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DEVELOPMENT OF ASSESSMENT STRATEGIES FOR
SIGN RETROREFLECTIVITY

by

Travis L. Evans

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

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

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Logan, Utah

2012

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ABSTRACT

Development of Assessment and Evaluation Strategies for
Sign Retroreflectivity

by

Travis L. Evans, Master of Science

Utah State University, 2012

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

The Manual on Uniform Traffic Control Devices (MUTCD) now specifies minimum retroreflectivity requirements. These requirements include an obligation for agencies to develop a strategy for maintaining compliance. With budget considerations, it is important that transportation agencies be able to efficiently assess the performance of their assets and adopt management strategies to comply with such requirements. As a foundational work, this research develops specific methodology for assessing the condition and performance of sign assets that are maintained by a large transportation agency. In doing so, this research provides for the determination of key elements that should be considered when developing any sign asset management strategy. This work incorporates and builds upon previous research in order to develop an assessment strategy that can provide new insight and understanding into where sign asset management efforts should be focused. Given the conditions unique to the Utah Department of

Transportation's (UDOT) sign assets, the findings of this research present a potential paradigm shift from the previous assumptions regarding the best prospective management practices. Sign damage was determined to be the primary issue affecting the nighttime visibility of UDOT maintained signs. By controlling damage issues within UDOT's sign assets, retroreflectivity compliance may be maintained. The findings of this research provide for new options and considerations in managing both sign retroreflectivity and nighttime visibility at a large scale.

(116 pages)

PUBLIC ABSTRACT

Development of Assessment and Evaluation Strategies for
Sign Retroreflectivity

by

Travis L. Evans, Master of Science

Utah State University, 2012

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

Traffic signs play a vital role in ensuring roadway safety. They are utilized in many ways such as providing navigational aid, the identification of potential hazards, and notifying motorists of laws and regulations present. In performing this role, it is important that traffic signs are able to properly convey their intended messages. This is of particular concern under nighttime conditions, as visibility is reduced. In an effort to improve the nighttime visibility of traffic signs, new minimum levels of retroreflectivity for sign sheeting have been established by the Federal Highway Administration (FHWA). As a measure of a particular material's ability to reflect light back at its source, retroreflectivity has been viewed as being central to evaluate a traffic sign's nighttime visibility. As such, requirements for maintaining minimum retroreflectivity levels include an obligation for agencies to develop a strategy for maintaining compliance.

With budget considerations, it is important that transportation agencies are able to efficiently assess the performance of their sign assets and adopt management strategies to comply with such requirements. This research develops practical methodology for assessing the condition and performance of traffic signs that are maintained by a large transportation agency. In doing so, this research provides for the determination of key elements that should be considered when developing any sign asset management strategy.

Given the conditions unique to the Utah Department of Transportation's (UDOT) sign assets, this research explores the key issues that are affecting UDOT's sign populations. In developing and applying a sign population assessment strategy for sign retroreflectivity, a shift from the previous assumptions in the best course of action for maintaining nighttime visibility was found. Sign damage was determined to be the primary issue affecting the nighttime visibility of UDOT maintained signs. Previous ideas in maintaining traffic sign nighttime visibility related to the tracking and prediction of retroreflectivity loss. This was determined to be both impossible and impractical due to widespread retroreflectivity loss from damage present on large portions of UDOT's sign population. By controlling damage issues with UDOT's sign assets, retroreflectivity compliance may be entirely maintained under normal construction and replacement cycles. The findings of this research provide for new options and considerations in managing both sign retroreflectivity and nighttime visibility at a large scale.

DEDICATION

This thesis is dedicated to my wife, Kristin, for all the patience and support she has provided as I have pursued my various academic endeavors. To my son, Conley, for always making me smile no matter what obstacle I may have been facing. To my parents, Glade and JoAnn, for providing encouragement and support always when needed. To Kyle, for introducing me to civil engineering and the guidance he has provided. And lastly, to all my family and friends for being great examples and providing support for overcoming any challenge that I have had; I thank you all.

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CHAPTER 1

INTRODUCTION

With budget constraints and limited resources, it is imperative that transportation agencies adopt comprehensive management strategies for managing an agency's assets. Transportation Asset Management is defined as the process to facilitate the construction, operation, safety, and maintenance of infrastructure while considering budget constraints (Obermann, Bittner, and Wittwer, 2002).

The 2003 edition of the Manual on Uniform Traffic Control Devices (MUTCD) later in 2007 included a revision that mandated minimum retroreflectivity levels that must be maintained for traffic signs (Federal Highway Administration, 2007a). Since the establishment of this mandate, and the requirement that agencies adopt a management strategy for sign retroreflectivity, there has been a significant emphasis on sign asset management.

There have been many concerns by transportation agencies over the implementation of the new standards. Maintaining minimum retroreflectivity levels can put constraints on maintenance budgets and have potentially negative impacts on transportation agencies (Opiela and Andersen, 2007).

In order to develop efficient management strategies, it is necessary to identify the situations that are unique to a particular agency that contribute to the overall compliance with sign retroreflectivity standards. Establishing protocol to identify asset characteristics, expected sign life, as well as special situations and geographic areas that

are high risk for premature retroreflectivity failure is an important step in being able to adequately implement a sign management strategy.

There are various methods proposed in order to manage the retroreflectivity of traffic signs. While potential management methods have been provided by the Federal Highway Administration, there is little guidance offered with regards to specific methodology. Currently there is no established methodology for assessing agency assets at a large scale. There is also limited practical guidance for the selection and implementation of any particular management strategy. Toolkits have been provided for agencies as a background to explain the various proposed management methods. Nevertheless, little has been provided with regards to implementation and specific methodology for the selection and usage of any particular method. Documented research has provided sampling procedures for attempts to model sign retroreflectivity deterioration but there is little guidance currently available for large agencies to assess asset performance beyond full inventories. For many agencies, attempting a full inventory is not possible before the required deadlines due to budgetary constraints. As such, any plan they develop to meet the MUTCD requirements of having a plan in place by 2012 may potentially be both inefficient and infeasible for a particular agency. Until recently, little has been done by transportation agencies to overcome this problem. When mandates were initially established it was assumed that new developments in technology would provide for agency's needs. Currently, technology such as mobile assessment and inventory equipment is still out of reach for practical use by almost all transportation agencies. As such, agencies now are scrambling to develop assessment and management

procedures for their traffic signs. In order to ensure compliance with the new retroreflectivity standards, it is also important to understand how sheeting performance may be tracked as well as the current state of compliance when considering any management method. The development of a management strategy must include an evaluation of various methods, as well of their potential effectiveness, in ensuring compliance with the new MUTCD standards.

Previous research regarding sign retroreflectivity that dealt with determining certain factors thought to be significantly correlated with sign retroreflective deterioration has proven inconclusive. While general trends have been established for some factors there have been limitations identified such as inadequate data, potentially important factors that were not considered, and unexplained results. This presents a unique problem, as many ideas proposed for managing sign retroreflectivity are dependent on the prediction of when sign sheeting will perform at a level below the minimum retroreflectivity standards. Better understanding is needed in determining when the retroreflectivity of sign sheeting will fail and how sign management for nighttime visibility should proceed.

Given the difficulty in predicting the retroreflectivity deterioration of sign sheeting, as well as limited installation and condition information for the assets of many agencies including the Utah Department of Transportation (UDOT), it is necessary to develop specific methodology for evaluating the overall state of the agency's assets. Given the limited research and information available to transportation agencies regarding asset performance assessment, and the practicality of implementing various management

methods, it is important that a basic foundation be established. It is also necessary to determine and incorporate new methods and ideology for the efficient management of an agencies sign assets. Retroreflectivity itself is not the only measure of a signs ability to convey their intended messages. An adequate management plan must explore all factors affecting sign visibility and message conveyance and key into what is most necessary and important. Relating relevant factors and situations, beyond just sign retroreflectivity, that effect nighttime visibility may prove crucial in determining the best course of action for a transportation agency to take for providing both safety enhancement and compliance with legal requirements that have been recently imposed.

It is the intent of this research to build upon the previous research done in determining and developing an appropriate procedure that will provide the information required in order to make informed decisions for the development of a sign management plan. As a foundational work, a framework will be established for which an agency will be able to begin the process of effectively and efficiently manage their sign assets in a way that includes retroreflectivity. The data collected will then be analyzed to determine options for management and assess the feasibility of various management methods. The data collected will be used to further understand what should be considered when managing the nighttime visibility of traffic signs. Where agencies are just beginning the process of developing such asset management strategies, practical research is necessary to determine the feasibility of management options and determine where management efforts should be focused. This research also identifies sign damage as another management area that is directly correlated to both sign retroreflectivity and nighttime

visibility management that has not been emphasized in the proposed management methods.

1.1 Research Question

The primary question posed for this research is “*How can UDOT effectively manage their sign assets for compliance with a minimum retroreflectivity standard?*” To develop a comprehensive and efficient sign asset management system that includes maintaining retroreflectivity, significant issues relating to the infield service life of signs must be identified. It is currently not known all factors that play a role in the nighttime visibility of traffic signs. Sheeting usage, damage, and placement are all assumed to affect the visibility of traffic signs but little is known as to how they interact and how to approach each issue within the budgetary constraints of an individual Department of Transportation. For this research, identifying current compliance issues and circumstances unique to UDOT’s assets will provide a basis for evaluating, and developing, a management strategy suitable to meet the needs of UDOT and ensure compliance with the new MUTCD standards. Additionally, this research will provide further insight into the management of traffic signs and plan development that can assist any agency in their early stages of plan development. In order for this to be accomplished, methodology for assessment and data analyses must be developed and implemented in this research.

1.2 Research Problem and General Approach

In order effectively develop a management plan to maintain the retroreflectivity of traffic signs at a large scale, this research will attempt to answer the following questions.

- What is the current state of art in managing sign assets for retroreflectivity?
- How can the current state of UDOT's sign assets be assessed?
- How do outside factors such as damage, placement, and sheeting usage affect the nighttime performance and visibility of traffic signs in Utah?
- What is the potential effectiveness of various proposed management strategies given conditions unique to UDOT?
- Are there other management strategies, outside those proposed by the Federal Highway Administration (FHWA), that are potentially more effective, or efficient, given conditions unique to UDOT's sign assets?

A great challenge in developing an adequate sign management strategy is being able to identify what attributes should be assessed and tracked to assist in maintaining compliance with the new MUTCD retroreflectivity standards. For large agencies that have limited knowledge of their sign assets, there is currently no established methodology for assessing large scale assets and determining a course of action for future maintenance. Additionally, at this time there are no accurate models that describe the deterioration of sign retroreflectivity over time under different conditions. For this, a starting point for assessing and managing sign assets must be established. Previous

research has concluded that sign age alone does not correlate with the rate of retroreflective deterioration in sign sheeting materials. Other factors such as sunlight exposure, elevation, temperature, and the weathering effects of wind and precipitation may prove significant in retroreflective deterioration. As it is known that eventually over time the retroreflectivity of a given sign will fall below minimum standards, protocol should be established to track performance and understand what of the many factors are most influential in contributing to failure. This protocol must be developed if future efforts are to be successful in determining contributing factors.

The uncertainty regarding the factors that effect retroreflective deterioration and the degree with which different factors may affect deterioration rates is of particular concern. If a particular management method to maintain retroreflectivity is used that is based on in-service life of particular signs, great inefficiencies may occur. Signs that may be adequate for continued use may be replaced long before it is necessary. Likewise it is possible that signs are left in field too long that are inadequate because factors exist that expedite the rate of deterioration.

With the proposed management strategies being dependent either upon inspection schedules or understanding the performance of sign sheeting, it is important to evaluate which assets are performing within compliance with the MUTCD standards, as well as potential problems that exist. It is also important to evaluate the effectiveness of particular management and assessment methods in managing sign retroreflectivity. Currently there is limited procedural methodology to assist in developing a plan to assess sign asset performance. To facilitate these needs a plan must be established to evaluate,

track, and predict the performance of assets maintained by a particular agency. This research intends to key in on collection strategy development, and the assessment of current asset performance, to assist in the development of a management strategy. This research also takes the information gained from data collection from UDOT maintained signs and uses it to determine several new potential strategies for managing traffic sign retroreflectivity. Inclusive in this research are new considerations regarding nighttime traffic sign visibility that are a potential change from the assumption that retroreflectivity should be the predominate measure for management purposes.

1.3 Research Reported

This report outlines the research that was performed. Chapter 2 will provide an exhaustive literature review of the research that has previously been performed. This includes research relating to sign asset management, the mechanics and standards associated with retroreflectivity, and research into the deterioration of the retroreflectivity of signs. Chapter 3 will provide the purpose and methodology used for data collection. Chapter 4 will provide the results of the data collection and their implementation in plan development for UDOT. Chapter 5 will provide conclusions to the study, as well as various future research opportunities.

CHAPTER 2

LITERATURE REVIEW

2.1 Purpose

The purpose of this literature review is to provide a base of information for the research performed by collecting the work that has previously been done. The intent is to provide a comprehensive knowledge of the research topic, to provide the current theories and conclusions on the research, and to identify deficiencies and gaps in the previous research, where future research is to be conducted.

2.2 Traffic Sign Asset Management

The general idea of asset management is associated with a desire to maintain and efficiently manage investments in various ventures. Asset Management is a multidisciplinary field that in recent years has been of particular interest to the transportation community. The increased interest by the transportation industry can be attributed to three primary factors: changes in the transportation environment, changes in public expectations, and advancements in technology (Federal Highway Administration, 1999).

2.2.1 Transportation asset management defined

Transportation Asset Management is defined as the process to facilitate the construction, operation, safety, and maintenance of infrastructure while considering budget constraints (Obermann, Bittner, and Wittwer, 2002). The Office of Asset

Management, under the Federal Highway Administration, describes transportation asset management as a "foundation from which to monitor the transportation system and optimize the preservation, upgrading, and timely replacement of highway assets" (Federal Highway Administration, 1999, p. 6). The purpose of Transportation Asset Management is to provide support for infrastructure management that can provide an efficient means to measure performance and assist with decisions in resource allocation. To be effective, asset management must be policy driven and policies must be evaluated based on performance. The allocation of resources must be based from the analysis of various options and tradeoffs and the decisions must be made on quality information (Cambridge Systematics and PB Consult, 2006).

2.2.2 Efforts in transportation asset management

In the past, transportation asset management has been primarily focused around the maintaining of road and bridge assets. Other specific areas of interest relating to asset management include tunnel maintenance, public transportation, and the management of other transportation assets. Currently two federal agencies, the Federal Highway Administration's Office of Asset Management and the Local Technical Assistance Program (LTAP), are focused on introducing the concept of asset management to agencies under their jurisdictions. Various other organizations including the National Cooperative Highway Research Program, the Midwest Regional University Transportation Center, the American Public Works Association and many others are also active in developing tools and strategies to assist with asset management (Obermann, Bittner, and Wittwer, 2002).

New requirements for maintaining sign retroreflectivity performance have brought new focus to the inclusion of traffic signs for agencies to proactively manage. In the case of UDOT, the agency has known that including sign management to their ordinary maintenance practices will be mandatory in the future but have large stalled on action hoping future technology would simplify the process. This has been a typical action for many large DOTs but with deadlines approaching, focus is currently turning toward asset assessment and plan development.

2.2.3 MUTCD minimum retroreflectivity level

Establishing standards for minimum levels of retroreflectivity for traffic signs was first directed by Congress to the Secretary of Transportation in 1992. This congressional mandate established the foundation for the future adoption of minimum retroreflectivity levels. The second revision of the 2003 edition of the Manual on Uniform Traffic Control Devices (MUTCD) included a revision that mandated minimum retroreflectivity levels that must be maintained for traffic signs. The revision also mandates that transportation agencies must outline an assessment or management method in order to maintain traffic sign retroreflectivity (Federal Highway Administration, 2007a). In addition to establishing minimum retroreflectivity levels, the MUTCD established 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 (Federal Highway Administration, 2009).

The minimum established retroreflectivity were carried over and included in the 2009 edition of the MUTCD. While the FHWA has looked into the possibilities of including requirements for brown and blue retroreflective sheeting, there are currently no requirements listed. The minimum values that must be maintained by transportation agencies are provided in Table 2.1.

Table 2.1 MUTCD minimum requirements for retroreflectivity. (Federal Highway Administration, 2009)

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			1
	Y [*] ; O [*]	Y ≥ 75; O ≥ 75			3
White on Red	W ≥ 35; R ≥ 7			4	
Black on White	W ≥ 50			-	
¹ The minimum maintained retroreflectivity levels shown in this table are in units of cd/b/m ² measured at an observation angle of 0.2° and an entrance angle of -4.0°.					
² For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs					
³ For text and fine symbol signs measuring less than 48 inches					
⁴ Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)					
[*] This sheeting type shall not be used for this color for this application.					
Bold Symbol Signs					
<ul style="list-style-type: none"> • W1-1,2 – Turn and Curve • W1-3,4 – Reverse Turn and Curve • W1-5 – Winding Road • W1-6,7 – Large Arrow • W1-8 – Chevron • W1-10 – Intersection in Curve • W1-11 – Hairpin Curve • W1-15 – 270 Degree Loop • W2-1 – Cross Road • W2-2,3 – Side Road • W2-4,5 – T and Y Intersection • W2-6 – Circular Intersection • W2-7,8 – Double Side Roads 		<ul style="list-style-type: none"> • W3-1 – Stop Ahead • W3-2 – Yield Ahead • W3-3 – Signal Ahead • W4-1 – Merge • W4-2 – Lane Ends • W4-3 – Added Lane • W4-5 – Entering Roadway Merge • W4-6 – Entering Roadway Added Lane • W5-1,2 – Divided Highway Begins and Ends • W5-3 – Two-Way Traffic • W10-1,2,3,4,11,12 – Grade Crossing Advance Warning 		<ul style="list-style-type: none"> • W11-2 – Pedestrian Crossing • W11-3,4,16-22 – Large Animals • W11-5 – Farm Equipment • W11-6 – Snowmobile Crossing • W11-7 – Equestrian Crossing • W11-8 – Fire Station • W11-10 – Truck Crossing • W12-1 – Double Arrow • W16-5P;6P;7P – Pointing Arrow Plaques • W20-7 – Flagger • W21-1 – Worker 	
Fine Symbol Signs (symbol signs not listed as bold symbol signs)					
Special Cases					
<ul style="list-style-type: none"> • W3-1 – Stop Ahead: Red retroreflectivity ≥ 7 • W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35 • W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7 • W3-5 – Speed Reduction: White retroreflectivity ≥ 50 • For non-diamond shaped signs, such as W14-3 (No Passing Zone), W4-4P (Cross Traffic Does Not Stop), or W13-1P,2,3,6,7 (Speed Advisory Plaques), use the largest sign dimension to determine the proper minimum retroreflectivity level. 					

For white on green there are two values listed, one for ground mounted signs and another for overhead signs. Black on yellow and black on orange have two values depending upon the sign type and size. The MUTCD also provides minimum values for the special case signs of Stop Ahead, Yield Ahead, Signal Ahead, and Speed Reduction signs. These signs represent unique signs and signs where color combinations do not match those listed in the initial values.

2.3 Retroreflectivity

2.3.1 Definition

Retroreflection is the phenomenon that occurs when a ray of light comes in contact with an object and then is redirected back to its source. Retroreflectivity is achieved through the use of materials with particular retroreflective properties. For traffic signs there are two basic material production methods that provide retroreflectivity. These include the use of either prismatic or spherical lenses (Black, McGee, and Hussain, 1992). Prismatic retroreflection is produced through internal reflection of light along prismatic surfaces. The incidental light hits the first front surface of the prism and is reflected to a back surface. The back surface then reflects the light again to a front surface, which in turns reflects the light back toward the light source. An example of prismatic retroreflection is shown in Figure 2.1.

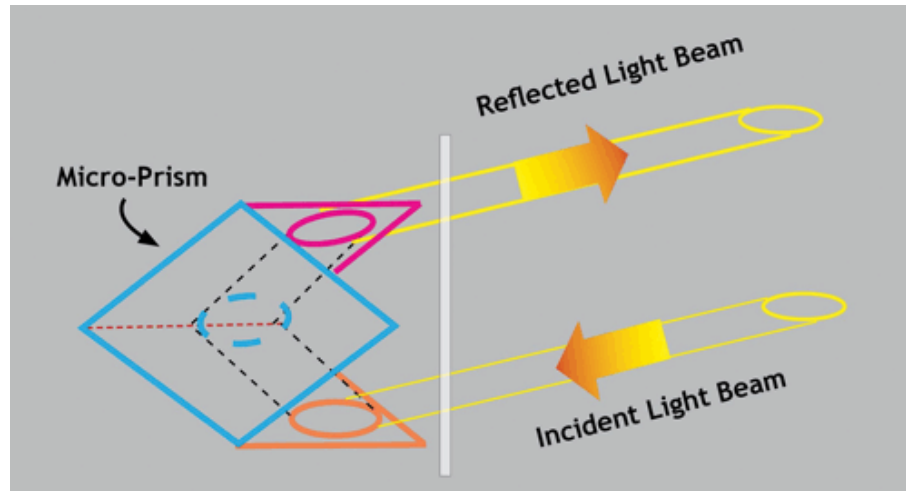


Figure 2.1 Cube corner prismatic retroreflection example. (McGee, 2010)

Spherical lens retroreflection is achieved through the use of a combination of glass spheres and a reflecting backing material that is placed at the focal point where light is refracted to the back of the sphere. The light is then reflected back and refracted through the sphere and is directed back toward the light source. An example of spherical lens retroreflection is shown in Figure 2.2.

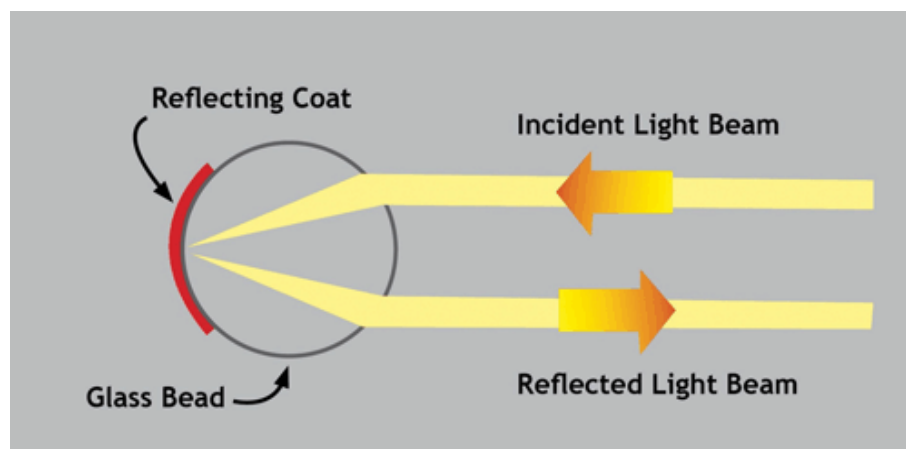


Figure 2.2 Spherical lens retroreflection example. (McGee, 2010)

There are three different forms of spherical lens retroreflective sheeting that consist of either exposed glass beads, enclosed glass beads, and encapsulated glass beads. Exposed glass bead sheeting is sheeting where the front half of the bead is exposed to the air. The first use of exposed glass beads was the 1930's for the cinema's "silver screens" to produce brighter images. By the late 1930's on the 3M Corporation had developed sign faces utilizing exposed beads to produce retroreflectivity (Lloyd, 2008). While the sheeting demonstrated retroreflective results there were problems with water adhering to the tiny surfaces of the beads. Under heavy rain situations the sheeting lost nearly all retroreflective properties (Lloyd, 2008). This type of sheeting is no longer recommended for traffic signs due to this problem. Enclosed glass bead sheeting was developed to overcome this problem. In enclosed glass bead sheeting, a layer of transparent plastic is applied to the open face of the beads that fills the crevices between them and provides a smooth top surface (Lloyd, 2008). While this type of sheeting does not perform as well as exposed glass bead sheeting, it does solve the performance problems under wet conditions. The reason that enclosed glass bead sheeting does not perform as well as exposed is the surface layer introduces additional light loss and reduces the retroreflective capability of the material (Lloyd, 2008). Encapsulated glass bead sheeting also consists of glass beads with a transparent laminate material but the laminate is suspended slightly above the beads. Again, a reflective surface backs the beads but the beads are surrounded by air. This airspace allows the sheeting to be more retroreflective than enclosed sheeting while allowing the sheeting to not lose retrorreflectivity under wet conditions (Black, McGee, and Hussain, 1992).

2.3.2 Retroreflectivity measurement

The Coefficient of Retroreflection (R_A) is the measure used to evaluate retroreflection of traffic signs. It is a measure of the ration of luminous intensity (R_I) returned back to the incident light source divided by the area (Austin and Schutlz, 2006). Measurement is performed through the use of a retroreflectometer.

There are two general configurations of handheld retroreflectometers: Annular Devices and Point Devices. In taking retroreflective measurements it is important to note the type of device that is being used as resulting measurements can vary depending on type of instrument and the procedure followed in taking measurements. Annular devices measure retroreflection by measuring light reflected back at the source in a 360-degree radius around the center point for measurement. The measurements recorded reflect an average of a great number of measurements with varying direction of illumination. Point instruments measure a coefficient of retroreflection that is identical to that performed in laboratory range tests. The procedure involves producing an incident light beam at a given entrance angle and a measurement taken of the reflected light at a specified observation angle (Delta, 2011).

2.3.3 Minimum standards and classification

With the many types of retroreflective sheeting, there was need to develop classification and standards of various types. The American Society for Testing and Materials established guidelines for the classification retroreflective sheeting for use on highway delineators, traffic control signs, barricades and other traffic control devices.

Established were nine different type designations of sheeting with five backing classifications.

Type I sheeting, also known as “engineering grade,” refers to enclosed lens glass-bead sheeting. This is the lowest performing of all retroreflective sheeting (ASTM, 2009).

Type II sheeting, or “super engineer grade,” again refers to enclosed lens sheet differing from engineering grade as it provides higher performance (ASTM, 2009).

Type III sheeting refers to encapsulated glass-bead sheeting. This type of sheeting is known as one type of “high-intensity” sheeting (ASTM, 2009).

Type IV sheeting is also known as “high-intensity” sheeting but refers to unmetalized microprismatic sheeting used for signing (ASTM, 2009).

Type V sheeting or “super high intensity” sheeting refers to metalized microprismatic retroreflective sheeting (ASTM, 2009).

Type VI sheeting refers to “an elastomeric retroreflective sheeting without adhesive.” which is “typically a vinyl microprismatic retroreflective material (ASTM 2009 p.2). This sheeting type is not typically used for traffic signs excepting orange temporary roll-up warning signs and other uses such as traffic cone collars and post bands.

Type VIII sheeting refers to unmetalized cube corner microprismatic sheeting (ASTM, 2009).

Type IX sheeting refers to unmetalized cube corner microprismatic sheeting with higher performance than that of type VIII (ASTM, 2009).

Type XI refers to unmetalized cube corner microprismatic sheeting that has higher performance than both type IX and type X (ASTM, 2009).

Type VII and Type X sheeting are both sheeting designations, which have been discontinued. Any sheeting previously classified as Type VII has been reclassified as Type VIII. Any sheeting previously classified as Type X has been reclassified as Type XIII (ASTM, 2009).

The five backing class classifications refer to various types of backing for retroreflective sheeting. These classes vary dependent upon adhesion type and mounting procedure as well as various performance measures such as the ability to be repositioned under certain temperature conditions (ASTM, 2009). The typical application for the various sheeting types are shown on Table 2.2.

The type classification of all sheeting types are dependent upon performance requirements that must be met such as daytime luminance and retroreflectivity. These requirements also state that performance measures must be met after outdoor weathering

Table 2.2 Retroreflective sheeting applications by type.

Applications for Retroreflective Sheeting Types	
Type	Typical Use
I	Highway signing, construction-zone devices, and delineators
II	Highway signing, construction-zone devices, and delineators
III	Highway signing, construction-zone devices, and delineators
IV	Highway signing, construction-zone devices, and delineators
V	Delineators
VI	Temporary roll-up signs, warning signs, traffic cone collars, and post bands
VII	Highway signing, construction-zone devices, and delineators
IX	Highway signing, construction-zone devices, and delineators
XI	Highway signing, construction-zone devices, and delineators

periods that vary between 12 and 36 months depending upon sheeting type and use. In considering the retroreflectivity of traffic signs it is most critical to note the minimum values required for new sheeting for the 0.2° observation angle and the -4° entrance angle for sheeting colors and types that are typically used in highway signs. These values required for new sheeting by type are shown in Table 2.3.

2.4 Managing Retroreflectivity

With the establishment of minimum required retroreflectivity levels the MUTCD also provides six assessment or management strategies as guidance. An agency using one of the recommended assessment or management methods will be considered in compliance with the mandate requiring all agencies to have a plan for ensuring overall compliance that is required by 2012.

Table 2.3 Minimum (RA) for new sheeting. (adapted from ASTM D4956-09)

Minimum Coefficient of Retroreflection(R_A) For New Sheeting					
Sheeting Type	<i>Observance Angle = 0.2° Entrance Angle = -4°</i>				
	Sheeting Color				
	White	Yellow	Orange	Green	Red
Type I-"Engineering Grade"	70	50	25	9	14
Type II-"Super Engineering Grade"	140	100	60	30	30
Type III-"High Intensity"	250	170	100	45	45
Type IV-"High Intensity"	360	270	145	50	65
Type V-"Super High Intensity"	700	470	280	120	120
Type VI	500	350	125	60	70
Type VIII	700	525	265	70	105
Type IX	380	285	145	38	76
Type XI	580	435	200	58	87

The methods acceptable for compliance are listed as follows from the MUTCD:

- A. Visual Nighttime Inspection
- B. Measured Sign Retroreflectivity
- C. Expected Sign Life
- D. Blanket Replacement
- E. Control Signs
- F. Other Methods

Methods A and B are classified as assessment methods and methods C, D, and E are classified as management methods for complying with the minimum required retroreflectivity standards.

2.4.1 Visual nighttime inspection

Visual nighttime inspection involves the assessment of the retroreflectivity of an existing 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 of associated with traffic signs. Agencies using this assessment method to meet the requirements must develop a training procedure for inspectors and establish guidelines for their individual agencies to manage the retroreflectivity of signs. This training should facilitate the ability of an instructor to discern between signs that meet minimum retroreflectivity levels and those that are near or below standards. (Carlson and Lupes, 2007) One of three procedures is generally recommended to support visual inspections. These procedures are the Calibration Signs Procedure, The Comparison Panels Procedure, and the Consistent Parameters Procedure. The key to effective

nighttime inspection is associated with having trained inspectors and conducting the inspections under similar conditions.

The Calibration Signs Procedure involves an inspector viewing signs that are close to the minimum required level to “calibrate” their eyes for the night’s inspection. A different calibration sign is used for each sheeting color. Inspectors then go and do inspections at night viewing signs from established viewing distances and use their judgment to determine whether signs should be replaced (Federal Highway Administration, 2007b).

The Comparison Panels Procedure involves using sheeting panels that are at or slightly above the minimum established levels of retroreflectivity. During inspections panels are placed against the signs to be inspected and are contrasted to determine whether the sign being inspected is above or below the minimum standards (Federal Highway Administration, 2007b).

The consistent parameters procedure involves inspections that are conducted under similar conditions and factors to those that were used in research to develop the minimum retroreflectivity levels. The factors required for this procedure involve using a sport utility vehicle or pick-up truck model year 2000 or newer. The inspector is to be an individual age 60 or older. Inspectors then travel inspecting signs under normal driving conditions and reject signs that are not legible from proper viewing distances (Federal Highway Administration, 2007b).

Each of the three procedures facilitates the ability to meet the minimum required level but is not without its individual drawbacks. Calibrated Signs and Comparison

Panels require that samples are maintained at or above the minimum level. Assessing that the samples are performing at a retroreflective level at or just above the minimum standards requires the use of a retroreflectometer. With purchase prices ranging from \$10,000 to \$20,000 dollars for retroreflectometers, the cost is prohibitive for many agencies. Using the Calibrated Signs and Consistent Parameters requires the judgment of the inspector which can vary between inspectors and with the amount of training received.

The major concern of Visual Nighttime Inspections is the subjective nature of the process. While this method may be more subjective when compared to other methods, research has shown that trained inspectors can accurately determine whether a sign meets minimum retroreflectivity levels. Research regarding previous inspector accuracy evaluation efforts was conducted by researchers at North Carolina State University (Rasdorf et al., 2006). Included in their overview, the performance of 17 nighttime inspectors was examined by Washington State to determine the accuracy of visual inspections (Lagergren, 1987). A section of uncontrolled highway that included both rural and urban segments was chosen for the study. Along this section of travel way was a total of 130 traffic control signs. The conclusion of the study was that 74% of warning signs and 75% stop signs were correctly identified as pass or fail.

In 2001, Texas Transportation Institute and Texas DOT conducted a study for sign inspector performance (Hawkins and Carlson, 2001). For this study 49 field signs, with varying degrees of retroreflectivity, were removed and placed on a 5-mile closed course. After relocation, 50 inspectors traversed the course and rated each sign using the

qualitative scale acceptable, marginal, or unacceptable. The sign inspectors identified 26 signs as being unacceptable, compared to the measured results of only one sign being unacceptable. The conclusion of this study was that visual inspection result in a higher failure rate than the FHWA minimum standards dictate. Because there was only one sign that was truly unacceptable, it can be concluded that the study did not provide an adequate sample size for determining inspector accuracy.

In 2006, North Carolina State University built upon the Washington State study for inspector accuracy (Rasdorf et al., 2006). The research team in charge of the study accompanied NCDOT sign inspectors, who had received limited training as they conducted a nighttime inspection. The research team then measured the retroreflectivity using a retroreflectometer on the same routes that the nighttime inspection took place on. At the completion of the study 1,057 signs were compared. This study compared well to the Washington State, although it did report greater percentages of Type II error. Type II error is when the inspector approves a sign, when it should have been failed. Whereas a Type I error is when a sign is failed that should had passed. The research team hypothesized that the increase was caused by NCDOT inspectors only failing signs they have the budget to replace. Because red signs were top priority for replacement, the percent correctly replaced displays the true inspector accuracy. The percent correct with the corresponding Type I and II errors for the study is shown in Table 2.4.

Table 2.4 Inspector accuracy- % Correct and Type I and II errors. (adapted from Rasdorf et al., 2006)

Sign Color	% Correct	% Type I	% Type II
White	67	0	33
Yellow	51	2	47
Red	74	4	22
Green	63	5	32

In the most recent study on inspector accuracy Indiana briefly trained university students as sign inspectors (Kilgour, White, and Bullock, 2007). The two man crew inspected a total of 1,743 first using visual nighttime inspection and then later returning to take measurements using a retroreflectometer to compare values. Table 2.5 summarizes the inspector's accuracy of the study in which sign groups described as:

- Group 1 – signs with white legend on red background.
- Group 2 – signs with black legend on white background.
- Group 3 – signs with black legend on yellow background considered bold symbol signs. (Caution, Road Direction, RR Crossing, etc.)

Table 2.5 Indiana inspector accuracy.
(adapted from Kilgour, White, and Bullock, 2007)

Sign Group	Sign Surveyed	Type I Error	Type II Error	Correct Rating	% Correct Rating
1	681	9	56	616	90.5
2	505	1	65	439	86.9
3	391	6	44	341	87.2
4	162	5	21	136	84
5	4	0	3	1	25
All Signs	1743	21	189	1533	88

- Group 4 – signs with black legend on yellow background considered fine symbol signs. (Lettered signs, Playground signs, etc.)
- Group 5 – all other sign not included in the previous groups.
- Type I Error – inspector failed the sign but sign measured value passed.
- Type II Error – inspector passed the sign but sign measured value failed.

An additional concern with nighttime inspections is the accruing of overtime pay for inspectors working during the late-evening and early morning hours.

2.4.2 Measured sign retroreflectivity

Measured Sign Retroreflectivity involves the use of a retroreflectometer to measure the retroreflectivity of an individual sign. These devices are generally hand-held contact devices but non-contact hand-held and mobile non-contact devices, while rare, are also available. The procedure for using a contact instrument is preformed as specified in ASTM Standard Test Method E1709-00e1, which requires four measurements to be taken of the sign background and legend (Carlson and Lupes, 2007). The measurements are then averaged for each color to determine the retroreflectivity values that can be compared with those tabulated in the MUTCD.

This approach is generally seen as the most direct means of assessing retroreflectivity levels in signs. The infield measurements yield retroreflective values that can be compared directly with those mandated in the MUTCD. Because of this, direct comparison the accuracy rate is extremely high so long as the retroreflectometer is reporting the correct values.

Concerns with this method include management and equipment costs as well as concerns with not considering factors other than measured retroreflectivity. Measuring retroreflectivity is labor intensive and the equipment costs are outside the means of smaller agencies. A primary concern with this method is that retroreflectivity on its own only considers one particular element of the sign's appearance. Other factors should also be taken into consideration when determining whether a sign is acceptable to remain in service. These factors include ambient light levels, glare, location and the visual background (Carlson and Lupes, 2007).

In a study performed by Purdue University, the bias and uncertainty in sign retroreflectometer readings were analyzed (Remias et al., 2011). Controlled measurements for 22 stop signs were taken. These signs were signs that had been removed from service in Indiana. Additionally 87 signs of various sheeting type and background color were measured in the field. The retroreflectivity measurements were then taken using three different retroreflectometers and performed by four different operators. This study was performed in order to determine whether uncertainty or bias in retroreflectivity readings occurred when performed by varying operators and equipment. For each sign, the coefficient of variation was calculated for comparison between the different sign colors and sheeting types. The study concluded that the coefficient of variation for an individual sign was between 4 and 14 percent. The study demonstrated that both bias and uncertainty should be accurately characterized for response to potential litigation from signs that fail to meet the minimum standards.

2.4.3 Expected sign life

The Expected Sign Life management procedure involves replacing signs before they reach the end of their expected service life. Sign lives are determined from either sheeting warranties, test deck measurements, or the measurement of signs in the field (Carlson and Lupes, 2007).

This management method requires some method to track the service life of signs, as well as their expected expiration. This can be accomplished in various ways. Stickers may be placed on the back of sheeting during the installation of signs that indicate when a sign was placed and when it should be removed from service. Alternatively signs may be recorded in a sign management system. Management systems range from simple databases to GIS based management systems that integrate mapping with data management. With the use of software based management systems, different approaches or algorithms may be used to evaluate what signs are in need of replacement.

The primary concerns with this method relate to the lack of data on how retroreflective sheeting deteriorates over time. Without models to describe the deterioration of sheeting under various conditions it can be difficult to predict the expected life of a sign in the field.

2.4.4 Blanket replacement

Blanket Replacement involves using the Expected Sign Life procedure on either a spatial or strategic basis (Carlson and Lupes, 2007). Signs are generally all replaced in batches at designated time periods based on geographic location. Time periods are

determined by agencies usually set in conjunction with the manufacturer warranty period for the sheeting.

Concerns with this method include inefficiencies from removing signs that are still adequate and uncertainty as to the proper replacement times.

2.4.5 Control signs

The Control Signs method of managing retroreflectivity involves either installing sets of signs in a maintenance yard or designating control signs from the in-service population for monitoring. Measurements of the control signs are taken over time. As the control signs perform below minimum retroreflective standards, all other signs of similar age and material are replaced. In order for this method to be used it requires agencies to track all of their signs through some inventory method. It must be known for all signs when they were placed and what sheeting type was used.

Understanding the uncertainty involved in predicting the time a sign may remain in service and be compliant with the new retroreflectivity standards researchers at Purdue developed survival curves based upon the probability that signs will be below the minimum required levels of retroreflectivity (Hulme et al., 2010). These survival curves were developed as a framework for addressing the new MUTCD standards to assist in the management of infield signs by attempting to predict the overall percentage of infield signs at a certain age and sheeting that will likely not be in compliance.

2.4.6 Management strategy effectiveness

For development of an asset management strategy to comply with the then proposed minimum levels of retroreflectivity of signs in North Carolina, a study was performed that reviewed various approaches to managing retroreflectivity (Vereen, Hummer, and Rasdorf, 2002). The work focused on the collection of retroreflectivity data and its use in the evaluation of the effectiveness of current inspection methods as well as the potentials of implementing various management strategies. While the minimum standards currently used had not been established this work provided a framework for comparing various management methods for effectiveness and efficiency.

2.5 Retroreflective Deterioration

While the Federal Highway Administration has outlined general guidelines for various methods of complying with the minimum retroreflectivity standards, individual management strategies are left to the agencies for development. These management and assessment strategies rely upon the ability to efficiently predict how retroreflectivity will deteriorate over time, whether to predict when signs are to be replaced or to determine the frequency with which sign inventories and assessments should be performed.

While there has been limited work in the area, there have been several studies in the past that have attempted to identify the factors that affect sign retroreflective deterioration. These deterioration studies were performed with the assumption that sign replacement needs could easily be predicted given the factors present at a specified location. On site, after signs have been placed, the performance of sheeting has been

known to vary. Early opinions included the idea that retroreflection would deteriorate according to some relationship with sheeting age.

In 1992 Black, McGee, and Hussain, in a study for the Federal Highway Administration, conducted the first major study looking into the retroreflective performance of sign sheeting that has been placed in use. The purpose of the study was to develop implementation strategies and to analyze the practicality of minimum retroreflective standards that were then proposed. In the study 8000 sign samples were taken from 26 states and analyzed. The sheeting types that were analyzed included Type II and Type III sheeting that was taken from areas that maintained existing sign inventories. The study could not determine any factors considered correlated to the deterioration of sign retroreflectivity.

Bischoff and Bullock (2002) at Purdue University performed a study for the Indiana Department of Transportation and the Federal Highway Administration to analyze the state of signs within the state of Indiana. The study sought to determine the percentage signs that would be noncompliant with the then proposed minimum retroreflective standards. In the study, the retroreflectivity results for red, white, and yellow signs of Type III were reviewed and compared with three minimum reference standards that were then proposed as the FHWA was developing a minimum standard for inclusion in the MUTCD. Additionally the study sought to identify a model that could describe the deterioration of sign retroreflectivity over time, as well as the effect that cleaning signs has upon the measurement. In addition to providing cost estimates to the state of Indiana for the implementation of various standards, the study yielded vague

results with regard to a deterioration model. Using linear regression the study produced loose correlations between sign age and measured coefficient of retroreflectivity. While there was evidence of a trend for retroreflectivity to decrease over time, low correlation coefficients were calculated for all sign sheeting colors. With yellow sheeting the study yielded a coefficient of 0.19 for retroreflectivity verses age of unwiped signs. White sheeting was found to have a far lower coefficient. Overall, a weak 33 percent correlation between the age and the average coefficient of retroreflectivity for the signs was determined. Azimuth direction analysis and the cleaning of signs where then considered. While the cleaning of signs did yield slightly better correlations, the improvements were relatively insignificant. Initially azimuth facing direction was thought to be a significant factor in the rate of deterioration but the study regarding red signs did not yield results to strongly support this claim.

In a study conducted for the Louisiana Department of Transportation, Brian Wolshon of Louisiana State University collected retroreflective data through the use of a commercially available traffic sign database program. The purpose was to evaluate the effectiveness of data collection for the purpose of sign management (Wolshon, 2003). Using the data collected from this data collection exercises study, empirical analyses was performed on the data focusing on the performance of the sign sheeting relative to the age of the signs though yielding limited results.

Kirk, Hunt, and Brooks (2001) performed a study for the Oregon Department of Transportation to try and identify specific factors that affect sign retroreflectivity. Continuing on the work done in the 1992 retroreflectivity study factors of age and sign

facing direction was evaluated. For the study retroreflectivity readings were taken for 80 Type III signs. There were 20 taken for each of red, yellow, green, and white. For this study all signs were cleaned and dried prior to any readings being taken. The results of the study did show a slight trend of decreasing retroreflectivity with age but resulting correlation coefficients conclude that there is a lack of relationship between sign age and the loss of retroreflectivity. The study found that with increasing age the variation in measured values increased. Sign orientation data was also analyzed to determine if the assumptions that sign orientation is an important factor that affects sign retroreflective deterioration were valid. While results again did show much greater variability with the measurements from signs in the west and south facing signs retroreflectivity deterioration, trends were not found with age when comparing average values for facing directions.

While trying to design an efficient nighttime inspection procedure for the North Carolina Department of Transportation researchers reviewed data collected to try and determine any correlations between sign age and retroreflective deterioration (Rasdorf et al., 2006). Data was collected for Type I and Type III signs in five counties. Regression analysis was performed for white, yellow, red, and green sheeting of the measured retroreflectivity versus the sign age. Linear, Logarithmic, Polynomial, Power, and Exponential curves were then fitted for each of the data sets. In all cases for white, yellow, and green there was little observed correlation as very low R^2 values were calculated. For red sheeting an R^2 value of 0.48 was calculated for a polynomial curve.

While not particularly high it is considerably higher than values calculated for the other sheeting types.

In studying in-service Type III high intensity traffic signs in Texas, researchers sampled signs throughout the state of Texas to reflect factors though to significantly correlate to sign retroreflectivity (Re, Miles, and Carlson, 2010). This study did not provide any solid conclusions as to factors that significantly correlated with sign retroreflectivity deterioration, however, such targeted attribute collection provided a basis to evaluate special considerations relevant to an agency's assets.

2.6 Data collection procedure

In the past, the majority of data collection efforts for the retroreflectivity of traffic signs have been focused solely upon understanding how the retroreflectivity of traffic signs deteriorates. The collection procedures of these studies do provide insight in what could be considered when collecting for the development of a practical plan.

In North Carolina, a study was performed to review various approaches to managing retroreflectivity (Vereen, Hummer, and Rasdorf, 2002). The work focused on the collection of retroreflectivity data and its use in the evaluation of the effectiveness of current inspection methods. The potentials of implementing various management strategies were also considered. The field data collection portion of the project was concerned with field inventories and compliance as well as the effectiveness of various methods of maintaining retroreflectivity. Collecting data with this focus provided a framework for which cost analyses and operational performance may be evaluated.

Research performed for the Louisiana Department of Transportation and Development evaluated data collection procedures with respect to the use of computer based technologies including GIS, GPS and inventory equipment (Wolshon, 2003). Key attributes were collected in order to allow for assessment of the possibility of performing larger scale inventories. The collection area was selected for its widely varied functional road classification, as well as a variation of in the commercialization of its regions. The data collection procedure was designed to provide a basis for future analyses and to assist in future decision making.

Pierce County in Washington State found that a complete sign inventory that included retroreflectivity measurements proved useful in assisting with the selection of a sign management strategy (Ellison, 2008). The county found that the data collected was beneficial for managing their traffic signs. Additionally their inventory provided an approximation of the control group size needed to maintain a desired degree of reliability in estimating the representation of the overall population.

For other small agencies, retroreflectivity measurements in the form of full scale inventories have been found instrumental in assisting to evaluating compliance with required minimum standards (Rogoff, Rodriguez, and McCarthy, 2005). Such an inventory provides significant assistance in identifying issues with the performance of assets currently in use.

2.7 Conclusions

With the new minimum required retroreflectivity standards that are to be upheld by agencies, future efforts in traffic sign asset management will be centered on maintaining nighttime visibility. Selection of materials, construction, and management methodology will have increasing importance to ensure overall compliance.

Each management or assessment method that is proposed by the Federal Highway Administration provides benefits and drawbacks that will be unique to the individual agency that is to implement a particular program. In order to develop a management plan that provides for efficient compliance, the current situation and condition of an individual agency's assets must be evaluated. With such information, the benefit cost of each individual management plan may be evaluated.

For efficiency in the use of many of the management options it is important to understand how assets will perform over time. This is difficult, as previous research has not provided any conclusive models to predict how sign retroreflectivity will deteriorate under varying conditions. Research has shown that the retroreflectivity of a sign will deteriorate over time but little is known as to how or at what rate. With so many factors potentially affecting retroreflectivity performance, as well as the wide field of sheeting materials available, management must be focused on what is most important to a particular agency. Budgetary constraints are often at the center of this focus and in developing a strategy the assets available to assess compliance over time should be considered.

Data collection is crucial in evaluating the condition of an agency's assets as well as conditions present that present unique challenges when managing such assets. The new focus of managing retroreflectivity of traffic signs has presented the challenge, and need, to assess how an agencies sign assets may meet the new performance standards. Learning from previous experiences in data collection for retroreflectivity management, it is necessary to establish a procedure that will provide an adequate sample of the overall population. Previous asset assessments have been performed as full scale inventories. For a large agency, methodology for smaller sampling and assessment must be established. This sampling procedure must also be established in a manner that provides the means to identify any special factors or circumstances present that must be considered when managing traffic signs.

There is a need for developing methodology for the assessment of agency assets in a manner that provides for efficient management while providing a better understanding of issues relating to the agency's sign performance. There is also a need for data collection to provide a better understanding of primary issues affecting the nighttime visibility performance of traffic signs that are either predictable or manageable.

CHAPTER 3

DATA COLLECTION AND METHODOLOGY

3.1 Introduction

In order to develop an adequate plan for effectively managing sign retroreflectivity, current issues specific to Utah relating to sign assets must be identified. The data collection methodology includes a complete and concise overview of the data collection process. As actively managing a minimum retroreflectivity level for a large population is new in practice, this development must provide a framework for which future efforts may be based and improved upon. Inclusive in this section is the method and manner with which data was collected, as well as process and reasoning for the selection of both locations and procedures. The data collected is to provide insight into the current state, performance, and special considerations with regards to UDOT's sign assets. This procedural development is important as it provides needed methodology for a large agency to collect the necessary information to determine situations affecting asset performance, specifically when little data is available and budgets do not allow for full scale inventories. Additionally, data was collected with regards to sign asset management and assessment methodologies.

3.2 Research Question

The focus of this research is to try and resolve an answer to the question "How can UDOT effectively manage their sign assets for compliance with a minimum

retroreflectivity standard?” To develop a comprehensive and efficient sign asset management system that includes maintaining retroreflectivity, significant issues relating to the infield service life of signs must be identified. Identifying current compliance issues and circumstances unique to UDOT’s assets will provide a basis for evaluating and developing a management strategy suitable to meet the needs of UDOT and ensure compliance with the new MUTCD standards.

In order to better answer this question the following areas will be targeted during the procedural development in order to accomplish the goals of this research.

- How can the current state of UDOT’s sign assets be assessed?
- What problems can be identified relating to UDOT’s assets and compliance with MUTCD standards?
- What are the other visibility issues related to the visibility of traffic signs in Utah and how do they relate to managing minimum retroreflectivity levels?
- How do outside factors such as damage, placement, and sheeting usage affect the nighttime performance and visibility of traffic signs in Utah?
- What is the potential effectiveness of various proposed management strategies given conditions unique to UDOT?
- Are there other management strategies, outside those proposed by the FHWA, that are potentially more effective or efficient given conditions unique to UDOT's sign assets.

3.3 Management Framework Development

In order to effectively manage any asset, an evolving framework must be established. Overtime, factors relating to managing transportation assets are constantly changing. These include changes in budgets, technology, policy, and practice. Additionally, with the condition of assets constantly changing, a framework for managing assets must include a plan to continuously update and revise management practices. Figure 3.1 provides a process outline for managing transportation assets. When little information is available, as with the case of UDOT’s traffic signs, the first few steps in the process are critical, as well as most difficult, when developing an initial strategy. For this reason, this research will focus upon the development of the first two stages of this process, initial assessment and policy development.

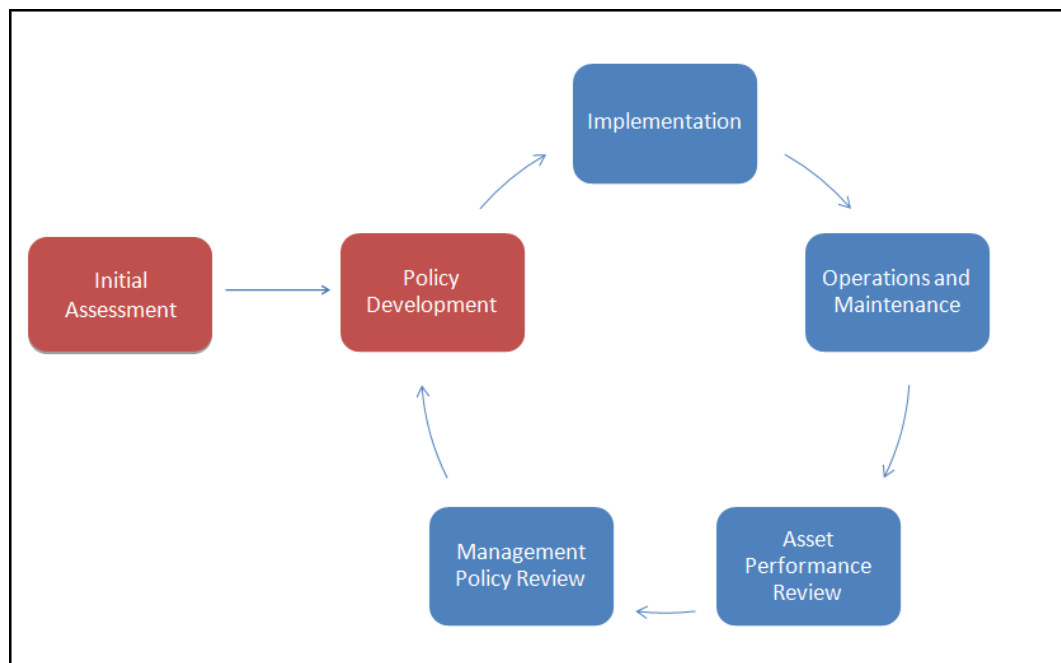


Figure 3.1 Asset management process outline.

3.4 DOT Surveys

With the deadline quickly approaching for the development of a strategy for managing sign retroreflectivity, it is known that many other DOTs will be beginning the process of developing some sort of plan for managing sign retroreflectivity. Literature review has determined that the efforts to develop a robust management plan are quite limited. Most agencies, including UDOT, understand the need to have methodology in place for managing sign retroreflectivity but are still quite unsure as to the best way to proceed. In order to better understand what other agencies are considering, and their reasoning, a survey western states was conducted. Their responses provide additional insight into what steps other agencies have taken, and the resources they intend to commit to such practices. In total four states responded with their current plans for meeting the 2012 requirement of having a management plan in place.

Idaho Department of Transportation (IDT) was contacted and confirmed they had established a method for meeting the 2012 retroreflectivity requirements. Currently maintenance crews conduct nighttime inspections and they will add the control sign method to this inspection process in 2012. IDT currently has a mainframe database system which they are attempting to utilize to optimize the retroreflectivity compliance. Additionally, installation dates will be recorded in the database so it can be cataloged if signs are truly lasting the extent of the manufactures warranties. This is the same system UDOT is currently attempting to use to manage all their transportation assets in a central location. Additional correspondence indicated that IDOT is currently having issues with full implementation and use of their management system. UDOT methods engineers

have indicated similar problems with using the system in integrating all their data into a single location.

Montana Department of Transportation (MDT) is planning on implementing a combination of assessment and management methods. They are going to combine visual nighttime inspection with the expected sign life method. For the visual nighttime inspection, regulatory, warning signs, and route markers will be replaced as they are determined not to meet minimum levels of retroreflectivity. These signs will be replaced by the MDT maintenance crews. Guide signs not meeting minimum retroreflective levels will be identified and replaced either by maintenance or through nominated projects. Using installation dates, an expected sign life management method will be implemented on signs known to be older than five years. Montana has not currently performed a retroreflectivity assessment of their assets. Montana has also updated its policy on sign sheeting materials for permanent signs. For regulatory and warning signs the retroreflective sheet shall be at minimum Type IV sheeting as defined by ASTM D4956-09. For ground mounted guide signs Type IV sheeting will be used for the legend, background, and border.

The Oregon Department of Transportation (ODOT) indicated that they were managing retroreflective compliance via visual nighttime inspection. Signs used in the calibration process of visual assessment will be produced by ODOT. Inspection will take place on an annual basis and will be conducted by personnel who have been trained for visual assessment. ODOT is currently working on creating a database that will be utilized for the collection of inspection results and they are nearing completion of a state wide

sign inventory. This inventory will be used to create a central data base which will also contain the results of the visual inspection. ODOT is one of the few agencies that have performed active research into retroreflectivity management. They performed an assessment of certain areas when the idea of minimum standards was first established.

Nevada Department of Transportation (NDOT) responded to the surveyed and indicated that the state has not decided upon a method to use for maintaining retroreflective compliance. Currently they will continue visual inspection and replace signs as they see fit.

Additional DOT surveyed information was obtained from report by the Vermont Agency of Transportation (Kipp and Fitch, 2009). From this survey, many other responses were obtained. Several States neighboring Utah were included. Arizona indicated that they were implementing a combination of replacement cycles and inventory. Additionally they reported that the factors involved in this selection were funding and simplicity. California planned on implementing a visual nighttime inspection method across the twelve maintenance districts. Because California maintenance already did visual inspection for signs they elected to add retroreflectivity to this process. This survey indicated that while data has been collected in an attempt to model retroreflectivity deterioration, active data collection for compliance and plan development for State DOTs is extremely limited.

3.5 UDOT Database Review

The development of new asset management plan requires a review of current practices utilized by the agency. This is important as to assess data currently available provides a measure of feasibility of implementing various plans based upon current practices. As part of this research intends to provide practical methodology for managing retroreflectivity, the feasibility of any particular management focus must be considered.

Information was provided by UDOT on over 2,500 signs and supports in all 4 regions of Utah. This data is what has been gathered for UDOT's Operations Management System (OMS), a database where various assets may be cataloged and managed from a central location. The sign database does not include any retroreflectivity information and are limited as inventory efforts are just in trial phases. While limited the information by area where inventories have been collected can prove useful when developing the collection strategy. The data provides necessary information such as current materials used by area where signs were inventoried as well as various sign attributes. The information concerning each sign attribute that was collected and is maintained inside the OMS system included the following:

- MUTCD Codes
- Sign Legend
- Sign Dimensions
- Sign Face Material
- Sign Backing Material
- Sign Illumination
- Sign Support ID
- Sign ID

The information provided included type of support, material used, dimensions of the support, and how it was fastened to the base. Furthermore, the location of the signs was provided. The route number and milepost were given, along with GPS coordinates. The orientation of the face of the sign was also given. Lastly, general information was included: the number of signs, the station, district and administrative unit of the sign, and the date in which it was inspected. Understanding the capabilities of this system is important in determining its usage with any particular management plan.

3.6 Retroreflective Data Collection

Retroreflective data was collected throughout Utah in order to evaluate current compliance with the mandated minimum levels of retroreflectivity. When collecting the retroreflective data, additional information was collected regarding conditions present and the attributes of the sign being evaluated, as well as the surrounding area. The current state of compliance as well as performance and maintenance considerations may only be evaluated through collecting data of in service traffic signs throughout the state.

3.6.1 Site selection

For the development of a management plan for maintaining sign retroreflectivity above a minimum standard, the overall level of current compliance must be determined. Additionally data must be collected in order to determine overall sign life performance as well as to determine additional factors that contribute to the need to remove and replace signs that are currently in service. In order to accomplish these goals site selection for data collection was performed to meet specific goals. Firstly a random sample set of

overall compliance for the set was collected. Secondly corridors where sign installation data was known were selected. Collection sites were selected to be representative of signs within the state to provide an overall snapshot of compliance and conditions present within different geographic areas. It is critical that the sample provide the best representation possible of the overall population given the resources available. The entire network of UDOT maintained routes are shown in Figure 3.2.

The structure of UDOT consists of four administrative regions. Each region is subdivided into maintenance stations where maintenance is overseen at the local level.

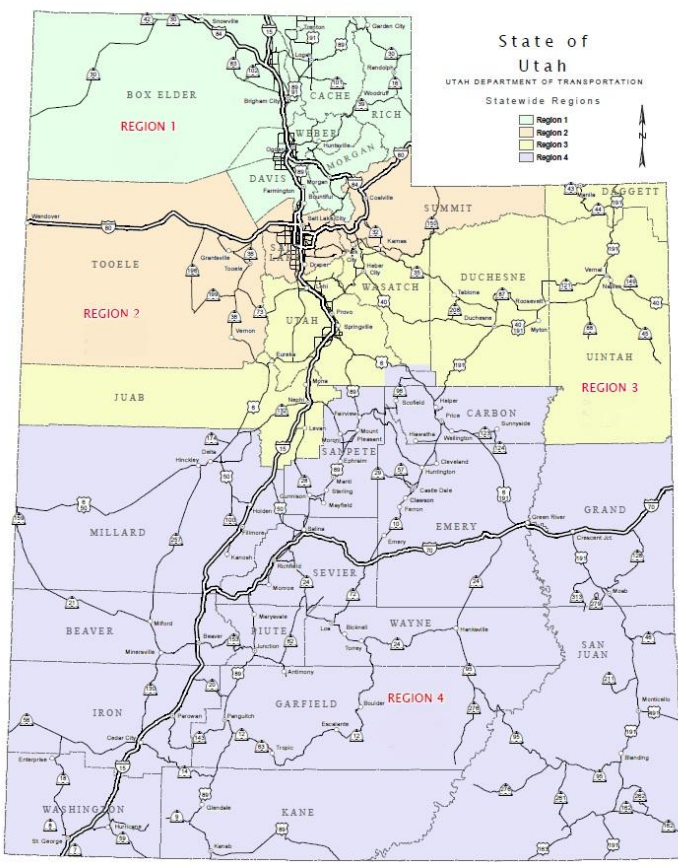


Figure 3.2 UDOT maintained routes.

In Utah, maintenance strategies are directed and overseen at the region level. There can be difficulty in establishing a sample set that is truly representative of the overall condition of signs as sign densities vary greatly and costs must be considered when establishing a sample set. In the case of UDOT with maintenance efforts varying greatly by region and individual maintenance sheds it was important to provide a representative sample.

In order to gather an adequate random sample set for the UDOT maintained state roads, several strategies were implemented. Sign data was collected for spatial regions to represent conditions present throughout the state. Data for Each UDOT region was collected separately. Junctions were then selected throughout each region to represent an overall sample set for the region. Junctions represent the highest densities of sign populations for the State's assets. In addition to the selected junctions, routes representing an overall sample based upon spatial location were selected. Signs were evaluated between at intervals between 5 and 15 miles to represent the overall populations of signs outside of junction areas. The interval was determined based upon geometric and geographic conditions present. Signs on routes traversing canyons areas and winding roadways were sampled at smallest intervals of one sign per sheeting color every 5 miles. Rural desert areas primarily consisting of lengthy sections of strait roadway way were sampled at the maximum interval of 15 miles with other areas including urban areas being sampled between the two limits. These intervals were selected in order to better represent the overall sign populations for the given areas.

While traveling between routes additional signs were also identified and evaluated where special considerations and situations were identified.

Where known sign installation data was available, additional collection efforts were taken in order to better understand how signs were performing on UDOT maintained roads under different conditions. When feasibly possible, signs containing installation dates were evaluated and retroreflectivity measurements were taken. New UDOT standards mandate that all signs placed into service be accompanied by a sticker on the sign face denoting the installation year. UDOT in the past has mandated that contractors place installation stickers on signs at the time of installation but this mandate was often disregarded. Figure 3.3 shows the placement of installation dates on recently placed signs.

During preliminary investigations reviewing placement of these date stickers, it was determined that there was no uniform size for the date stickers.



Figure 3.3 Date sticker examples.

The small size of some date stickers presents a challenge for passing investigators if part of an inspection process as many stickers are illegible at even very slow speeds from the roadway. On the newest signs, the front facing sticker is accompanied with one on the rear that details the sheeting type and manufacturer as well as the exact date the sign was constructed.

In collecting a representative sample, there is extreme difficulty in sampling guideway signs that are overhead on freeway routes. Safety and feasibility was a major concern, and as such, green guideway signs on interchanges were used as proxy for overhead freeway signs. While this practice may, or may not, provide an adequate representation of the signs that are placed overhead, practicality called for use of such a procedure.

3.6.2 Sign attribute collection

In order to analyze and determine special considerations unique to Utah with regards to sign asset management, specific attribute data was collected for signs. For each sign location where data was collected, information regarding specific attributes was collected. For sign attribute collection a Trimble GeoXT handheld data logger was utilized. The Trimble GeoXT handheld was used to facilitate rapid data collection where individual attributes collected may be attached to an associated GPS location. Trimble handheld GPS units are common to most transportation agencies and are widely used for asset data collection and inventory purposes. The Trimble allows for the creation of ESRI shape files that may be used in conjunction with a variety of GIS software and facilitate mapping where data may be associated with particular GPS locations or routes

known as “shapes.” A data dictionary was created in the Trimble GeoXT where drop down menus and text boxes were used to quickly collect the necessary data. The attributes collected included the following:

- Sign ID
- Sheeting Type
- Offset
- Mount Height
- Retroreflectivity Measurements
- Orientation
- Direction of Travel
- Sign Condition
- Installation Date (when known)
- Bracing and Mounting
- Exposure
- GPS Location
- Road Surface Type
- Shoulder Surface Type
- Major Damage Type
- Minor Damage Type
- Sheeting and Legend Color
- Photo Numbers

Sign ID refers to unique identifier assigned to each sign for which data was collected. Each sign was assigned a unique identifier to assist in data collection and processing.

Sheeting Type refers to the ASTM standard sheeting type for the sign. When known the manufacture will be noted in the comments section. Identification of sheeting types was accomplished by applying the Federal Highway Administrations identification guide (Federal Highway Administration, 2011).

Offset is the lateral offset of the sign from the road path measured from the edge of traveled way to the base of the signpost.

Mount Height is the vertical mounting height of each sign measured vertically from the corresponding edge of traveled way to the bottom of each sign.

Retroreflectivity Measurements refer to the measured coefficient of retroreflectivity in candelas per lux per meter squared. These measurements were taken with the use of a Delta RetroSign Model 4500 retroreflectometer. The Model 4500 illuminates the sign at an -4° angle with the angle of observation being 0.2° .

Orientation refers the azimuth orientation of the sign face taken as the angle measured perpendicular to the sign sheeting.

Direction of Travel is the travel direction of traffic that utilizes the particular installed sign.

Sign Condition, Damage Major, and Damage Minor refer to the condition of the sign and damage that was present. In the field, damage was identified by the degree and was aggregated into primary categories of Peeling, Cracking, Bending, and Vandalism when present. In order to classify damage issues of the signs and the associated effects on retroreflectivity five damage categories, shown in Figure 3.4, were used during the collection process. Damage categories included bending, peeling, vandalism, cracking, and other. These categories are defined as follows:

- *Bending damage* describes signs that had significant portions of the sheeting bent causing light to be reflected away from its origin.
- *Peeling damage* applies to the legend of a sign peeling off of the background sheeting.

- *Vandalism* is the most diverse category of damage and included damage caused by paintballs, bullet holes, beer bottle impacts, stickers, and graffiti.
- *Cracking damage* was only present upon Type I sheeting signs and consisted of the retroreflective background cracking and degrading over time.
- Other forms of damage recorded were fading, tree rubbing, and tree sap.

Installation Date is the date the current sign sheeting was placed in service, established either by known blanket replacements or by installation stickers. Because of the limited installation data, additional effort was taken beyond the random sampling to collect sign data where installation information was known. 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. Typically the sticker on the front of the sign has a transparent background with a black legend for the year it was installed, whereas the back contains the month and year of installation and the company that constructed the sign. Although mandatory since 2008, compliance with this policy was not consistently adopted by the stations and contractors installing signs for UDOT.

Bracing and Mounting is the type of mounting method used to mount the sign face to the support. Bracing indicates whether additional bracing was provided for the sign sheeting.

Exposure is used to categorize the surrounding area conditions where the sign resides. The exposure is either categorized as urban, rural, mountainous, or canyon.

GPS Location is the location measured at the base of the support.



A. Bending Damage

B. Peeling Damage



C. Vandalism



D. Cracking Damage



E. Other Damage Types

Figure 3.4 Damage categories.

Road Surface Type refers to the roadway surface type adjacent to the sign being evaluated. This was classified as either being asphalt, cement, or gravel.

Shoulder Surface Type refers to the condition and type of material between the edge of traveled way and the base of the sign.

Sheeting and *legend color* is the type color of the sheeting and legend. Unless denoted all legend color is determined as white.

Detailed photos were taken of each sign evaluated with additional photos taken when necessary when varying conditions are identified. The photos were used to further categorize damage after data has been collected.

Retroreflective measurements were taken with accordance with ASTM standard requirements for each sign, taking four measurements for each sheeting color on both the legend as well as the background. Locations for retroreflectivity measurements varied depending on the sign type with the general locations being shown in Figure 3.5.

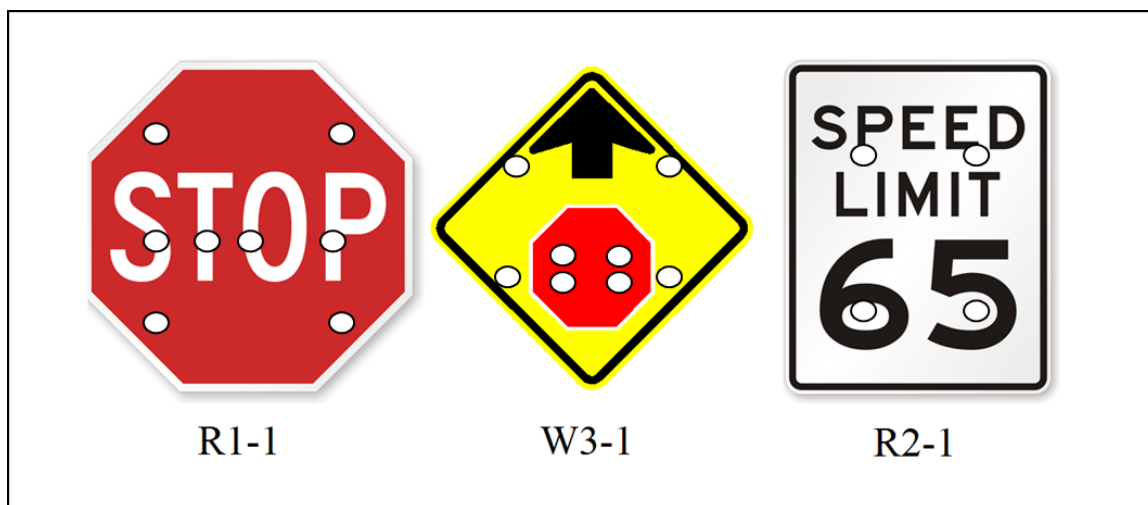


Figure 3.5 Retroreflectivity measurement locations example.

The overall measurement for the coefficient of retroreflectivity (Ra) is then calculated by averaging the points for each color upon the sign face. The calculated coefficient may then be compared with the table given in the MUTCD for compliance. In the case of stop signs, the contrast ratio between the retroreflective measurement of the background and legend is then calculated in order to evaluate compliance with the required 3:1 minimum contrast ratio of white to red.

3.6.3 Collection procedure

After a few preliminary trails it was determined that a three-person team would be used to increase safety and efficiency of the data collection process. For increased efficiency, each person would have specific task to complete for the various sign attributes. Researcher one was the driver of the vehicle and was in charge of loading and unloading the ladder as well as taking retroreflectivity measurements. Researcher two was the front seat passenger and was in charge of entering data into the hand held GPS unit. Researcher three was in charge of taking photographs and sign measurements. The sign survey process was broken up into three sequential stages: the (1) setup, (2) measurement, and (3) teardown.

As the member of the research team took the retroreflectivity measurements, the other members of the team began to enter attributes of the sign into the GPS unit. Following this survey process the research team was able to measure on average 15 signs per hour, which is comparative to pervious collection projects (Vereen, Hummer, and Rasdorf, 2002). This average included the time spent traveling between sign locations. In the case of a full sign inventory where sign densities were much higher, this collection

rate would likely prove much higher. It is also possible to increase this rate by reducing the number of attribute measurements per sign.

3.6.4 Nighttime inspections

With the assumption that daytime inspection and retroreflectivity measurements do not always reflect the nighttime visibility of traffic signs nighttime inspections were to be performed. Inspections were performed by driving corridors where sign measurements were taken during the day and issues were observed that had effects on nighttime visibility. Photos were taken of signs that inspectors determined had presented problems with nighttime visibility. The retroreflectivity measurements and condition of these signs as attained during the day were then reviewed. Nighttime inspections were also performed for signs that exhibited varying forms of damage to assess their effects during nighttime conditions.

CHAPTER 4

DATA ANALYSIS AND PLAN DEVELOPMENT

4.1 Data Collection Overview

To provide the data necessary, a total of 1,433 signs were inventoried and measured spanning UDOT's four regions. The sample size was approximately 1.5% of the 95,000 signs UDOT currently maintains. Under the assumption of a fully unbiased sample, this sample would provide for a 95% confidence level with an error of plus or minus 3% that the sample would be representative of the overall population. The signs sampled provided for a good representation of the overall population with only a few acknowledged exceptions. In further review, consistent sheeting usage and conditions present between neighboring maintenance sheds indicate that the signs sampled should be representative of the overall populations, although some special circumstances in those areas may have been missed. As expected, white and yellow signs make up the majority of the surveyed signs. Table 4.1 displays a summary of surveyed signs divided amongst UDOT's four regions.

Table 4.1 Surveyed signs overview.

Region	Signs by Color then Type																				Total
	Red					White					Yellow					Green					
	III	III HIP	IX	XI	I	III	III HIP	IX	XI	I	III	III HIP	IX	XI	I	III	III HIP	IX	XI		
One	4	2	2	0	44	107	17	23	0	17	91	3	23	0	4	96	5	5	0	443	
Two	12	13	7	0	0	6	35	19	8	1	15	6	6	1	0	4	8	6	1	148	
Three	7	4	1	3	20	73	3	4	10	11	50	4	12	14	4	46	21	13	7	307	
Four	86	12	4	13	13	100	18	21	9	7	81	35	26	8	7	58	4	18	15	535	
Total	109	31	14	16	77	286	73	67	27	36	237	48	67	23	15	204	38	42	23	1433	

The distribution of signs within the sample categorized by sheeting type and color is as follows:

Sheeting Type	Color
<ul style="list-style-type: none"> • 9% Type I • 58% Type III • 13% Type III HIP • 13% Type IX • 6% Type XI 	<ul style="list-style-type: none"> • 12% Red • 37% White • 29% Yellow • 22% Green

In accordance with ASTM E1709-09, four measurements for both the retroreflective background and legend, if applicable, were taken for each sign. These four measurements were averaged in order to determine the signs overall retroreflectivity per the ASTM standard. During the measurement of each sign, special considerations were taken to ensure that the retroreflectometer was held vertical and steady against the sheeting as well as taking measurements at the same four areas regardless of sign damage.

4.2 MUTCD Compliance

One goal of this research was to develop a strategy for assessing the current compliance of UDOT maintained signs with the new MUTCD minimum retroreflectivity levels. Also it was desired to determine how different sheeting types were performing within the overall UDOT population. When considering compliance, signs were only rejected if the measured retroreflectivity was below minimum retroreflectivity levels. Though damage was reported and categorized, in establishing compliance rates, signs were never rejected purely based on damage alone. The measurements did sometimes

reflect damage issues as often “dead spots” were found where damage was present on areas of the sign that resulted in full loss of the retroreflective properties of the sheeting.

Table 4.2 displays the compliance rate for the surveyed signs by sheeting type and color. The numbers shown are the number of signs that were found below the minimum retroreflectivity levels. The rejected column and row indicate the percentage of signs rejected within the overall population of the given sheeting type or color.

The vast majority of all rejected signs were Type I and Type III. This is as expected as Type I and Type III produce the lowest measured values of retroreflectivity. UDOT, in practice, has begun phasing out the use of Type I sheeting. The actions of UDOT to replace these signs have been justified because 69% of the remaining population failing to meet the minimum requirements. Although there were several rejections of Type IX sheeting, all of which were green, the rejection was determined to be due to special causes. For the six rejected red signs, one was a stop sign and the remaining five were exclusion signs. For the overall sign sample population the failure rate was 9%. Overall UDOT maintained signs were performing well with having 91% of their population at a level at or above the minimum required levels.

Table 4.2 Compliance rates by sheeting type and color.

Color	Sheeting Type					Rejected
	I	III	III HIP	IX	XI	
Red	0	6	0	0	0	4%
White	46	0	0	0	0	9%
Yellow	33	20	0	0	0	13%
Green	9	3	2	5	0	6%
Rejected	69%	3%	1%	3%	0%	

4.3 Sheeting Performance Overview

Currently there are five types of sheeting that has been utilized in the construction of traffic signs currently in service. These types of sheeting are Types I, III, IX, XI, and Type III HIP. The Type III HIP may be classified as other types depending on usage but is classified as Type III HIP by UDOT. Almost all signs observed were manufactured by 3M Corporation, with some exceptions where Avery sheeting was found. The Avery signs were distinctive because the signs had wood backing.

4.3.1 Type I

UDOT began phasing out the use of Type I sheeting due to its low levels of retroreflectance and corresponding short service life. At the completion of the survey period there were no Type I red sheeting signs surveyed. While UDOT currently does not place new Type I signs, there is still a considerable population of Type I white, yellow, and green signs still in service.

The individual manufacturers for each Type I sign were not identified as such identification is extremely difficult for engineering grade sheeting.

Figure 4.1 shows the box and whisker plots for the retroreflectivity values measured of Type I signs collected. On the plot, the horizontal lines shown detail the minimum required level of retroreflectivity listed currently in the MUTCD for each color. These values detail the minimum required level that must be maintained for the post mounted traffic signs that were evaluated.

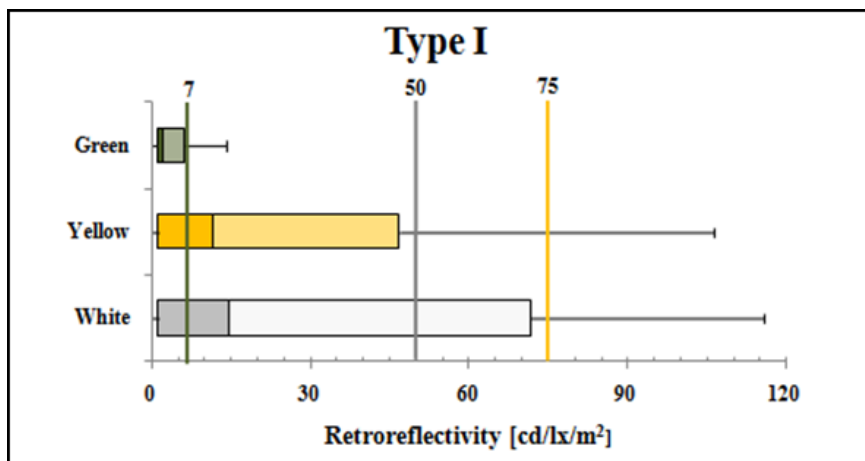


Figure 4.1 Type I sampled retroreflectivity box and whisker.

The mean retroreflectivity level for Type I white signs in the surveyed sample set was 36 (cd/lx/m²), which is well below the minimum level of 50 (cd/lx/m²). Sixty percent of all Type I whites failed. White Type I signs had a high rate of cracking damage which is likely the root cause for the increase in failures. Although the majority of Type I white signs were found to be non-compliant, there are a few examples that are still perform well. In the surveyed sample population, Type I white was usually used for route identifications and speed limit signs.

Yellow Type I had the highest failure rate of any Type I sign color with 80% have retroreflective measurements below the minimum levels. Yellow Type I had the high rate of vandalism and had mean retroreflective at a third of the minimum level. Such high failure rates are somewhat expected as by ASTM classification the minimum Type I measured retroreflectivity is at a level that is equal to the minimum Type I retroreflectivity level required by the MUTCD. For this reason the MUTCD has stated that Type I yellow sheeting should not be used for newly constructed traffic signs.

Green backgrounds made up the smallest percentage of Type I sheeting with only 15 being measured during the sign survey. Similar to the other Type I background colors, green had a mean measurement of 4 cd/lx/m^2 that is below the minimum retroreflective level. Of the green survey sample, 75% measured below the minimum level.

In reviewing all Type I signs and Type I failures there were several situations unique to this sheeting type.

Type I signs sometimes exhibited a type of damage only found in this sheeting. Classified when collected as cracking, an example of this type of damage is shown in Figure 4.2. This was assumed to occur when the sheeting face deteriorated to the point that the face became powdery and brittle. This type of damage is easily recognizable under daytime inspections.

Just over half of the Type I signs sampled exhibited this type of damage. Of the signs with cracking damage present 98% were found to be below the minimum requirements between all sheeting colors.



Figure 4.2 Type I cracking example.

Understanding this characteristic damage is important as it was found to be a clear indicator that a Type I sign had failed. While not every Type I sign that failed displayed this type of damage had failed, particularly with sheeting colors with high measured retroreflectivity such as white, this type of damage may be used under daytime inspections to adequately accept or reject a particular sign.

The percentage of Type I signs currently in service varied greatly by region. A summary of the percentage of Type I sheeting used in the populations of each region are shown in Table 4.3.

UDOT Region 2 has been the most active in using sheeting other than Type I. Primarily consisting of urban areas, signs have been replaced with better sheeting types as construction and maintenance has been performed in recent years. Region 4 had one of the smallest percentage of Type I signs in their overall populations but the Type I signs still were in some of the best condition.

Many of the Type I signs that were in compliance with the minimum required levels were found in this region.

Table 4.3 Type I sheeting sample by region.

Region	Type I Sheeting	
	# collected	% of population
One	65	15%
Two	1	1%
Three	35	11%
Four	27	5%

Region One and Three both maintained a significant number of Type I signs in their populations with the majority falling well below the minimum required retroreflectivity levels.

4.3.2 Type III

Type III beaded sheeting was determined to be the most commonly used sheeting by UDOT. Type III was found throughout the state and used for all manner of traffic signs. The number of Type III signs collected and percentage of overall populations within each region is shown in Table 4.4.

Regions One, Three, and Four all maintain large populations of signs with Type III sheeting within their overall sign populations. Region Two is the only exception with Region Two opting for usage of Type III HIP, Type IX and Type XI usage as signs have been replaced in the last few years as construction and maintenance has been performed.

The UDOT Type III signs were performing rather well with only three percent failing. 3M was found to be the primary manufacturer of the majority of Type III sheeting used for UDOT's signs.

Table 4.4 Type III sheeting sample by region.

Type III Sheeting		
Region	# collected	% of population
One	298	67%
Two	37	25%
Three	176	57%
Four	325	61%

Figure 4.3 shows the box and whisker plots for the Type III sheeting sampled during collection. Values for Type III red ranged from a value of 12 to 91 cd/lx/m² with a mean of 38 and a standard deviation of 21. Of 111 signs collected there were only six failures. The failures were all old sheeting where visible damage and fading was present. Two of these signs contained a large degree of vandalism. Retroreflectivity had been lost as solvents and cleaners had been used to remove graffiti from the signs' faces. Figure 4.4 displays an example of this loss as a result of attempting graffiti removal. Where an attempt was made to remove paint the retroreflective properties of the sheeting was completely lost. Other areas where no attempt to remove the paint was made measured values consistent with the sheeting type and age.

For all color signs, the maintenance practice of removing such vandalism is of particular concern. While the current practice of removing the paint from the sheeting surface improves the daytime legibility of the sign, the act was detrimental to the nighttime visibility.

Of 204 Type III green measured, only two signs were found to be failing. Values measured ranged from 19 to 73 cd/lx/m² with a mean of and standard deviation of 9 cd/lx/m². Very few issues were found with the Type III green population where the only exceptions being signs that exhibited extreme fading and cracking. The Type III yellow sample set contained the highest degree of variability with measured values ranging from 5 to 394 cd/lx/m². The mean measurement of the Type III yellow signs was 194 and the standard deviation 72.

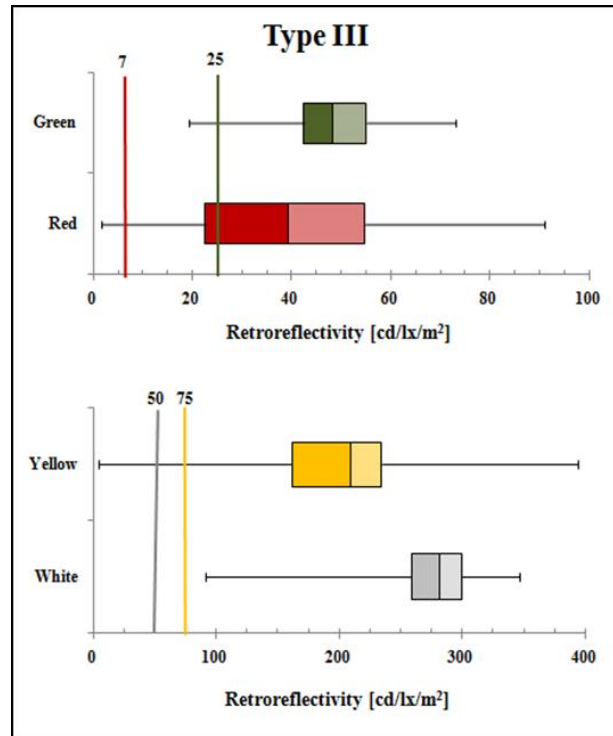


Figure 4.3 Type III sampled retroreflectivity box and whisker.



Figure 4.4 Graffiti cleaning attempt.

The majority of failed signs exhibited either extreme damage, weathering, or vandalism was present. Of all signs evaluated yellow sheeting was roughly three times more likely to display vandalism than any other sheeting. Damage was often visible from bullet holes, paintballs, and damage from projectiles thrown from vehicles such as glass bottles.

From the samples collected there were no Type III white sheeting failures. Observed values ranged from 91 to 394 cd/lx/m² with a mean 275 cd/lx/m² of and standard deviation of 36 cd/lx/m². The Type III population is performing extremely well with respect to compliance with the majority of signs well above the minimum required standards.

4.3.3 Type III HIP

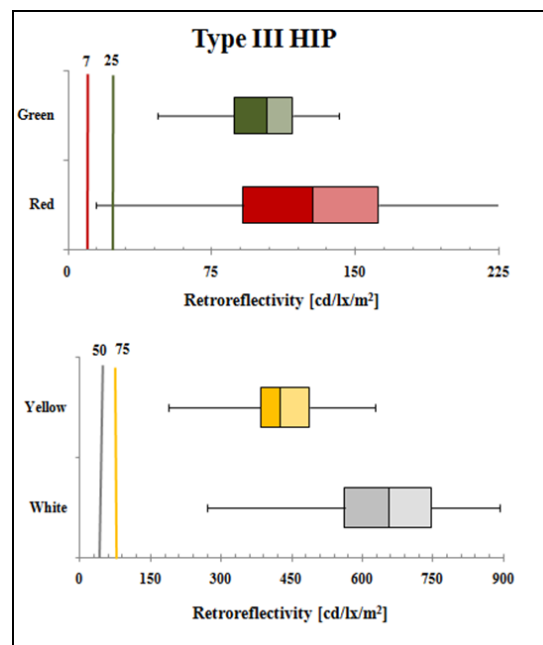
The Type III HIP population, though small, was performing very well within the state. Type III HIP sheeting refers to the Type III cube corner prismatic sheeting utilized by UDOT. While classified by UDOT as Type III HIP, these signs may also be classified as other sheeting types depending on usage. Because of this, the measured values of such sheeting are significantly higher, relative to Type III beaded sheeting. Table 4.5 shows the percentage of usage of Type III HIP signs within each region.

There was deviation between values of the measure values of Type III HIP signs. This is rather unusual as many of the signs measured appeared to be fairly recently placed into service. A possible explanation is provided in a following section relating to construction and orientation of signs using prismatic sheeting. The box and whisker plots displaying the values measured are shown in Figure 4.5.

Table 4.5 Type III HIP sheeting sample by region.

Type III HIP Sheeting		
Region	# collected	% of population
One	27	6%
Two	62	42%
Three	32	10%
Four	69	13%

Type III red values ranged from 15 to 225 cd/lx/m^2 with mean of 122 and a standard deviation of 52.7. White values ranged between 270 to 890 cd/lx/m^2 with a mean of 646.8 and standard deviation of 142.4. Yellow values ranged between 189 to 627 cd/lx/m^2 with a mean of 434.6 and standard deviation of 86. Green values ranged between 47 to 141 cd/lx/m^2 with a mean of 101.2 and a standard deviation of 20.3.

**Figure 4.5** Type III HIP sampled retroreflectivity box and whisker.

4.3.4 Type IX

In recent years there has been a push within UDOT to utilize prismatic sheeting. While Type III HIP, and Type XI sheeting is being placed for new projects, 3M Type IX sheeting is currently the most common sheeting placed during new construction and maintenance projects. Table 4.6 shows the percentage of usage of each sign per region.

Overall the Type IX population was performing very well with the oldest known signs placed in 2005. The only exceptions where signs were found to be failing were found with green Type IX signs. Further review of these signs identified special problems unique to the construction of these Type IX signs. The box and whisker plots for the overall Type IX populations of all colors are shown in Figure 4.6.

The mean and standard deviation for Type IX green was observed at 72.6 and 29.79 cd/lx/m², respectively. There were 5 Type IX green signs that failed. Almost all other signs maintained measured values far above the minimum standards. An investigation of these failures identified a problem with the construction of certain signs found in the Trapper's Loop area of Region One.

Table 4.6 Type IX sheeting sample by region.

Region	Type IX Sheeting	
	# collected	% of population
One	53	12%
Two	38	26%
Three	30	10%
Four	69	13%

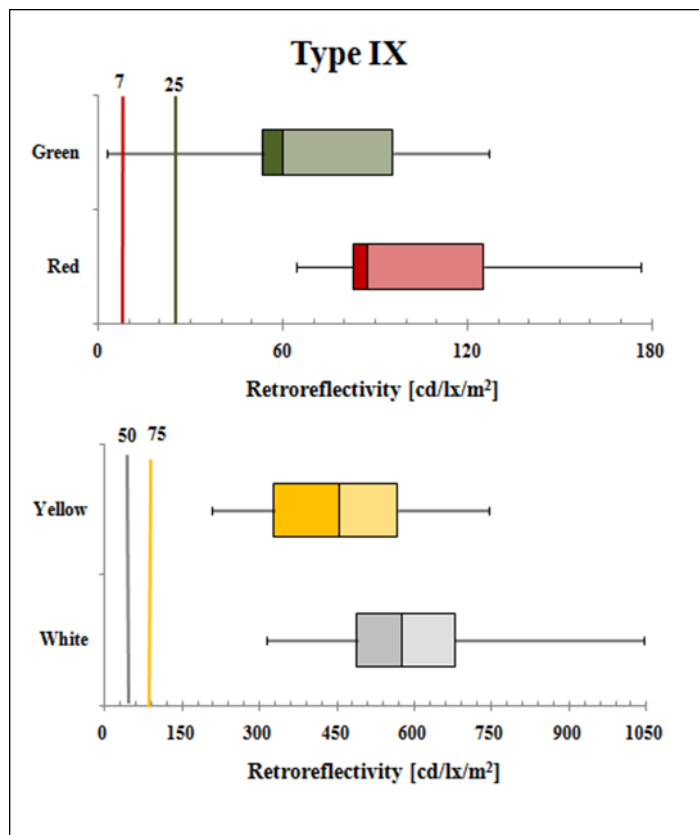


Figure 4.6 Type IX sampled retroreflectivity box and whisker.

The primary problem occurs where on certain signs where the legend was cut out of a green overlay and that overlay was placed over white sign sheeting. The manner of this construction resulted in cracking in across the face of the sign and premature failure in signs that were relatively recently placed. Figure 4.7 displays an example of this type of failure found.

There were also several signs with green Type IX backgrounds that were found failing where the white legend failed due to the improper use of Type III beaded sheeting as a legend overlay. This is not a problem With the Type IX sheeting itself but highlights the advantages of consistency of material usage within sign sheeting.



Figure 4.7 Type IX sheeting overlay failure.

The Type IX white signs were found to be far above the minimum, with the lowest recorded sign displaying a measurement of 338 cd/lx/m^2 . The overall population had a mean measured value and standard deviation of 587.55 and 160.96 cd/lx/m^2 , respectively.

There were two categories of Type IX Yellow currently being used, either yellow or fluorescent yellow green. The MUTCD allows for the usage of fluorescent yellow green sheeting for the applications of pedestrian, bicycle signs and school crossing signs and UDOT has used them in recent years for school crossings. During sampling, 68 yellow Type IX signs were collected along with 10 yellow green. The mean measured retroreflectivity and standard deviation for yellow sheeting was 452.14 and 134.14 cd/lx/m^2 , respectively. For the fluorescent yellow green the mean and standard deviation was 477.35 and 62.51 cd/lx/m^2 , respectively. Considering a minimum required level of 75 cd/lx/m^2 , the population of Type IX yellow sheeting was performing

extremely well. This is likely a result of the relatively new sheeting of Type IX signs in service, as well as the high starting coefficient of retroreflection required for new Type IX sheeting.

Type IX red sheeting currently in service again was performing extremely well with an average measured coefficient of retroreflectivity of 102.11 and a standard deviation of 34.49 cd/lx/m².

4.3.5 Type XI

Type XI sheeting was the least used sheeting type found from the sample of UDOT signs. The breakdown of population by region of the sample is shown in Table 4.7. There were no samples of Type XI collected in Region One although the actual population may differ if overhead guide way signs had been considered for the sampling procedure.

With respect to compliance with the minimum required retroreflectivity levels, the Type XI sheeting population performed the best as expected with the majority of signs well above the minimum required levels. As with other prismatic sheeting this is to be expected as these are some of the most recently placed signs and Type XI sheeting has the highest starting coefficient of retroreflectivity of any sheeting currently being used by UDOT.

Figure 4.8 displays the box and whisker plot of the signs that were sampled with Type XI sheeting and where they sit in accordance with the minimum required levels.

Table 4.7 Type XI sheeting sample by region.

Type XI Sheeting		
Region	# collected	% of population
One	0	0%
Two	10	7%
Three	34	11%
Four	45	8%

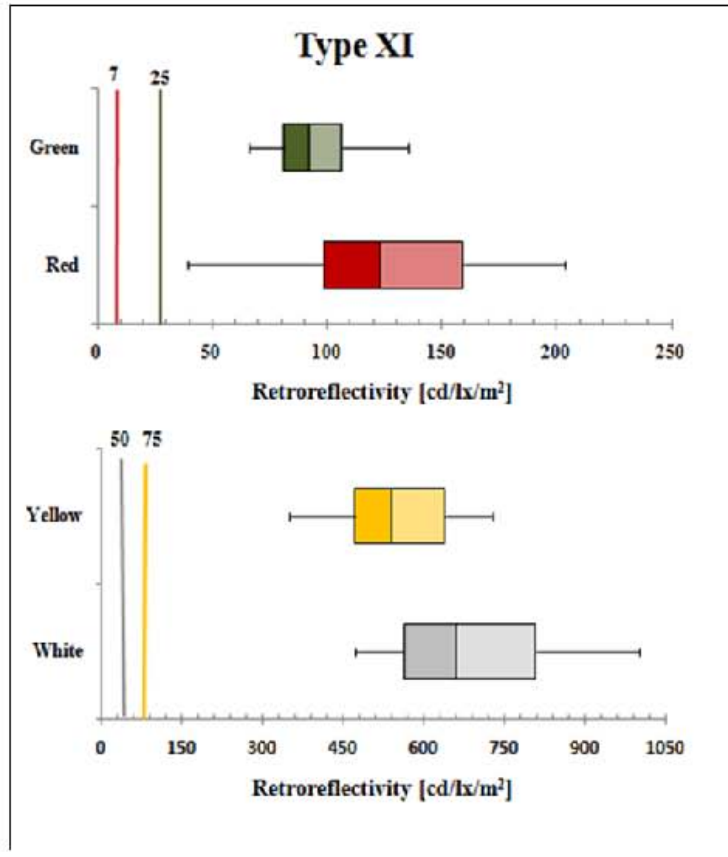


Figure 4.8 Type XI sampled retroreflectivity box and whisker.

- The Type XI green sheeting sample population had the tightest distribution of all the Type XI sheeting with a mean measured coefficient of retroreflectivity of 94.85 and a standard deviation of 18.98.
- The red Type XI sheeting sample population had a mean measured coefficient of retroreflectivity of 124.64 and 45.91.
- The yellow Type XI sheeting sample population had a mean measured coefficient of retroreflectivity of 56.77 and 101.28, respectively.
- The white Type XI sheeting sample population displayed a mean measured coefficient of retroreflectivity of 556.77 and 101.28, respectively.

All of these values were well above the minimum required levels. Assumptions on long term performance of Type XI are difficult to make as the majority of these signs have been newly introduced to the overall population of signs maintained by UDOT. With all other sheeting types, while exact installation dates may have been unknown, relative ages may be determined by construction type or location and can assist in determining if over all if there were specific problems contributing to premature retroreflectivity loss. Continued monitoring will be necessary to better understand how Type IX sheeting is performing.

4.4 Rotational Sensitivity

When collecting the sample sign data, a great degree in variation in the measurement of many recently placed traffic signs that utilized prismatic sheeting was observed. This tremendous variation was evident when reviewing the plots for signs

where installation dates were known. Because the tracking of sign installation data is a relatively new procedure for UDOT, and has taken some time for implementation, the samples with known sign installation data was fairly low. As such, for UDOT currently deterioration modeling would be quite difficult as there is such limited installation data available. Despite the small data set with known installation dates, an extreme degree of variation is clearly evident in signs that were recently placed as seen in Figure 4.9. These measurements were for signs that did not display signs of damage.

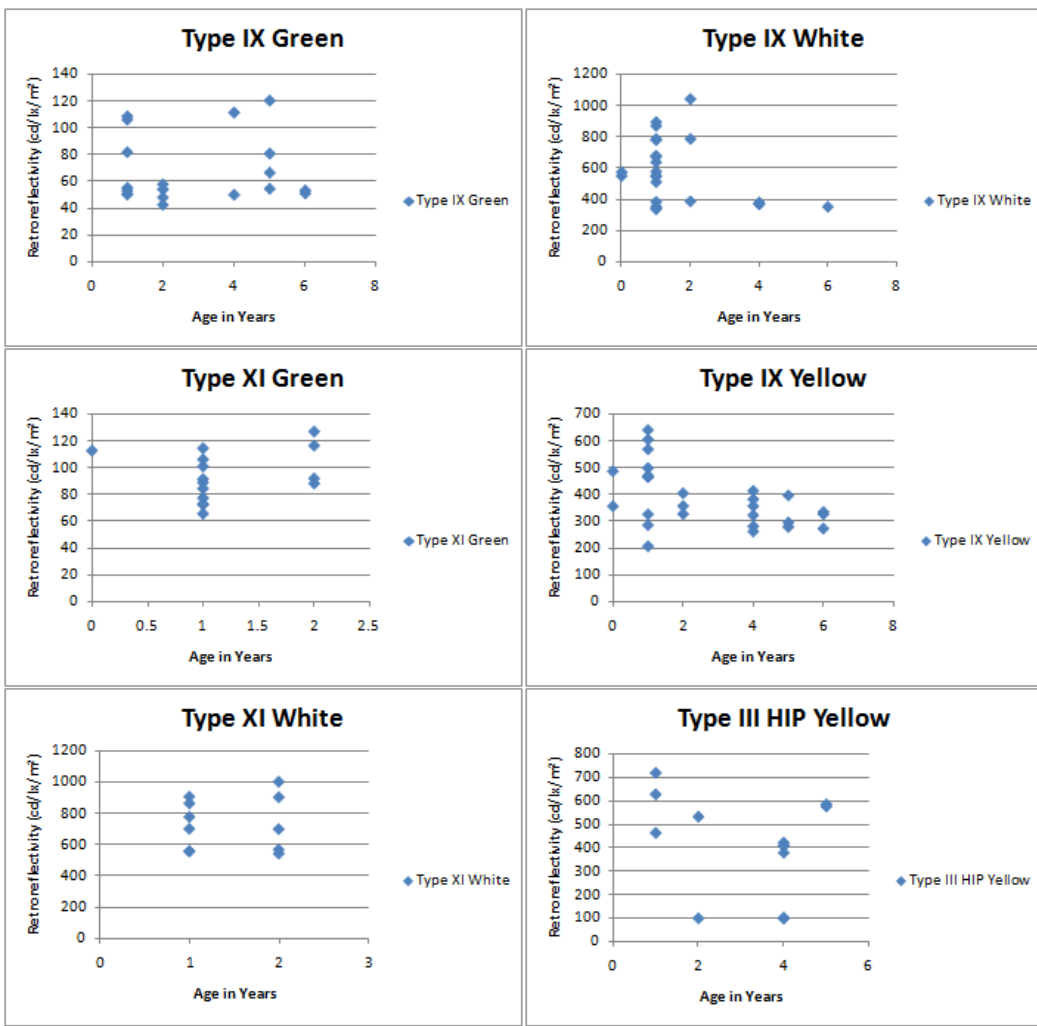


Figure 4.9 Known sign installation date plots.

From the extremely limited installation data, the overall sample for some colors and types was very small. While small, it still left to question why there was such wide range of values found from even newly placed signs of the same type and manufacturer with no damage or weathering present.

The greatest ranges of measurements were seen in Type IX, Type XI, signs with white and yellow backgrounds. To further determine possible causation for the range of values measured new signs, less than 1 year old, were reviewed. Table 4.8 provides an example of the range of values of measurements recorded by researchers for Type IX and Type XI signs that were placed within one year of inspection and had no visible damage or weathering. All these signs were constructed with sheeting produced by 3M.

Further evaluation of these signs identified a possible explanation to this variation regarding an issue of inefficiency with the construction of many of UDOT's newly placed traffic signs. The problem identified relates to the rotational sensitivity of the sheeting used for a large majority of signs placed within recent years.

Table 4.8 New prismatic sheeting measurement ranges.

Type	Retroreflective Measurements (cd/lx/m ²)				
	Color	Mean	Standard Deviation	Low	High
IX	Green	78	23	51	109
IX	Yellow	455	141	208	643
IX	White	597	188	338	898
XI	Green	88	16	66	115
XI	White	725	149	554	904

While the sheeting utilized by UDOT for many of their new signs is designed to be usable at any orientation, due to the utilization of cube corner retroreflection, the sheeting is most effective when placed at a specific orientation. The range of values measured varies greatly depending on the orientation with which the sheeting was placed with much sheeting not being placed at the optimal orientation. This issue was discovered primarily for Type III HIP, Type IX, and Type XI Sheeting where signs throughout the state were discovered that the sheeting was oriented at varying degrees. This issue is further exaggerated when measurements are taken with a point retroreflectometer. Figure 4.10 shows an example of the range of values possible from sign construction with sheeting in varying conditions when sign sheeting is placed at varying orientations. The measurements were taken from three types of white sheeting currently being used by UDOT. The figure shows the signs at 0 and 90 degree orientations. With the sheeting on these signs, the orientation can be determined by the pattern seen in the white background.

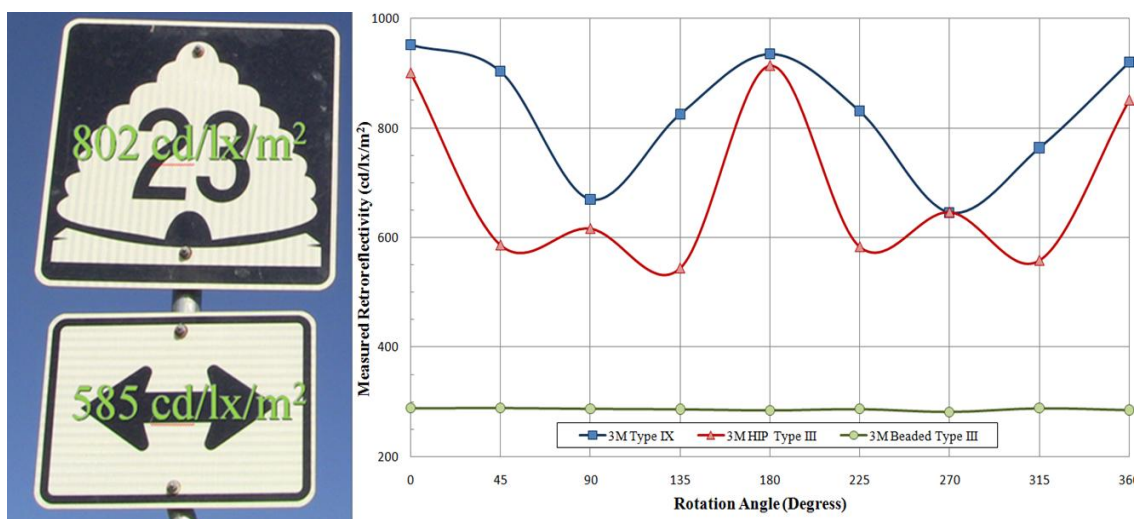


Figure 4.10 Rotational sensitivity of new white sheeting.

Similar distributions were found for other Type IX and Type XI sheeting currently being utilized by UDOT. Sheeting placement in varying orientations was found for all background color types. The majority of yellow signs constructed of any type of prismatic sheeting within UDOT were discovered to be placed at an orientation less than optimal.

There has been very limited research with regards to the overall effect of rotational sensitivity. In reviewing the effect researchers determined the visibility loss is largely dependent upon distance (Carlson and Hawkins, 2003). At closer distances the loss is relatively significant while at longer sight distances the effect was found at times negligible. The degree of sensitivity is largely dependent upon the construction of individual sheeting. ASTM standards detail that any sheeting with more than a 20% change in values when the sheeting is rotated, the sheeting must be marked with the direction that is optimal. Manufacturers have followed this in the construction of sign sheeting, but it was observed that both DOT's and local agencies often have disregarded the optimal orientation.

This has been identified as a great inefficiency problem with the management of traffic signs. The various methods identified by the FHWA for managing traffic sign retroreflectivity either depend upon performance through inspection, or assumed performance through control signs or replacement schedules. As signs are placed at varying orientations, the rotational sensitivity will create problems as signs will either need to be replaced sooner than necessary or predictions may not necessarily represent

the overall population of signs depending on differing sign sheeting construction procedures.

4.5 Sign Damage

Damage and weathering are of particular concern in the development of an asset management strategy to maintain the visibility of traffic signs. Damage is a problem that affects both the day and nighttime ability of signs to convey their proper messages and presents particular problems with respect to retroreflectivity. Even small amounts of damage that may not be fully visible during the daytime conditions can have a large effect upon the signs ability to convey messages under nighttime conditions. The overall percentage of damaged signs varied greatly by region and environment. Damage was classified as either being major or minor dependent upon the overall effect of the message of the sign. Major damage included any degree of damage on the sign face that affected the legibility of the sign. Table 4.9 summarizes damage rates throughout UDOT's four regions by percentage of overall population.

Damage is a major issue for UDOT maintained signs. Of the signs sampled for the project, there were a significant percentage of signs found with some degree of damage. Contrary to prior presumptions, large populations of damaged signs were not solely limited to rural areas. Varying types of damage were found in all regions and urban classifications although certain individual types tended to be more prevalent in some areas. Signs sampled in UDOT Region Two were among the lowest populations to exhibit some degree of damage.

Table 4.9 Damage summary by region and color.

Damage By Region				
Region	% Damaged (All Types)		% Vandalized	
	Major	Minor	Major	Minor
One	30%	18%	12%	5%
Two	5%	14%	1%	5%
Three	26%	34%	12%	12%
Four	12%	22%	6%	9%

Damage By Color				
Region	% Damaged (All Types)		% Vandalized	
	Major	Minor	Major	Minor
Red	13%	25%	5%	12%
White	18%	17%	6%	8%
Yellow	17%	27%	16%	10%
Green	14%	19%	5%	3%

Many of the signs were newer than found in other regions as in the more urban environments, maintenance activities that included sign replacement tended to be more active although damage was often found even with newly placed signs.

4.6 Nighttime Inspections

In order to better understand the overall effect that damage has upon the nighttime visibility of traffic signs, signs with varying types and degrees of damage were reviewed. Additionally, routes were driven under nighttime conditions to identify unique situations where local retroreflectivity has been lost on signs.

Types of damage can be segregated into two distinct groups, manmade or natural. Manmade damage includes vandalism, vehicle collision damage, and damage caused

inadvertently by vehicles such as snow and gravel thrown from a snowplow's blade or rocks and sand thrown from vehicles wheels. Natural damage includes damage from wind, snow and rain, the sun and other environmental strains. Signs with excessive weathering are generally found to be the result of a combination of natural exposure. It is sometimes difficult to determine the exact cause when bending has occurred on street signs have occurred. Deformation of signs that did not include any form of bracing was observed during inspections when vehicles of larger size and greater speed passed although it was generally assumed that higher degrees of bending around the base support was the effect of high natural winds.

Vandalism is of particular concern when considering sign retroreflectivity as often it has been found to have the most profound effect on sign retroreflectivity of any damage type. Additionally vandalism was shown to detract the most of any damage type from a sign's ability to convey its proper message. Types of vandalism found included bullet holes, paint balls, thrown projectile damage, graffiti, stickers and other damage.

Before field inspections, it was assumed that projectile damage from firearms would be the most detrimental of any manmade damage to nighttime visibility. This was determined to not necessarily be the case. While partially dependent upon projectile and sheeting type, in most cases observed this type of damage had little effect upon the nighttime visibility of the signs. Figure 4.11 shows an example of a sign with large amounts of projectile damage that, while in poor condition, the projectile damage itself does not remove its ability to convey the intended message. With some newer prismatic sheeting bullet hole damage presented a slightly greater problem as layers of the sheeting

appeared to delaminate after the initial damage had occurred resulting in a loss of the retroreflective properties surrounding the location of damage.

Perhaps one of the greatest surprises when collecting data during field evaluations was the overall frequency of occurrence, and detrimental effect, that paintball damage has on nighttime visibility. Paintball damage was found in nearly all areas sampled outside the very most urban. There are two general problems associated with paintball damage. First, the impact area itself displays a large loss in retroreflectivity due to a combination of damage and paint reducing the ability for light to reflect back at its source. Second, during data collection signs were found where paintball residue had been removed from signs and the removal process had cause significant problems. The cleaning solutions used had completely destroyed the sheeting's retroreflective properties.



Figure 4.11 Bullet hole damage.

Large populations were found with paintball damage in some areas. On some more rural routes, every sign on long stretches of highway had been hit by varying numbers of paintballs. The large impact zones leave large areas where retroreflectivity is lost. A few well placed paintballs can completely remove a sign's intended message. Paintball damage was also found to be difficult to assess during daytime inspections due to the faint residue that is left behind. Paintball damage shown under day and nighttime conditions is shown in Figure 4.12.

Similar to paintball damage, graffiti also can greatly affect nighttime visibility. Additionally, similar is the difficulty in its removal and the damage to retroreflective sheeting that can occur from the removal process. In most areas graffiti as well as sticker damage was most prevalent on signs that were placed close to the ground. Damage was also found on some signs of considerable height but often such was determined as areas where snow buildup allowed for easier access for vandals. This is a particular problem on roadways leading to and from ski resorts within the state where high densities of graffiti and sticker damage was found.



Figure 4.12 Paintball damage.

Bending damage was observed as a result of a variety of causes. The resultant damage can reduce nighttime visibility in a number of ways.

For both daytime and nighttime visibility, bending damage presents problems and signs can be bent away from the driver's view. With respect to retroreflection, this presents an additional problem with light not being reflected in the proper angle, optimal for the driver, further reducing the nighttime visibility of the sign. Though not extreme, such damage was observed to be most problematic with newer prismatic sheeting. Two issues were observed with these newer sheeting types. Cube corner prismatic sheeting does not provide the same efficiency of retroreflection when light enters from peripheral angles than from entrance at an angle perpendicular to the sheeting. Secondary to this issue, during data collection a problem was observed when extreme bending damage had occurred peeling was often present on the legend. The overlay on the prismatic sheeting came free from the background sheeting. The type of peeling observed as a result of bending was only observed for newer sheeting. Older Type I sheeting did appear to be as vulnerable to such bending issues. Figure 4.13 displays an example of the observed issues when bending occurs with newer sheeting types, both bending and retroreflectivity loss.

4.7 Conclusions on Findings and Contributions

The field collection and data analysis performed for this research has identified several unique considerations new to the management of the nighttime visibility of traffic signs.



Figure 4.13 Issues presented with bending damage on prismatic sheeting.

In the case of UDOT's sign assets, these findings present a potential paradigm shift from the previous assumptions regarding the best prospective management practices.

In addition to new findings, this research also highlights some considerations that, while previously known, should have greater precedence and concern than previously thought in current practices.

4.7.1 Damage management vs. retroreflectivity management

The findings provided by this research provide new insight into the management of retroreflectivity and nighttime visibility of traffic signs, through the usage of damage assessment. For UDOT maintained signs, reviewing signs that were sampled provide

indication that managing sign damage, as well as visible weathering, could be the key to managing the nighttime visibility of traffic signs in a practical manner.

The basic assumption prior to performing data collection for this research was that managing and tracking retroreflectivity alone was the central component to maintaining the nighttime visibility of an agency's traffic signs. This is understandable as this is the idea that led to establishing minimum retroreflectivity levels, with retroreflectivity itself being a proxy for nighttime visibility.

Prior to performing field evaluations, the high percentage of damaged signs found throughout UDOT maintained signs was unknown. Additionally, it was unknown the varying affects that each type and degree of damage had on both the retroreflectivity and nighttime visibility of UDOT maintained signs. Given the data collected, aside from Type I sheeting where current standards dictate should not be used, it appears that signs maintained by UDOT are far more likely to be damaged long before their intended warranty lives or potential useful lives as determined by retroreflectivity measurements alone. While not potentially the case for all agencies, in the case of UDOT, managing sign damage may prove the most practical and effective means for both maintaining sign retroreflectivity, as well as nighttime visibility.

Using the example of Type III Yellow signs, where the majority of failures outside of Type I signs, 85% of failures were found to exhibit easily visible damage and weathering. It is important to note that all these failures represent an extremely low percentage of the overall populations, as with any sheeting type above Type I there were very few failures. Additionally it is important to note as well that the Type III signs

sampled included signs that were assumed to be anywhere from 1 to 15 years old, with many a minimum of 10, very few failures were found. Yellow sheeting is also the most sensitive to failure of any color type. While review of the data indicates that presence of any damage type alone, aside from Type I cracking, is not indicative of retroreflectivity failure, field assessment provided indication that damage is potentially of greater concern than retroreflectivity failure for the sampled populations. This was validated as during collection when damage was found, such as paintball damage, which was detrimental to the nighttime message conveyance of the sign. In many cases the established procedure for retroreflectivity measurement indicated that such signs would pass retroreflectivity standards, but the damage itself would render the message difficult to interpret under nighttime conditions. Again, acknowledging that damaged signs do not always correlate to retroreflectivity failure, it is interesting when reviewing Type III yellow failures, the replacement of signs with vandalism present alone would eliminate nearly half of all failures.

Previously when considering nighttime visibility, damage has been viewed in relation to just retroreflectivity loss, rather than a primary player in the loss of nighttime visibility. With the high percentage of damaged UDOT signs, and a review of the problems sometime presented by such damage, it is far more logical for UDOT to maintain nighttime visibility of traffic signs through the daytime and nighttime assessment of damage and overall visibility. Given the sampled signs and experiences attained during field evaluations, such assessments would also provide for compliance with minimum retroreflectivity standards. In the case of UDOT, focusing on the

assessment of damage under nighttime conditions, while still removing signs with recognizable retroreflectivity loss, will likely ensure both compliance with the minimum retroreflectivity levels required, as well as fulfill its purpose of increasing nighttime visibility and safety.

Reviewing the data collected regarding cracking damage and failures also provided new insight into assessing retroreflectivity failure of Type I signs. Previous research has always indicated extreme difficulty in visually assessing retroreflectivity failure during daytime conditions. In most cases this is potentially true, with the exception of cracking damage found present on the majority of Type I failures of UDOT maintained signs. In Utah, on UDOT maintained signs, there is potential to assess Type I signs remaining for failure by quickly inspecting for the presence of cracking damage as demonstrated in this research. When evaluating Type I White and Green collected the data collected indicates potential for using this damage type for failure assessment. In reviewing all Type I White, and Type I Green signs collected, if assessment was made relative to the presence of cracking damage the success rates of selecting the failed signs out of the overall populations would be 77% and 91%, respectively. Such success rates either meet or exceed the success rates of most nighttime inspector accuracy studies. While these results are limited to assessment of the data collected from UDOT maintained signs, and further study and validation would need to be performed, it could prove useful for an agency that still maintained a large population of Type I signs similar to those utilized by UDOT.

4.7.2 Additional considerations for evaluation

This research brought attention to several additional considerations relating to the management of sign retroreflectivity. While previously known, such considerations have not been previously viewed to have the significant impact that was determined during the course of this research. Such knowledge can prove extremely beneficial to an agency that is developing their strategy to maintain their traffic sign assets. These considerations include sheeting uniformity on traffic signs, rotational sensitivity of sign sheeting, vandalism control and problems with maintenance practices.

In the construction of signs placed throughout UDOT's jurisdiction several cases were found where a certain type of sheeting had been overlaid upon another. In some cases this resulted in a premature failure of the sign that could have been averted if the legend had been constructed as the same material as the background.

Rotational sensitivity problems have been identified throughout Utah on signs maintained by both UDOT and other agencies. When managing signs for retroreflectivity, great inefficiencies can occur from sign construction with sheeting in varying orientations. Additionally, without uniformity in sheeting placement, future tracking and performance forecasting will prove extremely difficult.

Prior to field investigations, the vandalism problems that plague many of UDOT's maintained signs were unknown. In particular is the number of signs with paintball damage. Such vandalism can prove extremely detrimental to the ability of signs to maintain their nighttime visibility. While difficult, efforts to curb such vandalism may be beneficial to an agency such as UDOT considering the prevalence of such damage, as

well as the cost it carries on agency budgets. When considering such damage, the field evaluations also highlighted the need for great care to be taken during maintenance practices. Attempts to remove vandalism, while improving daytime visibility, if done improperly can completely destroy the signs nighttime visibility.

4.8 Plan Development

A sign management strategy that includes maintaining minimum retroreflectivity levels is a staged process that includes compliance, implementation, and continuing maintenance. Implementing all aspects of the plan becomes far more complex when considering the budgetary constraints that agencies must consider when managing such assets. With such complexities, the primary goal of maintaining the nighttime visibility of the traffic signs must be central to any plan. In the case of UDOT, the primary goal is to bring the assets currently maintained by the agency into compliance the simplest, cheapest, and most feasible method possible.

4.8.1 Compliance

To facilitate compliance with the minimum retroreflectivity levels provided in Table 2A-3 of the 2009 edition of the MUTCD there are several options available. These options include a total blanket replacement of all signs currently in service, full assessment of sign populations and replacement of non compliant signs, and replacement of signs of specific sheeting types or characteristics.

From reviewing the data collected from the sampled signs, for UDOT the most logical step to bring compliance would be the removal of all remaining Type I sheeting. From the signs sampled it is estimated that 69% of the current Type I population is below the minimum retroreflectivity levels required by the MUTCD. The remaining population itself is not far above the minimum standards required for each of the sheeting colors. If only the failing Type I were replaced, while it would bring a great degree of compliance careful monitoring would be required in order to catch the Type I signs as they failed in the future. The replacement of Type I sheeting is recommended as the best option for bringing compliance, as replacing all remaining Type I will increase the overall degree of compliance from 91% to 97%. The MUTCD already details that Type I yellow sheeting should not be used for traffic signs. The replacement of Type I sheeting and usage of Type III or better would require little field assessment and provide far better insurance of compliance than the continued use of Type I.

While replacing all Type I would be the simplest method of bringing overall compliance, such replacement would require a great amount of resources. There are several options for reducing the amount of resources necessary to bring current compliance. One such option includes the usage of the data gathered through the collection process. Cracking unique to Type I sheeting was found for 51% of the Type I population. This particular classification of weathering is easily identifiable and nearly 98% of signs that exhibited such damage failed to meet minimum retroreflectivity standards. The quick assessment and replacement of all Type I signs that exhibited cracking would provide estimated compliance of 95% throughout the state. While ideally

all Type I signs would be replaced as a plan is implemented to maintain minimum retroreflectivity levels of traffic signs, this could provide a cost effective option to temporarily ensure a high degree of compliance while other options may be explored.

Another feasible option to bringing UDOT's sign population into compliance is a full inventory that also includes either retroreflective measurement or visual nighttime inspection. These options, while carrying additional costs, provide the best overall assessment of performance. This may also be the most feasible option for continued maintenance and as such beneficial to incorporate when bringing the population into compliance. Nonetheless, given the lesser performance of Type I sheeting in contrast to all other sheeting types a complete blanket replacement of all Type I sheeting would be overall beneficial to the agency.

4.8.2 Plan selection and management options

In order to select a plan, or combination of plans, to maintain a minimum retroreflectivity level, individual strengths and weaknesses must be reviewed and contrasted with the situation of a particular agency. Each individual management or assessment method carries its own individual advantages and disadvantages. Additionally, the revealed problem of sign damage highlighted in this research opens the door to either new or other possible combinations of management strategies not previously considered for implementation.

Visual Nighttime Inspection can be a less expensive method of assessing nighttime visibility. It is also one of the easiest ways to assess other conditions affecting the nighttime visibility of signs beyond retroreflectivity, such as the effect of vandalism.

One drawback to performing nighttime inspections is the uncertainty regarding the accuracy with which inspectors reject signs below the minimum required retroreflectivity levels.

Measured Sign Retroreflectivity is the most direct method of assessing sign retroreflectivity. Measurements taken may be compared directly to those provided in the MUTCD. One major disadvantage is the additional cost involved with the time and equipment required. Additionally the measured values do not always completely reflect the actual nighttime visibility of the sign.

Expected Sign Life and Blanket Replacement utilize the expected service life in the determination of the optimal time for replacement. These methods are simple, however, but there are many issues including management and inefficiency. These methods do not account for damage as signs are replaced upon set schedules and not based upon performance.

Control Signs are used as samples for the overall population for sheeting of similar types to determine when signs are to be replaced. This method can provide assistance in determining how the agency's assets are performing over time. Drawbacks include the uncertainty with which the control signs represent the overall population. As with the other management methods, these methods do not account for signs that need replaced due to unforeseen reasons that occur.

To fully comply with the requirements given in Section 2A.08 of the MUTCD it is it would be advantages that UDOT adopt a combination of both visual assessment and management methods. This determination is made as a result of the data collected for

signs throughout the state considering performance, damage rates, maintenance and feasibility. This would also facilitate the ability to manage retroreflectivity and sign damage simultaneously. As damage was determined as the key factor in reducing the nighttime visibility of UDOT maintained traffic signs, visual assessments for sign damage will deal with both issues.

The review of UDOT's existing inventory and asset management structure revealed that any plan that relied heavily upon the tracking of assets is largely impossible, without large investments of resources for full inventories. Moving toward the future this may be an option that could be implemented over time but cannot serve as a primary management method for meeting current deadlines or total future compliance. Additionally, with the limited installation data that UDOT has maintained maintaining the current population through control signs or widespread replacement at warranty periods is impossible without complete blanket replacement of all of UDOT's assets as a starting place. Again given the damage issues present, as well of a gap in understanding of rates of damage and retroreflectivity loss, such a management plan would likely not be effective.

For initial implementation of a plan, the best option would be to adopt a method for visually assessing the retroreflectivity of signs. A visual assessment method can provide important data to UDOT, as the most vital function of a sign is to communicate a particular message to drivers. Research has shown that inspector accuracy in the selection of non compliant signs can be relatively high given proper training. If visual assessment is used it will be critical for UDOT to maintain focus on replacing damaged

signs that have loss visibility as it will be more efficient and crucial than previously assumed retroreflectivity assessment.

Given the damage rates recorded during the data collection process, a visual assessment method would provide the most direct means of assessing overall visibility. Management methods that rely on sign life or consistency of signs populations were determined to be largely impractical for UDOT given the likelihood a sign would be damaged, or experience extreme weathering, before its possible retroreflective life under controlled conditions.

While currently not feasible, the use of a management method, such as the use of control signs, may be both possible as well as advantageous for certain cases in the future. In highly urbanized areas and along urban interstates, sign damage is less prevalent and a management method is more feasible. However, in rural areas, damage and vandalism is more likely to be the determining factor of when replacement is necessary. This may be especially advantageous in managing costly overhead interstate signs that rarely see damage.

Establishing a control sign procedure can provide a useful tool for assessing the useful service life of sheeting being placed by DOTs. Currently there is insufficient data within Utah on the various sheeting used for traffic signs to properly determine replacement periods outside the manufacturer's warranty. Other state DOTs have determined that useful life may safely be extended beyond the manufacturer's warranty, which indicates that a blanket replacement at the end of the warranty would be inefficient. Establishing a control sign set for annual monitoring can provide assistance

with establishing these periods as well as the frequency with which visual inspections should be occurring. As data is collected from these control signs, additional guidance can be provided to increase the efficiency of sign replacement.

The data collected indicated a high rate of sign damage in UDOT Regions One, Three, and Four. With Region Two being consisting of more urban areas, sign damage was less prevalent. For this reason a more uniform sign management method is feasible in Region Two. Nighttime inspection is also necessary in order to ensure signs are properly conveying their intended messages. Developing a future plan that includes tracking and inventory management through an OMS system would create opportunities for increased efficiency. Performing a statewide inventory would be extremely beneficial if performed as funding allows.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

With budget constraints and limited resources, it is imperative that transportation agencies adopt comprehensive management strategies for managing an agency's assets. The requirements for maintaining sign assets listed in the MUTCD has increased awareness for the need for an efficient management strategy. This mandate has also increased the need to better understand all the relevant situations that relate to maintaining the nighttime visibility of traffic signs. This research was motivated from an urgent need to develop a practical methodology that can be employed for both assessing traffic sign assets and for policy development.

In reviewing current literature, this research identified a clear need for the development of a simple, as well as practical, methodology for assessing and analyzing the performance issues of traffic signs for a large DOT. Previous research relating sign management methodology has been largely theoretical and has yielded few conclusive results that may be used in the development of a plan to manage of traffic sign retroreflectivity. With deadlines quickly approaching for plan development, this research attempted to fill this gap by providing a methodology that would facilitate the fulfillment of these needs. Additionally, this research provides specific methodology for highlighting issues that must be addressed when developing an efficient plan to manage the nighttime visibility of traffic signs.

The application of this methodology proved successful in highlighting many issues and needs relating to the management and maintenance of traffic signs that were previously unknown to UDOT. This also provided for the development of a new option in managing sign retroreflectivity through the focus of damage evaluation and maintenance. The large percentages of damaged signs and the associated effects they have on nighttime visibility and retroreflectivity loss for UDOT maintained signs was previously unknown. The data collected provided new insight into where the focus of sign asset management should be for UDOT, and potentially for other DOTs. Focusing on managing signs through the assessment of sign damage can provide a method that maintains minimum retroreflectivity requirements, while fully reaching the goal of improving the nighttime visibility of traffic signs. The data collected provided for the determination that sign damage mitigation would alleviate relatively all of UDOT's sign retroreflectivity issues, with the only exception being the current use of inferior and inappropriate sign sheeting. The research also identified a new means for potentially identifying Type I sheeting failures through cracking evaluation.

The application of this methodology, as well as the resulting data analysis, also provided insights into key issues that must be addressed if large inefficiencies were to be eliminated in the DOT's management practices. Such issues include proper construction of traffic signs to account for rotational sensitivity and consistency in the use of certain sheetings for various applications. These highlighted issues provide important considerations for future management and research efforts relating to sign sheeting performance. Additionally, this research highlighted issues relating to the practicality of

some of methods proposed for managing sign retroreflectivity. For UDOT management methods that require detailed sign construction information and performance measurement are nearly impossible. This is likely similar for many other DOTs, as little is known as to how signs really perform over time after being placed in service. In the case of UDOT, applying the methodology highlighted the need to explore other issues that impact the nighttime visibility of traffic signs that possibly surpass the need to monitor retroreflectivity alone.

5.2 Future Work

Developing a practical methodology for the assessment and management of the nighttime visibility of traffic signs is just the first step in the development of a robust asset management strategy. This research highlighted the need to further assess areas outside of retroreflectivity alone, as is the case with sign damage, which must be addressed further. This research has identified other areas where future research will be vital in order further accomplish the overall goals of efficient and effective traffic sign asset management. These areas include:

- The development of a procedure to classify and identify damage as it relates to both daytime and nighttime visibility. The development of damage metrics to assist inspectors in the process of selecting signs in need of replacement.
- Research including the forecasting of sign damage and damage rates as well as timeliness of specific maintenance practices.

- Specific implementation strategies for managing traffic sign assets. There is a need to refine current tracking and management methodology in order to facilitate modeling the performance of traffic sign assets.
- The development of visual assessment methodology. Specific methodology for assessing traffic signs under both night and daytime conditions for assessing damage, visibility, and overall compliance.
- Additional validation in using cracking damage to determine failures in certain Type I sheeting.

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