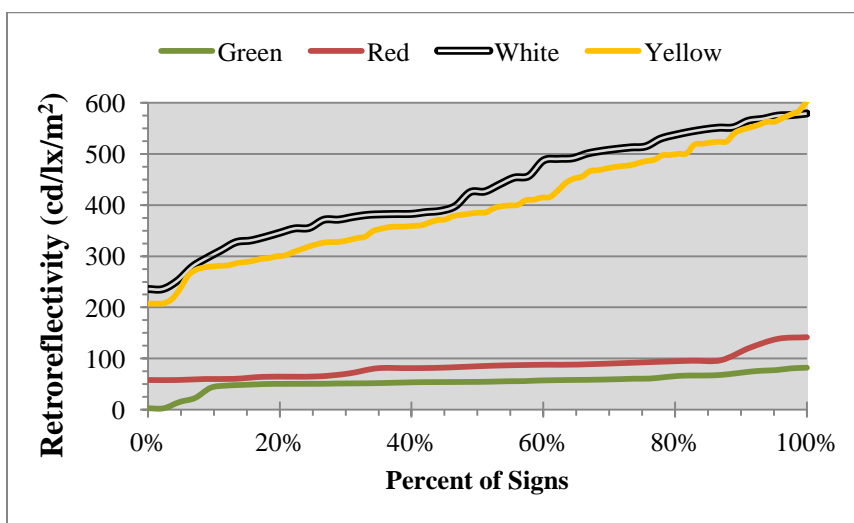


**FIGURE A.3 Type III HIP performance frequency graph**

At the completion of the sample survey, 180 Type IX traffic signs were measured. On average retroreflectivity levels were eight and a half times greater than the minimum levels. Like all prismatic sheeting, Type IX is rotationally sensitive with an 11 and 30 percent reduction in measured retroreflectivity at rotations of 45 and 90 degrees from

optimal. By the completion of the collection effort only two failures were observed. The two failing Type IX green traffic signs were the result of a construction issue in which the overlay on the sign failed. Both of the failures were limited to SR 167, which is commonly referred to as Trappers Loop. Figure A.4, displays the performance frequency graph for Type IX sheeting.

At the conclusion of the sample sign survey, a total of 190 Type XI were observed. Even though Type XI sheeting was the least used sheeting type, it was found in areas of new construction along the interstate.

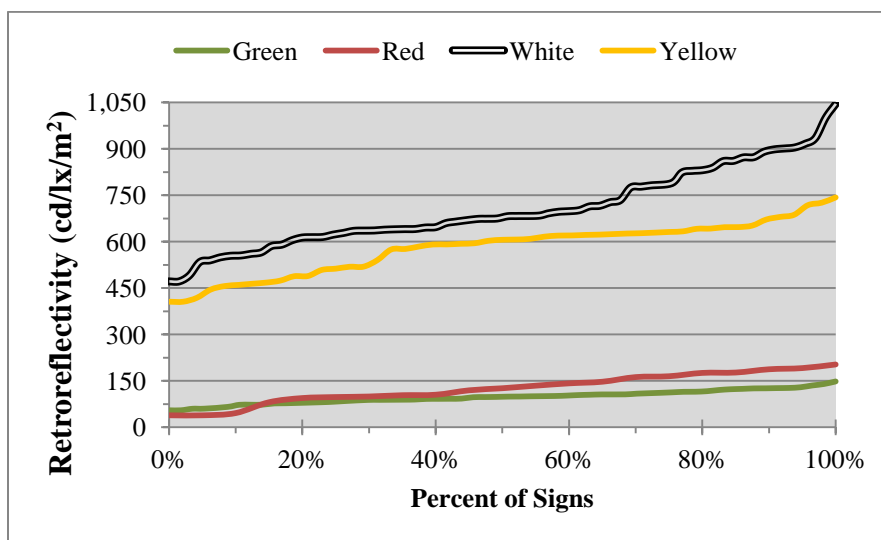


**FIGURE A.4 Type IX sheeting performance frequency**

With respect to the minimum retroreflectivity standards, Type XI sheeting is on average 12 times brighter than the minimum level which makes it the best performing sheeting type observed during the sample survey. This result is expected due the sheeting installations being relatively new and the minimum ASTM requirements for Type XI criteria being so high. The exact reduction was not determined during this study since

newly constructed Type XI sheeting traffic sign was not obtained from UDOT. Figure A.5, displays the performance frequency graph for Type XI sheeting.

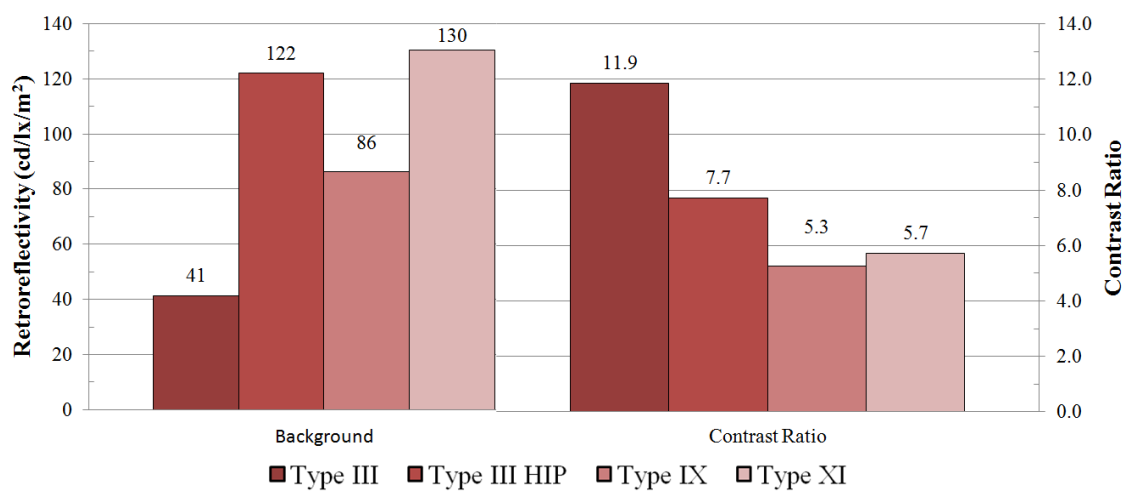
After further analysis on traffic sign performance, an interesting trend was discovered that is a particular concern for red signs. A required characteristic of red regulatory signs is that they must maintain a legend to background ratio of at least 3:1.



**FIGURE A.5 Type XI performance frequency graph**

Retroreflective measurements taken on in-service prismatic sheeting types show that the increase in retroreflectivity efficiency in the background has not been matched by the legend, thereby decreasing the contrast ratio of the traffic sign. Figure A.6, shows the relationship between measured retroreflectivity of the background and the resulting contrast ratio for the various sheeting types utilized by UDOT. As shown in the figure below as higher prismatic types are used on red signs there is a significant reduction in the average contrast ratio. This could lead to a higher rate of failure for newer prismatic sheeting signs far before they reach the minimum levels for the background and legend.

This issue can be quickly rectified by a slight change in construction practices. The minimum retroreflectivity for red sheeting is  $7 \text{ cd/lx/m}^2$ , regardless of the sheeting type. A high contrast ratio can easily be obtained by using Type III sheeting for the background and applying a prismatic legend to the sign. Doing so would produce average contrast ratios greater than 10.



**FIGURE A.6 Observed contrast ratio on different red sheeting types**

APPENDIX B. PERMISSION LETTERS

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8/28/2012

Wesley Boggs

1549 N. 540 W. Logan, UT 84341

boggs.wes@gmail.com

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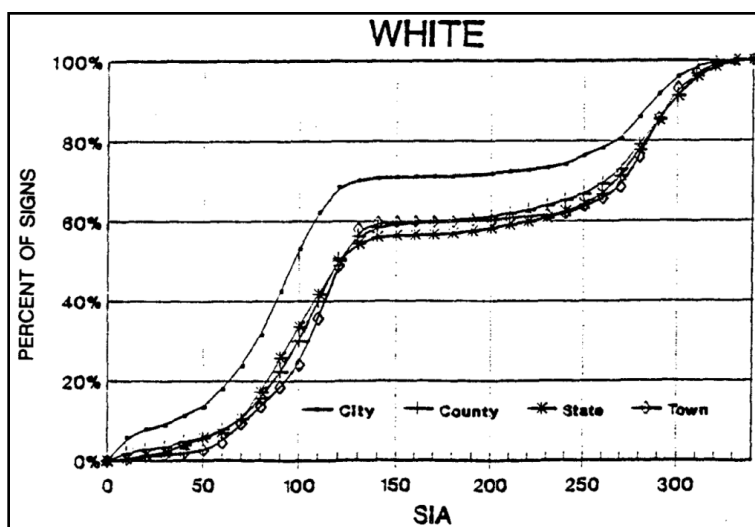
---

I hereby give permission to Wes Boggs to reprint the following material in his thesis.

Authors: K.L. Black, Hugh W. McGee, S.F. Hussain.

TITLE: IMPLEMENTATION STRATEGIES FOR SIGN RETROREFLECTIVITY  
STANDARDS, ISSUE 346

Identification: shown below.



2.4 Frequency graph for white sheeting

Thesis Title: An Analysis of Traffic Sign Performance for the Establishment of a Maintenance Plan

Citation: Black, K.L., H.W. McGee, and S.F. Hussain. *Implementation Strategies for Sign Retroreflectivity Standards*. NCHRP Project 5-11 (NCHRP Report 346, April 1992).



RESPONSE:

**From:** Chafee, Ellen

**Sent:** Tuesday, August 28, 2012 2:26 PM

**To:** 'Wesley Boggs'

**Cc:** Crawford, Maria

**Subject:** Permission granted--NCHRP Report 346

Dear Mr. Boggs,

The TRB through the National Academy of Sciences (NAS) grants Permission to use Figure 5. Frequency graph for white sheeting from Black, McGee, and Hussain (1992) *NCHRP Report 346: Implementation Strategies for Sign Retroreflectivity Standards* in your thesis for the Department of Civil and Environmental Engineering at Utah State University, to be completed in the Fall of 2012.

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Sincerely,

Ellen Chafee

Editor

CRP-TRB

echafee@nas.edu

8/28/2012  
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1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

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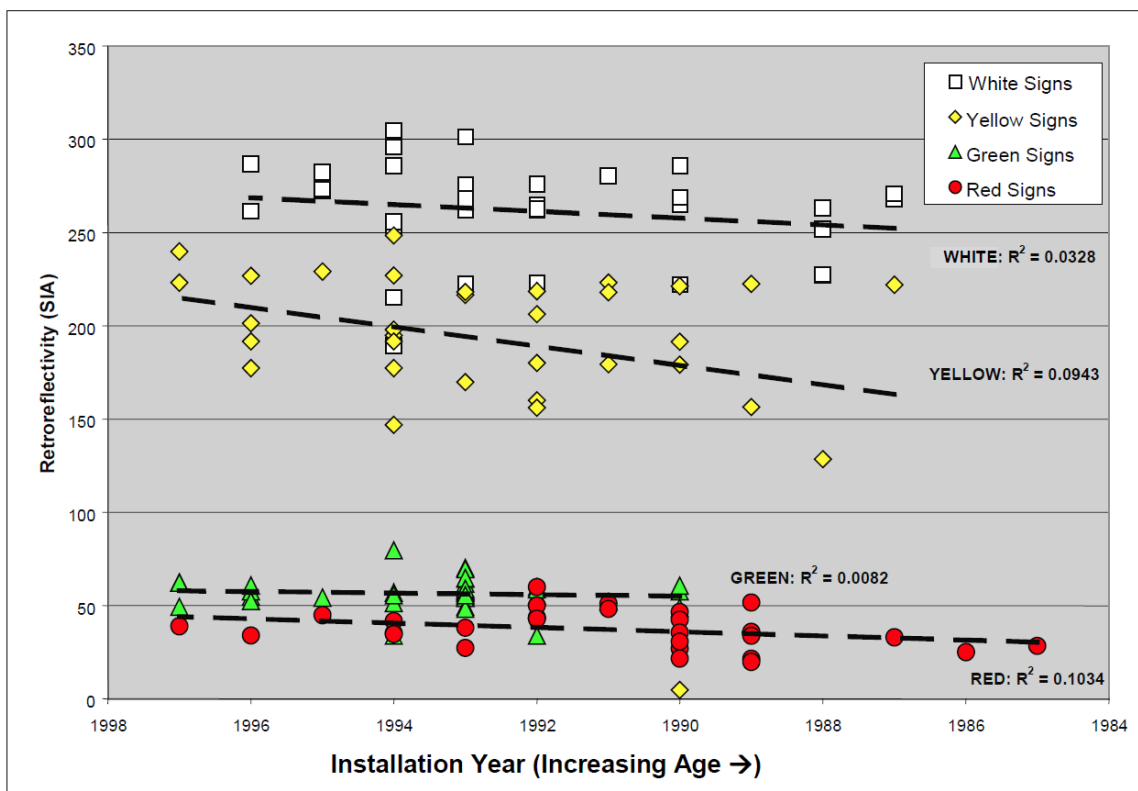
Thank you for your cooperation,  
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Citation: Kirk, A. R., Hunt, E. A., and Brooks, E. W. (2001). "Factors Affecting Sign Retroreflectivity." *Report No. OR-RD-01-09*, Oregon Department of Transportation, Salem, OR.

Figure 3.2 on Page 10, shown below.



### 3.4 Retroreflectivity and sign age

Fee \_\_\_\_\_

*Permit granted 08/28/2012*  
*Ramirez H.D.*  
*Research Section Manager*  
*503-986-2845*

Signed

8/28/2012  
Wesley Boggs  
1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

Dear Kyle Clevenger, Karen Colello, Jeannette Quirus:

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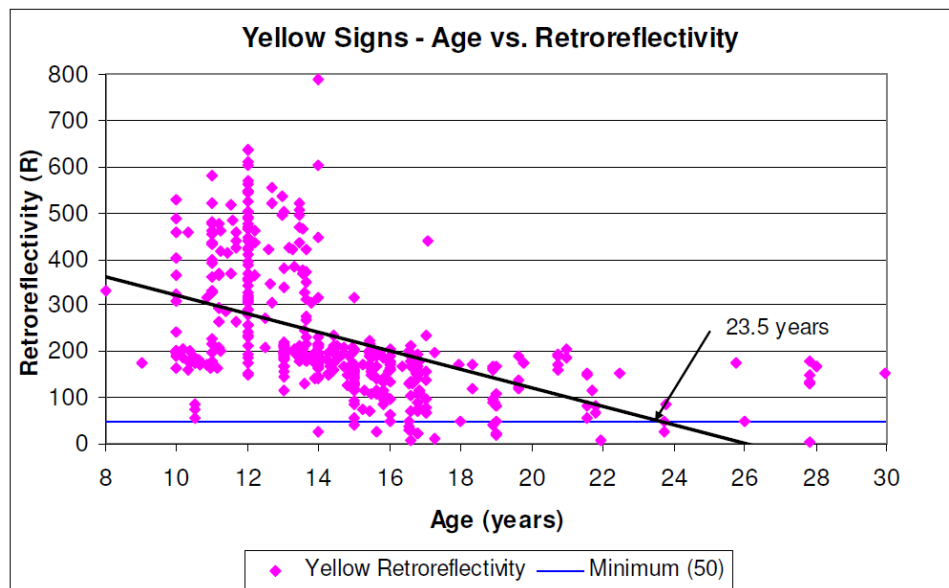
Thank you for your cooperation,  
Wesley Boggs

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Citation: Clevenger, K., Colello, K., and Quirus, J. ( 2012). "Retroreflectivity of Existing Signs in Pennsylvania." Report No. FHWA-PA-2012-003-E01041-WO9, Pennsylvania Department of Transportation, Harrisburg, PA.

Figure 2 found on Page 26, shown below.



**Figure 2 Age versus retroreflectivity for yellow signs**

Fee   N/A  

Signed   Kyle Chong

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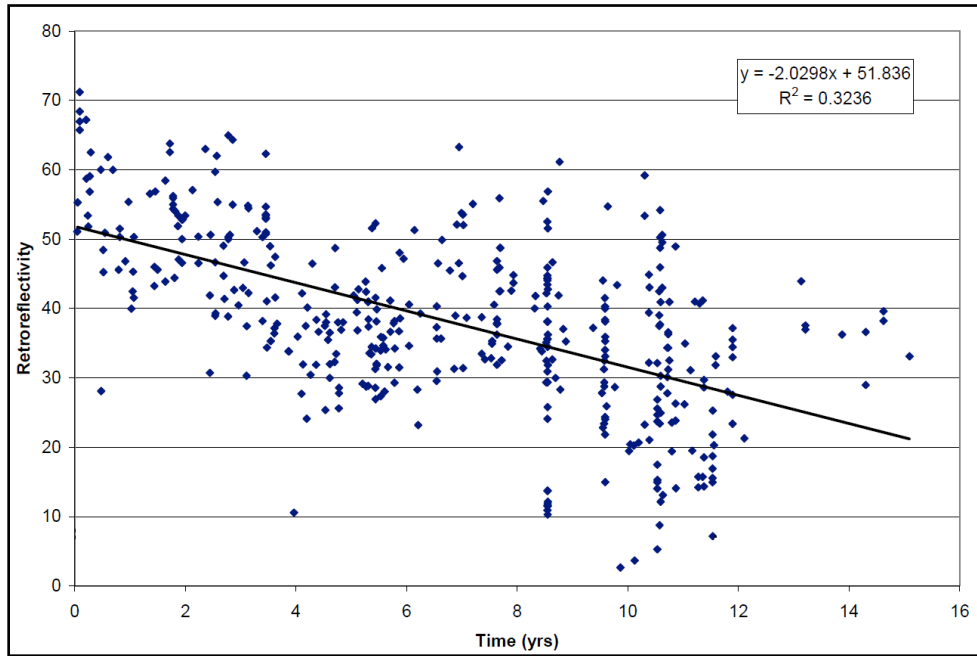
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Citation:

Bischoff, A. L., and D. M. Bullock. *Sign Retroreflectivity Study*. Publication FHWA/IN/JTRP-2002/22. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2002.  
doi:10.5703/1288284313313

Figure 4-2 on Page 44, shown below.



**Figure 4-2 Red ASTM Type III average unwiped background retroreflectivity versus time, excluding the Crawfordsville bonepile (n=415)**

Fee \_\_\_\_\_

\$0.00

Signed \_\_\_\_\_

8/28/2012  
Wesley Boggs  
1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

To whom it may concern,

I am in the process of preparing my thesis in the Department of Civil and Environmental Engineering at Utah State University. I hope to complete in the Fall of 2012.

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Wesley Boggs

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Citation:

Federal Highway Administration. (2011) 2011 Traffic Sign Retroreflective Sheeting Guide. Document. [Online]. [http://safety.fhwa.dot.gov/roadway\\_dept/night\\_visib/sign\\_visib/sheetguide/sheetguide.pdf](http://safety.fhwa.dot.gov/roadway_dept/night_visib/sign_visib/sheetguide/sheetguide.pdf).

Figure shown below.



2011 Traffic Sign Retroreflective Sheeting Identification Guide									
<p>This document is intended to help identify sign sheeting materials for rigid signs and their common specification designations. It is not a qualified product list. FHWA does not endorse or approve sign sheeting materials. Many other sheeting materials not listed here are available for delineation and construction/work zone uses.</p>									
<b>Retroreflective Sheeting Materials Made with Glass Beads</b>									
Example of Sheeting (Shown to scale)									
ASTM D4956-04	I	II	II	III	III	III	III	III	III
ASTM D4956-09	I	II	II	III	III	III	III	III	III
AASHTO M268-10	(1)	(1)	(1)	A	A	A	A	A	A
Manufacturer	Several companies	Avery Dennison®	Nippon Carbide	3M™	ATSM, Inc.	Avery Dennison®	Nippon Carbide	Oracal	
Brand Name	Engineer Grade	Super Engr Grade	Super Engr Grade	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity
Series	Several	T-2000	15000	2800 3800	ATSM HI	T-5500	N500	5800	
NOTES:	(2)	(3) (4)	(4)	(3) (4)	(4)	(4)	(4)	(4)	(4)
<p>(1) – Sheeting material does not meet minimum AASHTO classification criteria.                  (2) – Glass Bead Engineer Grade sheeting is uniform without any patterns or identifying marks. Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.                  (3) – Material no longer sold in the United States as of the date of this publication.                  (4) – Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new legends on green overhead signs.</p>									
<b>Retroreflective Sheeting Materials Made with Prisms</b>									
Example of Sheeting (Shown to scale)									
D4956-04	(5)	III, IV	III, IV, X	(5)	(5) / X	(5)	VIII	VII, VIII, X	VIII
D4956-09	I	III, IV	III, IV	IV	IV / VIII	VIII	VIII	VIII	VIII
M268-10	(6)	B	B	B	B	B	B	B	(9)
Manufacturer	3M™	Avery Dennison®	3M™	Reflexite®	Nippon Carbide	3M™	Avery Dennison®	3M™	
Brand Name	Engr Grade Prismatic	High Intensity Prismatic	High Intensity Prismatic	High Intensity Prismatic	Crystal Grade	Reflective Sheeting	MVP Prismatic	Diamond Grade™ LDP	
Series	3430	T-6500	3930	IC400	94000 / 92000	3940	T-7500	3970	
NOTES:	(7)				(8)			(10)	
Example of Sheeting (Shown to scale)						NOTE: The watermarks have been enhanced in this ID Guide. They are shown to scale but are not as visible on actual sheeting materials. It helps to view the sheeting materials at different angles to see the watermarks. The spacing of the watermarks varies and therefore watermarks may not be present on small pieces of sheeting.			
D4956-04	IX	IX	(5)	(5)	(5)				
D4956-09	IX	IX	IX	XI	XI				
M268-10	B	B	B	D	D				
Manufacturer	3M™	Avery Dennison®	Nippon Carbide	3M™	Avery Dennison®				
Brand Name	Diamond Grade™ VIP	OmniView™	Crystal Grade	Diamond Grade™ DG3	OmniCube™				
Series	3990	T-9500	95000	4000	T-11500				
NOTES:									
<p>(5) – Material was either unavailable in 2005 (previous version of this Guide) or unassigned in the 2004 version of ASTM D4956.                  (6) – Sheeting material does not meet minimum AASHTO classification criteria.                  (7) – Section 2A.08 of the 2009 MUTCD (<a href="http://mutcd.fhwa.dot.gov">http://mutcd.fhwa.dot.gov</a>) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.                  (8) – These two materials (94000 and 92000) are visually indistinguishable from one another.                  (9) – Material has been discontinued prior to AASHTO M268-10.                  (10) – Material no longer sold in the United States as of the date of this publication.</p>									

Figure X FHWA sheeting identification guide

RESPONSE:

Mr. Boggs,

Please feel free to use the graphic....If appropriate please give credit to FHWA.

Thanks,  
 Karen Timpone

8/28/2012  
Wesley Boggs  
1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

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Wesley Boggs

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Citation:

Rasdorf, W., Hummer, J. E., Harris, E.A., Yeom, C., and Immaneni, V. P.  
(2006). "Designing an Efficient Nighttime Sign Inspection Procedure to Ensure Motorist Safety." Report No. FHWA/NC/2006-08, North Carolina Department of Transportation, Raleigh, NC.

Figure 7.7 found on Page 109, shown below.

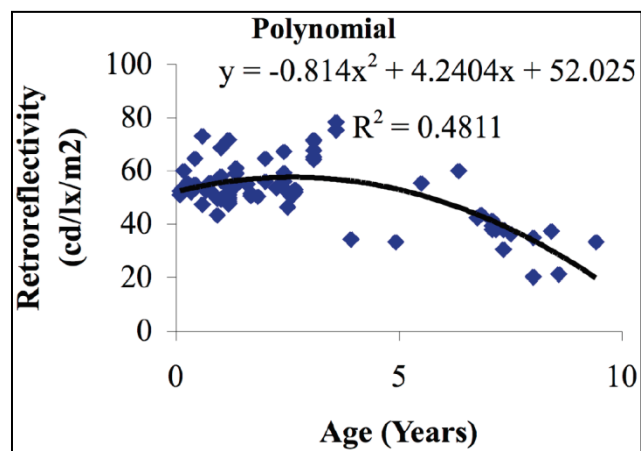


Figure 7.7 Deterioration curves for Type III red signs

Fee Ø

Signed [Signature] 9/3/12

8/28/2012  
Wesley Boggs  
1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

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---

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Citation:

Kilgour, M., J. White, and D.M. Bullock, " Sign Retroreflectivity: Fiscal Impact of Proposed Minimum Retroreflectivity Values on Local Governments in Indiana and Investigation of the Accuracy of Nighttime Inspections", Indiana LTAP Technical Report SP-1-2006, August 2006.

Table shown below.

Sign Group	Signs Surveyed	Type I Error	Type II Error	Percent Correct
White on Red	681	9	56	90.5%
Black on White	505	1	65	86.9%
Bold Black on Yellow	390	6	44	87.2%
Fine Black on Yellow	162	5	21	84.0%
All Other Colors	4	0	3	25.0%
$\Sigma=$	1,742	21	189	87.9%

**Figure X Purdue University inspector accuracy summary**

Fee \_\_\_\_\_

Signed \_\_\_\_\_

RESPONSE: No response was received.

8/28/2012  
Wesley Boggs  
1549 N. 540 W. Logan, UT 84341  
boggs.wes@gmail.com

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ASTM Standard D4956 - 11a, 2011, "Standard Specifications for Retroreflective Sheeting for Traffic Control," ASTM International, West Conshohocken, PA, 2011, DOI: 10.1520/D4956-11A, [www.astm.org](http://www.astm.org).  
Table 2.1 on Page 14, shown below.

**Table 2.1 Applications of Retroreflective Sheeting by Type**

Type	Applications	Intensity Rating
I	Permanent highway signing, construction zone devices, and delineators	Medium
II	Permanent highway signing, construction zone devices, and delineators	Medium-high
III	Permanent highway signing, construction zone devices, and delineators	High
IV	Permanent highway signing, construction zone devices, and delineators	High
V	Delineators	Super high
VI	Temporary roll-up signs, warning signs, traffic cones collars, and post bands	High
VIII	Permanent highway signing, construction zone devices, and delineators	Super high
IX	Permanent highway signing, construction zone devices, and delineators	Very high
XI	Permanent highway signing, construction zone devices, and delineators	Super high

And Table 2.2 on page 16, shown below.

**Table 2.2 Minimum Retroreflectivity for Sheeting Type Classification †**

Type	Sheeting Color										
										Fluorescent	
	White	Yellow	Orange	Green	Red	Blue	Brown	Yellow-Green	Yellow	Orange	
I	70	50	25	9	14	4	1	-	-	-	
II	140	100	60	30	30	10	5	-	-	-	
III	250	170	100	45	45	20	12	-	-	-	
IV	360	270	145	50	65	30	18	290	220	105	
VI	500	350	125	60	70	45	-	400	300	200	
VIII	700	525	265	70	105	32	21	560	420	210	
IX	380	285	145	38	76	17	-	300	230	115	
XI	580	435	200	58	87	26	17	460	350	175	

† Values for 0.2° observation angle and a -4° entrance angle

Fee NONE

Signed *Kathe Hooper*



**Kathe Hooper**

**Manager  
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