RESEARCH

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Plan Recommendation for Traffic Sign Management

Prepared For:

Utah Department of Transportation
Research and Innovation Division

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DISCLAIMER:

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16. Abstract

This report template reflects the "Guidelines for Preparing UDOT Research Reports," revised April 2012. It may be used for preparation of UDOT research reports. Include a brief summary of the report here in 200-250 words. The Federal Highway Administration (FHWA) is concerned with maintaining a minimum level of retro-reflectivity on traffic signs under both federal and state jurisdictions. New retro-reflectivity standards have been enacted by the FHWA that mandate all transportation agencies "must establish and implement a sign management or management method to maintain minimum levels of sign retro-reflectivity". In addition, full compliance with the new retro-reflectivity standards is mandated by January 2015. Non-compliance with these new retro-reflectivity requirements will leave transportation agencies vulnerable to lawsuits. Many agencies are now realizing the challenges of establishing and maintaining a sign management program.

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EXECUTIVE SUMMARY

The Utah Department of Transportation initiated this research as a response to the release of the 2009 Manual on Traffic Control Devices (MUTCD). The 2009 MUTCD established minimum maintained retroreflectivity levels that must be maintained via implementation and continued use of an assessment or management method. On May 14, 2012, final revisions were adopted to the MUTCD that limited the scope of traffic sign retroreflectivity management to only regulatory and warning signs. Although replacement dates for underperforming traffic signs are not stated within the MUTCD it is up to agencies to identify and schedule for replacements based on available resources. Starting June 13, 2014, UDOT is required to implement and continue to use an assessment or management method that maintains only regulatory and warning traffic sign retroreflectivity. As UDOT resources allow it guide (post-mounted and overhead) and street name signs need to be included into this retroreflectivity maintenance method.

The purpose of this research was to assess the current performance of traffic signs under UDOT's jurisdiction and develop an assessment or management method that is tailor to UDOT's specific traffic sign needs. From 2011-12 1,716 traffic signs were measured across all four of UDOT's maintenance regions in order to develop a snapshot of current retroreflectivity compliance. At the conclusion of the collection effort it was determined that UDOT's sign population was 93 percent compliant with the minimum maintained retroreflectivity levels. Additional issues specific to UDOT's sign population were identified and documented. From the collection effort it was determined that 28 percent of UDOT's traffic sign had severe enough damage that it detracted from the legibility of the traffic signs intended message. Analysis was conducted to determine factors that contributed to areas of high damage rates. By determining that UDOT signs had a damage issue it is recommended that a visual nighttime assessment method be utilized since it can simultaneously assess the legibility and visibility of a traffic sign. By implementing a visual nighttime inspection procedure UDOT will maintain compliance with the minimum levels and ensure the legibility of the traffic signs message, thereby increase motorist safety.

INTRODUCTION

The Utah Department of Transportation initiated this research as a response to the release of the 2009 MUTCD. According to the National Safety Council even though only a quarter of all travel occurs at night, about half of traffic fatalities occur during nighttime hours (1). A percentage of these nighttime fatalities can be attributed to intoxication and fatigue, but these factors are not controlled by agencies. In order to address the limited visual cues present during nighttime driving FHWA established the minimum maintained retroreflectivity levels, which would ensure adequate levels retroreflectivity on signs throughout the nation's roadways. The 2009 MUTCD established minimum maintained retroreflectivity levels that must be maintained via implementation and continued use of an assessment or management method. Incorporated with the minimum maintained retroreflectivity levels were three target compliance dates, which defined a time line for plan implementation and required sign replacements. On May 14, 2012, final revisions were adopted to the MUTCD that eliminated the three original target compliance dates for minimum retroreflectivity levels. On June 13, 2014 the following provision will take effect:

> *"Implementation and continued use of an assessment or management method that is designed to maintain* ***regulatory*** *and* ***warning*** *sign retroreflectivity at or above the established minimum levels (2)."*

Elimination of the original target dates coupled with the additional two years till required plan implementation provides UDOT with adequate time to develop a traffic sign management plan that is tailored to UDOT's specific needs.

While enhancing the retroreflectivity of traffic signs is beneficial to all motorist, it is particularly important to older drivers. The vision of a motorist declines as they age. Starting at age 20, the amount of light needed by a motorist to see doubles every 13 years. By the year 2020, one-fifth of the population in the United States will be over the age of 65 (1). By increasing the visibility of traffic signs it not only improves safety for all motorists, it also allows elderly motorist to retain their mobility and independence.

This research effort includes review of the current knowledge and theories of traffic sign management, damage rates, service life, and data collection and analysis of sign performance for a subset of UDOT maintained traffic signs. A data collection effort was launch in order to determine the current performance of in-service traffic signs maintained by UDOT. At its completion a subset of 1,716 traffic signs were record across all four of UDOT's maintenance regions. From this sample population it was determined that UDOT was currently 93 percent compliant with the minimum retroreflectivity levels. The high rate of compliance is expected due to UDOT's implementation of more efficient prismatic sheeting for new sign installations. In addition to this conclusion it was observed that 28 percent of UDOT maintained traffic signs had damage severe enough to diminish the legibility of the signs intended message.

The inadequacy of current knowledge of UDOT's sign population limited service life analysis due to the rarity of known installation dates. 294 installation dates, representing 17 percent of the population, were known by UDOT officials or observed by researchers on in-service signs. These known dates were spread across 16 different sheeting type and color combinations. Further complicating the deterioration analysis was the rotational sensitivity of newly installed prismatic sheeting, which lead to inconsistencies in retroreflectivity measurements. Additional sign attributes were collected, but had insignificant effects on the retroreflectivity of the traffic sign subset.

Since the observed damage rate was four times greater than the rate of failure analysis was conducted to determine the contributing factors to higher rates of damage. This analysis accounted for both the climate and location conditions of the traffic signs. The analysis determined that precipitation, elevation, temperature, and the exposure of a traffic sign had non-negligible contributions to higher rates of damage. It was also determined that one percent of traffic signs failed to meet the minimum levels that would not have been replaced due to damage. Therefore, the current issue for traffic signs under UDOT's jurisdiction is not the visibility, but rather the legibility of its intended message. With continued implementation of more efficient prismatic sheeting into UDOT's sign population ensuring the legibility of a sign will become the determining factor for defining a signs service life.

By analyzing the performance and damage vulnerability of UDOT's traffic sign population the research effort determined that visual assessment possibly combined with a selective blanket replacement would ensure both short and long term compliance with the minimum retroreflectivity levels, while continuing to promote motorist safety. With the continued implementation of more efficient prismatic sheeting a shift in maintenance strategy is required, which focuses on damage rates and message legibility.

RESEARCH METHODS

In order to develop a management plan that was customized to UDOT's traffic sign needs a review of current knowledge and practices was completed. This section includes a literature review of the principles of retroreflectivity, the establishment of minimum retroreflectivity levels, retroreflectivity deterioration studies, damage rate studies and a review of FHWA methods for maintaining traffic sign retroreflectivity.

Principles of Retroreflectivity

Retroreflectivity is a unique type of reflection that distinguishes itself by reflecting and focusing light back in the direction of the light source. Traffic sign sheeting is constructed of retroreflective elements that are specifically designed to reflected light from vehicle headlights conically back towards the vehicle. The retroreflective elements typically utilized for this process are spherical lenses (glass beads) or prismatic (cube-corner prisms), with prismatic sheeting being the more efficient of the two.

Retroreflectivity is formally defined as the coefficient of retroreflection (R_A) and has units of candelas per lux per square meter ($cd \cdot lx^{-1} \cdot m^{-2}$). The luminous intensity of light emitted from the headlights is measured in candelas (cd). This intensity of light applied to the surface of the sign is defined as illuminance and is measured in lux (lx). The light that is returned to the vehicle is defined as luminance with units of candelas per square meter ($cd \cdot m^{-2}$) (4). Figure 0.1, illustrates the retroreflectivity process where Point 1 represents a beam of light emitted from the headlights, Point 2 is the area that is illuminated by the emitted light, and Point 3 is retroreflected light which is redirected in the direction of the vehicle. In order to emphasize the conical spread of retroreflected light, the illustration only shows a very narrow beam of light emitted from the vehicle. In order to perceive the brightness of the sign, motorists must be within the conical spread of retroreflected light, which is defined as the cone of retroreflectivity. As the motorists drifts away from the center of the cone of retroreflection the perceived brightness of the sign diminishes. These basic properties are the same for all retroreflective materials, where these materials begin to distinguish themselves is with its R_A value. The R_A value is defined as the

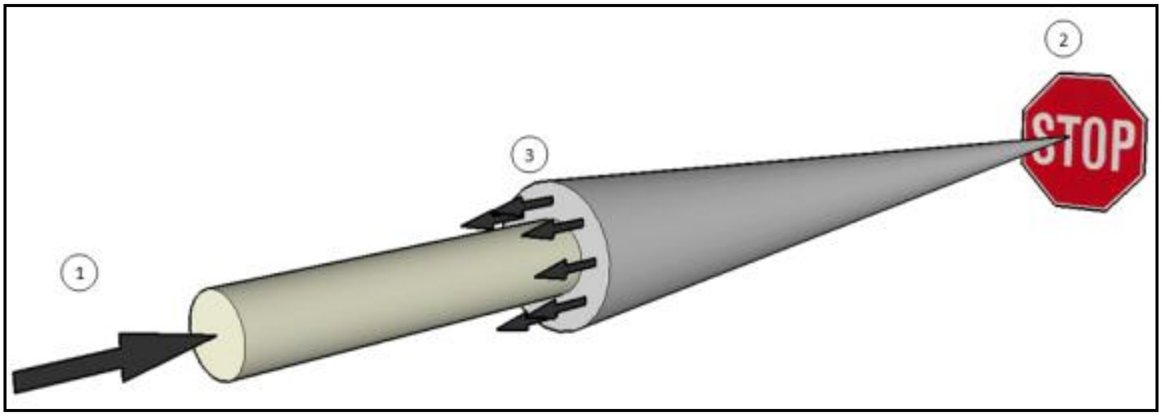


Figure 0.1 Illustration of Retroreflection Process

ratio of the amount of light coming out from a retroreflective material (luminance) to the amount of light emitted from the light source (illuminance), see Equation 1.1.

$$R_A = \frac{R_L}{R_I} \tag{1.1}$$

Where R_L is the luminance measurement and R_I is the illuminance intensity of the light emitted from the source measure. Larger measured values of retroreflectivity indicate a more efficient retroreflection process, and assuming the signs are exposed to the same light intensity it produces a visually brighter sign.

<u>Retroreflectivity Angularity</u>

The retroreflectance of traffic sign sheeting is always described in context of its angularity. The angularity of a traffic sign refers to the range of angles at which the sign will retain its retroreflectivity and is described by its entrance and observation angles (5). The entrance angle is the angle between the line from the headlights to the retroreflective sheeting and a line that is perpendicular to the sign surface, illustrated below in Figure 0.2. The entrance angle changes with distance between the vehicle and the sign and is a function of the location of the sign and the vehicle. R_A values are typically measure at entrance angles of -4 degrees and +30 degrees. An entrance angle of -4 degrees is intended for traffic signs located at the edge of the roadway, whereas an entrance angle of +30 degrees represents the widest angle between an intended motorist and a sign. Substantial changes in R_A are not seen until the entrance angle exceeds 20 degrees.

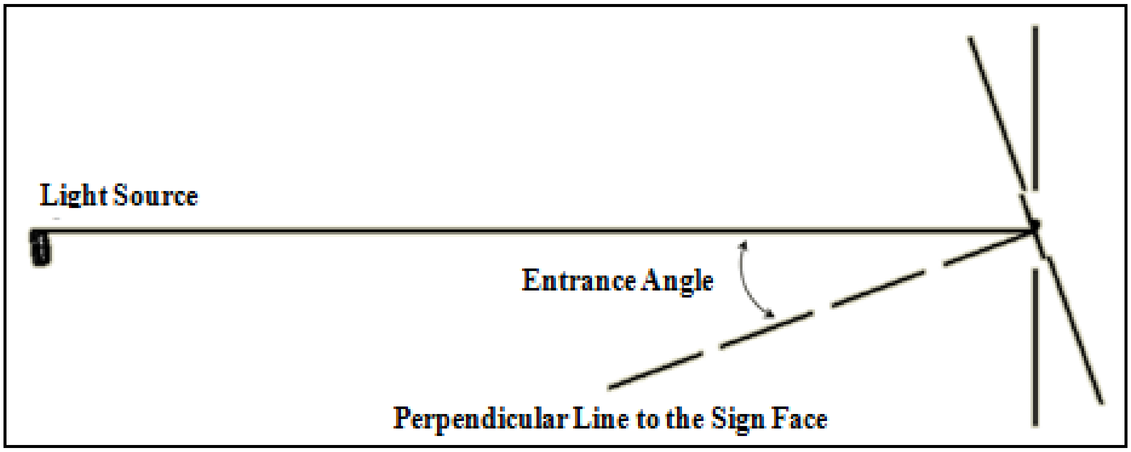


Figure 0.2 Entrance Angle Illustration

In order to obtain maximum retroreflectivity from traffic signs, and eliminate the specular glare, it is important to ensure that traffic signs are properly aligned. Specular glare is a mirror type of reflection, which can under direct sunlight decrease the legibility of a traffic sign. In order to avoid specular glare, traffic signs should be positioned slightly more than perpendicular to the roadway. Typically a position of 93 degrees is recommended by most sheeting manufacturers (3).

Contrasting from the insensitivity of the entrance angle research has determined that minor changes in the observation angle can have substantial effects on the retroreflectivity of a sign. The observation angle is defined as the angle between the eye level of the motorist and the headlight height with its apex located on the sign face, as shown in Figure 0.3. According to the American Association of State Highway and Transportation Officials (AASHTO) the average passenger car has a headlight height of 2 feet with a corresponding motorist eye level of 3.5 feet. (6). As previously described, retroreflective sheeting reflects light back in the direction of the headlights, but due to the conical spread of light the motorist is able to see the illuminated traffic sign. Since the distance between the eye level of the motorist and the headlights varies depending on vehicle types the observation angle needs to encompass all vehicle types, while maintaining the narrowest cone possible for optimal brightness. As the motorist's eye level is raised, the distance from the center of the cone of retroreflectance is increased causing a slight increase in the observation angel and decrease the perceived brightness of the sign.

Since the distance between the motorists eye level and the headlight height is fix for a particular vehicle as the distance between the vehicle and sign is halved the angle of observation is doubled (7). This means that the brightness of retroreflective sheeting decreases as the motorist approach the sign. For these reasons observation angles are generally measured at +0.2 degrees or +0.5 degrees which equates to sign sight distances of 500 ft and 200 ft, respectively (8).

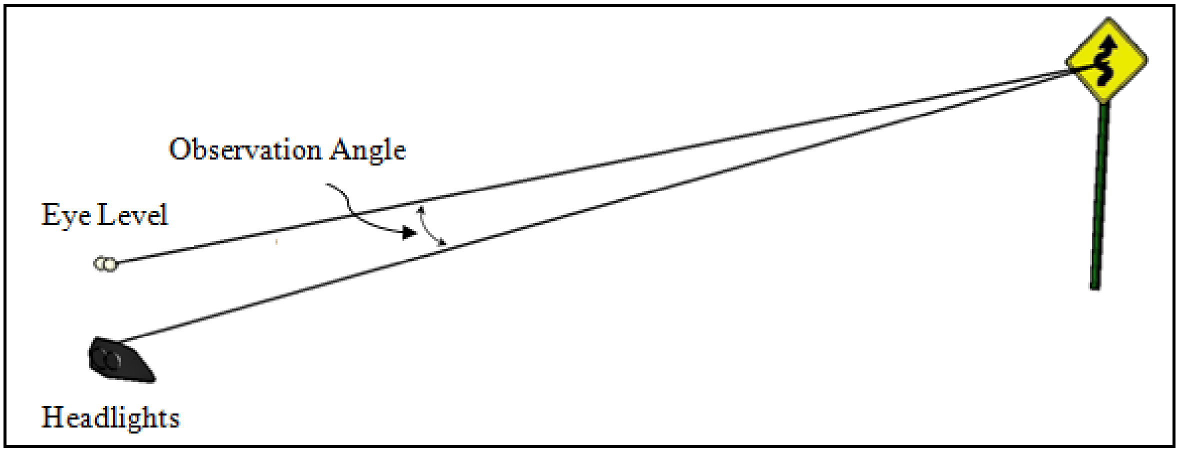


Figure 0.3 Observation Angle Illustration

Retroreflective Sheeting Types

Due to the variety of retroreflective sheeting available for traffic signs it became imperative to develop a standardized classification for sheeting performance. The American Society for Testing and Materials (ASTM) established standard specifications for retroreflective sheeting in ASTM D4956-11a (9). It should be noted that a higher sheeting types do not necessarily imply higher performance, rather the different performance characteristics.

Type I - A retroreflective sheeting referred to as "engineering grade" that is an enclosed lens glass-bead sheeting (10). Generally regarded to have a seven year sheeting life, but is known for its durability both in handling and damage resistance. There is no distinctive identifying pattern present on the sheeting to assist in identification.

Type II - A retroreflective sheeting referred to as "super engineering grade" that is an enclosed lens glass-bead sheeting (10). This sheeting achieves on average twice the retroreflectivity of Type I by using bigger glass beads. Typically has a service life of 10 years and can be identified my manufactures watermarks.

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

Type IV - A retroreflective sheeting referred to as "high-intensity" that is typically an unmetalized microprismatic retroreflective element material (10). The sheeting manufacturer can be identified by the square patterns superimposed upon the hexagonal lattice. Type IV sheeting produces retroreflectivity measurements that are seven times greater than Type I with costs and a service life that is comparable to Type III sheeting.

Type V - A retroreflective sheeting referred to as "super high-intensity" that is typically a metalized microprismatic retroreflective element material (10). Primarily used on delineators and raised pavement markers. The service life is five years and it cost five and a half times that of Type I.

Type VI - An elastomeric retroreflective sheeting without adhesive. This sheeting is typically a vinyl microprismatic retroreflective material (10). This sheeting is composed of a flexible vinyl cloth allowing it to be utilized on clothing and roll-up traffic signs. It cost six times as much as Type I sheeting and has a service life of two years.

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

Due to the fact that sheeting classifications change over time it should be noted that the following reclassifications are applicable as of November of 2011: all retroreflective sheeting material previously classified as a Type VII or Type X have been reclassified to Type VIII(10). The minimum coefficient of retroreflection to be considered as one type or another are summarized in Table 0.1.

Table 0.1 Minimum Retroreflectivity for Sheeting Type Classification † (9)

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

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

A minus sign denotes that there is currently no minimum for that color and type combination. In addition to the presented information ASTM D4956-11a includes detailed information about sheeting weathering requirements and accelerated weather for different observation and entrance angle combinations.

Establishment of Minimum Retroreflectivity Levels

In 1992, Congress mandated that the Secretary of Transportation revise the language in the MUTCD to include "a standard for minimum levels of retroreflectivity that would be applicable to all roadways open to public travel (11)." In order to directly address the Congressional mandate, the Federal Highway Administration (FHWA) conducted several studies which were summarized in 1993 and established the first minimum retroreflectivity levels (12). These initial minimum levels were derived from analyses based on the Computer Analysis of Retroreflectance of Traffic Signs (CARTS) model. The CARTS model estimated the minimum distance that was required for a motorist to respond to a vehicle and then utilized this information to establish the luminance required for the sign to convey its message at night (13). The initial minimum retroreflectivity levels were divided up into four tables depending on the color of the sign and were applicable to both post-mounted and overhead signs. The four tables were: white, yellow and orange, green, and red signs. The initial minimum levels also established a minimum contrast ration of 4:1 for white on red and white on green signs (14).

After the 1993 minimum retroreflectivity levels were published, reviewers of the work began to question many of the modeling assumptions. Most of the comments centered on the assumption of the driver being located directly above the headlight, which represented a motorcycle rather than a passenger vehicle. The CARTS model was adjusted to accommodate the effects of dual headlights on the observation angle (15). In 1997, new specifications were passed for headlights by the Federal Motor Vehicle Safety Standards. This addressed issues with the luminous intensity of headlights directed towards overhead signs. The FHWA sponsored additional research for minimum retroreflectivity levels for overhead and street-name signs and established the current minimum levels for both post-mounted and overhead guide signs (16). Final adjustments to the minimum retroreflectivity levels resulted from research conducted in 2003, in which consistent testing parameters for driver age, vehicle type, headlights, and retroreflective sheeting types were taken into account (17).

Section 2A.08 of the 2009 Edition of the MUTCD establishes the minimum retroreflectivity levels, displayed in Table 0.2, which must be maintained by public agencies or officials that have jurisdiction over traffic signs. In addition to establishing minimum retroreflectivity levels, the MUTCD introduced the follow standard:

> *"Public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels (18)."*

Incorporated with the above standard were three target compliance dates. By January 22, 2012 an agency must implement an assessment or management method that is designed to maintain traffic sign retroreflectivity at, or above, the established minimum levels. By January 22, 2015, signs that have been identified as failing, including regulatory, warning, and post mounted guide signs must be replaced. Finally, by January 22, 2018, the additional replacements for street signs and overhead guide signs are required (18).

Table 0.2 Minimum Maintained Retroreflectivity Levels (18)

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
White on Green	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			2
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 75; O ≥ 75			3
White on Red	W ≥ 35; R ≥ 7				4
Black on White	W ≥ 50				–

[1] The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m² measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Bold Symbol Signs

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

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

Special Cases

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

On August 31, 2011, a Notice of Proposed Amendments was published in the Federal Register, proposing to revise Table I-2 in the Introduction of the 2009 MUTCD. On May 14, 2012, the proposed amendment was accepted by FHWA and eliminated the majority of compliance dates for traffic sign retroreflectivity. The only remaining compliance date requires agencies to implement an assessment or management method for maintaining only regulatory and warning sign retroreflectivity above the minimum levels. Implementation and continued use of a retroreflectivity maintenance method is required by June 13, 2014 (19). The revision had no effect on the minimum retroreflectivity levels or the recommended methods for maintaining retroreflectivity compliance.

The MUTCD provides five different methods for maintaining retroreflectivity compliance, which are separated into two different categories: assessment or management. The assessment methods include visual nighttime inspection and measured sign retroreflectivity, whereas the management methods include expected sign life, blanket replacement, and control signs (18). Within the five different compliance methods inefficiencies exist because agencies are reliant upon manufactures warranties for establishing replacement rates or inventory intervals for the traffic signs under their jurisdiction. In order to decrease these inefficiencies, agencies have sought to create degradation curves to fine tune sign replacement and effectively allocate agency funding for traffic sign management.

Retroreflectivity Deterioration Studies

While the FHWA has outlined general guidelines for various methods of complying with the minimum retroreflectivity standards, individual management strategies are left to the agencies to develop. These assessment and management strategies rely upon the ability to efficiently predict how retroreflectivity will deteriorate over time, whether to determine the frequency of sign assessment or to predict the service life of signs. Sign deterioration studies are commonly conducted under controlled or uncontrolled conditions. Controlled conditions study the deterioration of traffic signs that are separated from the roadway and are commonly contained in an experimental sign retroreflectivity measurement facility (20). Uncontrolled signs are in-service signs that are exposed to traffic, damage, as well as natural weathering.

<u>Controlled Condition Deterioration Studies</u>

AASHTO established the National Transportation Product Evaluation Program (NTPEP) in 1994 to eliminate duplication of testing and auditing by states and manufacturers for products that are used on transportation infrastructure. In order for new sheeting material to be used in the United States, the manufacturer must submit it to NTPEP for testing. Currently the NTPEP operates four test deck facilities located in Arizona (Phoenix), Louisiana, Minnesota, and Virginia. Two additional facilities located in Arizona (Flagstaff) and North Carolina collected data until these sites were discontinued in 2003 (21). In accordance with ASTM D4956-11 and ASTM G7/G&M-11 standards sheeting types are oriented at a 45 degree angle and facing the equator (22). Sheeting types tested at this orientation have been shown to deteriorate twice as fast compared to vertically mounted samples (23). The NTPEP only collects data on sheeting materials for three years but, due to the orientation and setting of the samples, it effectively represents six years of deterioration. The weathered samples are compared against a control sample that has been stored in a protective environment. Controlled deterioration studies have less variability in their results because they only experience natural weathering and are examined by manufacturer representatives prior to testing to ensure quality. Even with only natural weather the results of controlled condition deterioration are inconclusive. As shown in Table 0.3, the difference in initial and final retroreflectivity varies by both test deck facility and sample within a test deck facility. In some cases, sheeting performance had increased overtime, whereas in other cases the file sample that was not exposed to natural weathering experienced a higher degree of deterioration than the exposed samples.

It is possible that some of the counterintuitive results could be eliminated by increasing the sample size of the control sign population. But since the closing of two test deck facilities in 2003, new sheeting types will have a maximum sample size of eight signs per sheeting type and color combination. Even the best testing facilities are subject to human error in measurement recording and this is evident in the Virginia samples. It is apparent that the point instrument was improperly rotated when the initial measurements were taken. Due to the rotational sensitivity of prismatic sheeting types, any use of a point instrument for portable retroreflectometer readings can produce inaccurate readings if testing procedures are not followed.

Table 0.3 NTPEP Measurements for 3m Diamond Grade DGcubed White Sheeting (24)

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

[a] Portable retroreflectometer was a point instrument at a rotation of 0°.

[b] Portable retroreflectometer was a annular instrument.

Uncontrolled Condition Deterioration Studies

The first project looking into retroreflectivity performance of in-service sign sheeting was completed in 1992. For the project, over 8,000 signs were collected and analyzed from 26 states to assess the practicality of the proposed minimum retroreflectivity levels (5, 25). Although traffic sign retroreflectivity was typically found to deteriorate with age, it could not determine what other factors contribute to the deterioration process. The primary goals of the project were to determine: overall retroreflectivity condition of the nation's traffic signs, estimate sign replacement and maintenance cost, estimate the number of in-service deficient traffic signs, and evaluate the economic cost of establishing minimum retroreflectivity measurements. The performance of traffic signs was segregated by color and summarized via frequency diagrams as seen in Figure 0.4 for white sheeting. Even though data was collected for Type II and Type III traffic signs this classification was eliminated during the presentation of sign performance (5). An additional hindrance to the performance forecasting value of this project was the limited installation date information. Only one jurisdiction managed an inventory that included the date of installation. At the conclusion of the project it was determined that signs R_A values deteriorate over time, but could not determine any significant factors that lead to rapid deterioration.

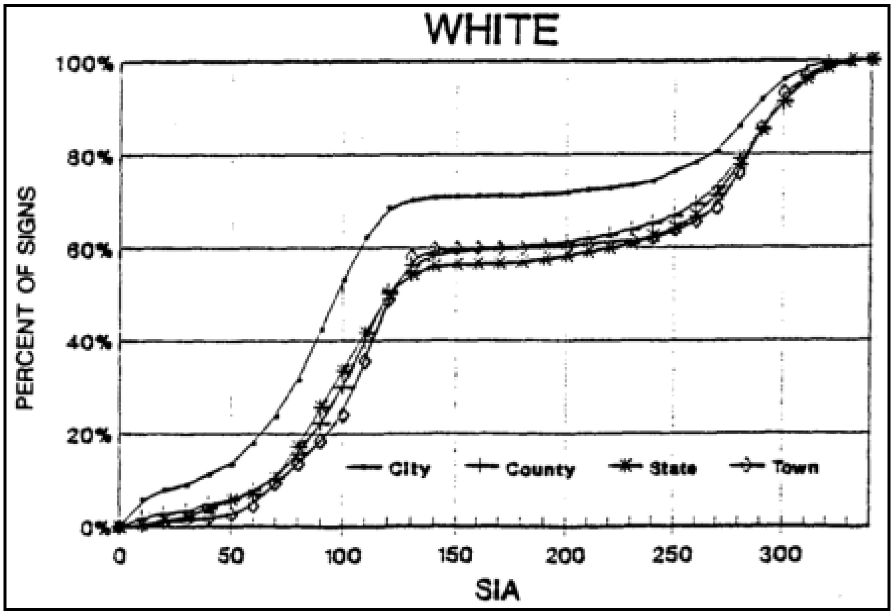


Figure 0.4 Frequency Graph for White Sheeting (5)

In addition it was determined that the R_A value for white on red signs increases overtime due to the red silk screen fading and exposing more of the white backing to light (5, 25).

In 2001, a research group for the Oregon Department of Transportation (ODOT) conducted a study with the goal of determining the relationship between retroreflectivity and the infield service life of traffic signs. At the completion of the report the sample sign population consisted of 157 traffic signs distributed across the four major sheeting colors. Collection of the 157 signs, all ASTM Type III, was focused in the mid-Willamette Valley in a portion of ODOT Maintenance Region 2 (26). At the conclusion of the project trend lines of the collected traffic signs demonstrated the low correlation between retroreflective performance and sign age as seen in Figure 0.5.

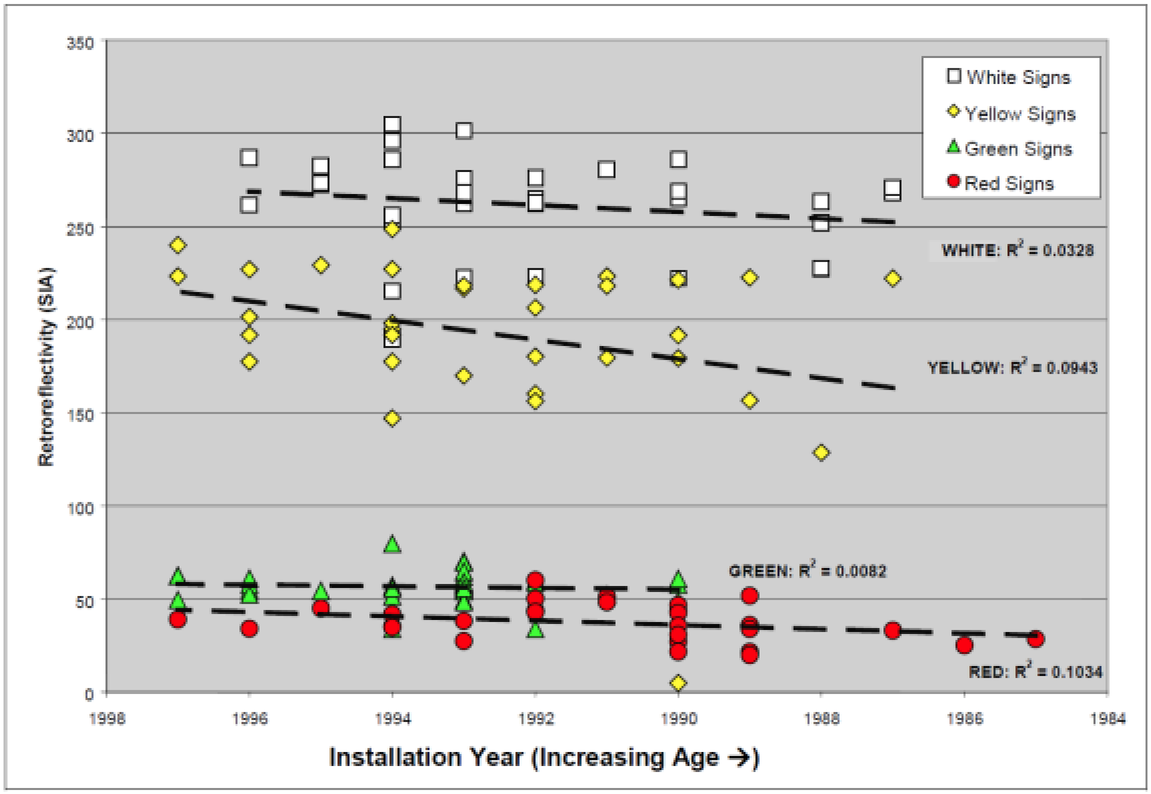


Figure 0.5 Retroreflectivity by Sign Age (26)

The researchers cited two major factors that contributed to the weak relationships: the age range of the traffic signs and the installation dates were not entirely reliable. Due to the fact that most manufacturer warranties for ASTM Type III sheeting are around 10 years, the idea that the age range was not big enough to provide an accurate depiction of sheeting deterioration is invalid. The accuracy of installation dates is crucial to any deterioration study and could easily distort the true deterioration of traffic sign sheeting. An additional issue was the washing of traffic signs prior to recording the retroreflectivity of the sheeting. Unless ODOT practices agency wide washing of traffic signs washing them before recording retroreflectivity produces higher performance readings, which do not reflect the true infield performance. Although ASTM E1709-09 states that a minimum of four measurements be taken per retroreflective sheeting present on the sign, researches only measured the background sheeting on each sign. Doing so does not provide enough information for white on red signs which are governed by a minimum retroreflectivity level and a contrast ratio. Although many of the data collection practices were less than ideal the researchers did increase the accuracy of retroreflective measurement by exceeding the minimum number of required measurements on each sign. Instead of recording the minimum of four measurements per sign, a total of ten measurements were recorded. This creates a more accurate representation of the true performance of the traffic sign, especially for larger interstate traffic signs.

In 2002, researchers from Louisiana State University conducted a study on furthering the evaluation of traffic sign deterioration and the factors that contribute to rapid deterioration of sheeting types under the Louisiana Department of Transportation and Development (DOTD) jurisdiction. At the conclusion of the collection process total of, 237 traffic signs were surveyed 124 ASTM Type I and 123 ASTM Type III (27). Although signs were measure after being clean, similar to the ODOT project, retroreflective measurements were also taken for the unclean sheeting surface as well. The study collected three major attributes for each sign: Age of the sign, distance to the edge of pavement, and the orientation of the sign. Retroreflectivity was plotted against sign age to produce Figure 0.6.

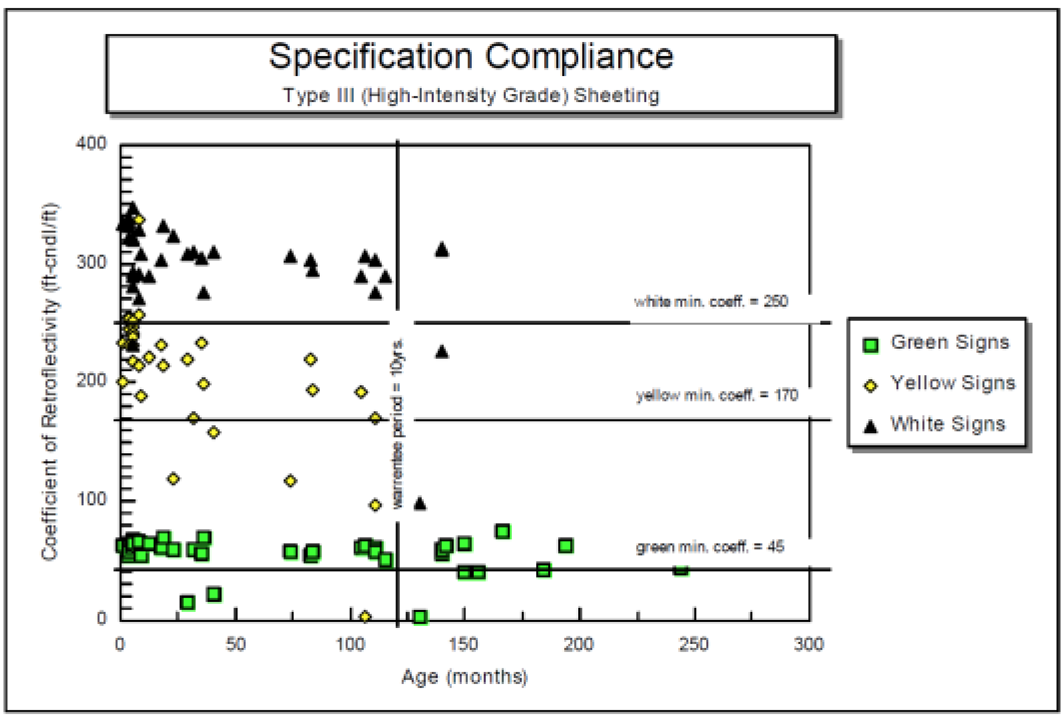


Figure 0.6 ASTM Type III Retroreflectivity Deterioration (27)

Even though the traffic signs were measured without being cleaned they closely mirrored the results from the ODOT project. Yellow sheeting deteriorates at a faster rate than white and green sheeting deteriorates at nearly a horizontal rate. Using these three attributes along with sheeting type and color 12 performance equations were developed, using linear modeling procedures, for forecasting the deterioration. Even though the distance to the edge of pavement and the orientation of the traffic sign had no statistical significance they were still included because their effects were not negligible (27).

Before this study there was anecdotal evidence that supported the theory that orientation was a significant factor in sheeting deterioration. For the sample population surveyed by the research team, the F-test on the data showed that there was no statistically significance connection to the orientation or the distance to the edge of pavement and its retroreflective performance. Since this study measured both dirty and cleaned sign is was able to evaluate the performance benefits of cleaning traffic signs. Cleaning ASTM Type I signs resulted in an average retroreflectivity increase of 40 percent, whereas cleaning ASTM Type III signs resulted in an average increase of 23 percent (27). Although the report produced, 12 predictive equations, six for dirty and six for cleaned signs they did not accurately predict deterioration of retroreflective sheeting. For dirty signs the predicted retroreflective measurement estimated by the equations where approximately half of that recorded in the field. As far as predicting the cleaned traffic signs the equation performance was even worse with predicted retroreflective measurements being only 25 percent of recorded measurements. This study also did not conduct any analysis on white on red sheeting, which are typically the highest priority signs managed by an agency.

In 2002, the Indiana Department of Transportation (INDOT) conducted a study to assess traffic sign performance on roadways under INDOT jurisdiction. The study focused on ASTM Type III sheeting for red, white, and yellow signs. The report conducted analysis on 1,341 in-service traffic signs with 31 percent white on red, 51 percent black on white, and 18 percent black on yellow (28). Although developing a deterioration model was not the primary focus of the study, analysis was carried out for the three different sheeting colors. The results for white sheeting matched those of the previous studies conducted by ODOT and DOTD, with a very slight decrease in retroreflectivity over time. For yellow colored sheeting, the deterioration trend line was steeper which again matched the data from the ODOT and DOTD reports. Where the INDOT report differs is the recorded deterioration rate for white on red sheeting over time.

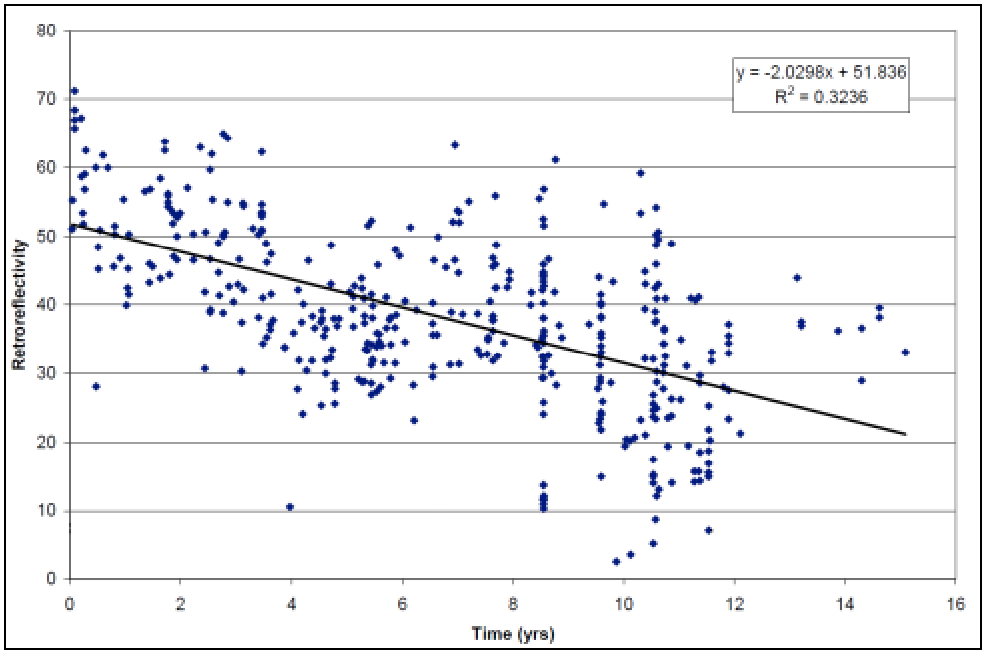


Figure 0.7 ASTM Type III Red Retroreflectivity Deterioration (28)

Contrary to the ODOT and FHWA study, (5) the INDOT report displays a steep deterioration trend line for white on red sheeting, shown in Figure 0.7.

The report also differed in the analysis of dirty and cleaned sheeting. The DOTD project reported increases in retroreflectivity by an average of 23 percent, whereas the INDOT reported that retroreflective performance improvements form cleaning traffic signs was essentially negligible. This difference in performance is likely the result of the different environments the traffic signs were in or from incomplete drying after the sheeting was cleaned. It should also be noted that the INDOT study did not follow ASTM E1709-09 standards because the researchers only took the average of three retroreflectivity measurements for each color of sheeting (28). This report did agree with the insignificance of sheeting deterioration due to the orientation of the signs face. Although orientation appeared to play a minor role in increasing the variability of white on red traffic sign background retroreflectivity.

While trying to design an efficient nighttime inspection procedure for the North Carolina Department of Transportation (NCDOT), researchers reviewed data to try and determine any potential correlations between sign age and retroreflective deterioration (29). ASTM Type I and Type III signs were collected for the white on red, black on white, black on yellow and white on green traffic signs. At the conclusion of the collection effect 60% of the traffic signs had ASTM Type I sheeting out of the, 1,029 measured traffic signs. A general regression analysis was performed on the different sheeting colors and results were plotted by measured retroreflectivity versus the sign age. Linear, Logarithmic, Polynomial, Power, and Exponential curves were then fitted for each of the data sets. The best correlation (R^2 = 0.48) was for ASTM Type III red sheeting using a polynomial curve, which is displayed in Figure 0.8.

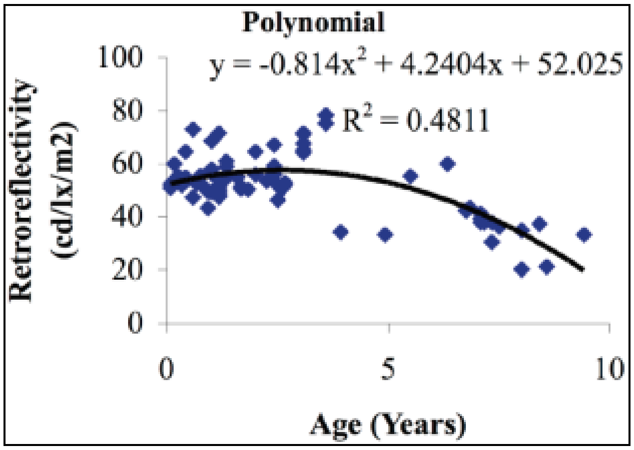


Figure 0.8 Polynomial Trend Line for Type III Red Sheeting (29)

Due to the low degree of correlation for all of the sheeting types and colors, the researchers decided to extract the data from previous deterioration studies and plot new curves. This new data set included data from data the FHWA(5, 25), ODOT(26), DOTD(27) and INDOT(28). Even with the increased sample population size, correlation between retroreflectivity and sign age was still consistently low for all types and colors. Extrapolating the expected service life of a sign from these curves produced service lives ranging from 17 to 80+ years. In addition, green sheeting tended to increase in retroreflectivity with age, which is counterintuitive.

The most resent deterioration analysis was completed for the Pennsylvania Department of Transportation (PennDOT). By the completion of the collection effort, 1,000 traffic sign were measured that had experience a minimum of ten years of service (30). The service life analysis was limited to Type III sheeting. The deterioration trend for Type III yellow sheeting is shown in Figure 0.9.

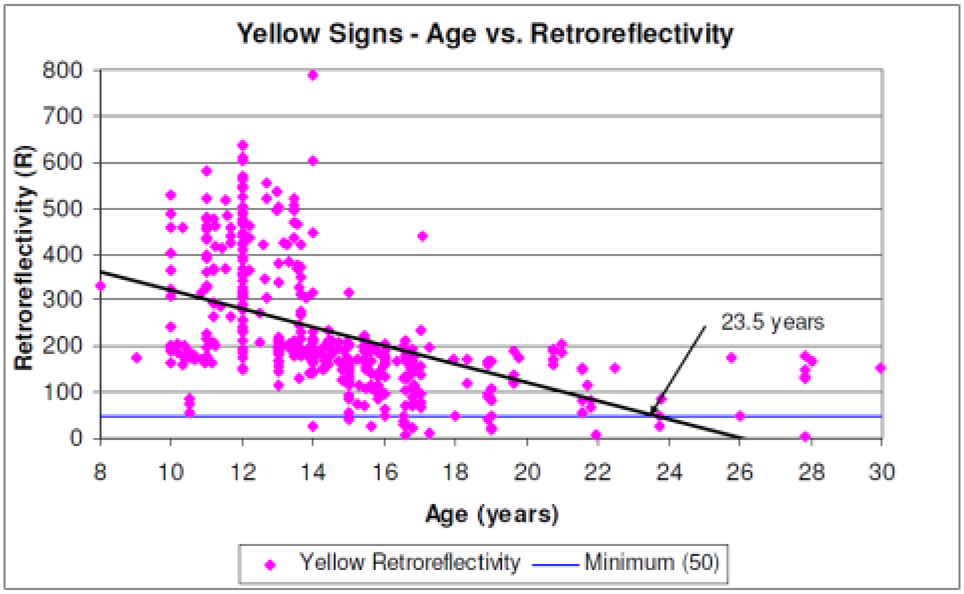


Figure 0.9 Yellow Type III Deterioration (30)

Although the linear trend of age and retroreflectivity had a weak coefficient of determination, $R^2 = 0.2533$, the researchers were confident that, for Type III sheeting of all colors, an expected life of 15 years could be expected.

<u>Deterioration Trends Summary</u>

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

Damage Rates of Traffic Signs

There has been limited previous research into the damage rates of traffic signs managed by an agency. Several studies have focused on the determination of the service life of traffic signs, but did not focus on the rate of sign damage. In 1991, a FHWA report stated that rural areas had a high frequency of vandalism damage (25). Another report by McGee and Paniati, while not discussing damage rates, concluded that the effects of damage on a traffic signs should not be ignored (7). The report recommended that signs be visually inspected in order to ensure legibility and visibility but was silent on the issue of the frequency of inspection. This conclusion was reinforced by a report for the North Carolina Department of Transportation in 2002 (31). From 2005 to 2010 researchers at North Carolina State University completed several reports that discussed observed damage rates of NCDOT traffic signs (29, 32). A total of 1,057 traffic signs were measured by the completion of the collection effort. Damage was organized into three categories: human caused, nature, and non deliberate human damage. Of note is that the majority of the sign population was made up of Type I and Type III sheeting with little evaluation of the damage sensitive prismatic sheeting. Within the sample, dominated by Type I and Type III sheeting, researchers found that approximately four percent of all annual sign replacements were the direct result of damage (32).

By identifing locations where increased damage rates are expected agencies can begin to fine-tune assessment intervals and to develop mitigation strategies in the continuing effort to increase motorist safety. With the continued implementation of prismatic sheeting in UDOT's sign population, maintaining the nighttime legibility of traffic signs is expected to become more important than simply ensuring its visibility.

Managing Traffic Sign Retroreflectivity

Coupled with the minimum retroreflectivity levels established in the MUTCD there were five recommended methods for maintaining sheeting retroreflectivity. These five recommended methods could be categorized into two groups: assessment and management (18). The difference being that assessment strategies evaluate the performance of individual traffic signs and management methods group signs by like attributes and manage them by expected group performance. The recommended methods provided in the MUTCD guidance section are:

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

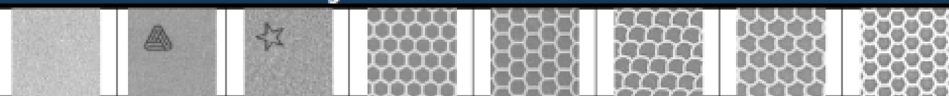
Where methods A and B are assessment methods and C, D, and E are management methods. Implementation of a single, combination or a different method (that has documentation proving its validity) would achieve compliance with the MUTCD standard for maintaining retroreflectivity. The standard states that "public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels" shown in Table 0.2. The support for the above standard states that as long as a method is being used an agency would be considered compliant ever if individual signs do not meet the minimum retroreflectivity levels (18). As of May 14, 2012, agencies will have two years to implement a method for traffic sign retroreflectivity management. Regardless of what method is selected by the agency, the proper identification of sheeting type is critical for accuracy and completeness. Therefore, FHWA has provided a Traffic Sign Retroreflectivity Sheeting Identification Guide which aides in determining sheeting type form various manufacturers (33). A segment of this guide is shown in Figure 0.10.

2011 Traffic Sign Retroreflective Sheeting Identification Guide

U.S. Department of Transportation Federal Highway Administration

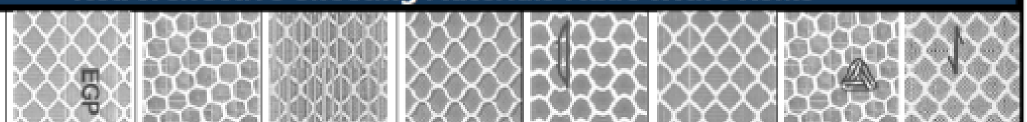
This document is intended to help identify sign sheeting materials for rigid signs and their common specification designations. It is not a qualified product list. FHWA does not endorse or approve sign sheeting materials. Many other sheeting materials not listed here are available for delineation and construction/work zone uses.

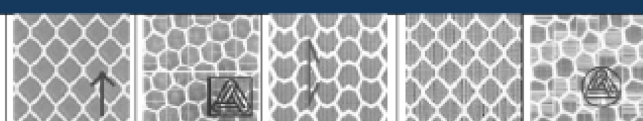
Retroreflective Sheeting Materials Made with Glass Beads

Example of Sheeting (Shown to scale)								
ASTM D4956-04	I	II	II	III	III	III	III	III
ASTM D4956-09	I	II	II	III	III	III	III	III
AASHTO M268-10	(1)	(1)	(1)	A	A	A	A	A
Manufacturer	Several companies	Avery Dennison®	Nippon Carbide	3M™	ATSM, Inc.	Avery Dennison®	Nippon Carbide	Oracal
Brand Name	Engineer Grade	Super Engr Grade	Super Engr Grade	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity
Series	Several	T-2000	15000	2800 3800	ATSM HI	T-5500	N500	5800
NOTES:	(2)	(3) (4)	(4)	(3) (4)	(4)	(4)	(4)	(4)

(1) – Sheeting material does not meet minimum AASHTO classification criteria.
(2) – Glass Bead Engineer Grade sheeting is uniform without any patterns or identifying marks. Section 2A.08 of the 2009 MUTCD (http://mutcd.fhwa.dot.gov) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.
(3) – Material no longer sold in the United States as of the date of this publication.
(4) – Section 2A.08 of the 2009 MUTCD (http://mutcd.fhwa.dot.gov) does not allow this sheeting type to be used for new legends on green overhead signs.

Retroreflective Sheeting Materials Made with Prisms

Example of Sheeting (Shown to scale)								
D4956-04	(5)	III, IV	III, IV, X	(5)	(5) / X	(5)	VIII	VII, VIII, X
D4956-09	I	III, IV	III, IV	IV	IV / VIII	VIII	VIII	VIII
M268-10	(6)	B	B	B	B	B	B	(9)
Manufacturer	3M™	Avery Dennison®	3M™	Reflexite®	Nippon Carbide	3M™	Avery Dennison®	3M™
Brand Name	Engr Grade Prismatic	High Intensity Prismatic	High Intensity Prismatic	High Intensity Prismatic	Crystal Grade	Reflective Sheeting	MVP Prismatic	Diamond Grade™ LDP
Series	3430	T-6500	3930	IC400	94000 / 92000	3940	T-7500	3970
NOTES:	(7)				(8)			(10)

Example of Sheeting (Shown to scale)					
D4956-04	IX	IX	(5)	(5)	(5)
D4956-09	IX	IX	IX	XI	XI
M268-10	B	B	B	D	D
Manufacturer	3M™	Avery Dennison®	Nippon Carbide	3M™	Avery Dennison®
Brand Name	Diamond Grade™ VIP	OmniView™	Crystal Grade	Diamond Grade™ DG3	OmniCube™
Series	3990	T-9500	95000	4000	T-11500
NOTES:					

NOTE: The watermarks have been enhanced in this ID Guide. They are shown to scale but are not as visible on actual sheeting materials. It helps to view the sheeting materials at different angles to see the watermarks. The spacing of the watermarks varies and therefore watermarks may not be present on small pieces of sheeting.

(5) – Material was either unavailable in 2005 (previous version of this Guide) or unassigned in the 2004 version of ASTM D4956.
(6) – Sheeting material does not meet minimum AASHTO classification criteria.
(7) – Section 2A.08 of the 2009 MUTCD (http://mutcd.fhwa.dot.gov) does not allow this sheeting type to be used for new yellow or orange signs, or new legends on green signs.
(8) – These two materials (94000 and 92000) are visually indistinguishable from one another.
(9) – Material has been discontinued prior to AASHTO M268-10.
(10) – Material no longer sold in the United States as of the date of this publication.

Figure 0.10 FHWA Sheeting Identification Guide (33)

Visual Nighttime Inspection

Visual nighttime inspection involves the assessment of the retroreflectivity of an in-service traffic sign by a trained sign inspector. Visual nighttime inspection has been demonstrated to be the most likely means for identifying a variety of nighttime visibility problems associated with traffic signs. Agencies using this assessment method should develop a training procedure for inspectors and establish guidelines for their individual agency to manage the retroreflectivity of signs. This training should facilitate the ability of an inspector to discern between signs that meet minimum retroreflectivity levels and those that are near or below standards (14). What makes visual inspection so advantageous to agencies is the ability to assess the retroreflectance of a traffic sign while identify other issues with nighttime visibility. Uniformity, damage, placement and obstruction can all detract from the ability of a sign to convey its message efficiently both at night and during the day. FHWA has approved three procedures for the visual inspection method: the calibration signs, comparison panel and consistent parameters procedure. No matter the visual inspection method the following general guidelines should be followed: inspection must take place at night, at normal travel way speeds, in the right most travel lane, while using low-beam headlights (14, 34)

Calibration Sign Procedure

Calibration sign procedure involves inspectors viewing full scale traffic signs that are close to the minimum required retroreflectivity level to “calibrate” their eyes for that night’s inspection. A different calibration sign is required for each sheeting color (34). Due to the observation angles that typically govern traffic signs (+0.2 degrees and +0.5 degrees), they should be viewed at a sight distance ranging from 200 ft to 500 ft (8). The calibration process should take place in the same vehicle used for nighttime inspection. The calibration signs can either be permanently mounted at a maintenance station or can be stored in between inspections to reduce the deterioration of the sheeting. Currently, minimum retroreflectivity kits produced by manufacturers are available for a quarter of the price of portable retroreflectometers (35). Even if calibration signs are stored in an ideal environment they will deteriorate gradually over time. Therefore, agencies should either purchase new kits or take retroreflectivity measurements via a portable retroreflectometer periodically to ensure that calibration signs meet or exceed the minimum retroreflectivity levels.

Comparison Panel Procedure

Comparison panel procedure require that inspectors clamp small sheeting panels on traffic signs that appear to perform below minimum retroreflective levels and determine if the sign is as bright as the panel. Typical dimensions for comparison panels are 6” by 6” sheeting samples (36). Unlike the calibration sign procedure inspection crews do not need to calibrate their eyes prior to beginning the inspection. Instead they identify signs that appear to be near the minimum retroreflectivity levels and clamp the panel to the sign. Using a flashlight of adequate brightness an inspector assessed the sign’s retroreflectance and determines if it exceeds the panel, as shown in Figure 0.11.

Figure 0.11 Example of Comparison Panel Procedure (36)

Signs that appear less bright than the panel should be scheduled for replacement, as is the case in Figure 0.11. As the inspection continues, the inspectors effectively calibrate their eyes throughout the night as they determine what the performance of a marginal traffic sign is. Because inspectors will need to exit the vehicle and clamp the comparison panels to the traffic sign, this visual inspection method would be more time consuming than the calibration sign procedure.

Consistent Parameters Procedure

Utilizing the consistent parameters procedure requires visual inspection of traffic sign to be conducted under conditions that are similar to those used in the development of the minimum retroreflective levels. This requires a sport utility vehicle or pick-up truck model year 2000 or newer. The inspector must be an individual age 60 or older. Inspectors then travel along the roadway at normal driving speeds and reject signs that are not legible for the 60 year old inspector (34). Due to the required inspector age, many agencies would have to hire senior citizens to assist in the inspection process. This requirement diminishes the feasibility of this method for most agencies.

Visual Inspection Accuracy

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

Inspectors in Washington State who only received limited training could correctly classify regulatory and warning signs with accuracies of 75 and 74 percent, respectively (37). Researchers at North Carolina State University (NCSU) shadowed NCDOT inspectors during the annual visual nighttime inspection and concluded that, for Type I sheeting so all background colors, inspectors could accurately detect failed signs 64 percent of the time (32). Depending on the inspection crew, correct detection for all traffic sign types varied between divisions ranging from 54 percent to 83 percent. Furthermore, NCSU determined that individual inspectors who received detailed training could increase the accuracy of regulatory signs up to 82 percent (29). There is limited data available for inspector accuracy when it comes to Type III sheeting because the majority of infield signs have not degraded near the minimum retroreflective levels.

In order to evaluate the effects of inspector age on the accuracy of visual inspection, Purdue University briefly trained college students as sign inspectors (38). A total number of 1,743 traffic signs were first assessed using nighttime inspection and then later by the measured retroreflectivity method. The results of the study are summarized in Table 0.4. Type I error is

Table 0.4 Purdue University Inspector Accuracy Summary (38)

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

defined as signs that inspectors failed but were later measured as passing signs and type II error is defined as signs that pass visual inspection but fail when the retroreflectivity was measured.

A contributing factor that should be considered in the accuracy of visual inspection is difference in retroreflective performance by sheeting type. As summarized beforehand in Table 0.1, newer sheeting types produce minimum coefficients of retroreflectivity that are six times brighter on average than the minimum retroreflectivity levels in Table 0.2. For example an ASTM Type IX white sheeting traffic sign would have to lose 86 percent of its retroreflectivity in order to be below minimum standards. This means that, as agencies begin to implement higher sheeting types into the traffic sign population under their jurisdiction that failure will become easier to identify.

An additional factor that might discourage agencies from implementing a visual nighttime inspection is accruing overtime pay for sign inspectors. There are several ways to avoid this scenario one of being to hire seasonal interns and train them as sign inspectors. As stated above in the Purdue University, report college age inspectors can correctly detect failing traffic signs with a high degree of accuracy (38).

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

"The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels should be replaced (39)."

Many agencies failed to recognize the support statement for this guidance in Paragraph 5 of Section 2A.08 which provides a reference to the 2007 Edition of FHWA's "Maintaining Traffic Sign Retroreflectivity" document that provides addition information on all of the recommended assessment and management methods (34). Within this document FHWA divided visual assessment into the three aforementioned methods. Therefore, if an agency wants to utilize a different form of visual inspection, like daytime inspection, they must provide an engineering study that proves the validity of the method.

Measured Sign Retroreflectivity

The other assessment method stated by FHWA in the MUTCD is measured sign retroreflectivity, which requires the agency to have access to a portable retroreflectometer. The retroreflectometer returns numerical values that can be directly compared to the minimum retroreflectivity levels. Following ASTM E1709-09 standards, four measurements are required for retroreflective background and legend, if applicable, for each traffic sign. In order to describe the overall performance of the traffic sign, the four measurements are averaged (8). Collecting retroreflectivity measurements for every sign within an agency's jurisdiction requires the dedication of people-hours and therefore is cost prohibitive. Collection rates vary, depending on the number of attributes that are being measured, from 10 to 25 signs per hour (37, 40, 41).

There are two types of portable retroreflectometers: point and annular instruments. Point and annular instruments receiver aperture have different shapes which affect the way the retroreflectivity is measured. Because of this point and annular instruments make geometrically different measurements of the R_A, which can produce differing values on the order of 10 percent. Both retroreflectometers calculate valid measurements, but there are differences in the operation and interpretation of these measurements based on whether the sheeting material is spherical or prismatic. Spherical sheeting can be considered as rotationally insensitive, therefore measurements by both types of retroreflectometers are practically identical. Most prismatic retroreflective sheeting however are rotationally sensitive, even at small entrance angles.

Therefore it is important to know the type of retroreflectometer and its proper "up" position before any measurements are recorded (8).

Point Retroreflectometers

The shape for the receiver aperture for a point instrument is shown in Figure 0.12. When a point instrument, is placed against a traffic sign in its proper "up" position it has a rotation angle equal to zero degrees. The rotation angle of the point instrument increases with clockwise rotation. For prismatic sheeting it is not uncommon to see a five percent variation in R_A for every five degrees of rotation (23). Therefore, it is critical for repeatability of measurements of retroreflectivity on prismatic sheeting that the device be positioned in the "up" position.

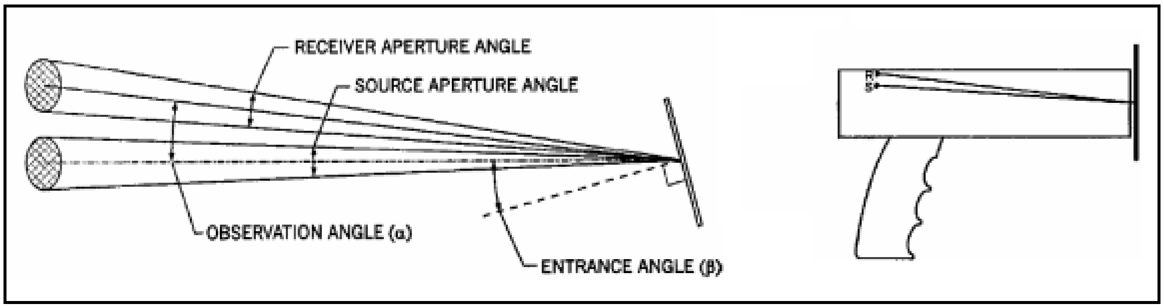


Figure 0.12 Point Aperture Retroreflectometer Illustration (8)

During the sample sign survey conducted for UDOT it was noted that there was high variance in values recorded from route identification signs, which share the same installation data and orientation. The inspection crew was using a Delta RetroSign Model 4500 retroreflectometer which is a point instrument (41). After careful inspection of the sheeting on the multiple signs present on the same support and installation date it was determined that the sheeting upon the signs themselves were rotated. This sheeting rotation was present in all prismatic sheeting types and colors. Repeating the techniques using by Carlson and Hawkins, but using a point retroreflectometer on different types of 3M sheeting used by UDOT produced Figure 0.13.

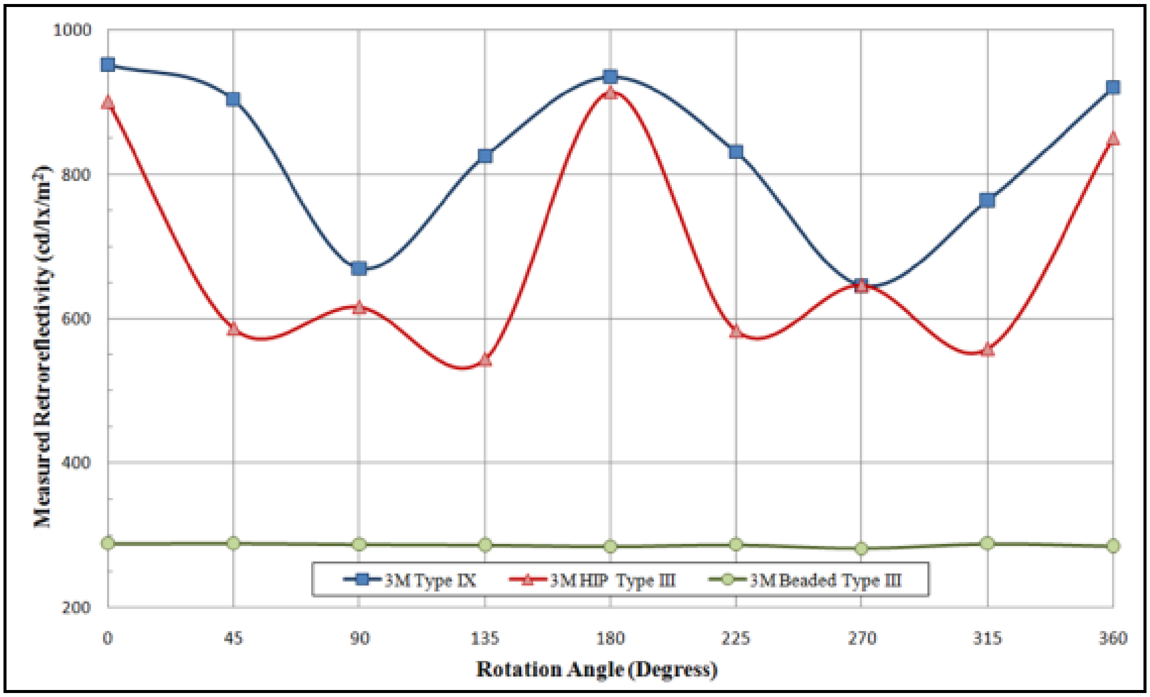


Figure 0.13 Rotational Sensitivity of Point Instrument (42)

Three types of ASTM sheeting were analyzed one spherical beaded, ASTM Type III, and two microprismatic ASTM Type III HIP and ASTM Type IX. The retroreflectometer started in its original "up" position and rotated clockwise in 15-degree intervals from 0 to 360 degrees. Four sections of the sign were measure and averaged to produce the lines in Figure 0.13. As expected the insensitive beaded ASTM Type III shows negligible sensitivity to the rotation of the retroreflectometer. Conversely the prismatic sheeting's retroreflectance decreases an average of 30 percent when rotated 90 degrees.

Annular Retroreflectometers

An annular retroreflectometer takes measurements of R_A similar to an average of a of several individual point measurements. Figure 0.14, shows the receiver aperture of an annular retroreflectometer.

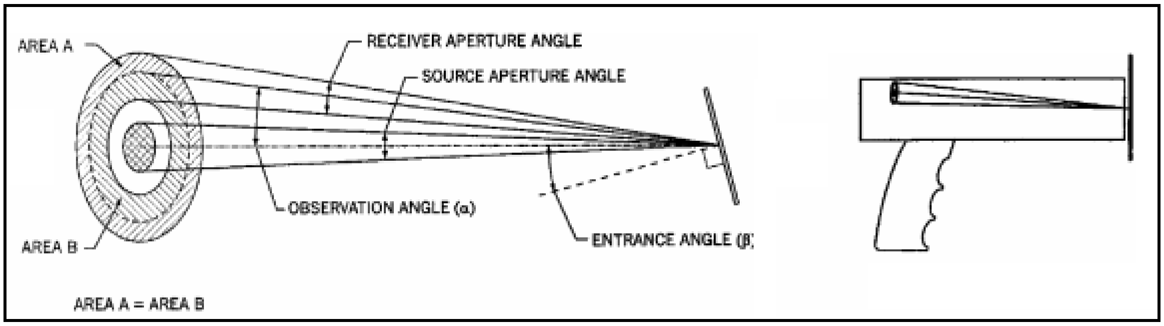


Figure 0.14 Annular Aperture Retroreflectometer Illustration (8)

According to ASTM E1709 the number of measurements should be at least 24. Comparing R_A between the two types of retroreflectometers can produce measurements with differences as high as 25 percent, but typically averaging on the order of 10 percent (8). Due to the averaging of the measurements the annular retroreflectometers do not require the precision in measurement position of the retroreflectometer that is required with point instruments. Positioning an angular instrument within ±15 degrees of the proper "up" position will produce practically identical R_A measurements. To demonstrate the rotational sensitivity retroreflective measurements using an annular retroreflectometer in 15-degree intervals from 0 to 360 degrees is shown in Figure 0.15.

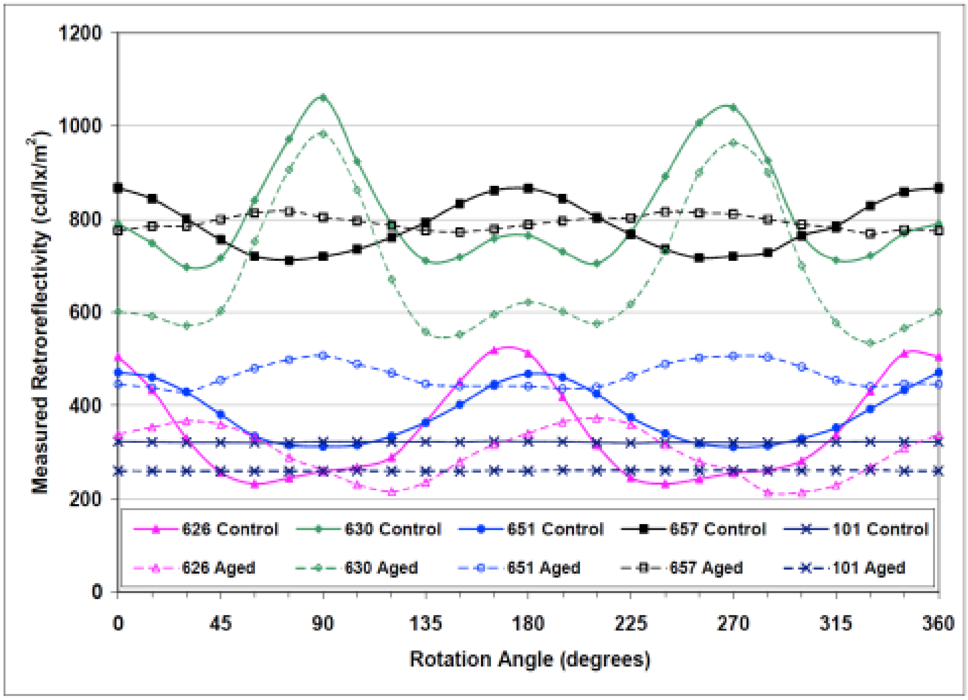


Figure 0.15 Rotational Sensitivity of Annular Instrument (23)

Measurements were taken on one beaded sheeting (Sample 101) and various prismatic sheeting types. The measurements were taken on weathered and an unweathered control sample. Table 0.5 summarizes the rotational sensitivity of the weathered sheeting samples.

Table 0.5 Rotational Sensitivity of Weathered Materials (23)

		R_A Measurements		
		Minimum	Maximum	
Sample #	Type	(cd/lx/m^2)	(cd/lx/m^2)	Ratio (Max/Min)
101	White Type III (Beaded)	259	262	1.01
626	Fluorescent Orange Type VII	214	373	1.74
630	White Type VII	535	983	1.84
651	Orange Type III	430	507	1.18
657	White Type VIII	769	817	1.06

Retroreflectometer Bias and Uncertainty

Further complicating the measured sign retroreflectivity method is the bias and uncertainty in retroreflectometer measurements. In a study performed by Purdue University measurement on 22 stop signs were measured under controlled laboratory conditions (43). The report focused on ASTM Type I and Type III sheeting that were measured by four different operators and three different retroreflectometers. In addition to the 22 stop signs 87 in-service regulatory and warning traffic signs were measured. The goal of this report was to determine the bias and uncertainty in retroreflectivity readings when recorded by different operators and retroreflectometers. The coefficient of variation for each traffic sign was calculated for comparison between signs of different colors and sheeting types. The study concluded that the coefficient of variation for an individual sign was between 4 and 14 percent (43).

<u>Retroreflectometer Summary</u>

Research has determined that the rotational sensitivity of prismatic sheeting is only significant at a sight distance of 100 feet. At further distances the degradation in retroreflectivity shown in Figure 0.14 and Figure 0.15 becomes negligible (23). This means that, from a visual assessment of the sign, the rotation is negligible but this is not true for the measured retroreflectivity. Any method that depends upon retroreflective measurements is susceptible to these rotational readings. There are two causes of rotational sensitivity in retroreflective measurement readings: instrument rotation and sign rotation. Instruments not oriented in the proper "up" position are commonly discussed as the reason for rotational sensitivity, but the bigger issue may be in sign rotation. Even under controlled conditions there is nontrivial bias and uncertainty in retroreflectometer measurements.

During the sample sign survey conducted for UDOT it was noted that there was high variance in values recorded from route identification signs, which share the same installation data and orientation. After careful inspection of the sheeting on the multiple signs present on the support it was determined that the sheeting upon the signs themselves were rotated. This sheeting rotation was present in all prismatic sheeting types and colors. Warning sign were particularly plagued by rotations due to the diamond shape of the sign (41). These irregularities in sign construction should be considered before any agency adopts a policy that is based on measured retroreflectivity.

<u>Expected Service Life Method</u>

For the expected life method, signs are replaced before the retroreflectivity degrades below the minimum levels. The expected service life can be based on manufacturers' warranties, measurements of infield control signs, retroreflective deterioration forecasting, and other various sources. What makes this method unique is its focus on managing signs based on installation date information. Installation dates can appear either on the sign itself and/or can be recorded in a centralized agency database. Examples of installation stickers utilized by other agencies are shown in Figure 0.16. Just like the other management methods the major hindrance in the expected life method is forecasting the deterioration of retroreflective sheeting in different environments.

Figure 0.16 Installation Stickers

The expected life of a sign can vary depending on the manufacturer, sheeting type and color, geographical location and various other attributes. Therefore, most agencies that implement this method will be reliant upon manufacturers' warranty periods until further research is completed on traffic sign sheeting deterioration. Until more accurate deterioration forecasting is completed, agencies will have to accept some level of error for the replacement of signs that both exceed and fail minimum levels. Although greatly dependent on manufacturer, typical warranty life for Type I, III, and IX signs are seven, ten, and twelve years, respectively (14). Commonly, manufacturers establish the warranties to cover the sheeting for 80 percent of its initial R_A value. Looking at newly installed from the sample, survey white ASTM Type IX and XI have average R_A measurements of 564 (cd/lx/m^2) and 745 (cd/lx/m^2), respectively. After these initial values deteriorated by 80 percent they would still have R_A measurements twice as large as the minimum retroreflectivity levels. By developing deterioration models, an agency can begin to look past the sign's warranty, and adjust replacement intervals to reduce sign waste.

Blanket Replacement Method

The blanket replacement method is a modification of the expected life method which is executed either by geographical area, corridor, or sheeting type and color instead of by installation dates. Ideally, blanket replacement can be implemented most effectively with a combination of both geographic and sign sheeting criteria. Because this method requires no physical labeling of signs nor the need to record installation dates, it can be simple for an agency to implement. An agency only needs to keep track of the last blanket replacement (14). The concerns that arise in the blanket replacement method are the high variance in expected sign deterioration levels. Similar to the expected life method if relevant data is not known about sign deterioration by region and sheeting types within the jurisdiction of agency, inefficiencies will arise. Within theses inefficiencies is the waste that can occur if traffic signs are replaced in between scheduled replacement periods. These relatively new signs could be taken out of service before the retroreflectivity of the sign nears minimum levels if they are not carefully inventoried. One method to reduce traffic sign waste is to use newly installed signs that were replaced in the previous blanket replacement as the signs that replace damaged or knocked down traffic signs.

Control Sign Method

Control sign method determines the life of the sign using control traffic signs placed within a maintenance yard or a sample set of in-service traffic signs. The subset of signs within the maintenance yard or the field must be representative of signs (sheeting type and color) in the region (14). Retroreflectivity is monitored via a retroreflectometer to determine the performance of the sample population. For individual sheeting types and colors, as the measurements near the minimum level, signs should be replaced. The sample set of signs needs to be representative of signs in the region, in order to properly manage the signs in that region. Determining that a sign can out last the manufactures warranty by just a couple of years can save agencies signing materials and resources. Questions that arise during the implementation of this method are the required sample size for the control sample population, the number of control sample sites, and the frequency of retroreflective measurements. These questions are all left for the agency to decide and justify.

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

Summary

The above section described the basic principles of retroreflectivity, the establishment of minimum retroreflectivity levels, retroreflectivity deterioration, traffic sign damage and the methods defined by FHWA for maintaining traffic sign retroreflectivity. Currently, forecasting retroreflectivity deterioration is difficult due to the amount contributing factors. Traffic sign sheeting is known to deteriorate over time, but defining traffic sign attributes that significantly contribute to rapid deterioration has proven problematic. Because, of this agencies must select a traffic sign management method that takes full advantage of their current known traffic sign information. Selection of an assessment or management method should take in to account efficiency of traffic sign assessment and accuracy of underperforming traffic sign detection. In Section 2A.06 of the MUTCD the support statements states that:

> *"The basic requirements of a sign are that it be legible to those for whom it is intended and that it be understandable in time to permit a proper response. Desirable attributes include high visibility during day and night and high legibility (18)."*

While FHWA has recently place an emphasis on maintaining retroreflectivity as a means to increase nighttime driver safety, ensuring efficient retroreflectivity only guarantees the visibility of a traffic sign. The goal of a traffic sign management plan should be to provide traffic signs that are both visible and legible to motorist, in the most cost efficient manner possible. In order to determine current signage issues for the population under UDOT's jurisdiction a collection effort was conducted to assess the performance of traffic signs across UDOT's maintenance regions.

TRAFFIC SIGN DATA COLLECTION

From 2011-12 researchers at Utah State University (USU) conducted a sample sign survey for traffic signs under UDOT's jurisdiction. The goal of the sample sign survey was to assess the current condition and retroreflective performance of UDOT traffic signs. At the end of the sample survey a total of 1,716 traffic signs had been assessed across all four of the UDOT maintenance regions. From this sample sign survey current issues within UDOT traffic signs population were identified. Knowledge gained from this collection effort will assist in the selection of a traffic sign management plan that is tailored to meet UDOT's specific signage needs.

For the remainder of this report the follow sign color definitions will be used: green for white on green signs, yellow for black on yellow signs, red for red on white signs, and white for black on white signs. Additionally due to infeasibility of obtaining retroreflectivity measurements for overhead traffic signs they were excluded from the collection effort.

Site Selection

In order to development a traffic sign management plan it was critical to conduct a sample survey to assess current issues, if any, present in UDOT's sign population. Various attributes were collected for each sign in order to determine the current rate of compliance and evaluate any contributing factors of rapid sheeting deterioration. Collection sites were selected across the four maintenance regions of UDOT to provide a representative sample of climates and maintenance practices throughout the state.

In order to gather an adequate random sample set of UDOT maintained traffic signs, several collection strategies were implemented. Sign data was collected for spatial regions to represent conditions present throughout the state. Data from each UDOT region was collected separately. Junctions where then selected throughout each region to represent an overall sample set for the region. Junctions had the highest sign densities and variety of sheeting color and were therefore prioritized during the collection process. In addition to the selected junctions, traffic signs were collected on state maintained routes that were representative of the maintenance region. Signs were evaluated 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. At the conclusion of the collection effort a total of 1,716 traffic signs were measured. Figure 0.1 displays the location of each traffic sign along with the boundaries of UDOT's maintenance regions.

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. When feasibly possible, signs containing installation dates were evaluated and retroreflectivity measurements were taken, these had the highest priority during the collection effort. New UDOT standards mandate that all signs placed into service be accompanied by a sticker on the sign face and back 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 0.2, shows the placement of installation dates on recently placed signs. UDOT has increase enforcement of the installation procedure, but as observed during the collection effort it is still a relatively new maintenance process. At the completion of the sample survey just over 17 percent of the sign population had known installation dates.

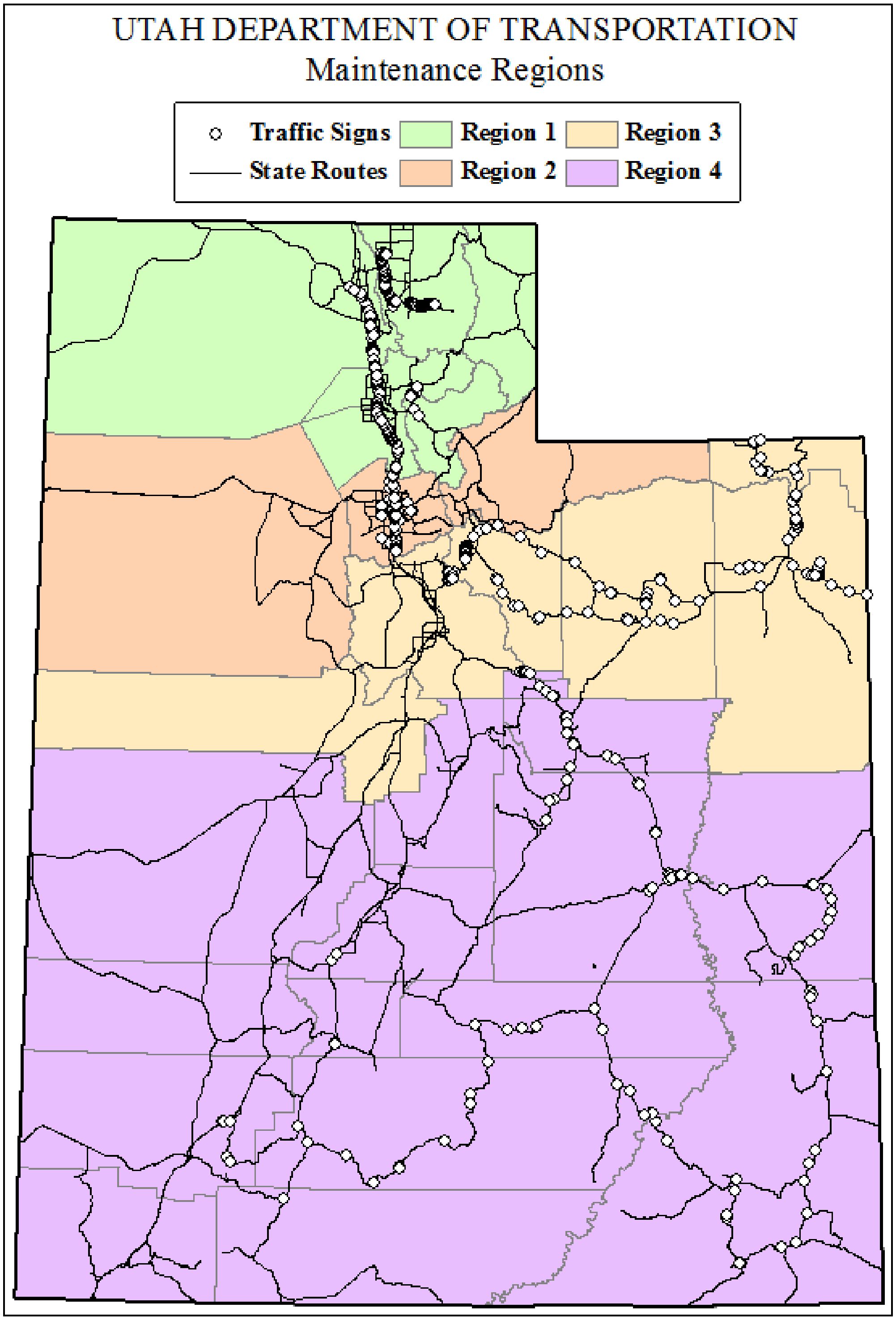


Figure 0.1 Location of Sample Sign Population

Figure 0.2 UDOT Installation Stickers

Collected Sign Attributes

In order to analyze and determine common sign attributes that might lead to rapid deterioration of the retroreflective sheeting specific attributes were collected throughout the sample survey. During the collection effort a Trimble GeoXT handheld data logger was utilized. The Trimble GeoXT handheld was used to facilitate rapid data collection, and because individual attributes collected may be attached to an associated GPS location. The Trimble allows for the creation of ESRI shapefiles that may be used in conjunction with a variety of GIS software and facilitate mapping. A customized data dictionary was created in the Trimble GeoXT with drop down menus and text boxes that allowed for quick and accurate collection of data. The attributes collected during the collection effort are listed below:

- Sign ID
- Photograph ID
- Sheeting Type
- Offset
- Mount Height
- Retroreflectivity Measurements
- Orientation
- Direction of Travel
- Bracing
- Exposure
- GPS Location
- Major Damage Type (if present)
- Minor Damage Type (if present)
- Sheeting and Legend Color
- MUTCD Code
- Installation Date (if present)

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 analysis process. Since damaged signs can require several photos a separate photograph ID was assign to each traffic sign.

Sheeting Type refers to the ASTM D4956 – 11a sheeting type for the sign (9). Identification of sheeting types was accomplished by applying the Federal Highway Administrations identification guide (33). It should be noted that in order to maintain continuity with UDOT maintenance terminology ASTM Type IV was referred to as Type III HIP throughout the collection effort. When known the manufacture was included in a comments section.

Offset is the lateral offset of the sign from the travel way measured from the edge of travel way to the support of the traffic sign. The offset measurement included the paved shoulder. Mount height is the vertical height of each sign measured from the elevation of the travel way to the base of the traffic sign.

Retroreflectivity measurements refer to the measured coefficient of retroreflectivity, R_A, in units of candelas per lux per meter squared ($cd/lx/m^2$). 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° and is a point instrument. All retroreflectivity measurements where take according the standards in ASTM E1709-09 (8). Locations for retroreflectivity measurements varied depending on the sign type with the general locations being shown in Figure 0.3.

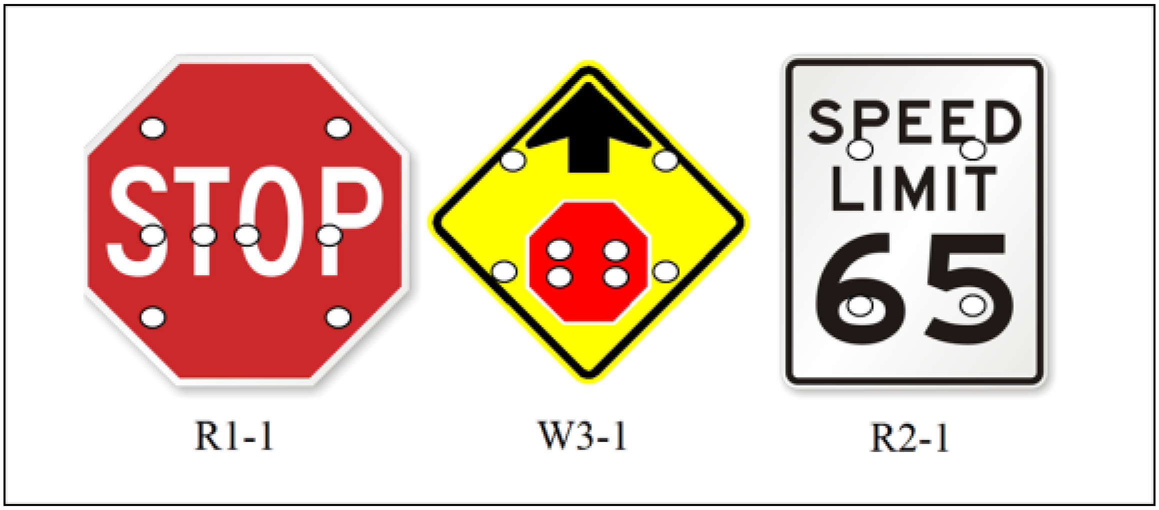


Figure 0.3 General Locations of Retroreflectivity Measurements

R_A is then calculated by averaging the points for each color upon the sign face. The calculated coefficient may then be compared with the minimum levels in order to determine compliance. In the case of red traffic 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.

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. The direction of travel was defined by the state route. The GPS location and corresponding elevation were recorded via the handled Trimble.

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 five categories of Peeling, Cracking, Bending, Vandalism and Other, shown in Figure 3.4. Detailed information on the distinction between the different damage categories and major or minor severity is discussed in Appendix A: Major and Minor Damage Examples.

Sheeting color was used as a proxy for MUTCD Code during the collection effort. Due to quantity of MUTCD Codes creation of a drop down list was not feasible. Therefore in order to avoid typos during the collection process the background/legend color was recorded during the in-field survey and correct MUTCD Code for each sign was added during data analysis.

Installation date is the date the sign was placed in service, identified by known blanket replacements, UDOT databases information or by the presence of installation stickers. 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 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.

A. Bending Damage
B. Peeling Damage
C. Vandalism
D. Cracking Damage
E. Other Damage Types

Figure 0.4 Damage Types

Data Collection Summary

In order to provide an adequate sample size, a total of 1,716 signs were measured across UDOT's four regions. The 1,716 traffic signs are just 1.8% of the estimated 95,000 signs under UDOT's jurisdiction. Under the assumption of a fully unbiased sample, the sample survey would provide for a 95% confidence level with an error of plus or minus 3% that the sample would be representative of the overall traffic sign population. The signs sampled provided for a good representation of the overall population with only a few acknowledged exceptions Table 0.1 displays a summary of surveyed signs divided by color, type and region. Other colored signs were fluorescent yellow, and blue signs.

Table 0.1 Summary of Sample Sign Survey

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

The distribution of traffic sign by color is shown in Figure 0.5. 69 percent of white signs were non-regulatory white which is classified as state route signs (MUTCD M1-4, M1-5) and the associated directional arrows. During this collection effort no white on brown, black on orange, or black on fluorescent orange were recorded.

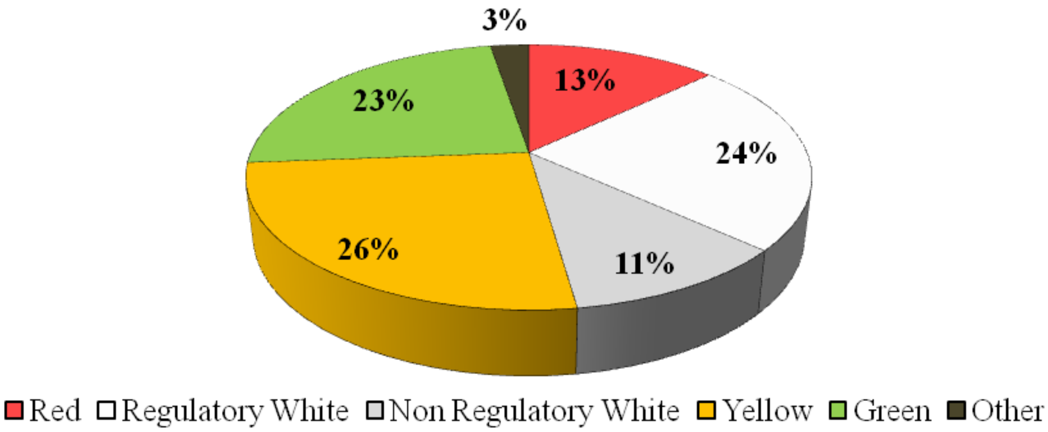


Figure 0.5 Sample Survey Signs by Color

The distribution of sheeting type by maintenance region is shown in Figure 0.6. The majority of UDOT's traffic sign population currently consists of ASTM Type III retroreflective sheeting. ASTM Type I, UDOT's legacy signs, are currently being phased out due to low retroreflectivity performance and sheeting age. The majority of new installations are Type III HIP (ASTM Type IV), Type IX and Type XI, which are all prismatic sheeting.

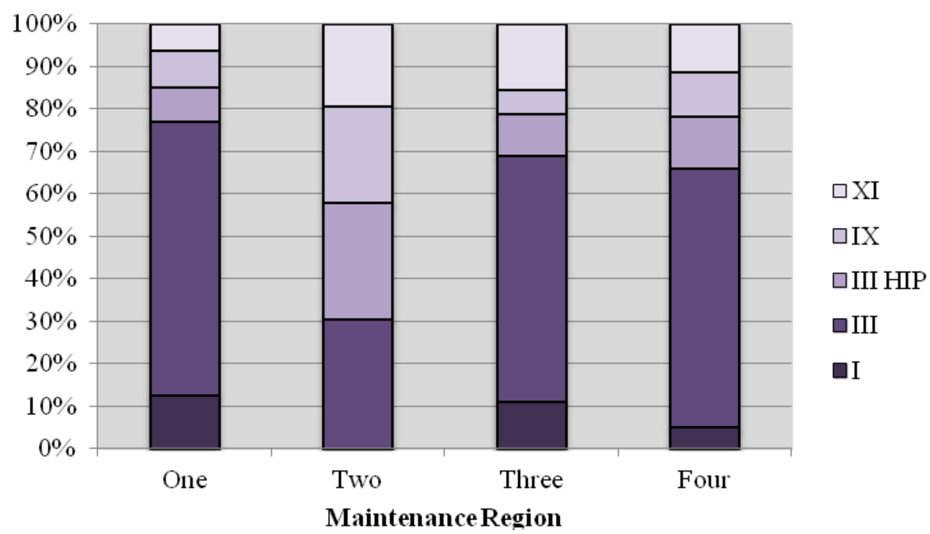


Figure 0.6 Distribution of Sheeting by Region

<u>Compliance with MUTCD Minimum Retroreflectivity Levels</u>

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. Coupled with the current statewide compliance is the performance of various sheeting types being used by UDOT. When considering compliance, signs were only rejected if the measured retroreflectivity was below minimum retroreflectivity levels. Though damage was reported and categorized, signs were never rejected purely based on damage. Table 0.2 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.

Table 0.2 Compliance Rate by Sheeting Type and Color

	Sheeting Type					
Color	I	III	III HIP	IX	XI	Failure
Red	0	7	1	0	1	4%
White	53	0	0	0	0	9%
Yellow	29	12	0	0	0	9%
Green	11	4	0	2	0	4%
Failure	68%	2%	0.5%	1%	1%	

The vast majority of all rejected signs were ASTM Type I and Type III sheeting. This is as expected as Type I and Type III produce the lowest measured values of retroreflectivity and are commonly the older signs in UDOT's population. UDOT has begun phasing out the use of Type I sheeting, due to its poor retroreflective performance. The actions of UDOT to replace these signs have been justified because 68% of Type I sheeting measured during the sample survey did not meet the minimum requirements. There were two observed rejections of Type IX sheeting, both present on green sheeting, which were determined to be caused by the construction of the signs. Overall, at the conclusion of the collection effort 120 traffic signs did not meet the minimum retroreflectivity levels. Overall the majority traffic signs under UDOT's jurisdiction are performing above the minimum retroreflectivity levels specified in the MUTCD. Under the assumption that UDOT maintains 95,000 traffic signs, the current failed sign population under UDOT's jurisdiction is 6,643. Therefore, it is estimated that UDOT is currently 93 percent compliant with the retroreflectivity levels specified in the MUTCD.

DATA ANALYSIS

This section of the report goes over the performance, damage rates and preliminary service life modeling of traffic signs under UDOT's jurisdiction. The sheeting performance section discusses the measured retroreflectivity of each observed sheeting type and color combination. It includes descriptive statistics and photographic examples of sign issues identified during the collection effort. The damage section discusses the contributing factors to increased sheeting damage. Analysis of damage rates was performed on both climate and location data for signs collected during the sample survey. The final section is a preliminary deterioration analysis of traffic signs under UDOT's jurisdiction. Due to the limited number of known installation dates the estimated service lives developed in this section are not recommended for traffic sign management. This section highlights significant variables of traffic sign deterioration and provides guidance for future deterioration analysis once more installation dates are known.

Sheeting Performance Overview

At the conclusion of the sample survey five different ASTM sheeting types were observed in UDOT's sign population. The different sheeting types were ASTM Type I, III, IV (3M Type III HIP), IX and XI. The majority of signs were manufactured by 3M Corporation, with some exceptions being produced by Avery Dennison. ASTM I and III are beaded sheeting which are considered rotationally insensitive, while ASTM IV (3M Type III HIP), IX and XI are prismatic sheeting that have varying degrees of sensitivity to sheeting rotation.

ASTM Type I Retroreflective Sheeting

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 there was a total of 136 Type I traffic signs were observed. While UDOT currently does not place new Type I signs, there is still a considerable population of these legacy signs still in-service. The majority of Type I signs were found on lower priority non-regulatory white route markers.

Figure 0.1, shows the box and whisker plots for the retroreflectivity values measured on Type I signs during the collection effort. The three vertical lines on the plot are the minimum retroreflectivity levels for each color. It is clear to see that the majority of Type I sheeting is performing below the minimum levels, which is predictable due to the expected age of this sheeting type. No Type I red sign were observed during the collection effort.

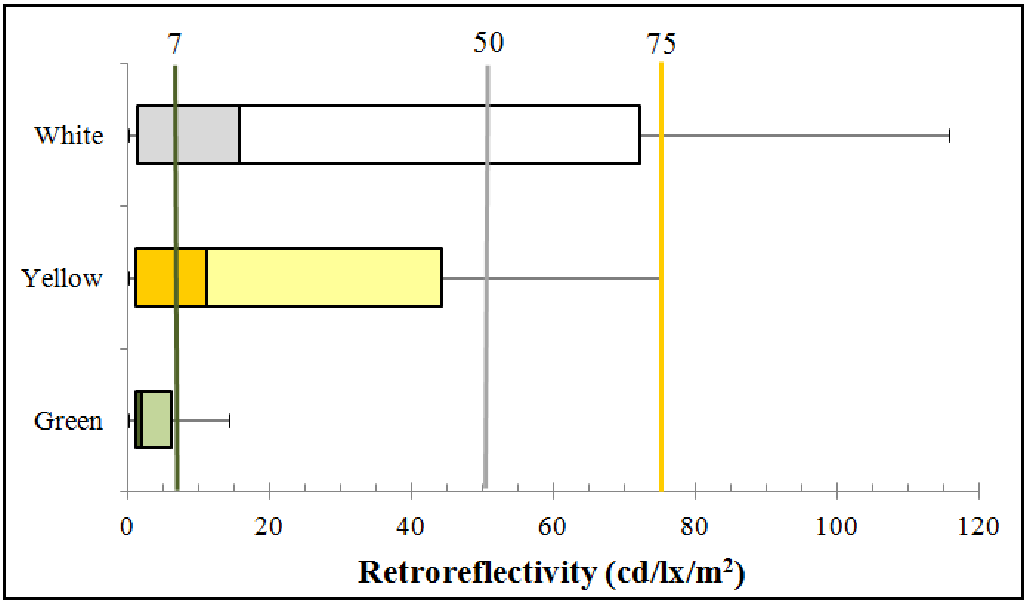


Figure 0.1 ASTM Type I Retroreflective Performance

The mean retroreflectivity level for green Type I sheeting was 4 cd/lx/m^2 which is 3 cd/lx/m^2 less that the required retroreflectivity level. Only 15 green Type I traffic signs were surveyed and 11 did not meet the minimum retroreflectivity levels. An example of a failed green Type I traffic sign is shown in Figure 0.2. According to the MUTCD white Type I sheeting shall not be utilized on the legend of a traffic signs, therefore no new Type I guide signs should be introduced into the sign population. The maximum recorded retroreflective measurement was 14 cd/lx/m^2.

Figure 0.2 Failed Type I Green Sign

By the conclusion of the collection effort 35 yellow Type I signs were measured. The mean retroreflectivity was 23 cd/lx/m^2 with a maximum measurement of 75 cd/lx/m^2. More than 80 percent of the Type I yellow signs failed the minimum retroreflectivity levels. The root cause of the majority of these failures is the minimum production requirements for yellow Type I sheeting. According to ASTM D 4956-11a the minimum required level of retroreflectivity for a yellow Type I is 50 cd/lx/m^2 which is identical to the minimum level specified in the MUTCD (9). This leaves little to no room for deterioration of the sheeting before it drops below the minimum levels. For this reason Type I yellow traffic signs shall not be used for any traffic sign application. Figure 0.3shows an example of a fail Type I yellow traffic sign.

Figure 0.3 Failed Type I Yellow Sign

There was a total of 86 white Type I traffic signs measured at the conclusion of the sample survey. The retroreflectivity values ranged from 0 cd/lx/m^2 to 116 cd/lx/m^2 with a average retroreflectivity being 36 cd/lx/m^2. The minimum retroreflectivity level for all white traffic signs is 50 cd/lx/m^2, which is well above the observed average. Over 60 percent of white Type I signs did not meet the minimum levels. Over 81 percent of white Type I was observed on non-regulatory traffic signs (M1-4, M1-5) which are U.S. and state route markers and are given lower priority then regulatory white signs.

The majority of failing Type I signs exhibited type of damage that was commonly found in this sheeting type. The damage type was categorized as cracking and an example is shown in Figure 0.4.

Figure 0.4 Cracking Damage on Type I Sheeting

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. Over 60 percent of the Type I signs sampled exhibited this cracking damage. Of the signs with cracking damage present 86 percent were found to be below the minimum requirements for the relevant sheeting color.

ASTM Type III Retroreflective Sheeting

Type III beaded sheeting was the most commonly used sheeting by UDOT representing more than half, 955 signs, of the sheeting utilized on UDOT traffic signs. For the most part the Type III traffic signs population was exceeding the minimum levels and only had a three percent rate of failure. Figure 0.5 shows the box and whisker plots for the Type III sheeting sampled during collection effort.

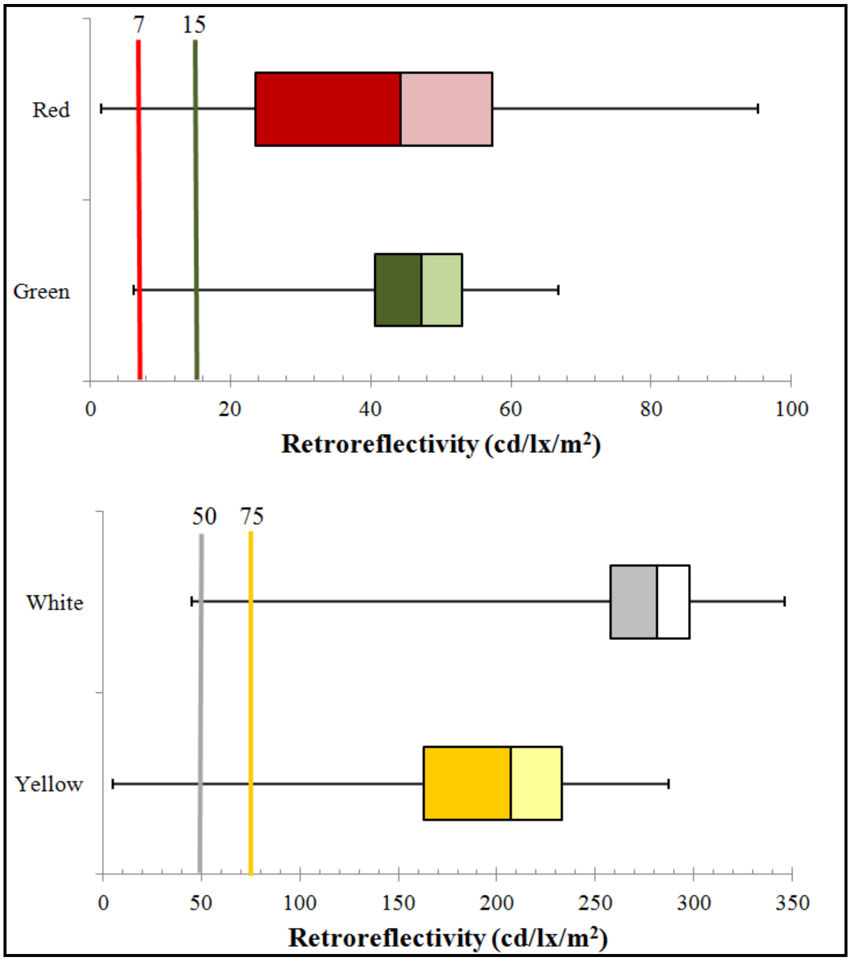


Figure 0.5 ASTM Type III Retroreflective Performance

Retroreflective measurements for Type III red sheeting ranged from 2 cd/lx/m^2 to 95 cd/lx/m^2. The overall average was 41 cd/lx/m^2 with a standard deviation of 21. At the completion of the sample survey there was a total of 150 Type III red traffic signs with only seven failures. As stated in the MUTCD red traffic signs must maintain a minimum background retroreflectivity greater than or equal to 7 cd/lx/m^2 and a legend retroreflectivity of 35 cd/lx/m^2. In addition to these minimum levels a contrast ratio between the legend and the background must be greater than or equal to three. Of these seven failures only one was the result of not meeting the required contrast ratio. The average observed contrast ratio was 12. Figure 0.6 shows different examples of Type III failures.

Figure 0.6 Failed Type III Red Signs

The R5-1 sign on the left failed to meet the minimum background levels and the R5-1 on the right did not maintain the required contrast ratio. No measured red Type III failed to meet the minimum legend level; with the overall average for the population being 275 cd/lx/m^2.

Overall the Type III green population measured during the sample survey was performing above the minimum levels. Only two percent of the 243 measured signs failing to meet the minimum levels. The minimum retroreflectivity level that must be maintained by Type III green sheeting is 15 cd/lx/m^2. Similar to red background, green traffic signs must maintain a specific legend brightness which is 120 cd/lx/m^2. Only one of the four Type III green failures was due the legend measurements being below the minimum level. Figure 0.7shows an example of a legend failure. The average background measurement for Type III green sheeting was 47 cd/lx/m^2 with values ranging from 6 to a maximum of 67 cd/lx/m^2 with a standard deviation of 10. Overall the legend measurements were performing above the minimum levels with an average measurement of 282 cd/lx/m^2.

Figure 0.7 Failed Type III Green Sign

At the conclusion of the collection effort a total of 241 yellow Type III traffic signs were measured. The minimum retroreflectivity levels specified in the MUTCD for warning signs are segregated into two categories. The distinction between the two categories is whether the warning sign is a bold or fine symbol sign. Table 0.1 displays all bold signs as defined by the MUTCD.

Table 0.1 Bold Warning Traffic Signs

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

All warning signs not listed in the above table are considered as fine symbol signs. The minimum retroreflectivity level for bold signs and fine signs that measure at least 48 inches is 50 cd/lx/m^2. For fine symbol warning signs that measure less than 48 inches the minimum retroreflectivity level is 75 cd/lx/m^2. The average measured minimum retroreflectivity was 188 cd/lx/m^2 with values ranging from 6 to 287 cd/lx/m^2. Overall the retroreflectivity measurements had a standard deviation of 61. Examples of Type III yellow traffic signs the preformed below the minimum retroreflectivity levels are shown in Figure 0.8.

Figure 0.8 Failed Type III Yellow Sign

The W1-2L on the left failed due to excessive damage from bottle and bullet impacts that made the sheeting flake off and had a measured retroreflectivity of 26 cd/lx/m^2. The W1-2L on the right failed due to paintball or egg residue reducing the amount of reflected light and had a measured retroreflectivity of 45 cd/lx/m^2. At the conclusion of the sample survey five percent of the traffic signs did not meet the minimum retroreflectivity levels.

White Type III was the largest color and sheeting type combination observed during the sample survey with 322 traffic signs. Overall Type III sheeting is performing exceptionally well and had no underperforming signs observed during the collection effort. Although there is no distinction between regulatory and non-regulatory white traffic signs with respect to the minimum retroreflectivity levels, regulatory signs have a higher priority within UDOT maintenance procedures. Due to the frequency of collection at roadway junctions 67% of the Type III white population consists of non-regulatory traffic signs. The average measured retroreflectivity was 275 cd/lx/m^2 with values ranging from 91 to 346 cd/lx/m^2 with a standard deviation of 35. Figure 0.9, displays the Type III white with the lowest measured retroreflectivity, the reason for the low retroreflectivity is a sizable paintball impact in the lower left corner.

Figure 0.9 Lowest Performing Type III White Sign

<u>ASTM Type IV Retroreflective Sheeting</u>

According to ASTM D4956 – 11a, 3M Type III High Intensity Prismatic (HIP) is properly defined as a Type IV sheeting due to its use of micro-prism to achieve its retroreflectivity (9). For the remainder of this report ASTM Type IV sheeting will be referred to as Type III HIP to be consistent with terminology used by UDOT.

A total of 209 Type III HIP traffic signs were observed by the completion of the sample survey. The vast majority of Type III HIP sheeting out preformed the minimum retroreflectivity levels even with the presence of damage. Less than half a percent of the population failed to meet the minimum retroreflectivity levels. On average Type III HIP signs exceed the minimum levels by an order of magnitude of greater than 10. Unlike the previous beaded sheeting types, Type III HIP is rotationally sensitive. At rotations of 45 degrees from the proper "up" position Type III HIP retroreflectivity reduces by up to 36 percent. For this reason it is critical to position sheeting in the proper orientation if retroreflectivity is ever going to be consistently measured via a retroreflectometer. Figure 0.10, displays the box and whisker plot of Type III HIP retroreflective performance.

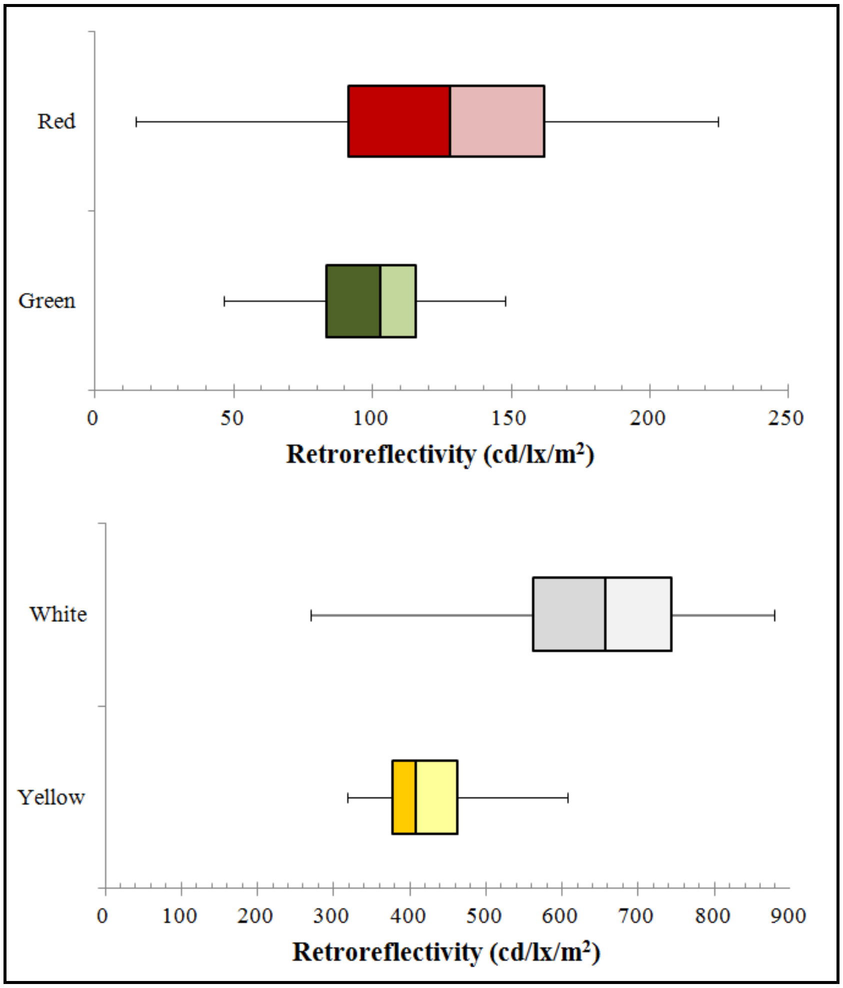


Figure 0.10 Type III HIP Retroreflective Performance

At the completion of the sample survey a total of 31 red Type III HIP traffic signs were measured. The majority of Type III HIP had retroreflectivity measures far greater than the minimum levels. The only Type III HIP failure is a red stop sign that did not meet the required contrast ratio, shown in Figure 0.11. Even with a legend retroreflectivity measurement of 647 cd/lx/m^2, it only produced a contrast ratio of 2.88 due to the relative high retroreflectivity of the background sheeting.

Figure 0.11 Failed Type III HIP Red Sign

The average contrast ratio for red Type III HIP sheeting was 7.72 compared to Type III which was 11.86. On average the Type III HIP background retroreflectivity was 3 times higher than Type III, compared to a 2.3 times increase in the retroreflective legend. Therefore, even with higher performing sheeting failures can still occur. The average measured retroreflectivity for red Type III HIP was 122 cd/lx/m^2 with values ranging from 15 to 225 cd/lx/m^2 with a standard deviation of 53.

A total of 48 Type III HIP green traffic signs were observed during the course of the sample survey. None of which failed the current minimum retroreflectivity levels. The average measured retroreflectivity was 100 cd/lx/m^2 with values ranging from 47 to 148 cd/lx/m^2 and a standard deviation of 21. Although it is no longer included in the current MUTCD standards in the initial minimum retroreflectivity levels a contrast ratio of 4:1 was required for guide signs. If this standard was still in place 60 percent of the Type III HIP green signs would not meet this criterion. Due to green sheeting being a relatively dark background color it is important that a noticeable contrast is present between the legend and the background. UDOT should take this into consideration to ensure proper message conveyance and reaction time for motorists. Examples of low contrast ratio present on Type III HIP green sheeting are shown in Figure 0.12.

Figure 0.12 Low Contrast Ratio Type III HIP Green Signs

The root cause of the low contrast ratio is the Type III white legend which is placed on a Type III HIP green background. During the sample survey the sheeting type of the legend was not recorded, because it was assumed to be the same as the background. By viewing the photographs of Type III HIP green signs taken during the sample survey over half of the population had Type III legend. It should be noted that all of the Type III legends were found on mileposts (D10-1, D10-2 and D10-3) similar to those shown in Figure 0.12. Excluding milepost from the contrast ratio calculation brings the average ratio to 6.27 which would provide adequate contrast for message conveyance.

A total of 53 Type III HIP yellow traffic signs were measured by the completion of the sample survey. There were no recorded failures of Type III HIP yellow traffic signs. The average measured retroreflectivity was 421 cd/lx/m^2 with values ranging from 318 to 608 cd/lx/m^2 with a standard deviation of 67. Even with the exceptional retroreflectivity measurements an issue was still present with yellow Type III HIP traffic signs. Due to the diamond shape that most warning signs have, the sheeting was typically rotated 45 degrees from its proper orientation. As discussed previously, Section 0 in this report prismatic sheeting has varying degrees of sensitivity due to rotation based on the sheeting type. Type III HIP had the highest sensitivity of measured prismatic sheeting with an average measured retroreflectivity reduction of 36 percent at a rotation of 45 degrees from the proper orientation. Even though the affects of this rotation is only visually significant at distances of 100 ft or less, it still affects the measured retroreflectivity value. An example of this 45 degree rotation is show in Figure 0.13. The striped water mark that transverses the sign diagonally indicates that it is not oriented in the proper “up” position.

Figure 0.13 Rotated Type III HIP Yellow Sign

Warning signs are typically produced at non-optimal rotation to reduce the amount of sheeting waste. Due to this practice it becomes increasingly difficult to measure the deterioration of Type III HIP deterioration because measured retroreflectivity values will not reflect the true performance of the sheeting. This rotation issue was predominately found in warning signs, but has been observed in other sheeting colors.

During the collection effort 77 white Type III HIP traffic signs were observed. White sheeting was performing far above the minimum levels with an average measured retroreflectivity of 642 cd/lx/m^2, it had a standard deviation of 139 with values ranging from 270 to 878 cd/lx/m^2. The reason for the large spread in retroreflectivity measurements is improper sheeting orientation. A small set of the population was observed at rotations of 90 degrees from the proper orientation. An example of the 90 degree rotation is shown in Figure 0.14.

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Figure 0.14 White Type III HIP with Different Sheeting Orientations

The M1-5 on the top has its sheeting placed at the proper vertical orientation, whereas the M6-1R is rotated 90 degrees from the optimum orientation. The measured retroreflectivity for the state route sign was 811 cd/lx/m^2 compared to the 699 cd/lx/m^2 on the directional arrow. Improper sheeting rotation was typically seen on the smaller traffic signs maintained by UDOT. At the completion of the sample sign survey 30 percent of the Type III HIP white population was classified as regulatory white signs.

ASTM Type IX Retroreflective Sheeting

At the completion of the sample survey 180 Type IX traffic signs were measured. On average retroreflectivity levels were eight and a half times greater than the minimum levels. Since Type IX is a prismatic sheeting it is rotationally sensitive. On average there is an 11 and 30 percent reduction in measured retroreflectivity at rotations of 45 and 90 degrees from optimal. The performance box and whisker plot for Type IX sheeting is shown in Figure 0.15. There was one issue identified with Type IX sheeting which resulted in two guide sign failures.

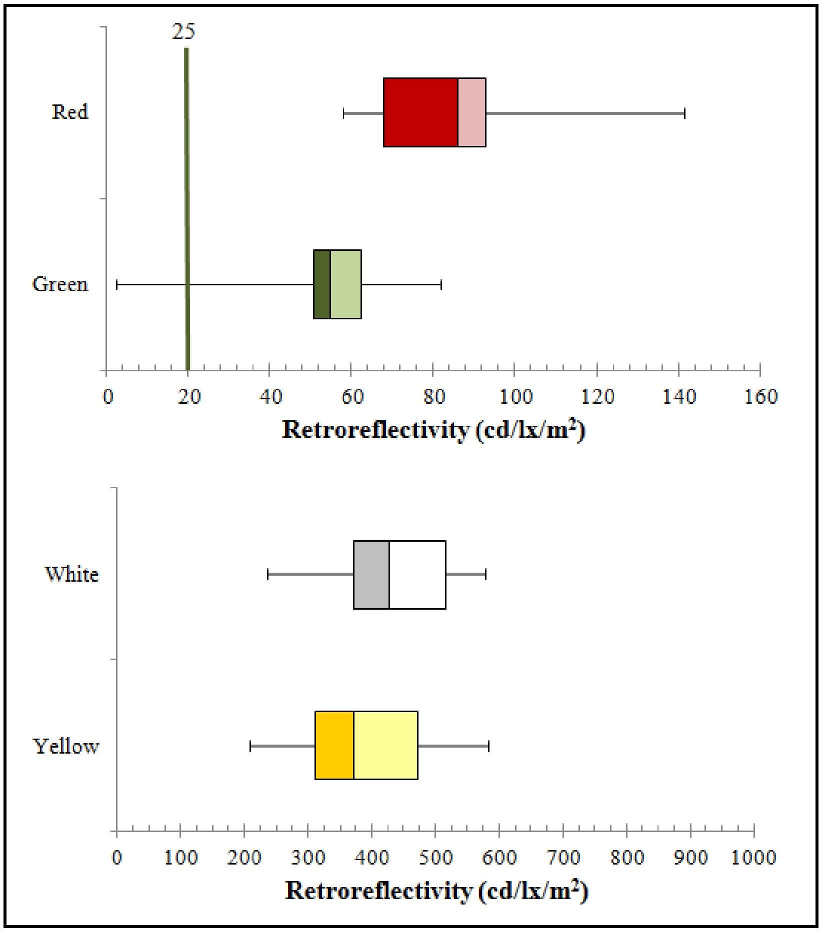

Figure 0.15 ASTM Type IX Retroreflective Performance

There were a total of 23 red Type IX sheeting observed by the end of the sample survey. Type IX red signs are performing very well and there were no observed sheeting failures. Similar to the Type III HIP red sheeting Type IX background brightness increased more than the legend brightness. Compared to Type III red sheeting Type IX red background produces retroreflectivity measurements that are 2.2 time greater compared to a legend retroreflectivity increase of 1.7 times. The average measured retroreflectivity was 86 cd/lx/m^2 with values ranging from 58 to 142 cd/lx/m^2 and a standard deviation of 23.

At the completion of the sample survey a total of 42 Type IX green signs were observed. As expected the majority of these signs had retroreflectivity measurements above the minimum levels. The average measured retroreflectivity was 55 cd/lx/m^2 with values ranging from 3 to 82 cd/lx/m^2 and a standard deviation of 15. The two failing Type IX green traffic signs were the result of a construction issue in which the overlay on the sign failed. An example of this failure is shown in Figure 0.16. Both failures were limited to SR 0167, which is commonly referred to as Trappers Loop.

Figure 0.16 Type IX Sheeting Overlay Failure

A total of 70 Type IX yellow sheeting sign were measured by the completion of the sample survey. The average measured retroreflectivity was 390 cd/lx/m^2 with values ranging from 208 to 584 cd/lx/m^2 and a standard deviation of 101. Even though Type IX has less rotational sensitivity when compared to Type III HIP, Type IX yellow sheet had a greater coefficient of variation. This might be caused by the age of the Type IX yellow sheet measured during the sample survey. In total 36 of the 70 Type IX had installation dates ranging from 2005 to 2011. The lower measure retroreflectivity were found and signs that were damaged or aged. Figure 0.17, shows an example of a damaged Type IX yellow sign that was installed in 2007.

Figure 0.17 Damage Type IX Yellow Sign

There were a total of 45 Type IX white traffic signs that were measured during the sample survey. As expected these signs were performing far above the minimum levels. The average measured retroreflectivity was 436 cd/lx/m^2 with values ranging from 236 to 579 cd/lx/m^2 and a standard variance of 97. The large coefficient of variation was caused by measurements that were taken during inclement weather on R6-1L signs as shown in Figure 0.18. The presence of water or ice can greatly reduce the signs retroreflectivity efficiency and should be considered during visual assessment or physical measurement of the sign.

Figure 0.18 Poor Performing Type IX White Sign

ASTM Type XI Retroreflective Sheeting

At the conclusion of the sample sign survey a total of 190 Type XI where observed. Even though Type XI sheeting was the least used sheeting type, it was found in areas of new construction along the interstate. With respect to the minimum retroreflectivity standards Type XI sheeting is on average 12 times brighter than the minimum level, which makes it the best performing sheeting type observed during the sample survey. This result is expected due the sheeting installations being relatively new and the minimum ASTM requirements for Type XI criteria being so high. Since Type XI is a prismatic sheeting it is rotational. The exact reduction was not determined during this study since newly constructed Type XI sheeting traffic sign was not obtained from UDOT. The performance box and whisker plot for Type XI sheeting is shown in Figure 0.19. Overall the Type XI population was performing above the minimum levels and only one failure observed.

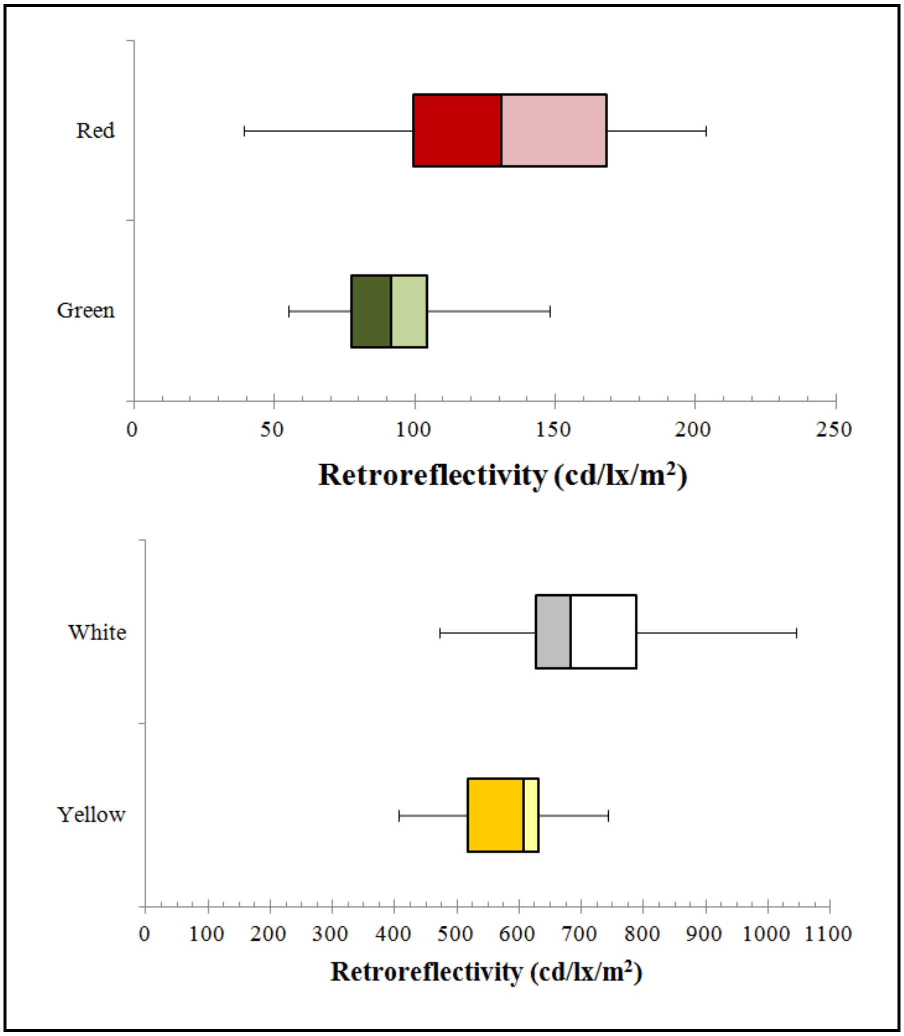

Figure 0.19 ASTM Type XI Retroreflective Performance

A total of 20 Type XI red traffic signs were measured by the completion of the sample survey. Similar to the other prismatic traffic sign sheeting types the only present issue is the maintenance of the three to one contrast ratio that is required for red sheeting. The only measured failure for Type XI traffic signs was caused by this requirement. On average the background and legend retroreflectivity measurements were 3.17 and 2.25 times brighter than beaded Type III traffic signs. Due to the background retroreflectivity brightness increasing more than the legend this makes it more difficult to maintain the required contrast ratio. The failed sign is shown in Figure 0.20 and it does not seem that the red overlay has experienced excessive fading due to exposure.

Figure 0.20 Failed Type XI Red Sign

The average contrast ratio for all Type XI red signs was 5.72, which is well above the minimum. The average measured retroreflectivity was 130 cd/lx/m^2 with values ranging from 39 to 204 cd/lx/m^2 and a standard deviation of 47.

At the completion of the sample survey a total of 57 Type XI green traffic signs were measured. The average measured retroreflectivity was 99 cd/lx/m^2 with values ranging from 55 to 148 cd/lx/m^2 and a standard deviation of 21. The majority of these signs were located on the interstate and were less than 2 years old. There were no major retroreflectivity or contrast ratio issues presented by this sheeting color.

There were 48 Type XI yellow traffic signs measured during the sample survey. The average measured retroreflectivity was 584 cd/lx/m^2 with values ranging from 406 to 743 cd/lx/m^2 and a standard deviation of 83. Overall there are no major issues with this segment of the sign population.

A total of 65 white Type XI traffic signs were measured during the sample survey. The average measured retroreflectivity was 709 cd/lx/m^2 with values varying from 472 to 1,045 cd/lx/m^2 with a standard deviation of 127. The majority of the Type XI white signs were regulatory speed limit signs. The lower retroreflectivity measurements were the results of improver orientation and inclement weather conditions during the sample survey.

Retroreflective Sheeting Colors with No Minimum Maintenance Levels

Although research reports have looked into minimum retroreflectivity levels for white on blue and white on brown traffic signs (44) there is no minimum level for these signs in the MUTCD. According to Paul Carlson even though white on blue and white on brown do not have minimum required retroreflectivity levels they need to be retroreflective when they are installed. In addition florescent yellow and florescent orange do not have unique minimum levels, but are covered by the existing yellow and orange rows in the minimum maintained retroreflectivity level table in the MUTCD (45).

Installation Dates

In order to determine performance of traffic signs under UDOT's jurisdiction the date of installation must be known. By the completion of the sample survey only 17 percent of traffic signs had a known installation date. The vast majority of these installation dates were milepost which UDOT had a record of installation dates. Looking at traffic signs that had installation stickers the total number of known installation dates reduces to 150 signs or just under nine percent. Installation dates are vital for determining the factors that contribute to sheeting deterioration. 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. The earliest recorded installation date by the completion of the sample survey was 2003.

Putting the lack of installation stickers aside there are still various issues with installation stickers found on traffic signs. During the sample survey several instances of newly installed prismatic sheeting were observed with either no installation sticker or stickers that did not provide adequate information. Figure 0.21 displays a sticker found across the state which only displays the name of the company that produced/installed the traffic sign.

Figure 0.21 Inadequate Installation Sticker

There was also a wide variety of installation stickers observed throughout the state by the end of the sample survey. Some stickers simply displayed that date of installation, while other included information about the sheeting type. Figure 0.22 displays different types of installation stickers observed during the sample survey. These stickers were placed on the back of the traffic sign and were commonly accompanied by a sticker with a transparent background and black legend which displayed the year of installation on the front of the traffic sign.

Figure 0.22 Observed Installation Stickers

For the installation stickers that were found on in-service traffic signs two additional issues were identified: hole puncher errors and the service life of the installation date sticker. A portion of the installation date stickers required that the installer punch out the proper installation month and year. Due to the size of the hole puncher relative to the size of the font on the sticker this created the scenario for multiple months or years to be punched at the same time, as shown in Figure 0.23. This error could be eliminated by provide adequate spacing between months or by producing unique stickers for each month and year combination. It was also observed during the sample survey that installation stickers on taller interstate post-mounted traffic signs were hard to read/detect due to the relative size of the sticker. The second major issue with installation stickers is the service life of the sticker itself.

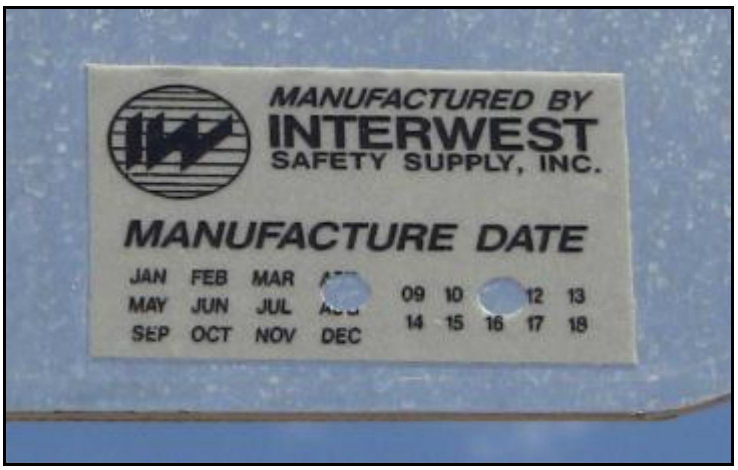

Figure 0.23 Hole Puncher Error on Installation Sticker

On several traffic signs the installation date was present on the front of the sign but hand peeled off on the pack of the sign or vice versa. If installation stickers are not able to last past the manufacturer's warranty for the specific traffic sign sheeting, then they fail their purpose. Examples of peeling installation stickers are shown in Figure 0.24. Peeling stickers were not very prevalent, but neither were traffic signs with installation stickers. Depending on the management method that UDOT adopts, installation stickers will have different purposes. Regardless of the selected maintenance method adopted by UDOT installation stickers will always be essential in ensuring that the traffic sign exceeded the manufactures' warranty.

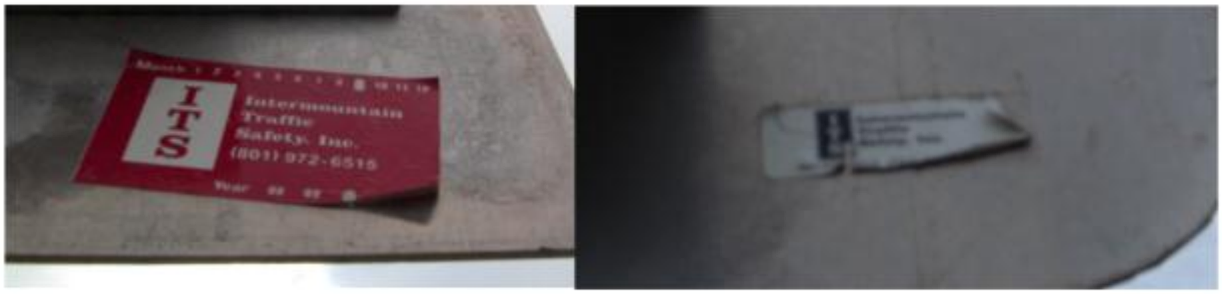

Figure0.24 Peeling Installation Stickers

Traffic signs under UDOT’s jurisdiction have a variety of installation stickers placed upon them depending on the contractor. Stickers displayed different information and some were susceptible to hole puncher error on both the month and year of installation. It is recommended by the research team that UDOT oversee that development of more uniform stickers that do not require the month and year to be punched into the sticker. The best examples observed in the field were Utah Correctional Industries and Rainbow Sign and Banner. Both of these sticker provided the sheeting type and installation date. Since retroreflective sheeting can begin to deteriorate even when stored in ideal conditions UDOT should look into stamping the date of manufacture into the aluminum backing of the sign, as shown in Figure 0.25. This would ensure that every sign had an installation date, while avoiding the peeling issue observed on some stickers.

Figure 0.25 Stamped Installation Date

Sheeting Performance Summary

At the completion of the collection effort a total of 1,716 traffic signs were measured. From this sample several retroreflectivity issues were discovered. The first issue was the performance Type I sheeting. These legacy signs are among the oldest in UDOT's signage population. After a retroreflectivity study conducted by UDOT from 1999-2001 Type I sheeting began to be phased out due to its poor performance. Although the majority of traffic signs under UDOT's jurisdiction are not Type I a significant population still exist. Under the assumption that the sample survey was a true representative sample of the statewide sign population and the number of traffic signs maintained by UDOT is 95,000 the expected Type I sheeting population would be greater than 7,500 signs. The Type I signs measured during the sample survey had a 68% failure rate, assuming this is true for the entire Type I population would result in 5,148 failed traffic signs. Type I signs make up the majority of failed signs, in total the estimated underperforming traffic sign population is 6,643 signs.

Two additional issues were identified in the prismatic portion of UDOT's sign population. Although there were only four observed retroreflectivity failures for prismatic sheeting there was wide variation in measured retroreflectivity. This was caused by the rotational sensitivity of prismatic sheeting. During the construction of some traffic signs sheeting was not placed in its optimal orientation. This produced retroreflectivity measurements that were up to 36 percent reduced from the true retroreflectivity potential. In addition to the rotational sensitivity of the prismatic sheeting was the reduction in contrast ratios for red signs.

Compared to ASTM Type III sheeting the increase in retroreflectivity was greater for the background than the legend on all prismatic sheeting. This caused two failures on relatively new stop signs since they did not meet the required 3:1 legend to background ratio. Figure 0.26 shows the relationship between the retroreflectivity performance of the background and the measured contrast ratio for the various sheeting types utilized by UDOT. Although the MUTCD does not require a minimum contrast ratio for green sheeting, due to the relative darkness of the background sheeting the contrast ratio should not be ignored. As shown in the figure below as higher prismatic types are used on red signs there is a significant reduction in the average contrast ratio. This could lead to a higher rate of failure for newer prismatic sheeting signs far before they reach the minimum levels for the background and legend. Compared to red signs, green signs had a more constant average contrast ratio across sheeting types. Higher contrast ratios can be achieved by implementing different sign manufacturing methods, included utilizing different sheeting types for the background and legend of a traffic sign.

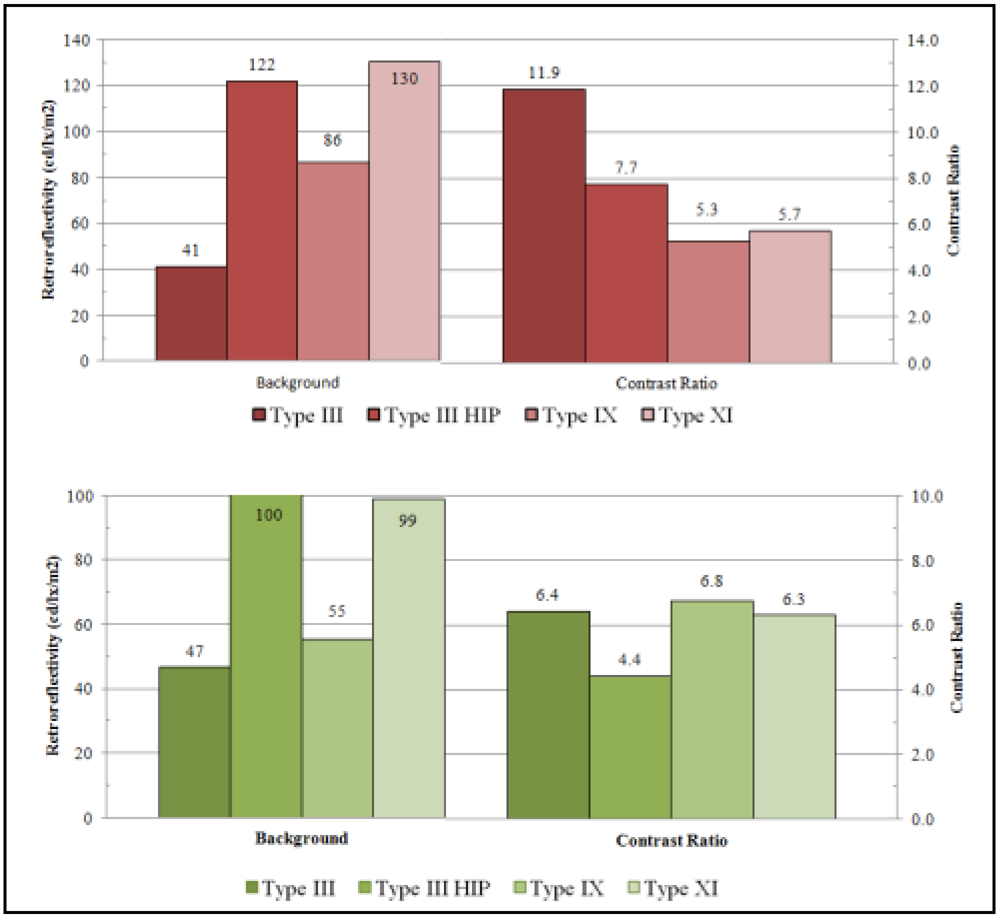

Figure 0.26 Background and Contrast Ratio Performance

At the conclusion of the sample survey 120 traffic signs were performing below the minimum retroreflectivity levels. This represented seven percent rate of failure for the 1,716 traffic signs. Assuming that UDOT maintains 95,000 traffic signs, the current underperforming sign population is 6,643. The 1,716 traffic signs are just 1.8% of the estimated 95,000 signs under UDOT's jurisdiction. Under the assumption of a fully unbiased sample, the size of the 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 traffic sign population. Therefore, it is estimated that UDOT is currently 93 percent compliant with the minimum retroreflectivity levels. Complete analysis of traffic sign performance by sheeting type and color can be found in Appendix B: Sheeting Performance.

Traffic Signs Damage

During the collection effort, it was observed that traffic signs exhibited a wide variety and severity of damaged to the face of the sign. Seven percent of the sample sign population did not meet the minimum retroreflectivity levels, while 28 percent had damaged present on the sign face that diminished the legibility of its message. This damage was divided into two different severity categories. Major damaged severity was damage that caused substantial decline in overall legibility, whereas minor damage severity had negligible affects on sign legibility. Since minor damage had negligible effect on the shape, color, legend or illumination of traffic signs, only signs with major damage are shown in this report. Major and minor damage severity for different damage types is described in Appendix A: Major and Minor Damage Examples. Table 0.2 displays the number of sign failures by damage category.

Table 0.2 Retroreflective Performance of Damaged Signs

Retroreflective Performance	Damage Category						
	Bending	Cracking	Other	Peeling	Vandalism	None	Total
Above	48	72	74	37	150	1,215	1,596
Below	0	76	17	3	10	14	120
Total	48	148	91	40	160	1,229	1,716

Above and below refers to the minimum retroreflectivity level recorded via a portable retroreflectometer. The damage categories have different relationships with the retroreflective performance of the traffic signs. Cracking damage is indicative of lower performance but this does not hold true for the other types of damage. Peeling and vandalism damage typically exceed the minimum retroreflectivity levels with failure rates of eight and six percent, respectively. As defined by the MUTCD, the basic requirements of a sign are, “that it be legible to those for whom it is intended and that it be understandable in time to permit a proper response (2).” Therefore, the effects that damage has on the legibility of a traffic sign should be managed at the same importance as maintaining its retroreflectivity. Simply ensuring that a traffic sign will have adequate brightness during nighttime conditions does not guarantee message conveyance.

Contributing Factors of Traffic Sign Damage

In order to determine the contributing factors of traffic sign damage, weather observation and location data was collected form sites across the state of Utah. Weather observation data was collected from several sources in order to ensure completeness and accuracy. The four types of weather observation data that were used during this report are average annual precipitation, seasonal temperature swing, average wind speeds, and average wind gust speeds.

The average annual precipitation data was obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping system (46). PRISM data sets are recognized world-wide as the highest quality spatial climate data sets currently available. For the analysis in this report, the thirty year average (1981-2010) data set was used.

The seasonal temperature swing data was collected via MesoWest databases using two types of weather stations (47). The weather stations were a combination of National Weather Service (NWS) and Bureau of Land Management remote automated weather stations (RAWS). Hourly temperature data was downloaded for the last 10-years in order to represent temperatures seen by a sign during its service life. In order to represent the temperature range seen by a sign, seasonal highs and lows were averaged. For the summer months, the temperatures during the hottest 12 hour period for each day were averaged. For the winter months, the coldest 12 hour period was averaged. The difference between the summer and winter 12 hour averages was defined as seasonal temperature swing. Figure 0.27 shows the location of the NWS and RAWS weather stations along with the location of traffic signs recorded during the collection effort.

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

Location data was organized into two categories: elevation and exposure. Both the elevation and exposure information were recorded during the collection effort. The elevation of each traffic sign was recorded by the portable data logger. The exposure of a sign was based on the environment that that surrounded the sign and was categorized into four different groups: canyon, mountain, rural, and urban. Routes that transitioned from rural to mountainous areas were classified as having canyon exposure. The only distinction between mountain and rural areas is that mountain areas had elevations greater than 6,000 ft. Urban exposure was latter defined by the US Bureau of Census (BOC) urbanized area boundaries data set (48). The BOC defines urban areas as having populations greater than 50,000. Traffic signs that were located within these urban boundaries were classified as having urban exposure.

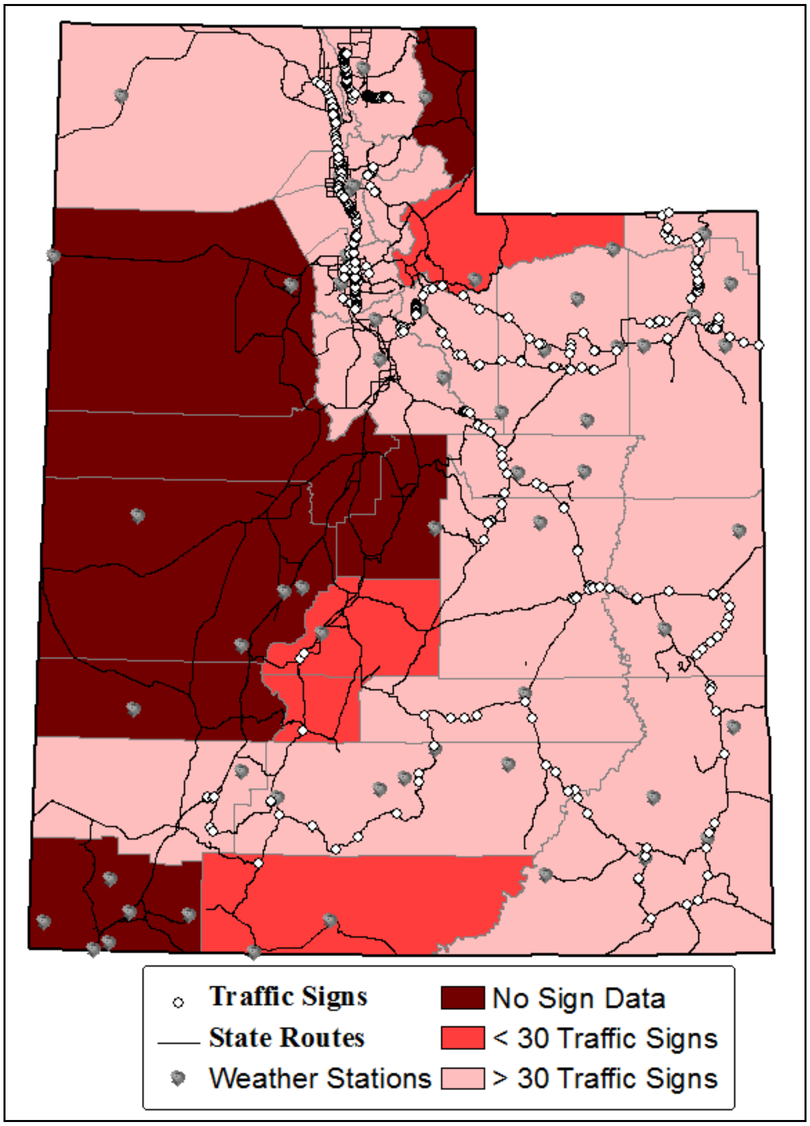

Figure 0.27 Locations of Traffic Signs and NWS/RAW Weather Stations

Damage Analysis

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

Average Annual Precipitation

Measurements for average annual precipitation for each individual sign was extracted from the average annual precipitation PRISM raster data using ArcGIS. The results of this extraction are summarized in Table 0.3. As shown in Table 0.3 and Figure 0.28, the majority of Utah's climate is classified as desert to semi-arid coupled with alpine mountains. From this data, it is apparent that the average annual precipitation plays a role in damage rate of traffic signs. Both damage and failure rates increased with an increase in average annual precipitation. The occurrence of peeling damage was three times as likely for traffic signs that experienced more than 16 inches of precipitation.

Elevation

The elevation of individual traffic signs was recorded during the data collection effort via a portable data logger. The effects of elevation on traffic sign damage rates are summarized in Table 0.4. The GTOPO30 digital elevation model from the United States Geological Survey's EROS Data Center assisted in the creation of Figure 0.29 (49). Similar to the damage rates observed with average annual precipitation, there is an observed increase in damage rates with elevation.

With the increase in elevation comes an increase in UV radiation and snow frequency. The increase in UV radiation can lead to rapid fading of darker background sheeting colors, which caused a decrease in overall contrast of the sign. This is a particular concern for red signs since they must maintain a minimum retroreflectivity level and legend to background contrast ratio. As shown in both Figure 0.28 and Figure 0.29, in Utah an increase in elevation typically equates to an increase in precipitation. Only 35 percent of the signs were located in areas that had greater than 16 inches of precipitation and at an elevation of at least 6,000 ft. Therefore, even though there is a correlation between precipitation and elevation, the majority of signs do not have both high precipitation and elevation. As snow plows clear roadways a significant amount of snow and roadway debris is thrown against the face of the traffic sign. This causes bending damage to signs in areas that do not frequently have high wind and gust speeds.

Table 0.3 Damage by Average Annual Precipitation

Precipitation (in)	# of Traffic Signs	Damage Type				Percent Damage	Percent Fail
		Bending	Cracking	Other	Peeling		
< 8	165	1	7	8	1	10.3%	6.7%
8-16	610	15	48	33	7	16.9%	5.9%
16-24	786	24	77	44	26	21.8%	7.5%
> 24	155	8	16	6	6	23.2%	9.0%

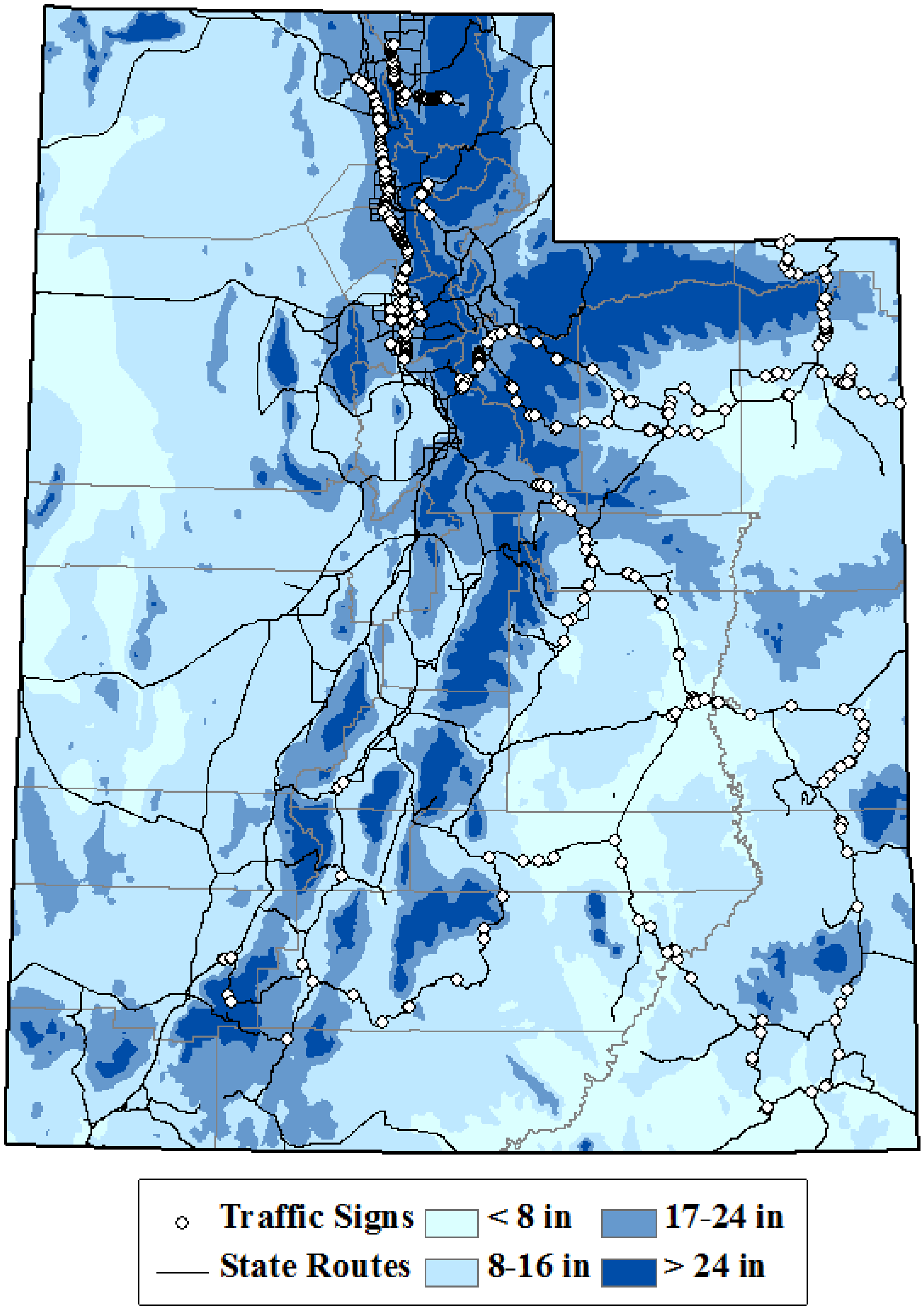

Figure 0.28 Average Annual Precipitation Map

Table 0.4 Damage Rates by Elevation

Elevation (ft)	# of Traffic Signs	Damage Type				Percent Damage	Percent Fail
		Bending	Cracking	Other	Peeling		
< 4,500	527	9	26	25	19	15.0%	3.8%
4,500-6,000	836	18	83	49	12	19.4%	8.3%
6,000-7,500	258	16	29	14	2	23.6%	8.9%
> 7,500	95	5	10	3	7	26.3%	8.4%

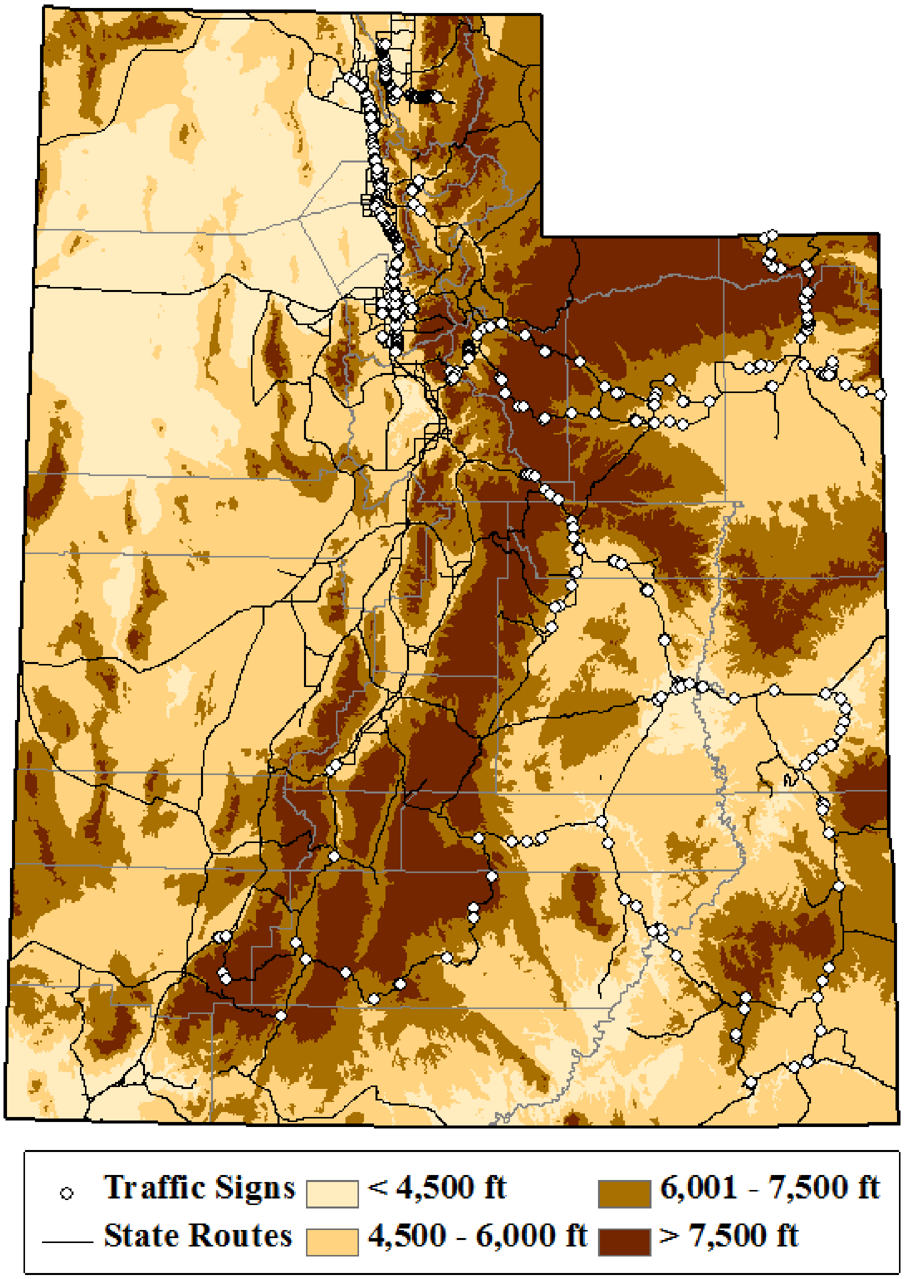

Figure 0.29 Elevation Map

<u>Seasonal Temperature Swing</u>

To account for expected highs and lows in annual temperature, temperature data was collected from weather stations across the state of Utah. For the summer months, the 12 highest hourly temperatures for each day were averaged, whereas for the winter months, the 12 lowest were averaged. By taking the difference of these measurements for the last 10-years, seasonal temperature swings focused on signs that experience a wide range in temperature. As summarized in Table 0.5, the majority of the sign population experience seasonal temperature swings from 50 to 64 degrees. Sign locations that had lower seasonal temperature swings experienced a lower rate of damage. In order to produce Figure 0.30, the seasonal temperature swing data for areas in between weather stations was interpolated using ArcGIS. Values for individual traffic signs were determined by extracting values from that raster file created by the interpolation process.

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

Table 0.5 Damage Rates by Seasonal Temperature Swing

STS (°F)	# of Traffic Signs	Damage Type				Percent Damage	Percent Fail
		Bending	Cracking	Other	Peeling		
< 50	152	1	8	4	4	11.2%	2.0%
50-57	880	29	69	48	15	18.3%	6.8%
57-64	630	17	64	35	19	21.4%	8.3%
> 64	54	1	7	4	2	25.9%	9.3%

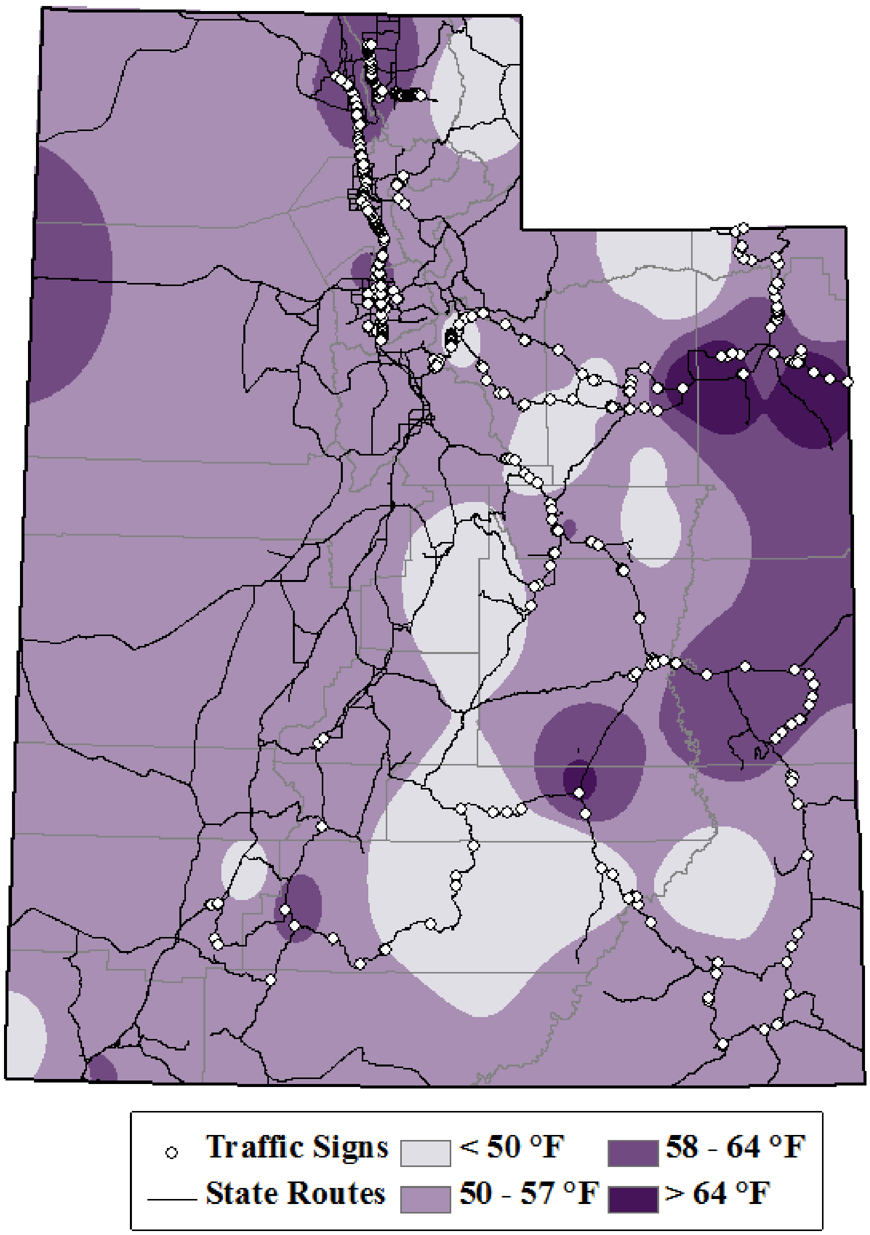

Figure 0.30 Seasonal Temperature Swing Map

Wind Speeds and Wind Gust Speeds

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

Exposure

The affect that vandalism damage has on the legibility of a traffic sign depends greatly on the type of vandalism. Paintball and egg damage limits the available amount of light that can be retroreflected, but during the day it has little effect on the overall legibility of the sign; compared to bullet holes, bumper stickers, and spray paint that can be seen during both day and nighttime conditions. In order to determine areas that exhibited high rates of vandalism damage, the traffic signs were organized into different exposure categories. Urban areas were determined by 2010 BOC urbanized area boundaries data. Using ArcGIS, traffic signs that intersected these areas were defined as having urban exposure. The remaining traffic signs were designated as having canyon, mountain, or rural exposures. Because vandalism damage is solely the result of humans it was excluded from the previous analysis section.

During a preliminary collection, it was quickly observed by the researches that the damage rate for rural signs was greater than urban signs. Therefore, exposure was added to the collection attributes for each traffic sign. By the completion of the collection effort, this trend held true for signs across the state of Utah. As shown in Table 0.6, canyon areas had the highest rate of damage, while the urban sign population had the lowest observed damage rate.

Organizing the signs by exposure illustrates how much higher the rate of damage is compared to the minimum retroreflectivity failure rate. For all exposures, the damage rate was at least three times greater than the rate of failure. Canyon exposure had the lowest percentage of cracking damage signs coupled with the highest rate of vandalized signs. A particular area of concern are dead end canyon routes which had the highest rate of damage observed during the collection effort. Unlike signs with canyon exposure, the majority of mountain exposed sign damage was cracking damaged. In addition to the cracking damage, mountain exposed signs had the highest rate of bending and other damage. Rural exposed signs had the most evenly distributed sign damage of any of the exposures. Unexpectedly, urban exposure had the lowest damage rate with the majority of its damaged signs being from cracking instead of vandalism damage.

Table 0.6 Damage Rates by Exposure

Exposure	# of Traffic Signs	Damage Type					Percent Damage	Percent Fail
		Bending	Cracking	Other	Peeling	Vandalism		
Canyon	197	8	14	11	6	35	37.6%	7.1%
Mountain	262	16	30	14	6	20	32.8%	9.5%
Rural	778	16	63	40	18	83	28.3%	6.4%
Urban	479	8	41	26	10	22	22.3%	6.5%

Summary of Damage Analysis

It should be recognized that the different damage categories are not completely independent of each other. In service, traffic signs often had a combination of damage types, and only the most prevalent damage type was recorded as the major damage for the sign. It was observed that vandalism or bending damage that cut, cracked, or punctured the layers of a sign would often lead to cracking damage over seasons of service. Although the initial damage was caused by bullet holes, cracking due to bending, etc. since the overlay had begun to delaminate across the face of the sign it was categorized as having aging damage.

At the completion of the data collection effort, it was determined that over 28 percent of the recorded traffic sign population had major damage to the retroreflective sheeting. The observed rate of damage far exceeded the seven percent of signs that did not meet the minimum levels. It was determined that precipitation, elevation, temperature, and exposure had significant effects of the observed rate of damage. The results of this analysis determined that there is a higher rate of damage associated with areas that receive more annual precipitation. It was also determined that for every 1,500 ft above 4,500 ft the rate of damage increased by 3.8 percent. A damage rate increase of 4.9 percent was determined for every 7 degrees increase in seasonal temperature swing. When the signs were segregated by exposure, it was determined the rural canyon routes had vandalism damage rates of 17.8 percent with an overall damage rate of 37.6 percent. Wind gust speed data was also analyzed, but due to the bracing practices implemented by UDOT the damaging effects of high wind gust speed were negligible.

The vast majority of state routes in Utah are located in rural areas. Figure 0.31, shows the percentage of lane mile by maintenance region under UDOT's jurisdiction.

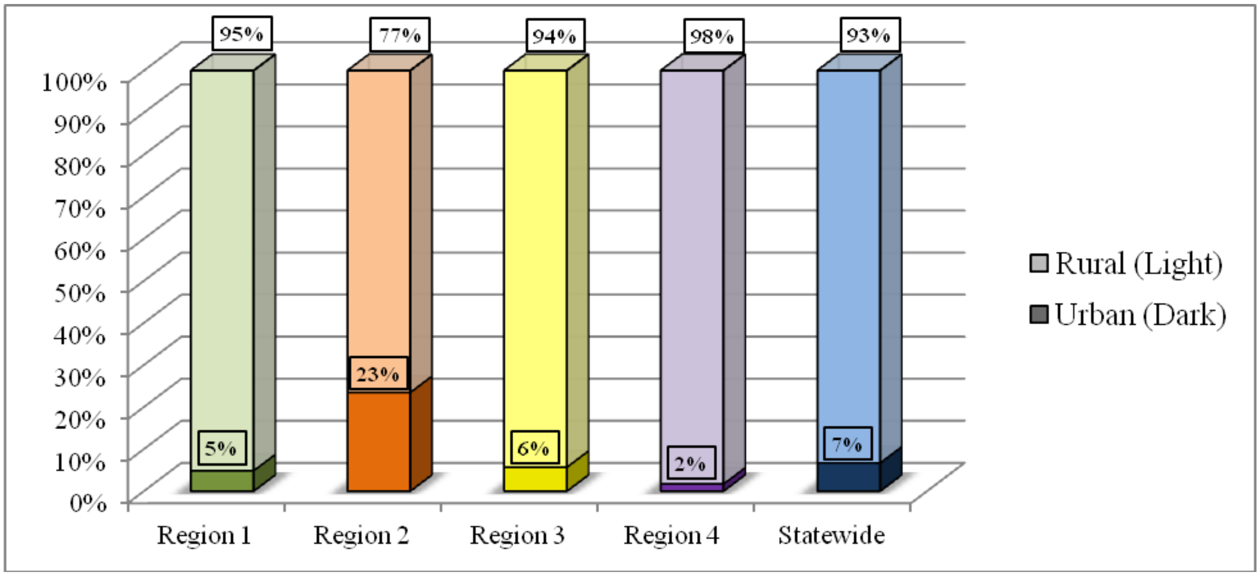

Figure 0.31 Urban and Rural Lane Miles by Region

Therefore, the rate of damage observed outside of urban areas needs to be considered during the selection of a management method. Table 0.7 organizes the sample sign population by maintenance region and reflects this observation.

Table 0.7 Damage Type by Region

Region	Damage Type					Percent Damaged
	Bending	Cracking	Other	Peeling	Vandalism	
One	9%	35%	17%	9%	30%	33%
Two	11%	13%	29%	18%	29%	15%
Three	8%	36%	13%	6%	37%	37%
Four	13%	23%	24%	5%	35%	24%
Totals	10%	30%	19%	8%	33%	28%

Another observation was that yellow signs have the highest damage rate. This is likely due to the density of these signs increasing in rural, mountain, and canyon exposures. Table 0.8 shows the distribution of damage by sheeting color.

Table 0.8 Damage Type by Sheeting Color

Sheeting Color	Damage Type					Percent Damaged
	Bending	Cracking	Other	Peeling	Vandalism	
Red	8%	17%	40%	0%	35%	29%
White	16%	40%	14%	6%	25%	24%
Yellow	8%	17%	19%	9%	46%	40%
Green	4%	53%	10%	12%	21%	23%

Note: Observed blue, brown, and fluorescent colors were not included in this table

In order for the intended message of a traffic sign to be conveyed to motorists the sign needs to be both legible and visible. UDOT currently estimates that it maintains 95,000 traffic signs, applying the observed statewide damage rate of 28 percent results in an estimated damage population of 26,600 traffic signs. This is far greater than the 6,643 signs that do not meet the minimum retroreflectivity levels.

A third of the damage sign population was vandalism. Currently UDOT does have a policy, UDOT 06A-40: Sign Vandalism, which establishes a reward of $200 for personal that provides information leading to the apprehension of anyone willfully destroying or damaging traffic signs. This policy has been in place since 1968 so vandalized signs are clearly not a new issue for UDOT. It may be possible to reduce the percentage of vandalized traffic signs by producing public service announcements or posting signage that makes the public aware of the criminal offences of vandalizing traffic signs and the associated reward for reporting individuals seen damaging UDOT signs.

Cleaning Vandalized Traffic Signs

For sticker and spray paint vandalism researchers observed several cleaning attempts that proved to more detrimental than the original damage. Figure 0.32 displays an example where an attempt was made to clean graffiti off of the sign face resulted in removing the red overlay of the stop sign. Although cleaning the graffiti off of the sign was an attempt to improve legibility of the signs intended message, the end result was a traffic sign that was less legible than before it was cleaned. For signs that have graffiti an individual assessment is required to determine the severity of message conveyance degradation and decide whether or not a replacement is required.

Figure 0.32 Graffiti Cleaner Damage

There are other types of vandalism, stickers and paintballs, which are not as detrimental to retroreflective sheeting if proper cleaning techniques are adhered to. Figure 0.33displays an attempt to remove a sticker which was done with cleaner that damaged the sheeting.

Figure 0.33 Sticker Remover Damage

Both Avery Dennison and 3M provide documentation about cleaning retroreflective sheeting. The follow is from the Reflective Films Division of Avery Dennison:

"The cleaning solution should have a pH range of 4 to 10 (within mild acid or mild alkaline limits). Use a mild soap or detergent along with warm water and a soft cloth or sponge. The cleaning solution should be non abrasive and free of strong solvents. If it becomes necessary to clean and remove heavy oil and grease a damp chemical rag with kerosene, mineral spirits, heptanes, or V.M. & P naphtha. Test the cleaner on a small section or sample of the material before use. Do not use high pressure sprays, and avoid direct sprays at the sheeting edges. Spray or wipe (with soft cloth or sponge) the cleaning solution over the entire surface of the film to be cleaned (avoid abrading the film surface with unnecessary scrubbing); thoroughly agitate and mix the cleaning solution into the dirt on the films surface; rinse the entire surface with clean water and let air dry or dab dry careful not to lift film edges (50)."

The cleaning procedure recommended by 3M is very similar to Avery Dennison's, but has slight differences due to the different sheeting properties.

"Cleaner - A wet, non-abrasive cleaner suitable for high quality painted surfaces is recommended. The cleaner must be non-abrasive, neither highly acidic nor alkaline (pH of 6 to 8 is recommended) and free of damaging solvents. If there is any doubt concerning the suitability of the cleaner we recommend testing it on a separate piece of sheeting or on a small section of a sign. Avoid high pressure sprayers. Do not direct sprays at sheeting edges. Do not abrade the sign by using brushes with stiff bristles or by unnecessary scrubbing.

1. Flush the entire surface with clean water to remove loose dirt particles.

2. Wash the sign face with a soft brush, rag or sponge, using detergent or any suitable commercial cleaners. Wash thoroughly from the top down avoiding abrasion. Once cleaner has been applied, keep a steady stream of water flowing on the surface to wash away dirt particles.

3. Rinse the entire sign face with clean water. Allow to drain dry.

If this material remains after steps 1 through 3 above, moisten soft cloth with 3M™ Citrus Cleaner, kerosene, mineral spirits or VM&P Naptha and wipe the area lightly. Following solvent wipe, wash with detergent and water, then rinse with clean water. Allow to drain dry(51)."

Both manufacturers offer protective overlay films that allow for graffiti cleanup without damaging the retroreflective properties of the sheeting. But this requires that the protective overlay be applied to the sheeting prior to any graffiti, therefore for current traffic signs under UDOT's jurisdiction that have graffiti damage restoration can be attempted but will normally be unsuccessful. For areas that graffiti damage is widespread replacement sign should have these protective overlays to allow for traffic signs to be cleaned without harming the retroreflective sheeting.

Preliminary Deterioration Analysis on UDOT Traffic Signs

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

<u>Sheeting Age</u>

As discussed in Section 0 of this report installation dates were not frequently observed on in-service traffic signs. It is common knowledge that retroreflective sheeting deteriorates over time, but little is known about what contributes to this deterioration. Figure 0.34 shows Type IX yellow traffic signs with known service life and its corresponding measured retroreflectivity.

Figure 0.34 Type IX Yellow Deterioration

The linear regression shows that there is a downward trend in measured retroreflectivity, but values for certain years exhibit a wide degree of variance. The expected service life for this sheeting type and color combination would be 18 years. The darker guide signs experienced a minor downward trend of retroreflectivity performance as the sheeting aged, as shown in Figure 0.35.

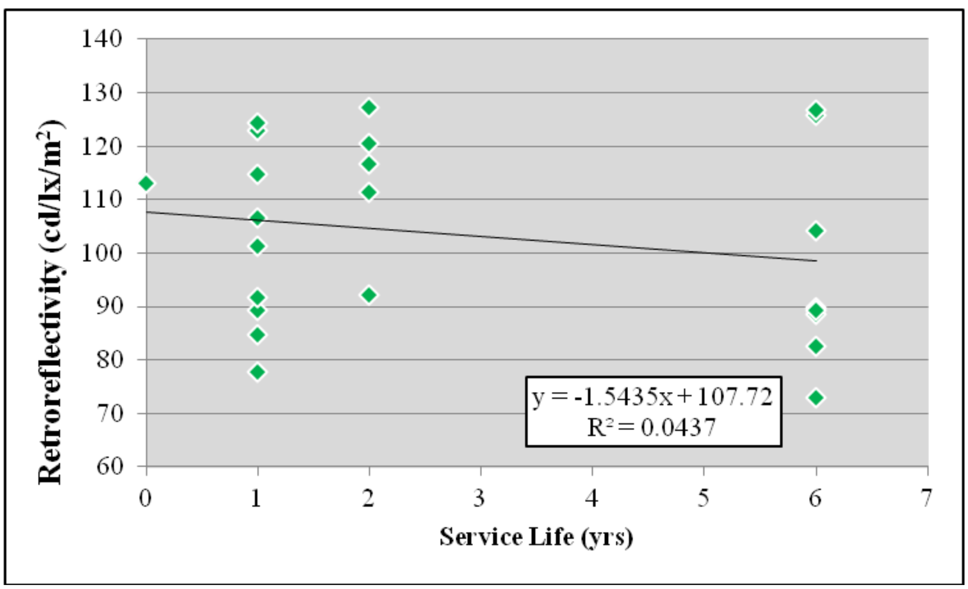

Figure 0.35 Type XI Green Deterioration

The relatively flat deterioration trend line for Type XI green may be the result of the green overlay fading over time and exposing more of the retroreflective material to the light source. Figure 0.36, shows the measured retroreflectivity of the legend for the same traffic signs. During the collection effort the sheeting type for the legend was not recorded, because it was assumed to be the same as the background.

Figure 0.36 Type XI Green Legend Deterioration

Figure 0.36, shows that Type III, Type IX and Type XI white was utilized for the legend on Type IX green traffic signs. This makes determining the deterioration of the contrast ratio very difficult for this color.

In addition it was observed that the higher green prismatic sheeting types had background retroreflectivity measurements were grouped fairly close together. This is caused by either the negative silk screen or overlay film limiting the amount of light that is able to be reflected back towards the source. Type III HIP and Type XI green sheeting had nearly identical retroreflectivity efficiencies, even though Type XI typically cost twice as much. For larger interstate guide signs the increase in cost becomes significant. Therefore, sheeting type performance should be considered prior to sign creation.

From the data collected during the collection effort it is clear that over time retroreflective sheeting deteriorates. Analysis results for each sheeting type and color combination are shown in their entirety in Appendix C: Deterioration Trends for UDOT Traffic Signs. But as shown in the figures above traffic signs that have the same installation year display a large variance in measured retroreflectivity. In an attempt to determine what causes this variation in retroreflective performance additional analysis was conducted on the sign placement attributes.

Sign Placement Attributes

During the sample survey three placement attributes were recorded for each traffic sign: orientation, offset and mount height. At the completion of the sample survey the offset and mount height were combined to determine the effective distance of the traffic sign. Figure 0.37 illustrates the different sign placement attributes. The first section analyzes the effects of effective distance and service life, while the second discusses the effects of the orientation of the sign face.

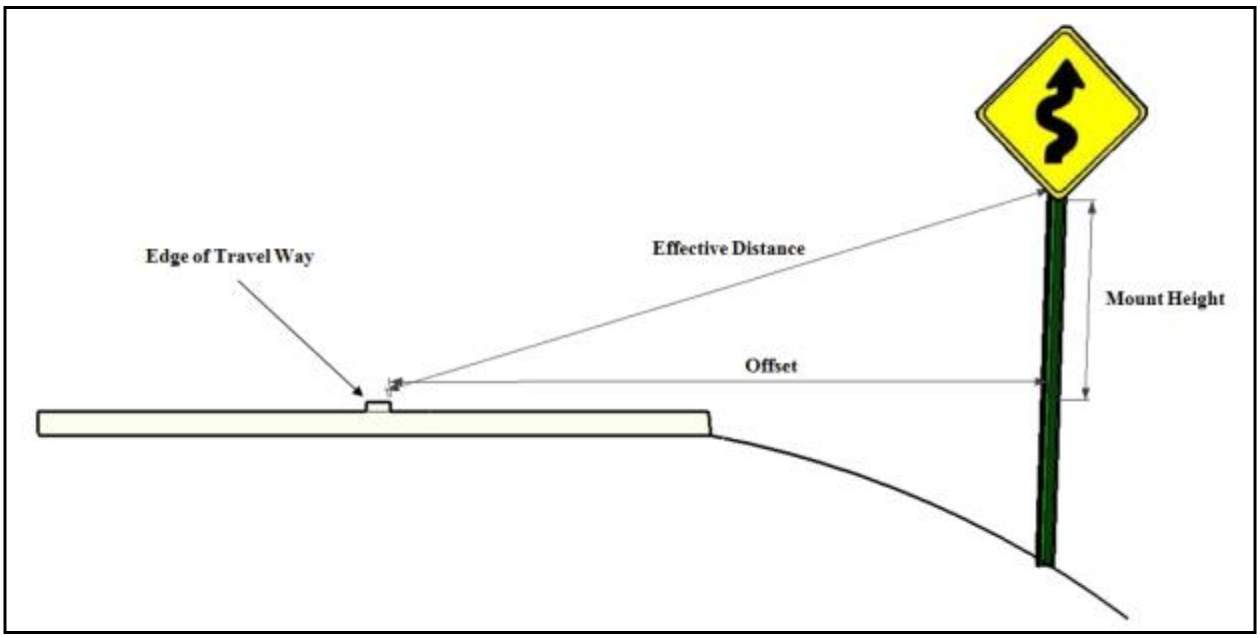

Figure0.37 Illustration of Sign Placement Attributes

Analysis was conducted on the effects that effective distance had on the portion of the sign population that had known installation dates. Linear regressions preformed on undamaged signs with known installation dates are summarized in Table 0.9. Values that are shown in grey were found to have no significant variables contributing to retroreflectivity deterioration. The best fits were for Type IX green and yellow sheeting, which only took into consideration the years of service of the sign. For green Type III HIP sheeting it was determined that the effective distance was significant for retroreflective performance, but the years of service was not. Even the bolded values in Table 0.9 do not provide accurate estimates of the deterioration of retroreflectivity and should not be used to estimate the service life of that sheeting type and color combination. Once UDOT increases the number of known installation dates, these equation could be improved upon. Currently this preliminary analysis only highlights a few significant variables that contribute to retroreflective deterioration.

Table 0.9 Linear Regression Analysis

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

Due to the small sample size of signs with known installation dates determining the significance of sign face orientation was unfeasible. Therefore, orientation analysis was conducted on all recorded traffic signs. During the collection effort the true north-based azimuths, shown in Table 0.10, were used for orientation entry. One of the possible reasons for the poor fits for the regression equations was that the majority of known installation dates were observed on prismatic sheeting. Since prismatic sheeting are rotationally sensitive, and were commonly found orientated in its non-optimal orientation this causes a wide range of measured retroreflective variation for signs installed in the same year. In order to avoid rotational sensitivity, for the orientation analysis only Type III signs were analyzed. The measured retroreflectivity of Type III sheeting plotted against its orientation is shown in Figure 0.38.

Table 0.10 True North-based Azimuths

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

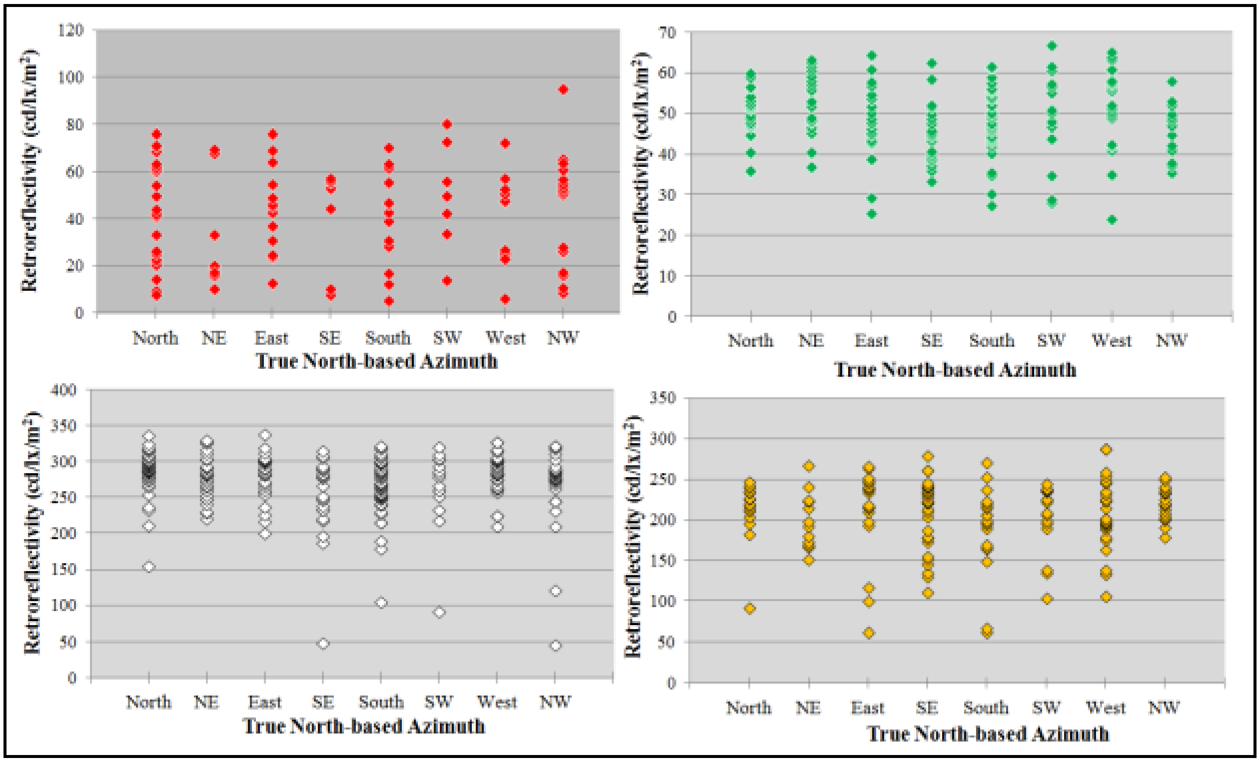

Figure0.38 Retroreflective Performance by Sign Face Orientation

The top half of the figure displays the darker red and green sheeting colors. Compared to the green retroreflective sheeting, the measure retroreflectivity of red signs varied greatly. Comparing the coefficient of variations (CV) the standard deviation for red Type III sheeting is 52 percent of the mean, compared to a CV of 21 percent for green Type III. Variation in measured retroreflectivity is consistent across all orientations for red Type III sheeting and shows no downward trend toward southern orientations. Type III green signs varied half as much as Type III red, with over 70 percent of measurements being between 40 and 60 cd/lx/m^2. Type III white had similar grouping, with the exception of a few outlier, with over 66 percent of measurements between 265 and 325 cd/lx/m^2. Contrasting to the CV of white Type III which was 13 percent of the mean, Type III yellow CV was 33 percent of the mean. A slight sensitivity towards southern facing signs was observed for yellow signs, but is far from being significant.

From analysis conducted on the detrimental effects of orientation on retroreflective performance it was concluded that the orientation of a sign was negligible. Since knowledge of know installation dates was limited the analysis was conducted without knowing the service life of the sheeting. As the number of known installation dates increases the effects of orientation, mount height, offset and effective distance might become more defined. With this current knowledge of UDOT maintained traffic signs the only contributing factor to retroreflectivity deterioration was the service life of the sign. Although the service life was not significant for all sheeting type and color combination, it was the most significant attribute that contributed to sheeting deterioration.

Feasibility of FHWA Retroreflectivity Maintenance Methods for UDOT

This section discusses the feasibility and estimated cost of implementing the five approved FHWA methods in the MUTCD for managing UDOT's traffic sign retroreflectivity compliance. Because of the similarities the three management methods have been grouped together.

<u>Visual Nighttime Inspection</u>

What makes visual inspection so advantageous to agencies is the ability to assess the retroreflectance of a traffic sign while identify other issues with nighttime visibility. Uniformity, damage, placement and obstruction can all detract from the ability of a sign to convey its message efficiently. FHWA has approved three procedures for the visual inspection method. These procedures are the calibration signs, comparison panel and consistent parameters procedure. No matter the visual inspection method the following general guidelines should be followed: inspection must take place at night, at normal travel way speeds, in the right most travel lane, while using low-beam headlights (14, 34). Since the inclement weather can diminish the amount of available light to be retroreflected, it is recommend that collection only take place during the summer months.

Currently Avery Dennison offers a minimum reflectivity standard (MRS) kit which includes a full sets of calibration signs and comparison panels. The MRS kit cost $3,000 dollars and includes eight 24" x 24" calibration signs and 12 6" x 6" comparison panels (36). Purchasing a single MRS kit provides equipment for both the calibration and comparison sign methods. One crew could utilize the calibration signs, while the other would use the comparison panels. Studies have shown that inspector's age is negligible in visually assessing traffic signs that do not exceed the minimum levels (38). Therefore, inspection crews could be made-up of temporary college student interns, which would reduce the need for overtime pay of current maintenance staff. Due to the infeasibility of hiring 60-year old inspectors and the inherent danger of senior citizens conducting extending nighttime inspections, the consistent parameters method is not considered feasible for UDOT to implement.

As with any assessment method the majority of the cost of implementation comes from the in-field collection of traffic sign performance. To ensure that visual inspection of traffic signs is conducted at night, assessment can only begin 30 minutes after the sun has set and must end 30 minutes before the sign rises. Using data collected by the United States Naval Observatory during the summer months there is an average of nine hours of darkness each day (52). Therefore, visual inspection can be done for a maximum eight hours each night. Determining the amount of time need to complete a statewide inventory depends on the number of signs that need to be inspected. Table 0.11, displays the estimated time necessary to complete a statewide visual inspection varying by the number of traffic signs that need to be inspected.

Table 0.11 Estimated Time Required for Visual Inspection

# of Signs Requiring Inspection	# of Signs Assessed	Visual Inspection Method		
		Calibration Signs (hrs)	Comparison Panels (hrs)	Combination (hrs)
1:1	95,000	1,835	5,002	3,419
1:10	9,500	410	727	569
1:20	4,750	331	489	410
1:30	3,167	305	410	357

Travel time is the main cost contributor in the visual inspection method. UDOT maintains 5,949 miles of highway and 977 miles of interstate highway. Since signs performance can only be assessed in the direction of travel roadways will have to be driven twice, which equates to 13,852 miles. Therefore, at a speed of 55 mph the required travel time for each inspection interval would be 252 hours. The calibration sign method requires no infield equipment setup and has an estimated collection rate of one minute per assessed sign. Since the comparison panel method requires an inspector setting up a ladder in order to clamp the panel to the sign it has an estimated collection rate of three minutes per assessed sign. The combination method assumed that 50 percent of signs were inspected by the calibration sign method and the other half by comparison panel method. Since either visual inspection method ensures both the legibility and the visibility of traffic signs it is deemed feasible for UDOT.

Measured Sign Retroreflectivity

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

Currently UDOT owns four retroreflectometers that could be utilized in a measured sign retroreflectivity method and could all be service for $1,200. If additional retroreflectometers are needed current prices range from $1,500 per month for rentals to $10,000 for purchasing. Extension poles can also be purchased to enable taking measurements on traffic signs without utilizing a ladder for $1,500 (53, 54).

Measurement of retroreflective sheeting using a portable retroreflectometer must be done in accordance to ASTM E1709 – 09, which requires a minimum of four measurements be taken per retroreflective sheeting present on the sign (8). This ASTM provides no guidance on where measurements should be taken. These measurements are then averaged to calculate the retroreflectivity of the traffic sign. Figure 0.39 shows a S3-1 during daytime and nighttime conditions. During the sample survey the required minimum of four points were measured on this traffic sign and the resulting measured retroreflectivity was 138 cd/lx/m^2, which is well above the minimum level. This sign could easily pass or fail the minimum levels depending on the location of the measurements.

Figure 0.39 Measured Retroreflectivity Day and Night Conditions

This brings up the question of how many measurements are required to provide a representative retroreflectivity. In addition to damage, the size of the traffic sign should play a role in determining the number of required retroreflective measurements. Four measurements provide a better assessment of a rural stop signs retroreflectivity compared to an interstate guide sign. Taking into account the rotational sensitivity of sheeting and the bias and uncertainty of retroreflectometer measurements further increases the subjectivity of this method.

Depending on sign density and number of sign attributes that are being measured collection rates vary from 10 to 25 signs per hour (37, 40, 41). UDOT currently maintains an estimated 95,000 traffic signs which would require a minimum of 3,800 person-hours to collect. Even if UDOT increased the number of measurements per retroreflectivity sheeting the increase in person-hours would be minimum due to the fact that the majority of time is spent traveling between signs.

The collection rate during the sample survey was 15 signs per hour, but this could be increased by reducing the number of sign attributes that needed to be recorded. Table 0.12 displays the expected time required for a statewide measured retroreflectivity effort.

Table 0.12 Cost of Measured Sign Retroreflectivity Method

Collection Rate (signs/hr)	Required 8-hr Days
10	1,188
15	792
20	594
25	475

Measured sign retroreflectivity provides a numerical value that can be directly compared to the minimum retroreflectivity levels. The increase in person-hours required by this method is supposed to result in measured retroreflectivity values with limited subjectivity. Measured retroreflectivity can only ensure the visibility of the sheeting that it measures and can never guarantee the legibility of the sign. Factors like sheeting orientation, location of measurements and number of measurements increase the subjectivity of this method. Due to the cost of this method and the uncertainty in it ensuring both the legibility and visibility of a traffic sign this method is not recommended.

Management Methods

There are three management methods recommended within the MUTCD: Expected Service Life, Blanket Replacement and Control Sign Method. Since 2008, UDOT has mandated that all signs placed into the field have an installation sticker on both the front and back of the sign. Compliance with this policy was not consistently adopted by the stations and contractors installing signs for UDOT and by the completion of the sample survey only 17 percent of the traffic signs had observed installation dates. Table 0.13 shows known installation dates by sheeting type from the sample survey. UDOT currently maintains a recorded of installation dates for milepost sign, but the vast majority of in place traffic signs have unknown installation dates. With the majority of traffic signs having unknown installation dates managing them by the expected service life method is unfeasible.

Table 0.13 Known Installation Dates by Type and Year

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

Since the majority of UDOT signs have unknown installation dates implementing a blanket replacement method seems practical. Depending on the replacement interval UDOT would divide the state into different regions and replace all the signs in that region. This method would require no installation record keeping and would be simplistic to implement and budget for. By replacing every traffic sign throughout its jurisdiction UDOT could start anew and fix various issues with its current sign population. But this comes at a cost since the vast majority of UDOT traffic signs are performing well above the minimum levels. The cost of replacing a sign varies with the size of the sign. For this blanket replacement analysis an average sign cost of $350 was used. Although this price might be higher than typically replacement cost, it is averaging the sheeting area of larger interstate signs with smaller rural road traffic signs. Table 0.14 displays the expected annual cost for each replacement interval. The replacement intervals correspond with the anticipated sheeting life for the different types of sheeting.

Table 0.14 Annual Cost of Blanket Replacement

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

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

All three of the management methods specified by FHWA in the MUTCD are viable methods for maintaining traffic sign retroreflectivity if the agency has adequate information about the traffic signs they manage. UDOT’s current knowledge of is traffic signs is not substantial enough to implement any of the management methods without incurring large amount of traffic sign and budgetary waste. This narrows the feasible maintenance methods down to visual nighttime inspection and measured sign retroreflectivity. Measured sign retroreflectivity is presented to be the most simplistic method for comparing traffic sign sheeting performance to the minimum levels. But studies have shown that even under controlled conditions there is nontrivial bias and uncertainty in retroreflectometer measurements. This method is further complicated by prismatic sheeting that is placed at non optimal orientations. These issues have the ability to limit deterioration forecasting and other benefits of measuring traffic sign retroreflectivity. With UDOT’s current knowledge of its traffic sign population and issues highlighted during the sample survey it was determined that implementing a visual nighttime inspection would be the most efficient method for maintaining compliance with the minimum retroreflectivity levels.

UDOT TRAFFIC SIGN RETROREFLECTIVITY MANAGEMENT PLAN

The overall goal of a traffic sign management plan should be to provide adequate message conveyance and reaction time for motorist traveling on roadways under UDOT's jurisdiction. The goal of this project is to select a method that is cost efficient, while still promoting motorist safety. Vital information about the performance of traffic signs under UDOT's jurisdiction was obtained from a sample sign survey. This information has assisted in the selection of the sign management plan that is tailored to UDOT traffic sign population.

Establishment of a Traffic Sign Inventory

Even though a traffic sign inventory is not required it is important for UDOT to know the traffic signs assets that they manage. Beginning in 2012 UDOT has begun a mobile collection of the traffic signs under its jurisdiction. Although the accuracy of mobile collection has been questioned, UDOT chose to do a mobile over a manual collection. The establishment of a traffic sign inventory is an important step in any traffic sign management. Knowing the exact size of the sign population that it maintains will enable UDOT to effectively budget for annual sign maintenance. The collection effort is not part of this project, therefore for the remainder of this report it will be assumed that UDOT has a current traffic sign inventory.

Traffic Sign Management Plan Recommendations

The FHWA provided guidance within the MUTCD for approved methods for maintaining traffic sign retroreflectivity. The approved methods are visual inspection, measured retroreflectivity, expected sign life, blanket replacement and control signs. The recommended management plan for UDOT is a combination of visual inspection and blanket replacement.

Visual Inspection

FHWA preapproved three different visual inspection techniques: calibration sign, comparison panel and consistent parameters which are described in detail in Section 0 of this report. Due to the required inspector age requirement for the consistent parameters procedure UDOT would have to hire senior citizens to assist in the inspection process. This requirement diminishes the feasibility of this method and it is not recommended.

Calibration sign and comparison panel procedures are very similar to each other. The only difference is when the inspectors calibrate their eyes. Following the calibration sign procedure inspectors calibrate their eyes prior to inspection, whereas for comparison panels the calibration occurs during the inspection process. As the inspectors visually assess signs they identify a sign that they believe is performing below the minimum retroreflectivity levels. The inspectors then clamp the comparison panel, which has been produced at or just above the minimum retroreflectivity level, and step back and compare the retroreflectivity between the sign and the panel. Since the inspectors have to leave the vehicle to assess the traffic the comparison panel method is more time consuming. Section 0 of this report discuses several studies on inspector accuracy. According to these studies an adequately trained sign inspector can properly determine if a traffic sign is above minimum retroreflectivity levels 87 percent of the time. Using the comparison panels increases the accuracy of inspectors and limits the number of early replacements while ensuring that underperforming signs are scheduled for replacement.

Currently Avery Dennison is the only company that produces a minimum retroreflectivity kit. At a cost of $3,000 the MRS kit includes eight 24” by 24” calibration signs, twelve 6” by 6” comparison panels, two clamps and a LED flashlight (36). The MRS kit has the ability to do both calibration signs and comparison panels procedures. Unless UDOT can find a manufacturer of retroreflective sheeting that is at the minimum retroreflectivity levels it is recommend that this kit be utilized for visual assessment. Because the kit contains both calibration signs and comparison panels it is recommended to UDOT that the kit be divided among two inspection crews.

Regardless of the visual inspection procedure it is recommend that UDOT hire seasonal interns to avoid costly overtime pay for current maintenance crews. Studies have identified that young inspectors, if well trained, can identify traffic signs below minimum retroreflectivity (38). The inspection crew will always be a two man crews to ensure that the driver can focus on the task of driving. The collection intervals for UDOT visual inspection are recommended to start at five years for all roads and be adjusted as UDOT officials see fit. A five year inspection interval would provide UDOT with sufficient time to replace underperforming traffic signs. Since the retroreflectivity of a traffic sign is affected by moisture, it is recommend that all visual inspections take place during the summer months.

UDOT Calibration Sign Procedure

For the crew that has the calibration sign the following procedure should be followed. The calibration signs should be setup 300 ft to 500 ft from the front of the inspection vehicle. Depending on UDOT's preference the calibration signs can either be permanently mounted or stored in the protective case. Avery Dennison warrants that even if the calibration signs are permanently mounted that the sheeting will maintain its retroreflectivity for two years (36). In order to ensure the longevity of the calibration signs they can also be taken down and stored indoors. Due to the size and potential need for mobile sign supports the mobility of this procedure is limited. The calibration signs need to be mounted at heights of at least 5 ft and meet all MUTCD guidelines. An example of a calibration sign procedure set up is shown in Figure 0.1.

The inspection crew must wait half an hour after the sun sets to ensure proper darkness for inspection. During this time the inspectors should setup the calibration signs 300 ft to 500 ft from the front of the inspection vehicle. Signs should always be viewed at distance of 500 ft if the calibration area has adequate space. The inspectors will calibrate their eyes for two minutes and ensure that the Trimble or mobile app device has an adequate charge and charging equipment. Once the minimum of two minutes has passed the inspection crew can begin the visual nighttime inspection. During the inspection if a traffic sign appears to be below minimum standards the inspectors will stop the vehicle next to the sign support. Using a customized data dictionary in the Trimble or mobile app the crew will take a GPS point and record the color, MUTCD code, sheeting type, and installation date (if present) of the sign.

Figure 0.1 Calibration Sign Procedure (36)

The inspection will continue throughout the night ensuring that both directions of a state route are inspected. At the completion of the inspection the data should be downloaded for the applicable device and sent UDOT staff.

UDOT Comparison Panel Procedure

The crew that is using the comparison panels for visual nighttime inspection will wait half an hour past sunset to ensure proper darkness is present prior to inspection. Because the crew does not have to calibrate their eyes prior to inspection they can now start the inspection. Once the inspectors observe a sign that they believe is below or near the minimum levels they will stop the vehicle. Using a ladder one inspector clamps the comparison panel to the traffic sign. If the sign has a retroreflective legend than the appropriate legend comparison panel will also be clamped to the sign. Once the panel is clamped to the sign the other inspector standing a minimum of 25 ft away from the base of the support illuminates the traffic sign and comparison panel(s) with a flashlight of adequate brightness. If the comparison panel appears to be brighter than the traffic sign the inspectors will record the traffic sign using a Trimble or mobile app device. It is recommended that the color, MUTCD code, sheeting type and installation date of the sign be recorded in order to facilitate in the replacement of the traffic sign.

The inspection will continue throughout the night ensuring that both direction of a state route are inspected. At the completion of the inspection the data should be downloaded for the applicable device and sent UDOT staff. The comparison panel crew effectively calibrates their eyes as they conduct the nighttime inspection.

Ensuring Message Conveyance

Visual assessment method allows for the message conveyance and retroreflectivity of a traffic sign to be assessed at the same time. Therefore, during either visual inspection method inspectors should be assessing the overall legibility of the traffic sign's intended message. As observed during the sample survey damage is a major issue to traffic signs under UDOT's jurisdiction. Over 28 percent of all signs exhibited some form of major damage. The effects of damage on the legibility of a traffic signs is largely based on the location and severity of the damage.

During the sample survey damage was categorized into five different types: bending, peeling, vandalism, cracking, and other. Each type of damage has varying effects on the legibility and visibility of the traffic sign. During the inspection process signs should be assessed for proper shape, color, sight distance and retroreflectivity. Any major damage or obstruction of sight distance that diminishes the legibility of a traffic sign should be recorded. Figure 0.2 depicts a traffic sign that should be recorded as a failure during either visual assessment. Since the stop sign shape has begun to peeling away from the backing this sign would be recorded and scheduled for replacement.

Figure 0.2 Failure Due to Damage

The above picture shows damage that is visible during both day and nighttime conditions. During the sample survey a high rate of paintball damage was observed on UDOT maintained traffic signs. What makes paintball damage especially dangerous is the difference between daytime and nighttime conditions. During the day paintballs are barely noticeable to motorist, but at night the dried paint blocks light from the sheeting and can make traffic signs illegible as shown in Figure 0.3.

These two examples demonstrate the importance of visually assessing traffic signs. Both of these sign are Type III sheeting, which has a warranty of 10 years and according to a study by PennDOT has an expected service life of 15 years. Allowing damage traffic signs to remain in service for decades leaves UDOT vulnerable to potential tort claims. Therefore, during visual nighttime inspections damaged and underperforming traffic signs share the same replacement priority.

Figure 0.3 Paintball Damage

<u>Blanket Replacement of ASTM Type I</u>

From the sample survey it was concluded that 68 percent of ASTM Type I are performing below the minimum retroreflectivity levels. Given this information it is recommended that UDOT begins to eliminate ASTM Type I sheeting from the traffic sign population. According to the company that is in charge of the mobile collection effort for UDOT it will be able to determine the sheeting type for the signs that it records. Therefore, UDOT will be presented with its present population of Type I signs and be able to budget for their replacement. Figure 0.4 shows Type I sheeting that is performing below minimum retroreflectivity levels.

Figure 0.4 Type I Sheeting Failures

The main reason behind the high failure rate of Type I traffic signs is the age of this population. Although the exact installation dates are not know, Type I sheeting is present on UDOT's legacy traffic signs which are slowly being replaced. It is estimated that UDOT currently has 7,500 Type I traffic signs under its jurisdiction. With 68 percent of these expected to be performing below the minimum levels this equates to 5,148 replacements. This blanket replacement is not required since these signs would be recorded and replaced eventually by the visual inspection crews. By removing Type I sheeting UDOT would reduce the majority of signs that do not meet the minimum levels and would bring UDOT's overall retroreflectivity compliance up to 98 percent.

<u>Installation Recording</u>

Once the traffic sign inventory is completed UDOT needs to collected date for new installations and replacements and implement them into the inventory. To ensure that installation dates are known it is recommended that UDOT continues its practice of placing installation date information on traffic signs.

Although installation dates will not currently be utilized for traffic sign management it is important that installation dates are placed on all new traffic signs. First of all this will ensure that sheeting is performing above minimum levels until the end of the warranty period. Secondly this will allow for UDOT to adjust its management methods in the future. Once installation dates are coupled with the traffic sign inventory UDOT can begin to identify areas of frequent damage and adjust the inspection intervals accordingly. The ideal solution would be requiring the date of manufacture and sheeting type be stamped into the backing of the sign. This would ensure that this information is never lost due to stickers peeling off. If stickers are going to be utilized it is recommended that UDOT develop a uniform sticker. This would ensure that both the installation date and sheeting type are present on the sticker. Figure 0.5 shows stickers that UDOT should model their installation sticker after. These stickers do not require hole punching and have large font which can easily be read on signs with high mount heights.

Figure 0.5 Installation Sticker Designs

After traffic signs are placed in the field UDOT should utilize a handheld data logger or mobile app to add the new or replacement sign information to the inventory. Knowing the sheeting type, size, and support type of each traffic sign will facilitate efficient replacement and management. Additional information like orientation, mount height, and offset could eventually assist in developing service life curves for the different sheeting color and type combinations.

Management Plan Conclusion

Implementing the above assessment and management procedures for traffic signs management would ensure that UDOT meets the MUTCD compliance for developing and implementing a method for traffic sign retroreflectivity compliance. As of May 14, 2012, this plan only needs to maintain the retroreflectivity on regulatory and warning traffic signs. But it is recommended that UDOT's visual inspection include guide, overhead and street name signs.

Compliance with the minimum retroreflectivity levels is defined with the Support statement in Paragraph 3 of Section 2A.08 of the MUTCD:

> *Compliance is achieved by having a method in place and using the method to maintain the minimum levels. Provided that an assessment or management method is being used, an agency or official having jurisdiction would be in compliance even if there are some individual signs that do not meet the minimum retroreflectivity levels at a particular point in time (2).”*

Even though specific replacement dates are not specified within the MUTCD, signs identified via visual inspection to be performing below the minimum levels need to be scheduled for replacement. UDOT is responsible for justifying its replacement schedule based on its resources and relative priorities. Replacement prioritization should be based on engineering considerations, similar to other traffic control devices. Therefore, Type I signs identified via the mobile inventory or underperforming signs reported during the visual assessment do not have to be replaced instantly, rather UDOT can wait until it has the resources and then can prioritize the replacement of underperforming signs. Since UDOT is already conducting a traffic sign inventory, it is currently compliant with the FHWA retroreflectivity mandate. In order to maintain this compliance UDOT needs to periodically assess the visibility and legibility of the traffic signs under its jurisdiction. The assessment intervals can simply be established or can be based on knowledge of traffic sign performance.

CONCLUSIONS & RECOMMENDATIONS

The Utah Department of Transportation initiated this research as a response to the release of the 2009 MUTCD, which established minimum maintained retroreflectivity levels for traffic signs. Since its establishment the retroreflectivity mandate has be revised to only require a management plan for regulatory and warning signs. Even though guide and street name sign performance assessment has no specific compliance date, UDOT is expected to include these signs as their resources allow. With budget constraints and limited agency resources, it is imperative that UDOT develop a management plan that is tailored to its specific needs.

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

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

The measure retroreflectivity of prismatic sheeting is sensitive to the rotation of the sheeting. Current signage construction practices do not always ensure that sheeting is placed at its optimal orientation. Although this is done to limit waste during the sign construction it eliminates measured retroreflectivity as a feasible method. At rotations of 45 degrees from proper, measured retroreflectivity is reduced by up 36 percent. Coupled with the rotation sensitivity of prismatic sheeting is the location required number of measurements to properly portray the overall visibility of a traffic sign. Current ASTM standards do not indicate where measurements should be taken an only specifies that a minimum of four measurements per retroreflective sheeting is required. Depending on damage and size of the sign the location and number of measurements can greatly affect the measured retroreflectivity.

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

There has been limited previous research into the damage rates of traffic signs managed by an agency. By the conclusion of the collection effort the observed damage rate of UDOT signs was four times greater than the rate of retroreflective failure. In order to determine contributing factors to increased damage rates weather observation and location data was collected. It was determined that average annual precipitation, elevation, seasonal temperature swing and the exposure of the sign significantly contributed to the rate of damage. Due to the observed rate of damage the feasibility of any management method became questionable. The only preapproved MUTCD method is visual nighttime inspection.

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

Because of the flexibility provided by FHWA on the replacement requirements of underperforming traffic signs two different recommended scenario are provided in this report. By the completion of the collection effort 78 percent of all underperforming traffic signs were Type I sheeting. Replacing UDOT's Type I population would bring the rate of compliance up to 98 percent. The current estimated Type I population is 7,529, which under an estimated replacement cost of $250 a sign equates to $1.8 million. Since there are no specific replacement dates these signs could be replaced over a period of time, justified by UDOT's available resources. The distinction between the two recommended scenarios is when or even if a blanket replacement takes place. In the first scenario the Type I blanket replacement takes place in prior to the start of a visual assessment. The blanket replacement could be divided up over the coming years to limit its burden on the agency's budget. Once the blanket replacement is completed then visual nighttime inspection would start. The second scenario would start visually assessing traffic signs and replace the Type I population as they were identified as failing. This scenario would begin identifying underperforming traffic signs of all types and colors and replacements could be prioritized as UDOT officials see fit. It is not recommended to conduct a blanket replacement in conjunction with a visual nighttime inspection because signs would be identified as need replacement by both methods and may cause confusion. The FHWA leaves the inspection interval for visual nighttime inspection up to UDOT to determine and is recommended to start initially at five years. The inspection interval should be adjusted to match observed damage frequencies in different areas across the state.

This traffic sign management plan should be adjusted to reflect UDOT's current knowledge of the traffic signs it manages. As the subset of signs with known installation dates begins to age additional analysis should be conducted on sheeting deterioration and expected service life. For areas that frequently experience higher rates of vandalism damage it might be more efficient to implement a five year blanket replacement rather than visual inspect signs. The introduction of new technologies can drastically change the way UDOT manages its traffic signs. No matter the method the end goal of UDOT's traffic sign management plan should always be to ensure the legibility and visibility of traffic signs on roadways that they manage.

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APPENDIX A: MAJOR AND MINOR DAMAGE EXAMPLES

Within this appendix are severity examples for each of the five different categories of damage: bending, peeling, vandalism, cracking and other. Damage was further divided into major and minor damage severity, with the distinction being the effect of the damage on the legibility and visibility of the sign.

Bending damage applies to signs that had significant portions of the sheeting bent causing light to be reflected away from its origin. Examples of minor and major damage are shown in Figure A.1. The R2-1 speed limit sign is an example of minor bending because the bend in the top right corner slightly alters the overall shape of the traffic sign and did not cause any cracking in the sheeting. The W3-1 on the right is an example of major bending because the bend is follows the support across the entire face of the sign. In addition the bend was so severe that it cracked the sheeting on the sign face causing it to peel off. The combination of the bend and peeling of the sheeting has changed the shape of the sign and limited its ability to provide an easy to understand message.

Figure A.1 Examples of Minor and Major Bending Damage

Peeling damage applies to the legend of a sign peeling off of the background sheeting. Examples of minor and major damage are shown in Figure A.2. The signal overlay on the W3-3 has begun to peeling away from the backing but has not significantly detracted from the message of the sign; therefore it is classified as minor peeling. The D1-2A on the right is experience major peeling on both its legend and its boarder. Since the destination is no longer legible it is classified as major peeling. It should be noted that this major peeling happened on a guide sign that was installed in 2007.

FigureA.2 Examples of Minor and Major Peeling Damage

Vandalism is the most diverse category of damage and included damage caused by paintballs, bullet holes, glass bottle impacts, stickers, and graffiti. For discussion in this section vandalism will be separated into two categories projectile and locality. Paintballs, bullet holes, and glass bottle impacts are all examples of projectile vandalism, whereas stickers and graffiti are examples of locality vandalism.

Projectile vandalism is the most prevalent form of damage observed during the collection effort. State routes located in rural areas are plagued by these three forms of vandalism, but each one has a varying degree of damaging effect on the retroreflectivity of the sign. Paintballs are particularly harmful to retroreflectivity sheeting because it doesn't just eliminate the retroreflectivity at the point of impact. The paint spread increases the radius of the dead spot, either by particulate matter collecting on the paint as it dries or by the paintball dye itself. Signs that have paintball damage can be cleaned in order to recover their retroreflectivity, but most commercial solvents will damage the sensitive retroreflective sheeting and should be avoided. While signs can be cleaned using pressure washers or mops, signs that have cracking, or peeling damage can be further damaged by this process. Examples of minor and major damage are shown in Figure A.3. The S3-1 on the left has a single bullet hole which does not diminish the ability for the sign to convey its intended message. Whereas, the W1-5L on the right has sustained severe paintball and bullet damage that has destroyed the intended message of the traffic sign.

FigureA.3 Examples of Minor and Major Projectile Vandalism

Locality vandalism is typically limited to urban and ski resort/touristy areas. Due to the snowpack reducing the effective mount height of signs, stickers can be placed with relative ease. Depending on the adhesive, stickers can typically be removed with little damage to a sign's retroreflectivity. Removal of the sticker might not solve the issue thought, because the remaining residue could collect particulate matter and cause the dead spot to remain. Although signs with graffiti were relatively rare in Utah, if the damage is severe enough the sign must be replaced. Solvents that are commonly used to remove graffiti from other surfaces completely destroy the retroreflective qualities of the sheeting. It appears the only way to deal with graffiti is to replace the sign if there is a significant amount present. Examples of minor and major damage are shown in Figure A.4. The first guide sign has a few stickers on it which has limited effect on the shape or message of the sign, compared to the D2-1 which is covered by stickers and is not longer legibility to motorists. Both signs had relatively low mount heights, which made them prone for this type of damage.

Figure A.4 Examples of Minor and Major Locality Vandalism

Cracking damage was frequently present upon aged Type I sheeting signs. As these legacy signs deteriorated over time the retroreflective background begins crack. Examples of major damage are shown in Figure A.5. It should be noted that due to the high failure rates associated with this type of damage it is recommended that all signs be recorded as having major damage and be scheduled for replacement. For single layer engineering grade traffic signs cracking damage was a death sentence, due to its associated failure rate of 89 percent. This did not hold true for multi-layer signs for 95 percent of cracking damage signs exceeded the minimum retroreflectivity levels. Even though these multi-layer signs have adequate visibility, the overall legibility begins to be questioned. Once a multi-layer sign is cut, cracked, or punctured it allows water to begin to collect within the layers of the sign sheeting. Over several seasons, the damage worsens via the freeze-thaw cycle causing the cracks to fan out across the face of the sign. Not only does this begin to expose the retroreflective under layer to the elements, it also diminishes the contrast required for adequate legibility and visibility.

Figure A.5 Examples of Major Cracking Damage

Other forms of damage recorded were fading, tree rubbing, and transportation/installation damage. Similar to other forms of damage the distinction between major and minor depended on the location and severity of the damage. The top half of Figure A.6 displays examples of minor and major tree rubbing, and the bottom half displays example of minor and major fading. Minor cuts were observed on new prismatic sheeting and were the result of transportation/installation of the traffic sign. Due to limited space on trucks used to transport traffic signs the sheeting is scratched and compressed. Initial the effects of these scratches are negligible when assessing the overall legibility and visibility of a traffic sign. But over seasons of service water can enter these scratches and cause cracking in the overlay. Compared to Type I sheeting, the new multi-layered signs are more vulnerable to damage during transport and installation.

Figure A.6 Examples of Minor and Major Other Damage

There is no exacted metric for determining a failed sign due to damage. Therefore, it is essential that traffic signs be assessed on an individual bases in order to determine the visibility and legibility of its intended message. The inspector needs to account for location and severity of the damage while determining if the message is properly conveyed.

APPENDIX B: SHEETING PERFORMANCE

ASTM Type I

UDOT ASTM Type I White

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2)

General Sample Information	
Sample Size	86
Failures	53
Estimated Population	4,761
Estimated Failures	2,934

Traffic Sign Information (cd/lx/m^2)	
Mean:	35.8
Standard Deviation:	38.7
First Quartile:	1.3
Third Quartile:	72.3

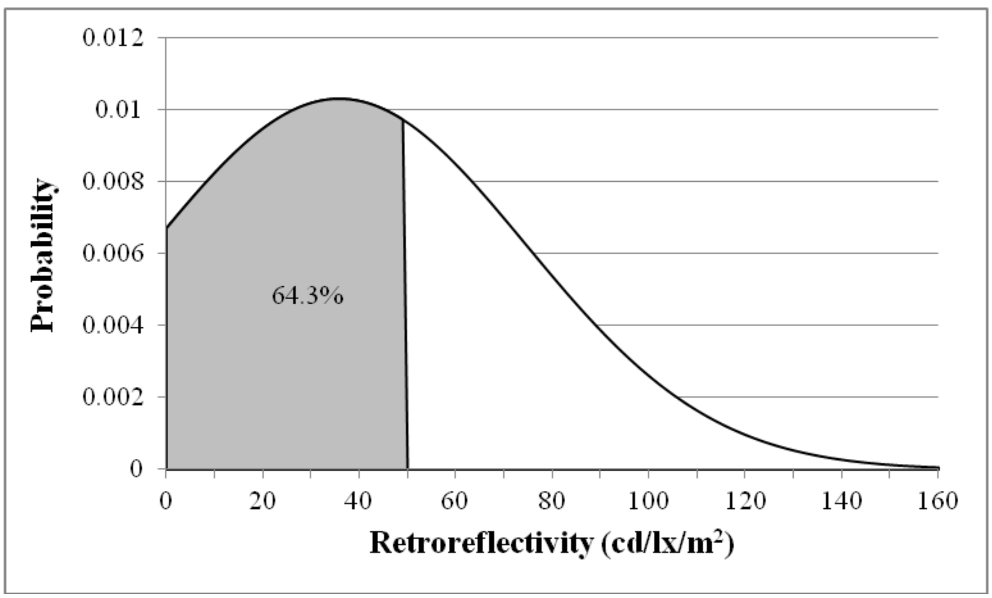

Figure B.1 Probability of Type I White Failure

UDOT ASTM Type I Yellow

Minimum Maintained Retroreflectivity Level	50 (cd/lx/m^2) For all bold and fine symbol signs ≥ 48 "
	75 (cd/lx/m^2) For fine symbol signs < 48 "

General Sample Information	
Sample Size	35
Failures	29
Estimated Population	1,938
Estimated Failures	2,339

Traffic Sign Information (cd/lx/m^2)	
Mean:	23.3
Standard Deviation:	25.7
First Quartile:	1.1
Third Quartile:	44.3

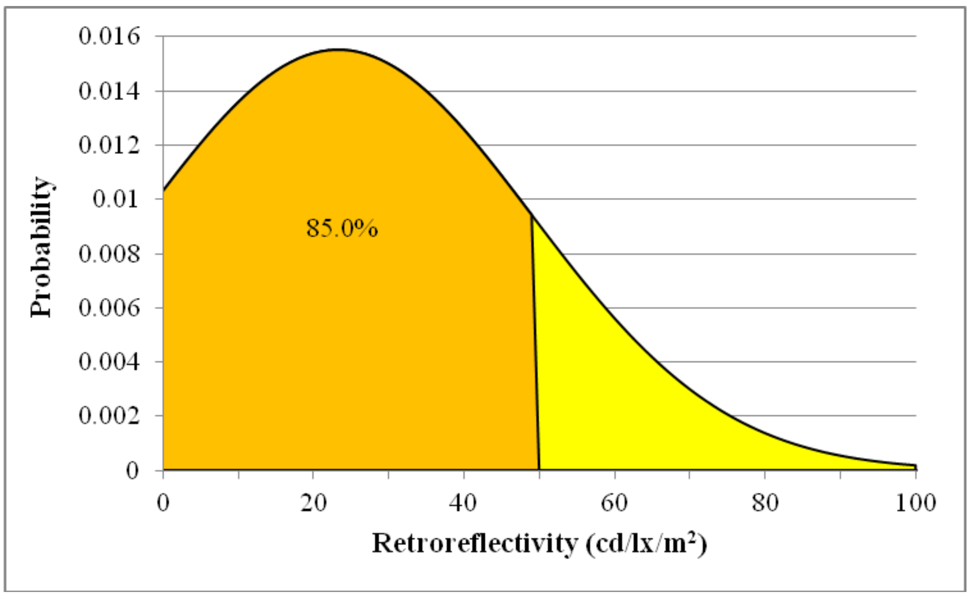

Figure B.2 Probability of Type I Yellow Failure

UDOT ASTM Type I Green

Minimum Maintained Retroreflectivity Level Background 7 (cd/lx/m2)

Legend (Shall not be used for this application.)

General Sample Information	
Sample Size	15
Failures	11
Estimated Population	830
Estimated Failures	609

Traffic Sign Information (cd/lx/m^2)	
Mean:	4.0
Standard Deviation:	4.6
First Quartile:	1.0
Third Quartile:	6.0
Avg. Contrast Ratio:	7.6

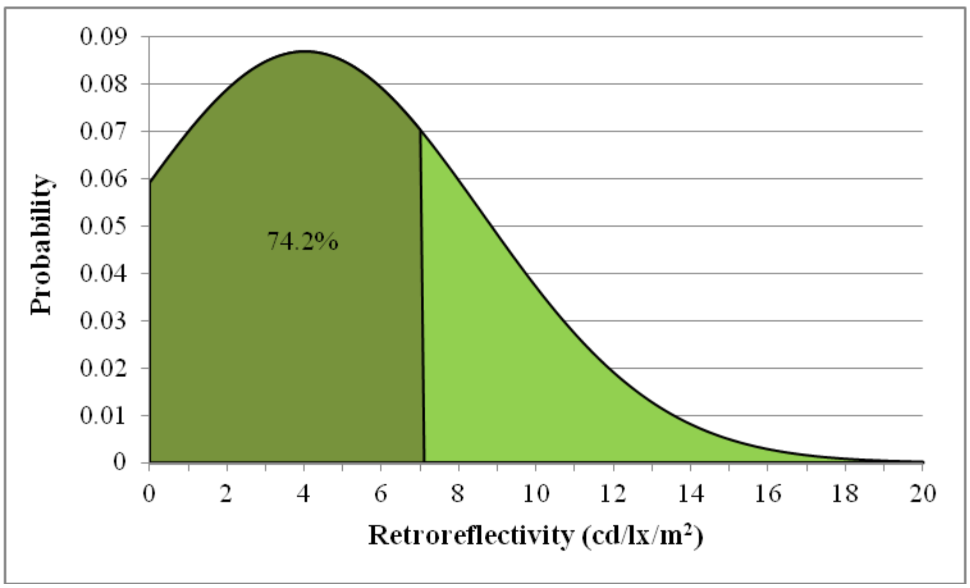

Figure B.3 Probability of Type I Green Failure

Table B.1 Distribution of Type I Signs by Color and Maintenance Region

Region	White	Yellow	Green	Total
One	53	17	4	74
Two	0	1	0	1
Three	20	10	4	34
Four	13	7	7	27
Total	86	35	15	136

Table B.2 ASTM Type I Descriptive Statistics

Color	Min	Max	Mean	STDV
Red	-	-	-	-
White	0	116	36	39
Yellow	0	75	23	26
Green	0	14	4	5

ASTM Type III

UDOT ASTM Type III Red

Minimum Maintained Retroreflectivity Level Background 7 (cd/lx/m^2)
Legend 35 (cd/lx/m^2)
Contrast Ratio L:B ≥ 3:1

General Sample Information	
Sample Size	150
Failures	7
Estimated Population	8,304
Estimated Failures	388

Traffic Sign Information (cd/lx/m^2)	
Mean:	41
Standard Deviation:	21
First Quartile:	24
Third Quartile:	57
Avg. Contrast Ratio:	12

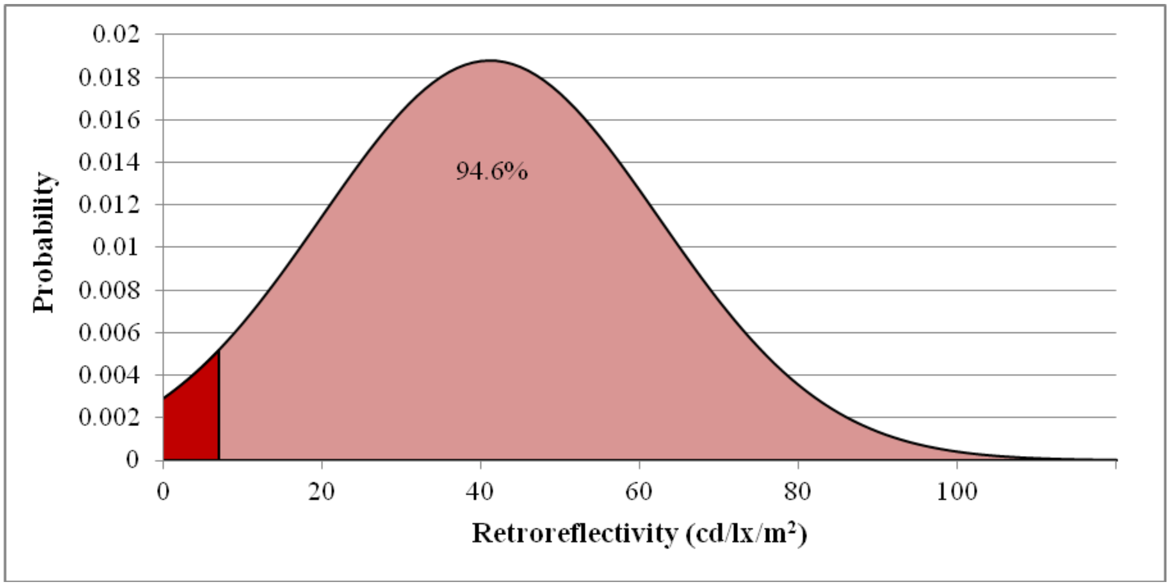

Figure B.4 Probability of Type III Red Exceeding the Minimum Levels

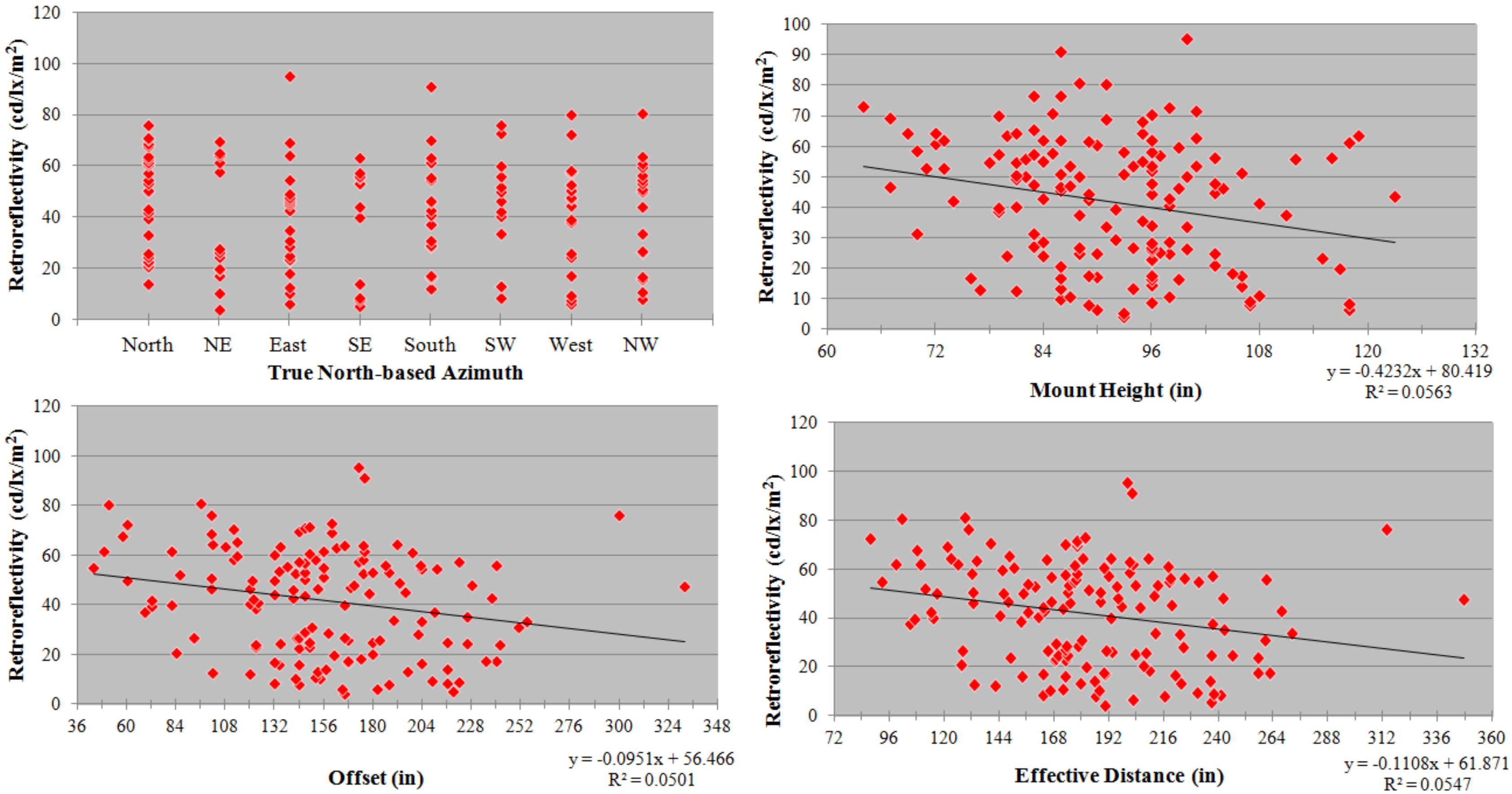

Figure B.5 Type III Red Performance Trends

UDOT ASTM Type III White

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2)

General Sample Information	
Sample Size	322
Failures	0
Estimated Population	17,826
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	275
Standard Deviation:	35
First Quartile:	259
Third Quartile:	298

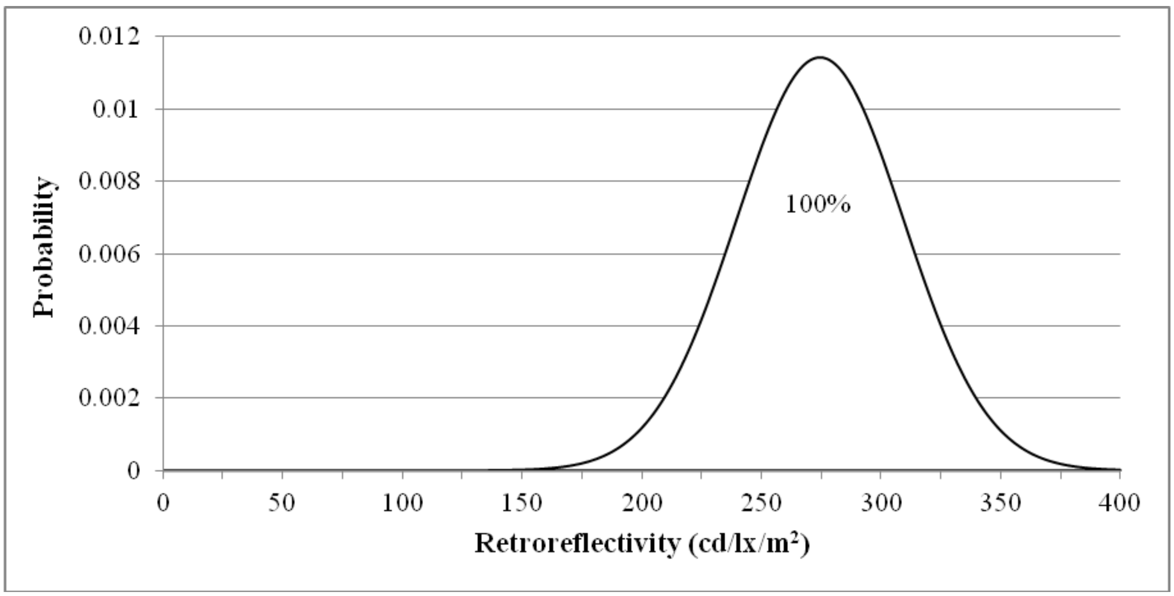

Figure B.6 Probability of Type III White Exceeding the Minimum Levels

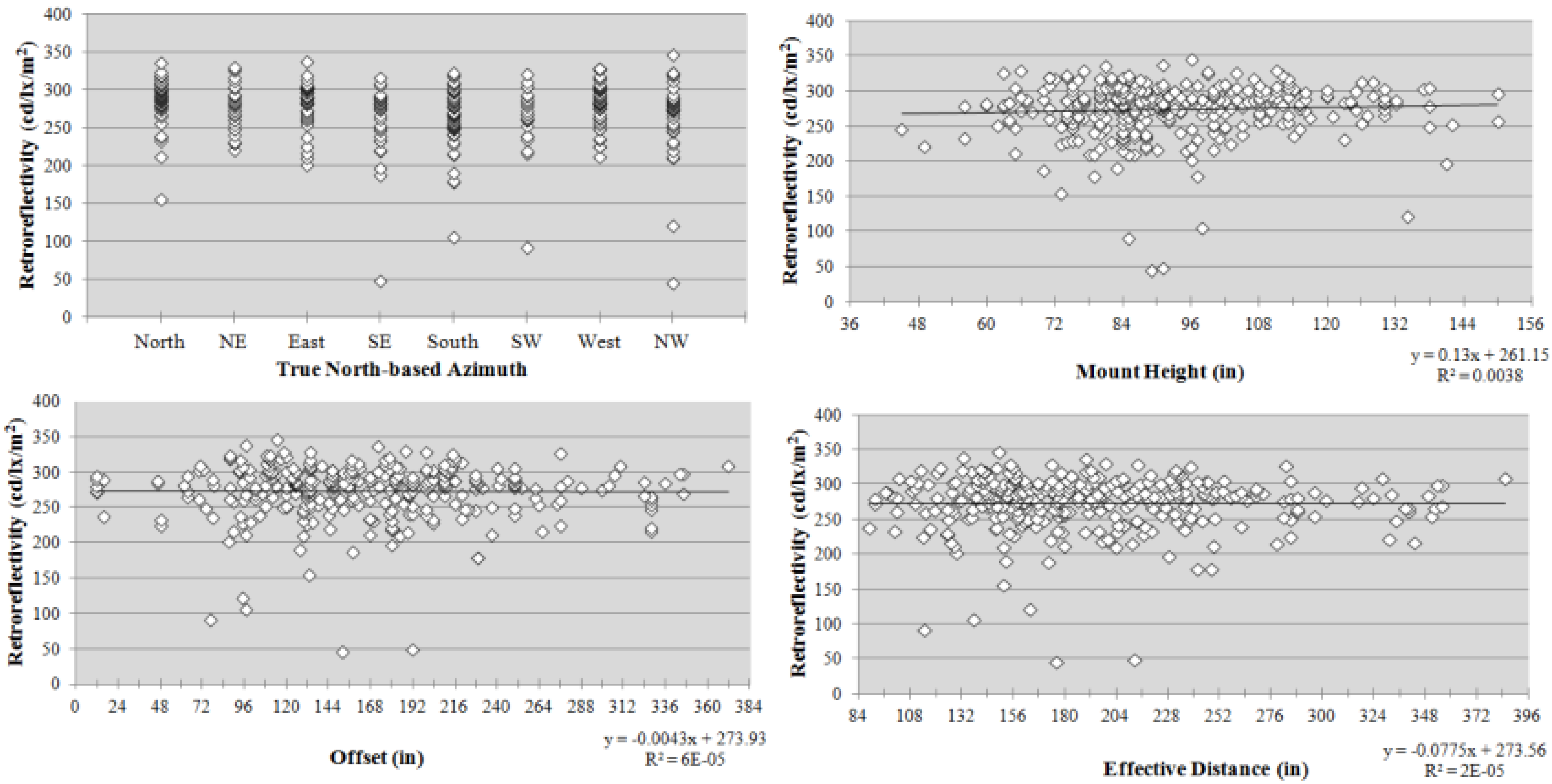

Figure B.7 Type III White Performance Trends

UDOT ASTM Type III Yellow

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2) For all bold and fine symbol signs ≥ 48 "
75 (cd/lx/m^2) For fine symbol signs < 48 "

General Sample Information	
Sample Size	241
Failures	12
Estimated Population	13342
Estimated Failures	664

Traffic Sign Information (cd/lx/m^2)	
Mean:	188
Standard Deviation:	61
First Quartile:	164
Third Quartile:	233

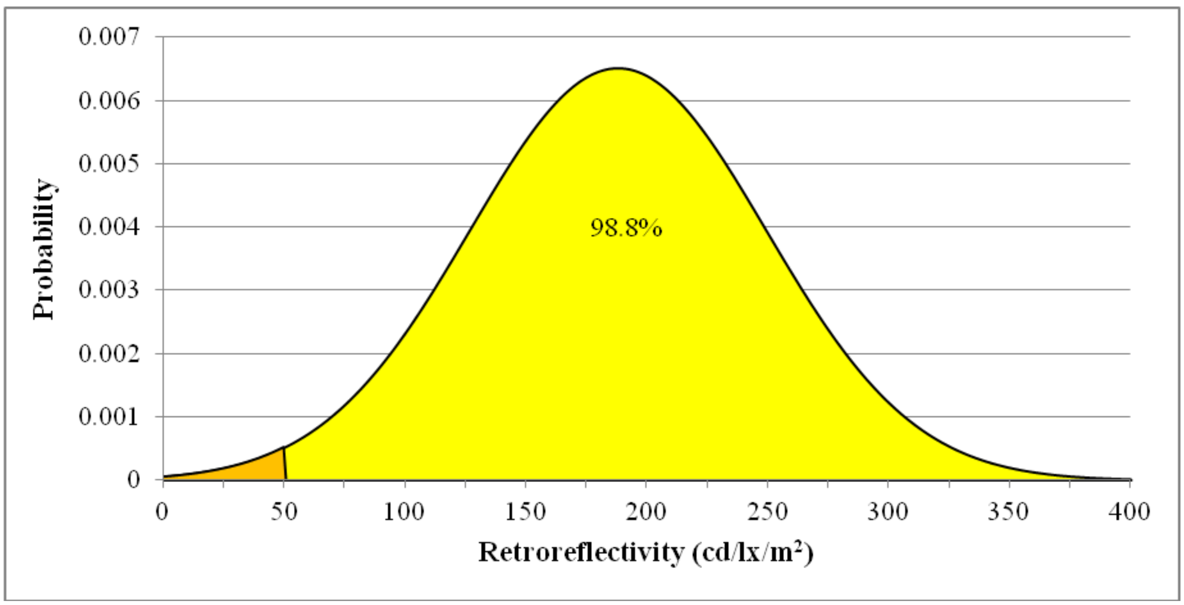

Figure B.8 Probability of Type III Yellow Exceeding the Minimum Levels

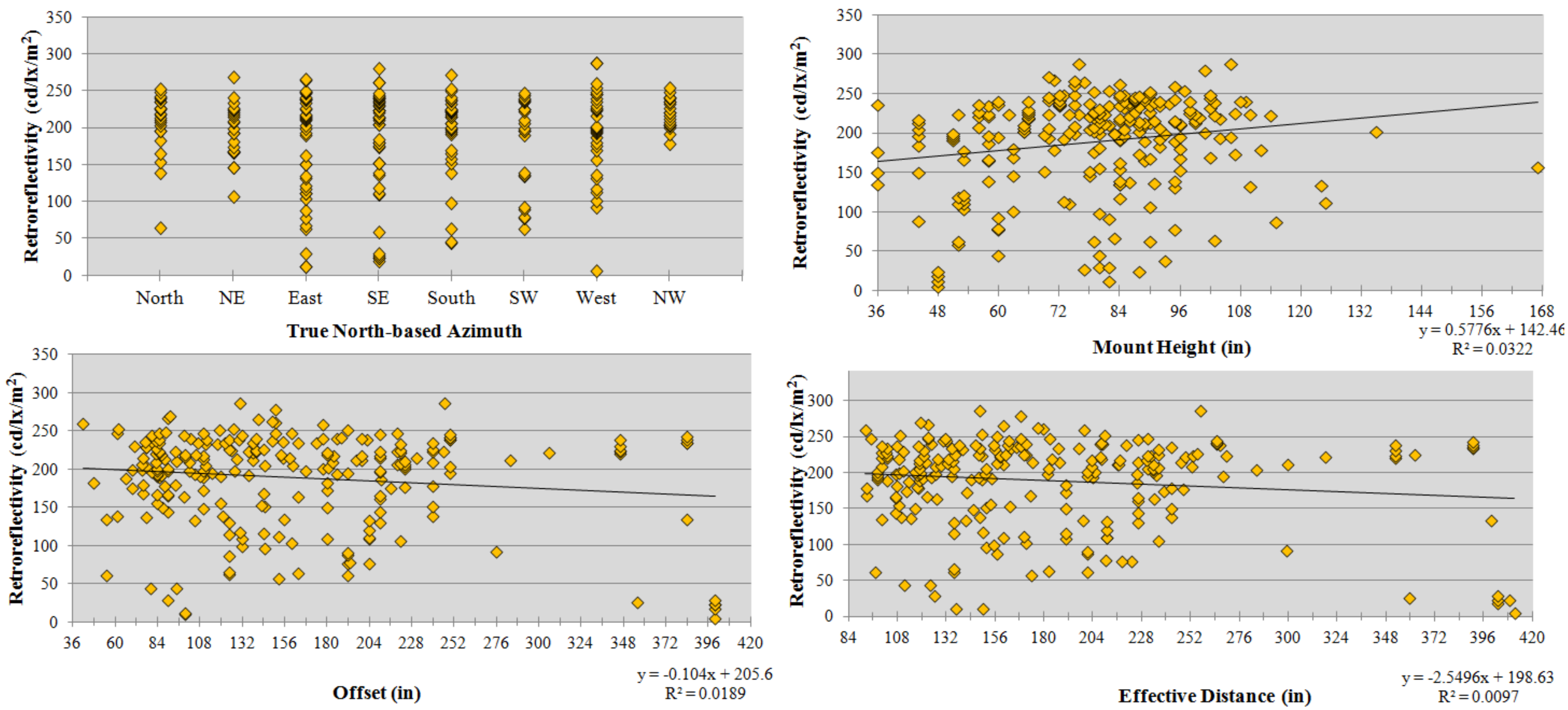

Figure B.9 Type III Yellow Performance Trends

UDOT ASTM Type III Green

Minimum Maintained Retroreflectivity Level Background 15 (cd/lx/m2)

Legend 120 (cd/lx/m^2)

General Sample Information	
Sample Size	243
Failures	4
Estimated Population	13,453
Estimated Failures	221

Traffic Sign Information (cd/lx/m^2)	
Mean:	47
Standard Deviation:	10
First Quartile:	41
Third Quartile:	53
Avg. Contrast Ratio:	6

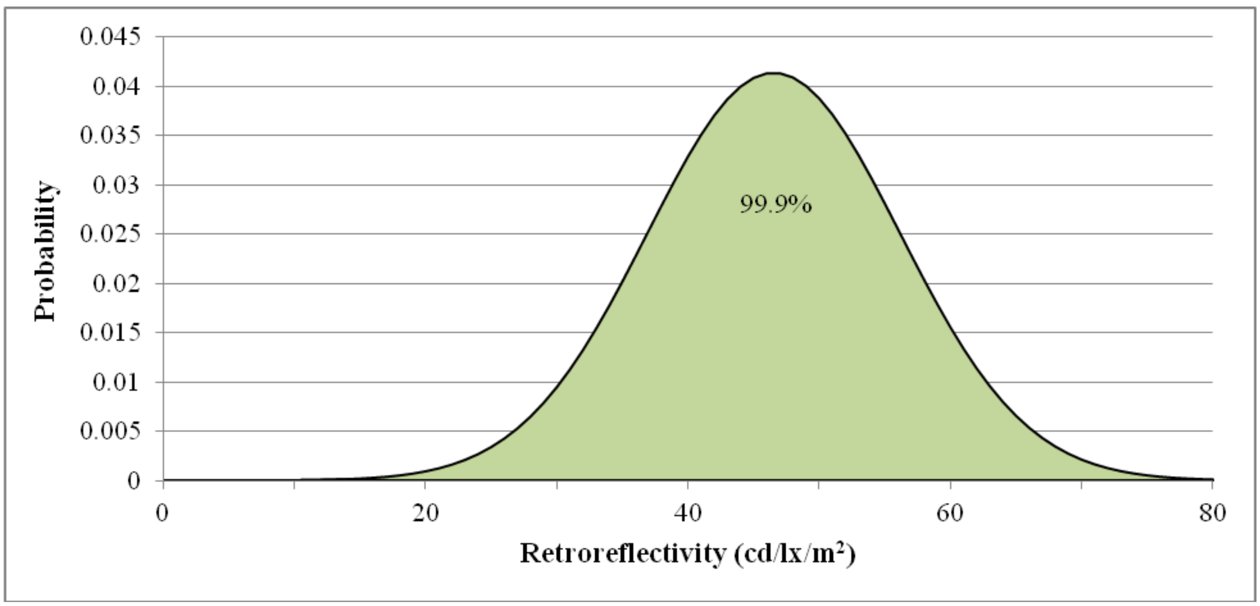

Figure B.10 Probability of Type III Green Exceeding the Minimum Levels

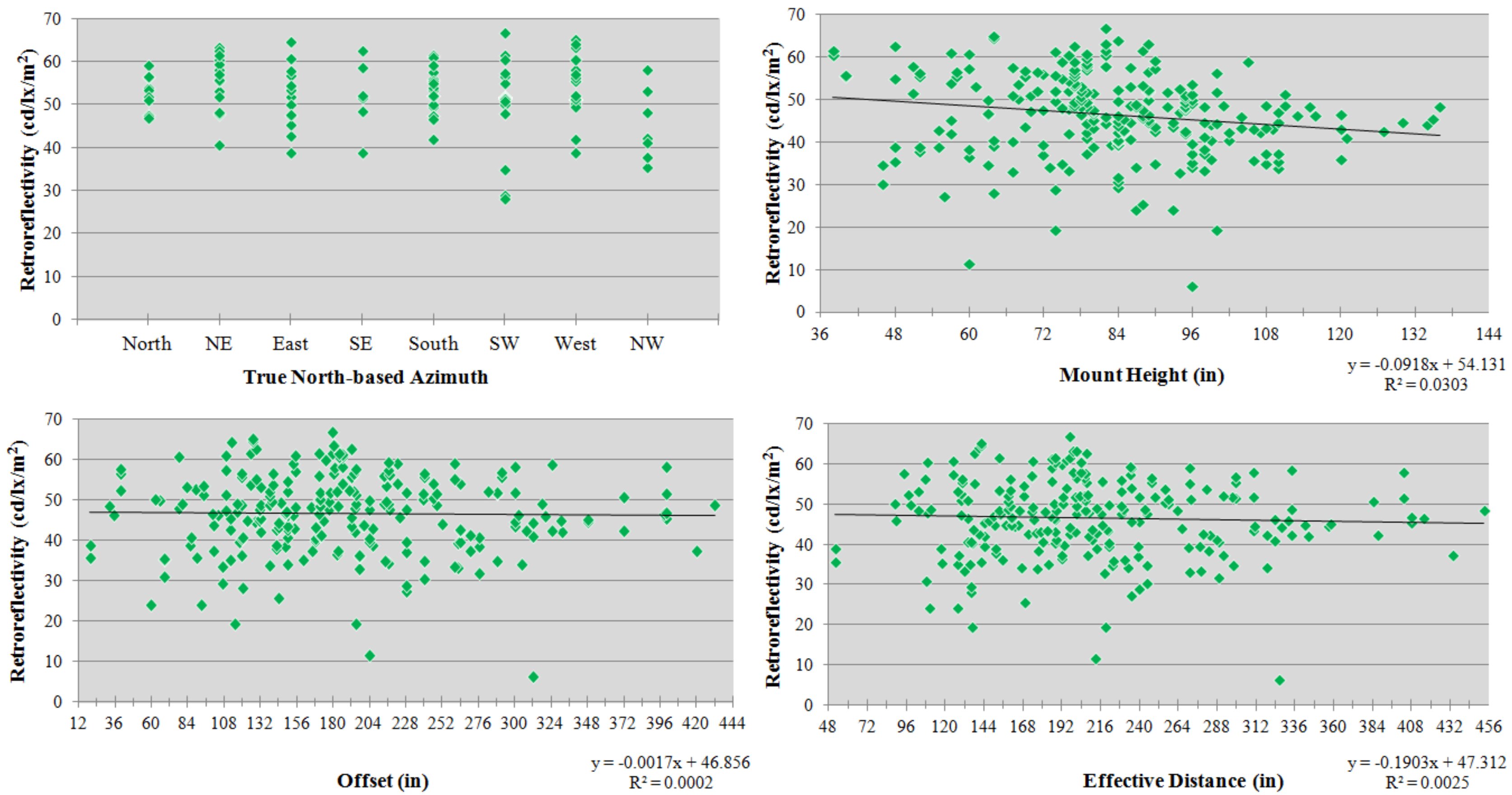

Figure B.11 Type III Green Performance Trends

Table B.3 Distribution of Type III Signs by Color and Maintenance Region

Region	Red	White	Yellow	Green	Total
One	31	140	95	118	384
Two	24	10	16	21	71
Three	7	73	50	46	176
Four	88	99	80	58	325
Total	150	322	241	243	956

Table B.4 ASTM Type III Descriptive Statistics

Color	Min	Max	Mean	STDV
Red	2	95	41	21
White	91	346	275	35
Yellow	5	287	188	61
Green	6	67	47	10

Type III HIP

UDOT ASTM Type III HIP Red

Minimum Maintained Retroreflectivity Level

Background 7 (cd/lx/m^2)
Legend 35 (cd/lx/m^2)
Contrast Ratio L:B ≥ 3:1

General Sample Information	
Sample Size	31
Failures	1
Estimated Population	1,716
Estimated Failures	55

Traffic Sign Information (cd/lx/m^2)	
Mean:	122
Standard Deviation:	53
First Quartile:	91
Third Quartile:	162
Avg. Contrast Ratio:	8

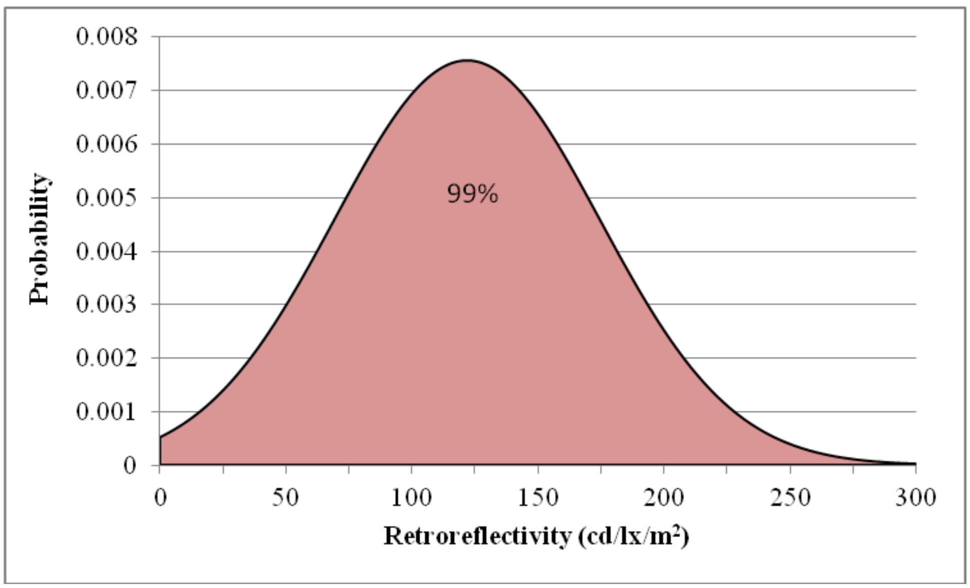

Figure B.12 Probability of Type III HIP Red Exceeding the Minimum Levels

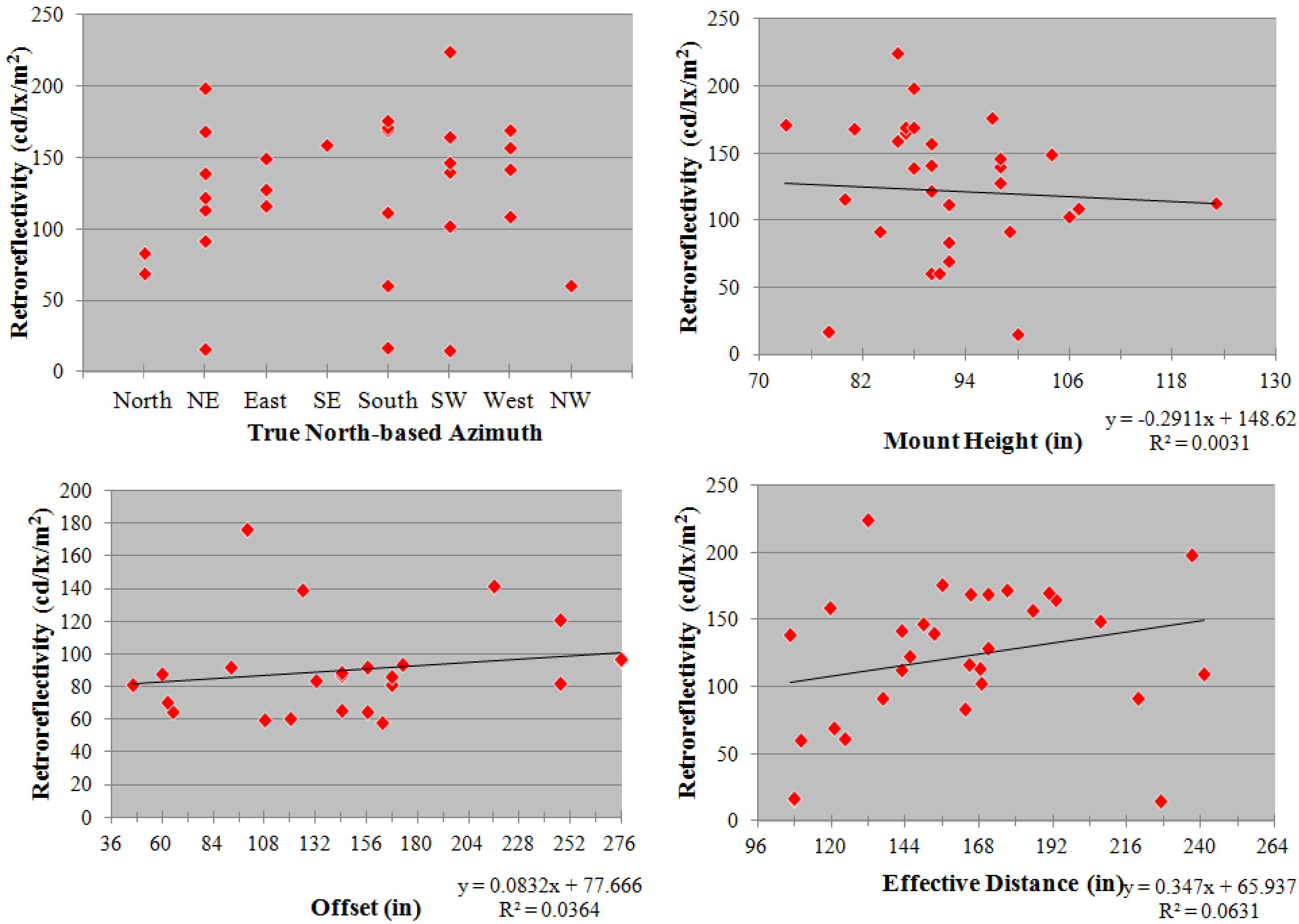

Figure B.13 Type III HIP Red Performance Trends

UDOT ASTM Type III HIP White

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2)

General Sample Information	
Sample Size	77
Failures	0
Estimated Population	4,263
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	641.58
Standard Deviation:	138.75
First Quartile:	562.00
Third Quartile:	743.00

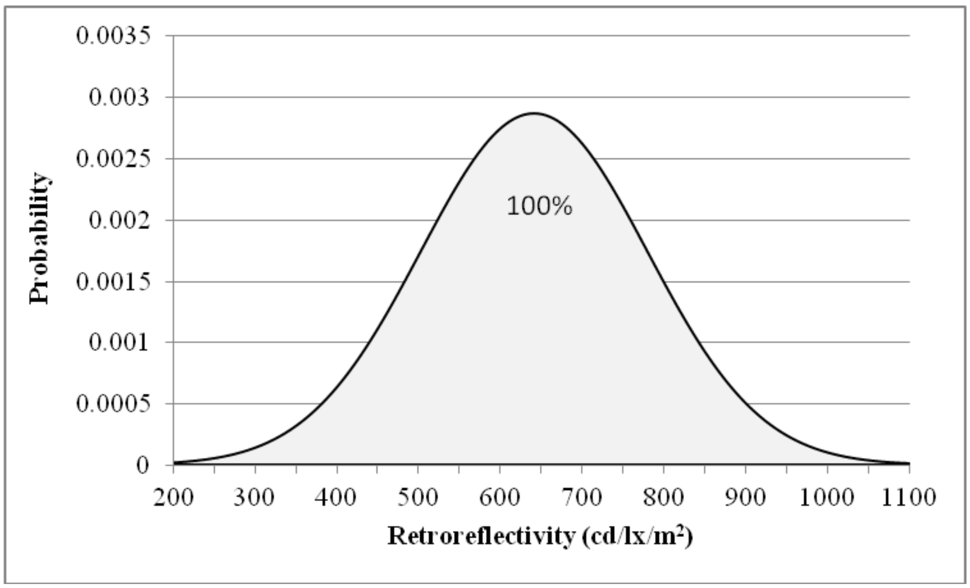

Figure B.14 Probability of Type III HIP White Exceeding the Minimum Levels

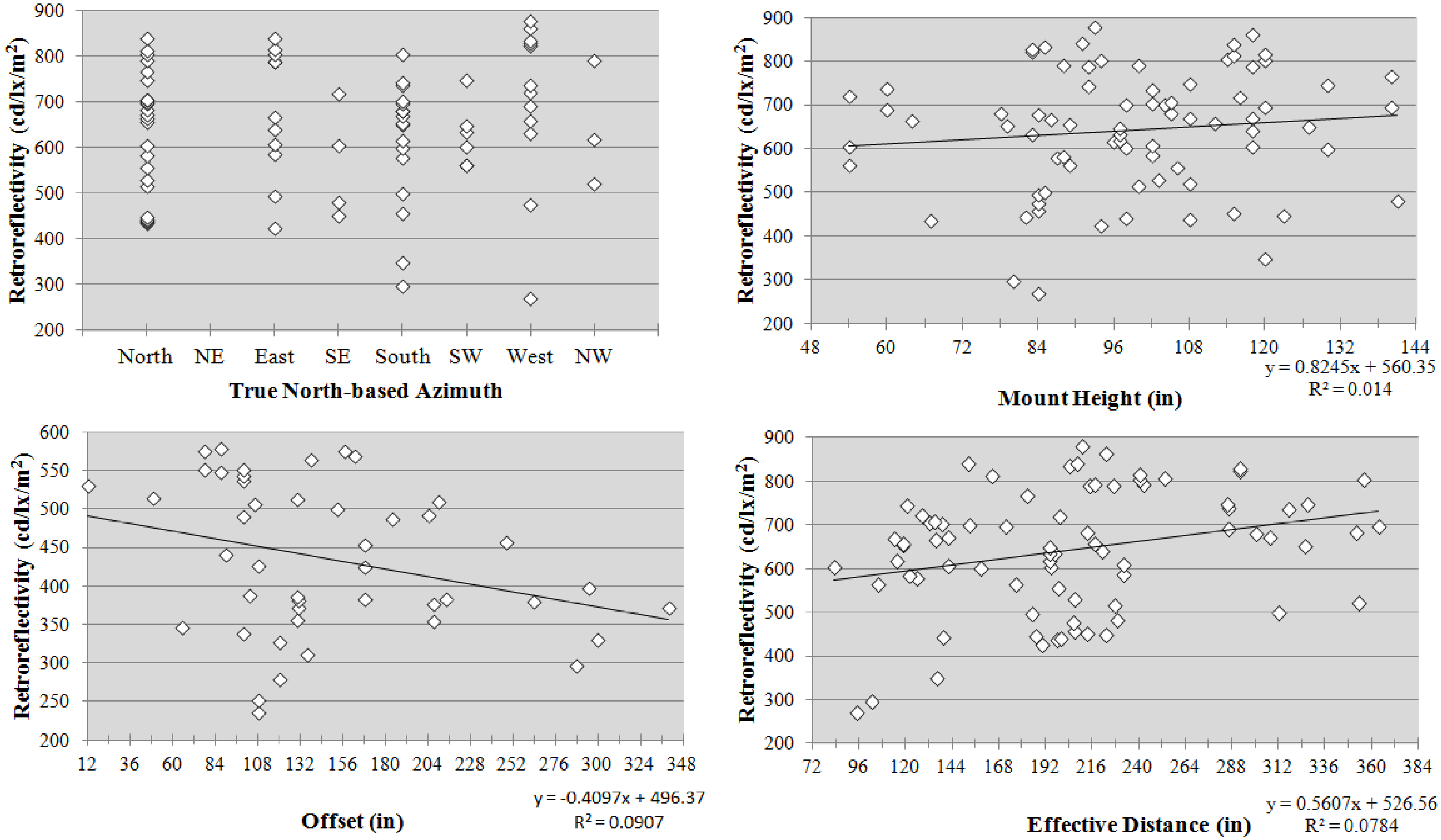

Figure B.15 Type III HIP White Performance Trends

UDOT ASTM Type III HIP Yellow

Minimum Maintained Retroreflectivity Level — 50 (cd/lx/m^2) For all bold and fine symbol signs ≥ 48"
75 (cd/lx/m^2) For fine symbol signs < 48 "

General Sample Information	
Sample Size	53
Failures	0
Estimated Population	2,934
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	420.52
Standard Deviation:	66.71
First Quartile:	378.00
Third Quartile:	462.50

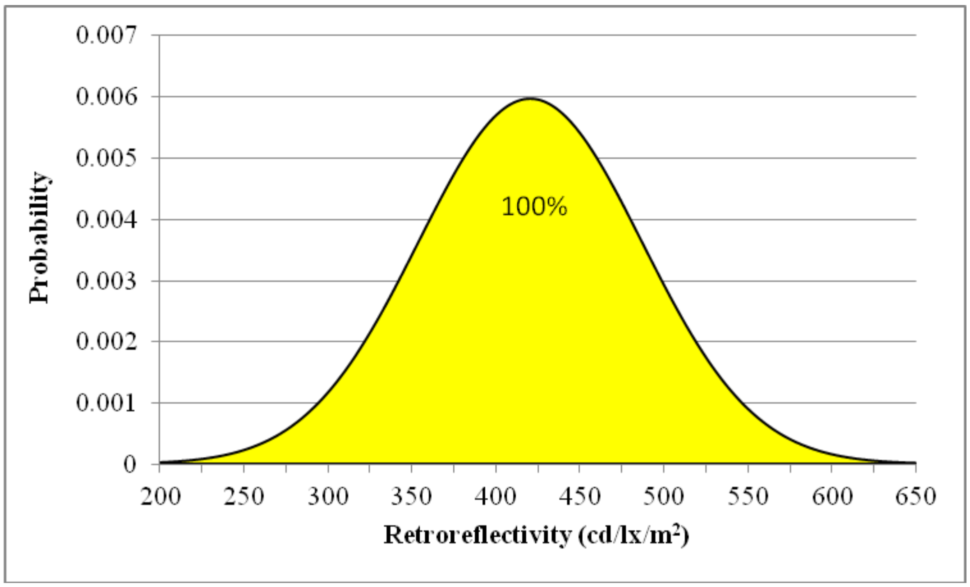

Figure B.16 Probability of Type III HIP Yellow Exceeding the Minimum Levels

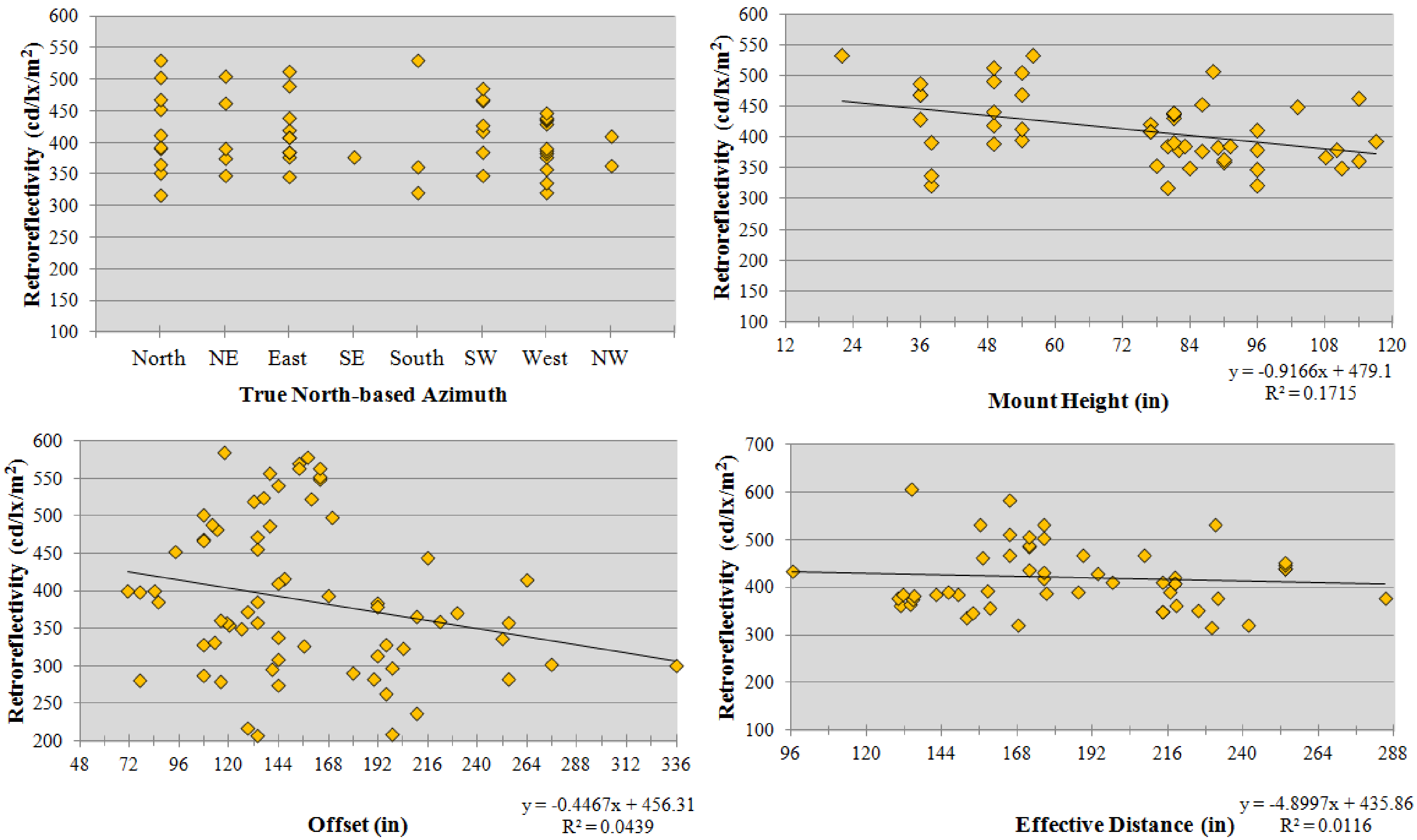

Figure B.17 Type III HIP Yellow Performance Trends

UDOT ASTM Type III HIP Green

Minimum Maintained Retroreflectivity Level Background 15 (cd/lx/m2)

Legend 120 (cd/lx/m^2)

General Sample Information	
Sample Size	48
Failures	0
Estimated Population	2,657
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	100
Standard Deviation:	21
First Quartile:	83
Third Quartile:	116
Avg. Contrast Ratio:	4

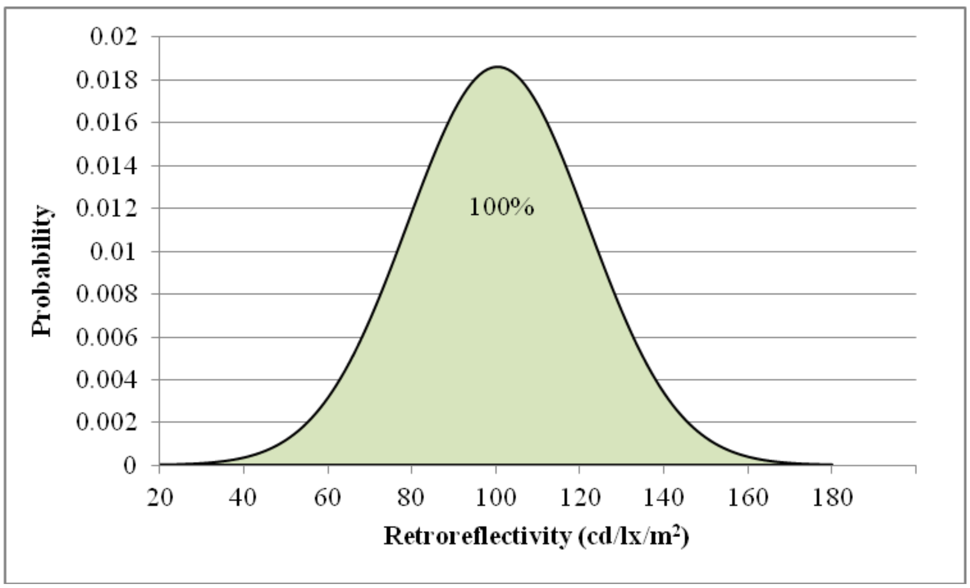

Figure B.18 Probability of Type III HIP Green Exceeding the Minimum Levels

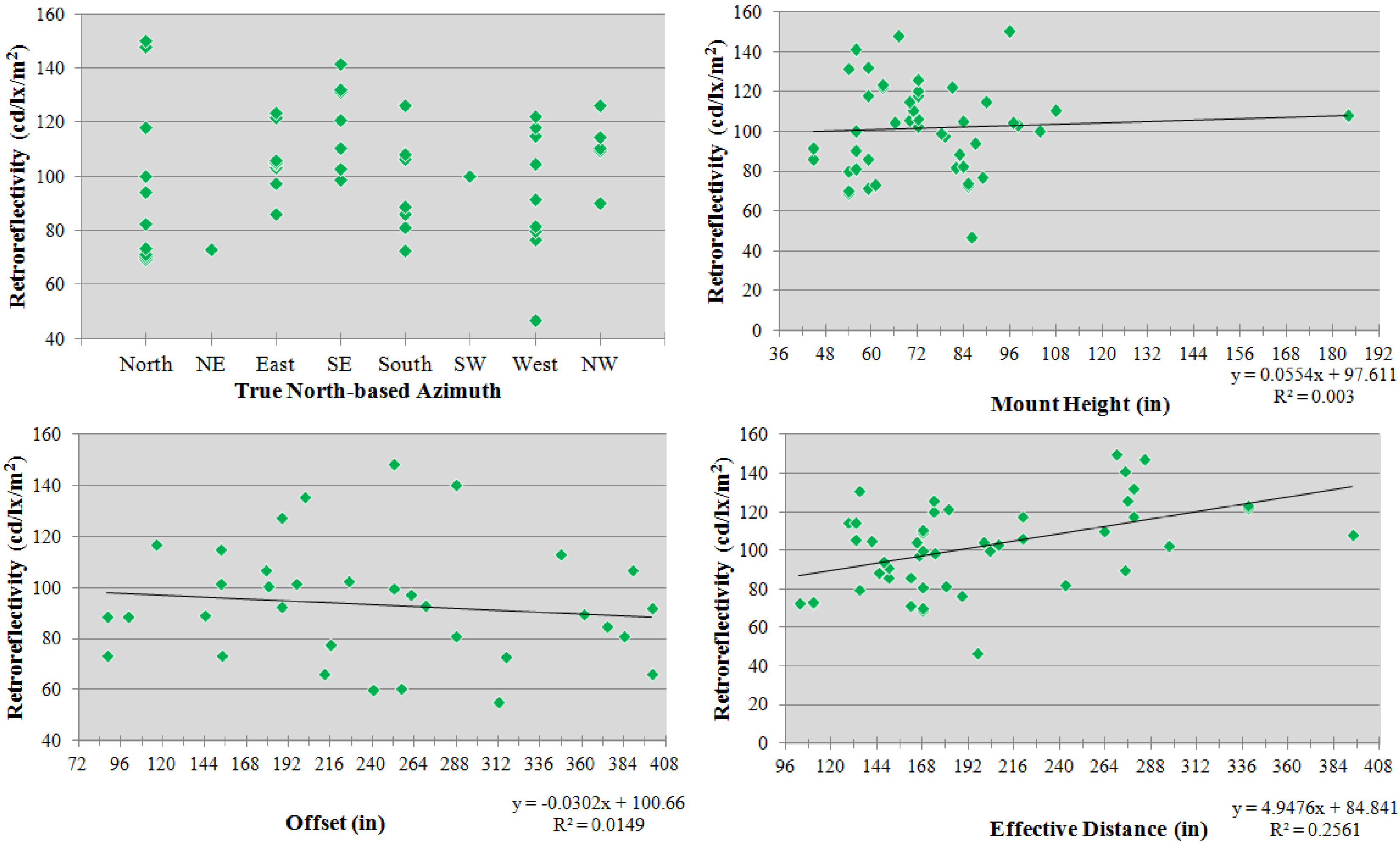

Figure B.19 Type III HIP Green Performance Trends

Table B.5 Distribution of Type III HIP Signs by Color and Maintenance Region

Region	Red	White	Yellow	Green	Total
One	2	21	10	15	48
Two	13	36	8	8	65
Three	4	3	2	21	30
Four	12	17	33	4	66
Total	31	77	53	48	209

Table B.6 Type III HIP Descriptive Statistics

Color	Min	Max	Mean	STDV
Red	15	225	122	53
White	270	878	642	139
Yellow	318	608	421	67
Green	47	148	100	21

ASTM Type IX

UDOT ASTM Type IX Red

Minimum Maintained Retroreflectivity Level Background 7 (cd/lx/m^2)
Legend 35 (cd/lx/m^2)
Contrast Ratio L:B ≥ 3:1

General Sample Information	
Sample Size	23
Failures	0
Estimated Population	1,273
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	86.37
Standard Deviation:	22.62
First Quartile:	67.75
Third Quartile:	92.75
Avg. Contrast Ratio:	5.26

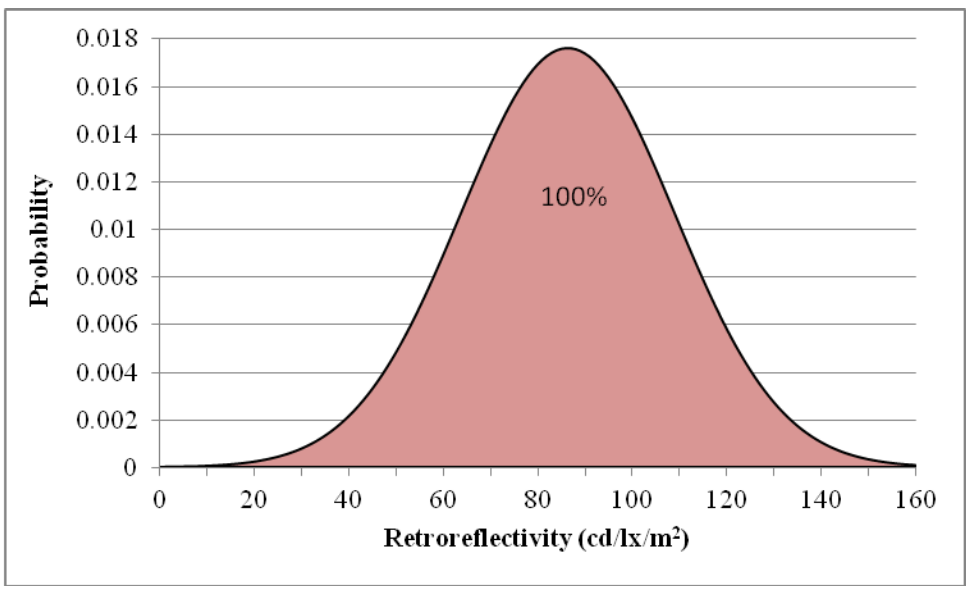

Figure B.20 Probability of Type IX Red Exceeding the Minimum Levels

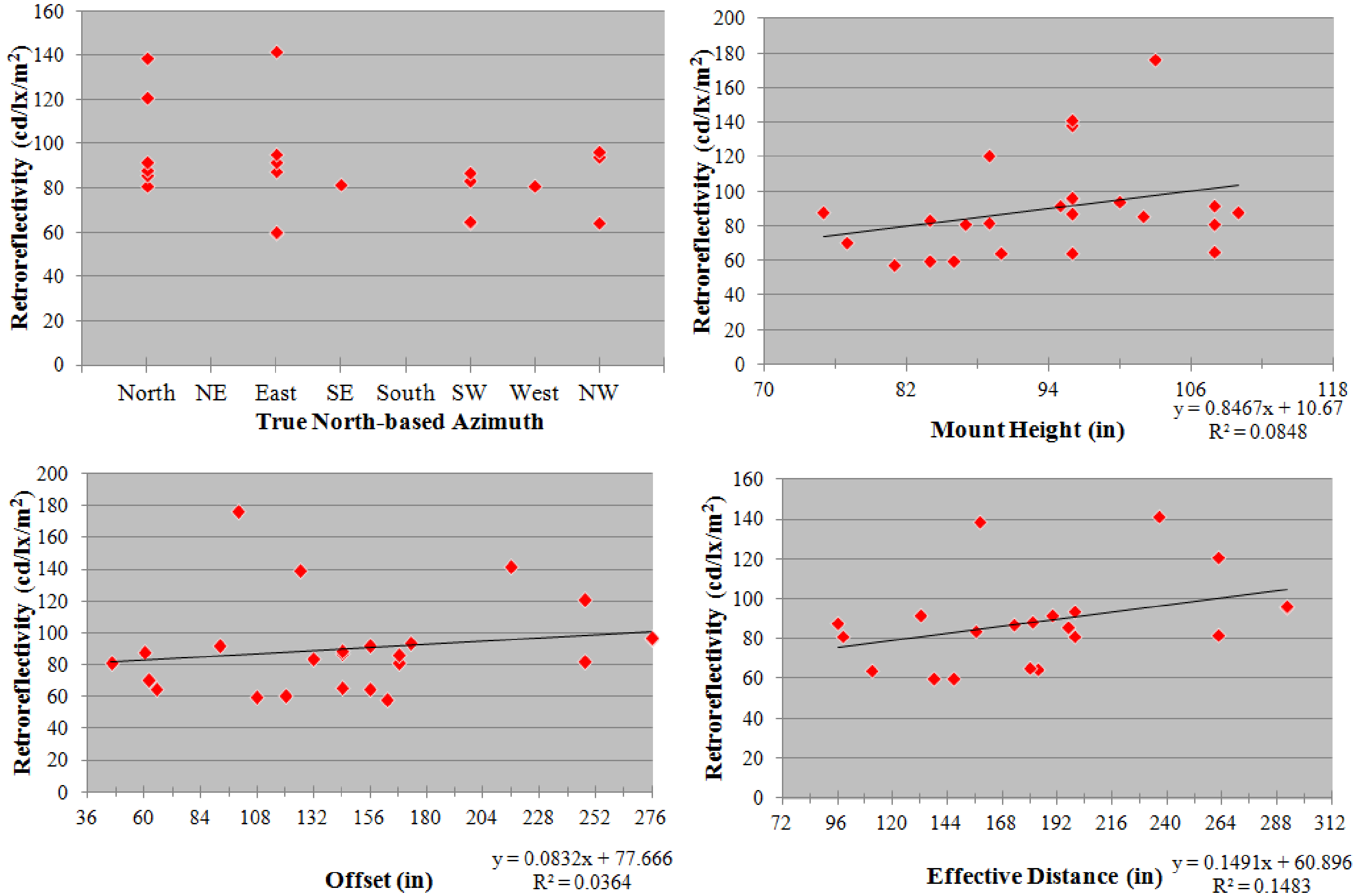

Figure B.21 Type IX Red Performance Trends

UDOT ASTM Type IX White

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2)

General Sample Information	
Sample Size	45
Failures	0
Estimated Population	2,491
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	435.52
Standard Deviation:	97.27
First Quartile:	371.50
Third Quartile:	515.00

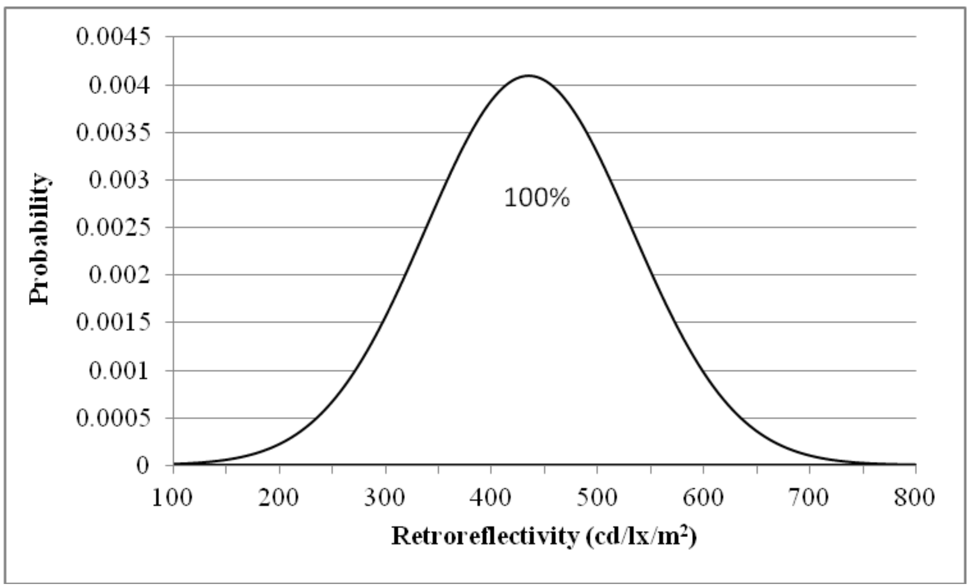

Figure B.22 Probability of Type IX White Exceeding the Minimum Levels

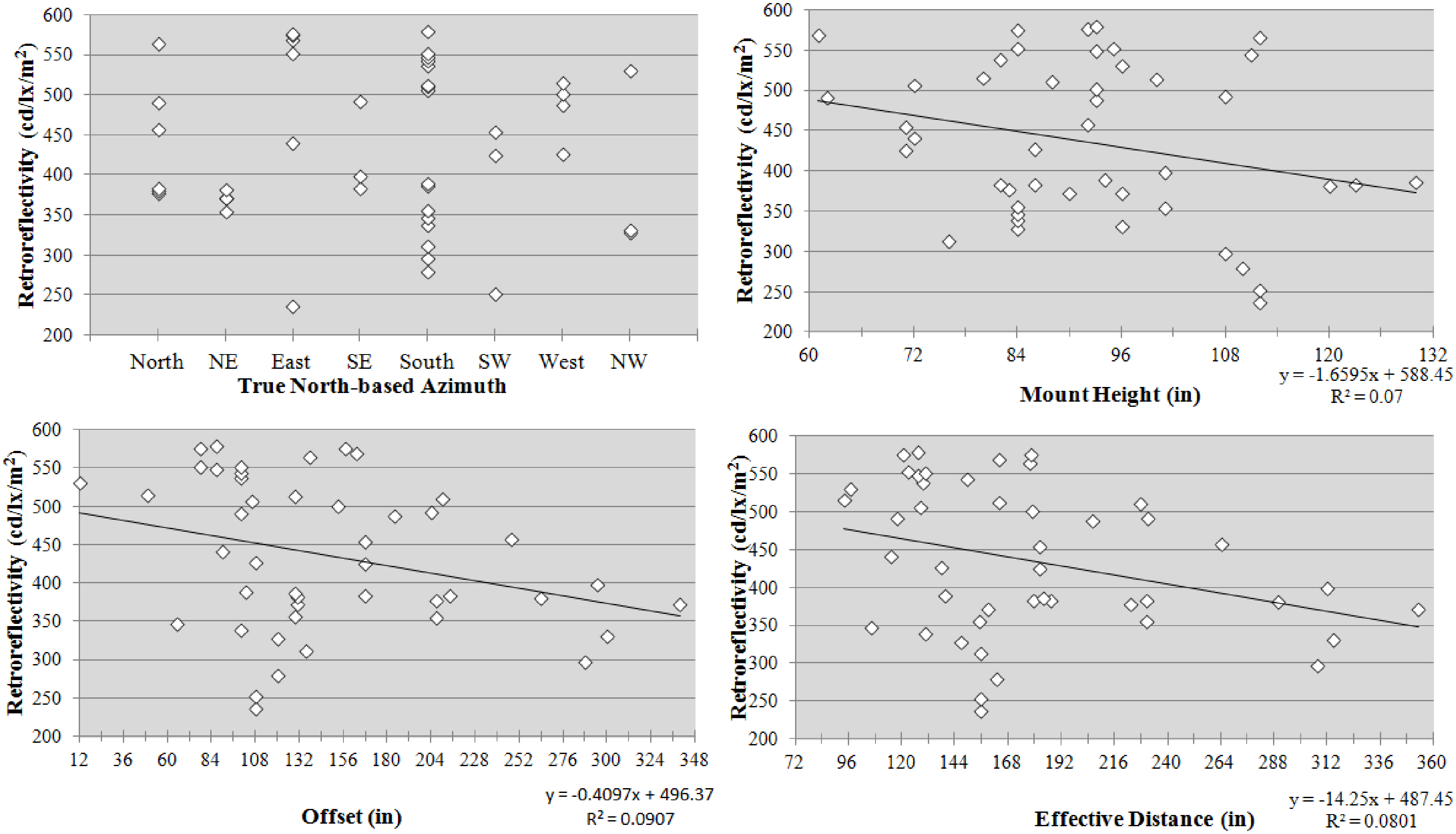

Figure B.23 Type IX White Performance Trends

<u>UDOT ASTM Type IX Yellow</u>

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2) For all bold and fine symbol signs ≥ 48"
75 (cd/lx/m^2) For fine symbol signs < 48"

General Sample Information	
Sample Size	70
Failures	0
Estimated Population	3,875
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	390.24
Standard Deviation:	101.47
First Quartile:	309.13
Third Quartile:	470.63

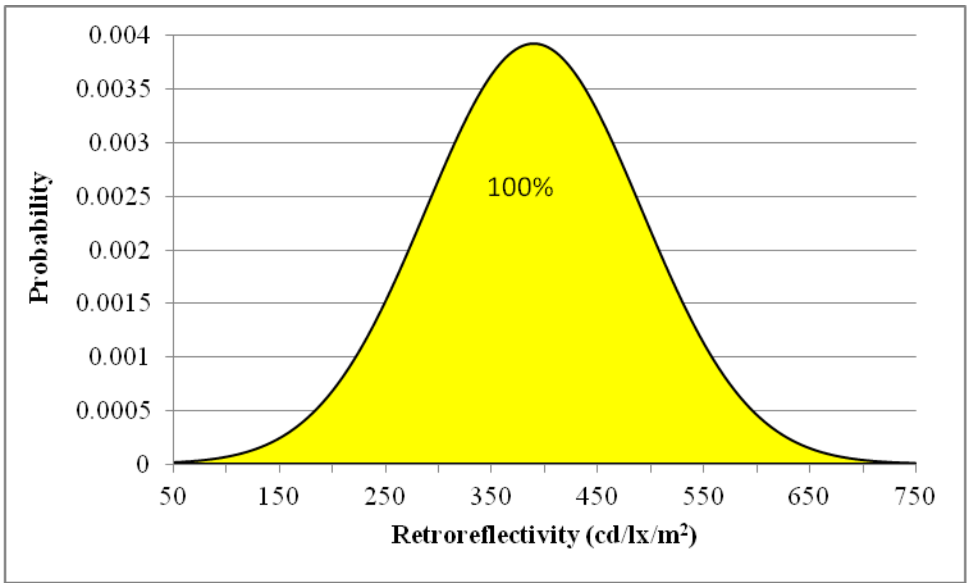

Figure B.24 Probability of Type IX Yellow Exceeding the Minimum Levels

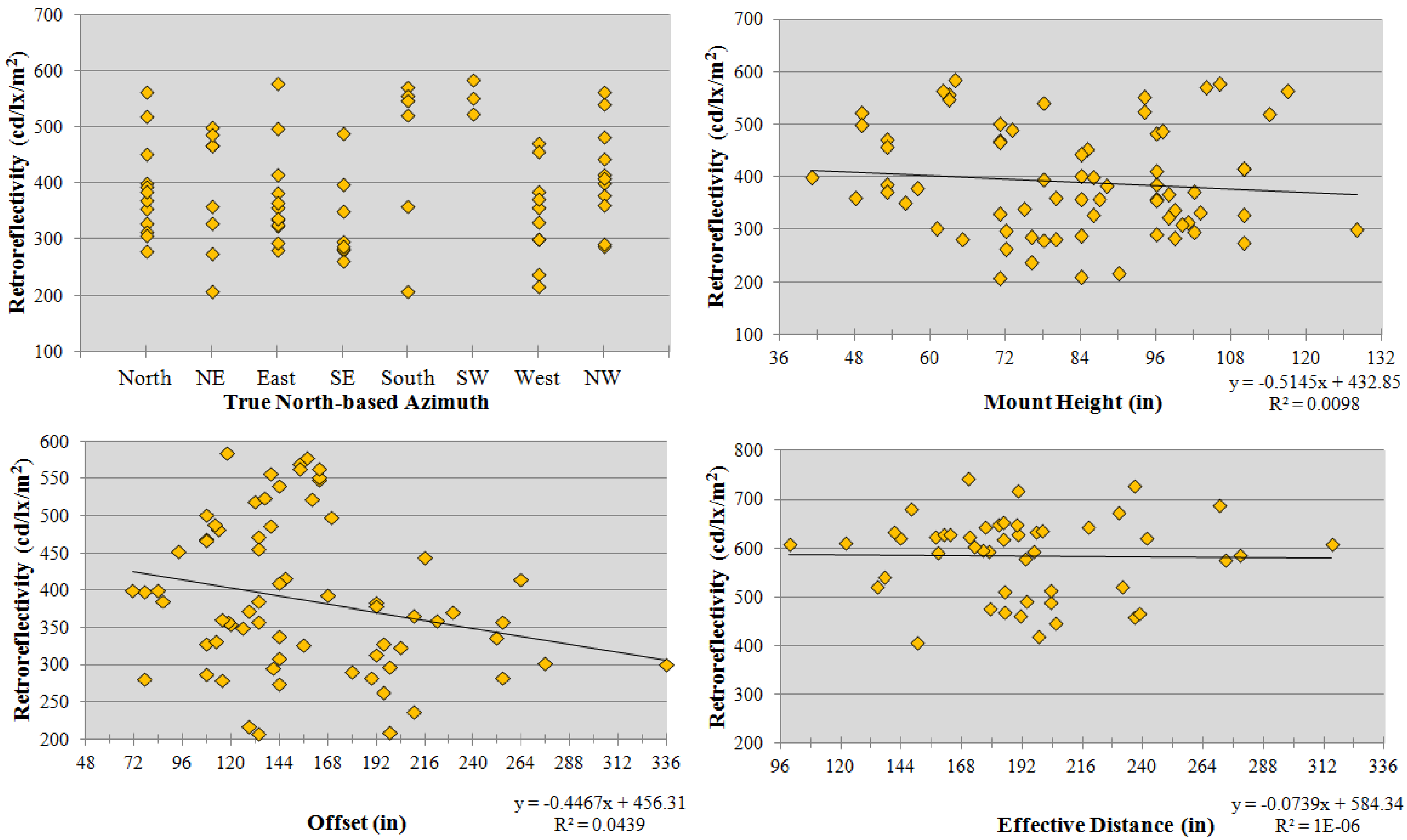

Figure B.25 Type IX Yellow Performance Trends

UDOT ASTM Type IX Green

Minimum Maintained Retroreflectivity Level Background 15 (cd/lx/m2)

Legend 120 (cd/lx/m^2)

General Sample Information	
Sample Size	42
Failures	2
Estimated Population	2,325
Estimated Failures	111

Traffic Sign Information (cd/lx/m^2)	
Mean:	55
Standard Deviation:	15
First Quartile:	51
Third Quartile:	61
Avg. Contrast Ratio:	7

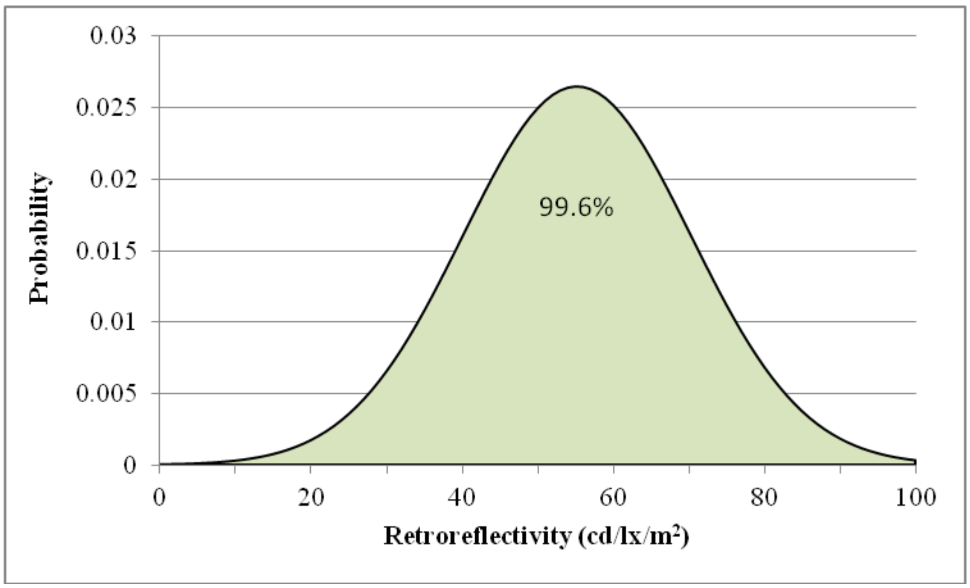

Figure B.26 Probability of Type IX Green Exceeding the Minimum Levels

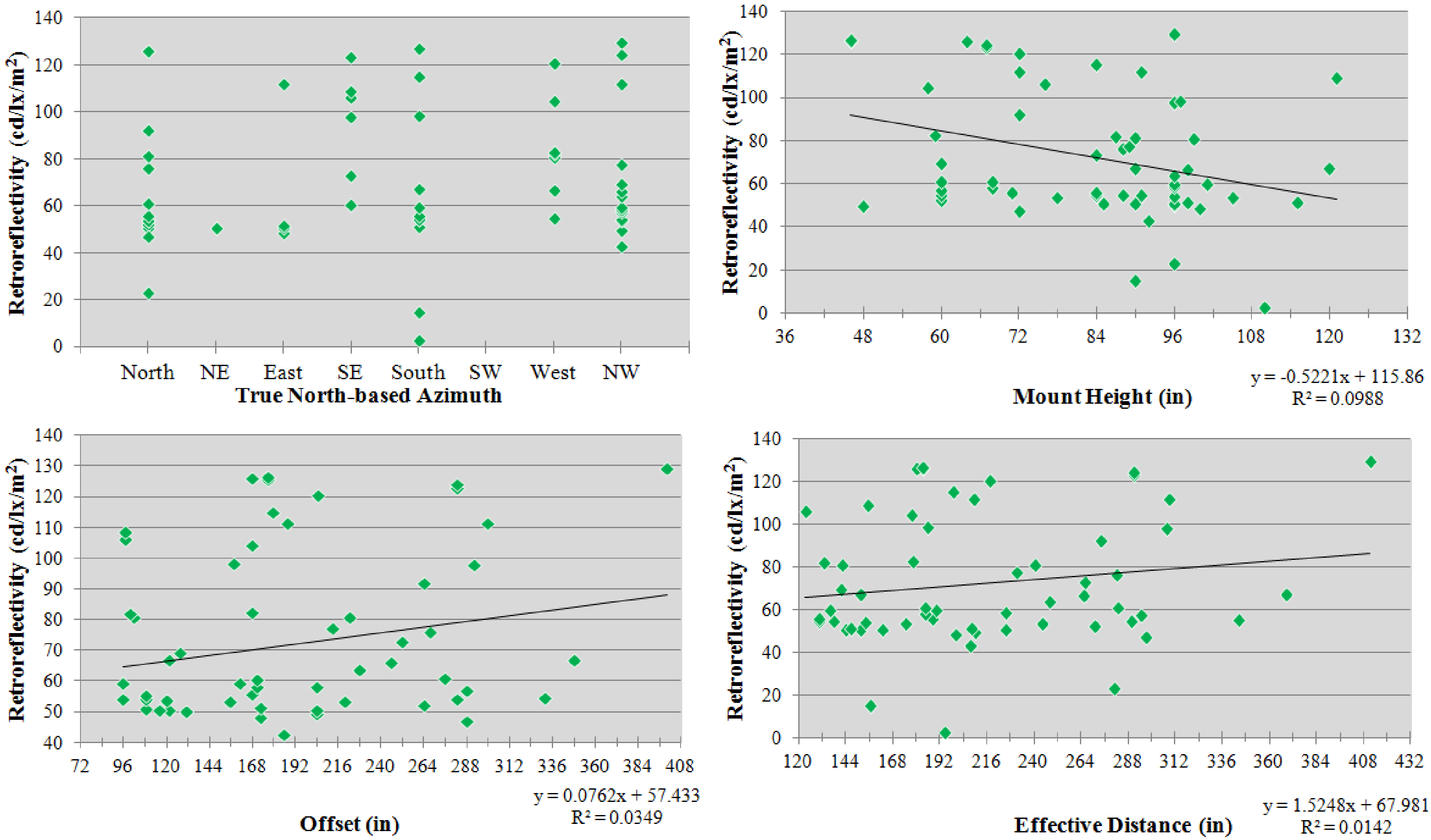

Figure B.27 Type IX Green Performance Trends

Table B.7 Distribution of Type IX Signs by Color and Maintenance Region

Region	Red	White	Yellow	Green	Total
One	4	13	23	12	52
Two	14	20	10	10	54
Three	1	1	11	5	18
Four	4	11	26	15	56
Total	23	45	70	42	180

Table B.8 ASTM Type IX Descriptive Statistics

Color	Min	Max	Mean	STDV
Red	58	142	86	23
White	236	579	436	97
Yellow	208	584	390	101
Green	3	82	55	15

ASTM Type XI

UDOT ASTM Type XI Red

Minimum Maintained Retroreflectivity Level Background 7 (cd/lx/m^2)
Legend 35 (cd/lx/m^2)
Contrast Ratio L:B ≥ 3:1

General Sample Information	
Sample Size	20
Failures	1
Estimated Population	1,107
Estimated Failures	55

Traffic Sign Information (cd/lx/m^2)	
Mean:	130
Standard Deviation:	47
First Quartile:	100
Third Quartile:	168
Avg. Contrast Ratio:	6

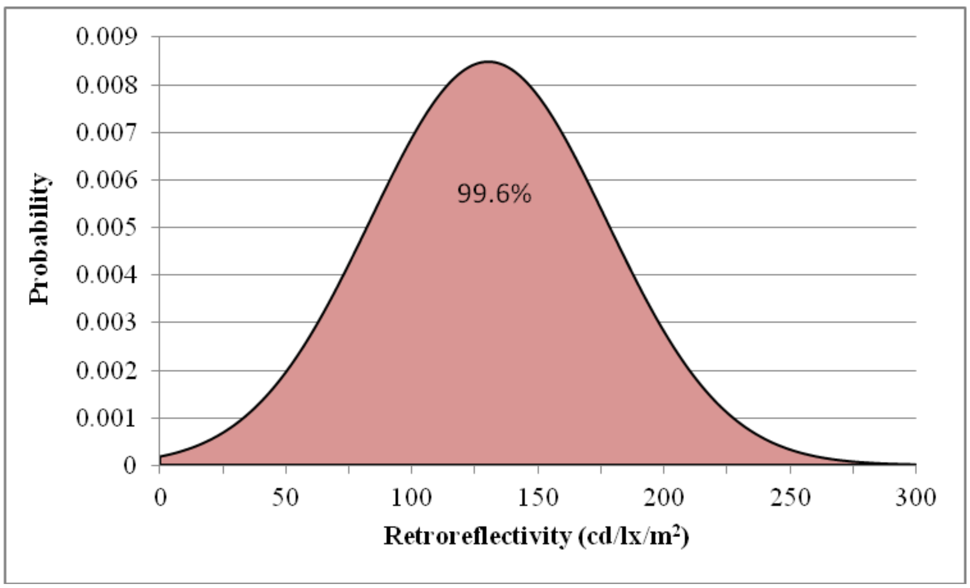

Figure B.28 Probability of Type XI Red Exceeding the Minimum Levels

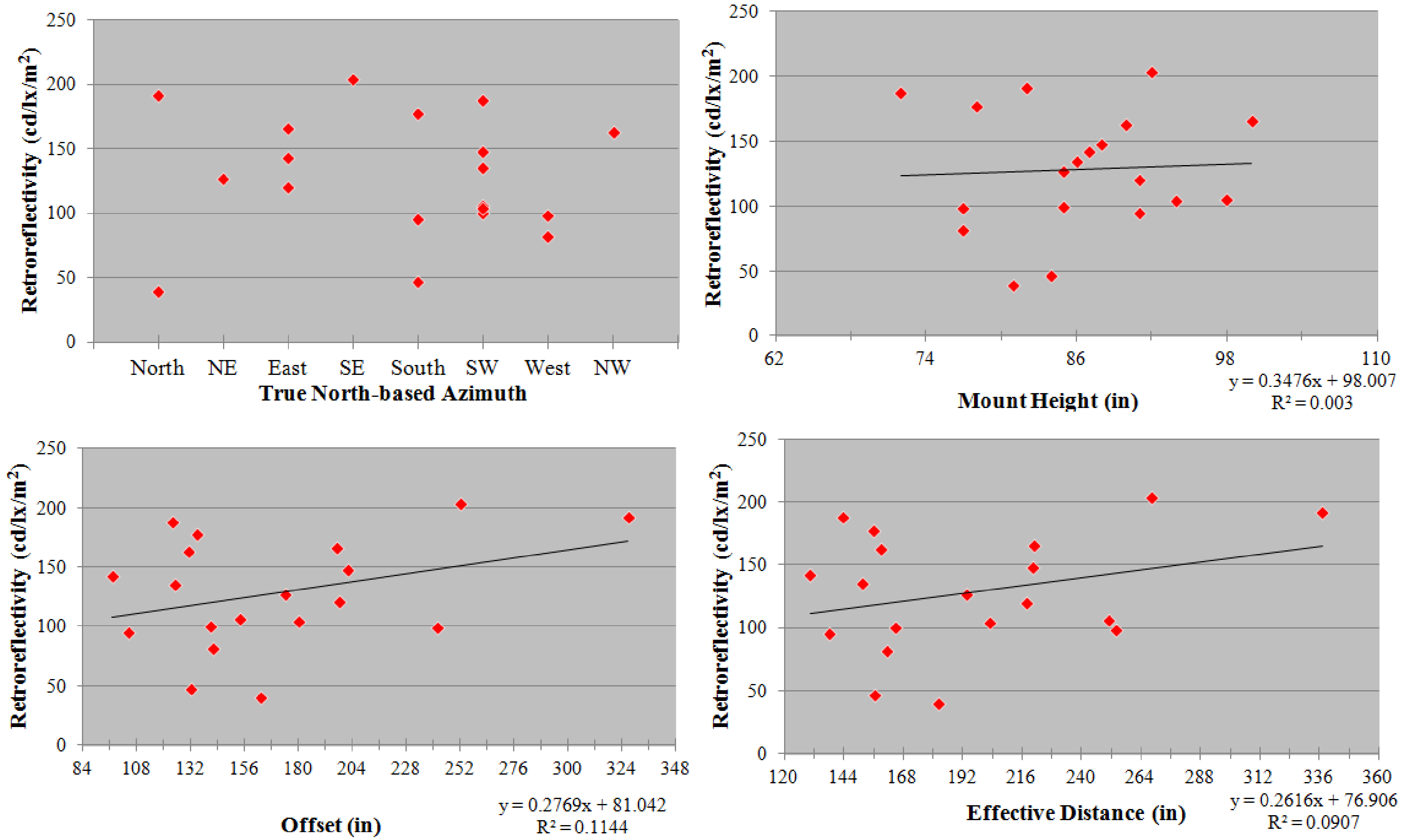

Figure B.29 Type IX Red Performance Trends

UDOT ASTM Type XI White

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2)

General Sample Information	
Sample Size	65
Failures	0
Estimated Population	3,598
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	709
Standard Deviation:	127
First Quartile:	628
Third Quartile:	789

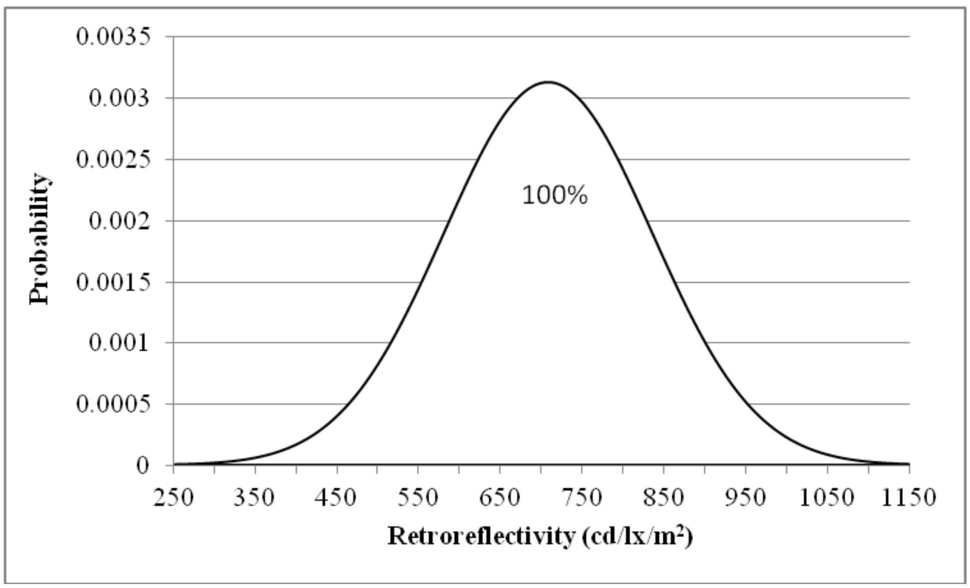

Figure B.30 Probability of Type XI White Exceeding the Minimum Levels

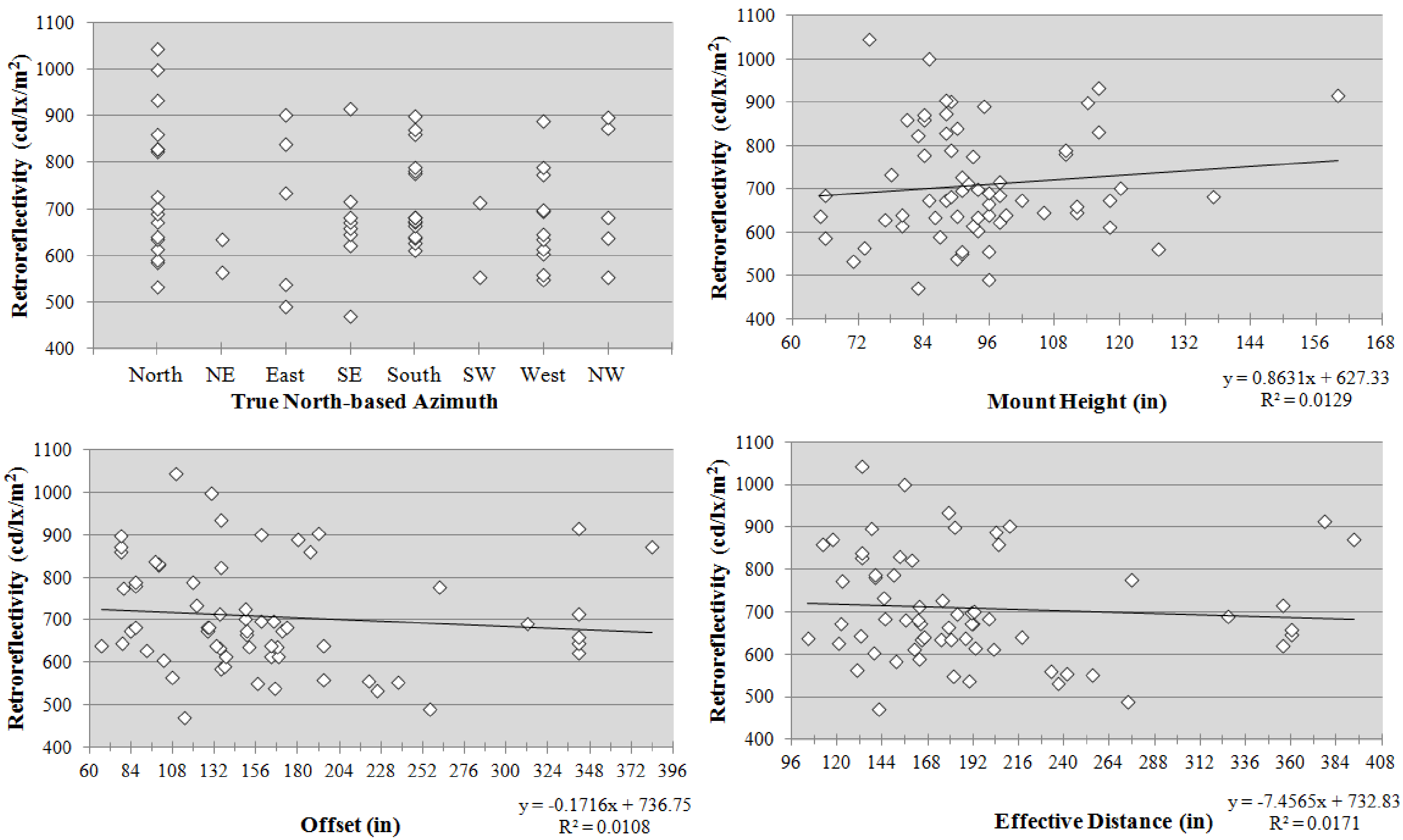

Figure B.31 Type XI White Performance Trends

UDOT ASTM Type XI Yellow

Minimum Maintained Retroreflectivity Level 50 (cd/lx/m^2) For all bold and fine symbol signs ≥ 48"
75 (cd/lx/m^2) For fine symbol signs < 48"

General Sample Information	
Sample Size	48
Failures	0
Estimated Population	2,657
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	584
Standard Deviation:	83
First Quartile:	517
Third Quartile:	632

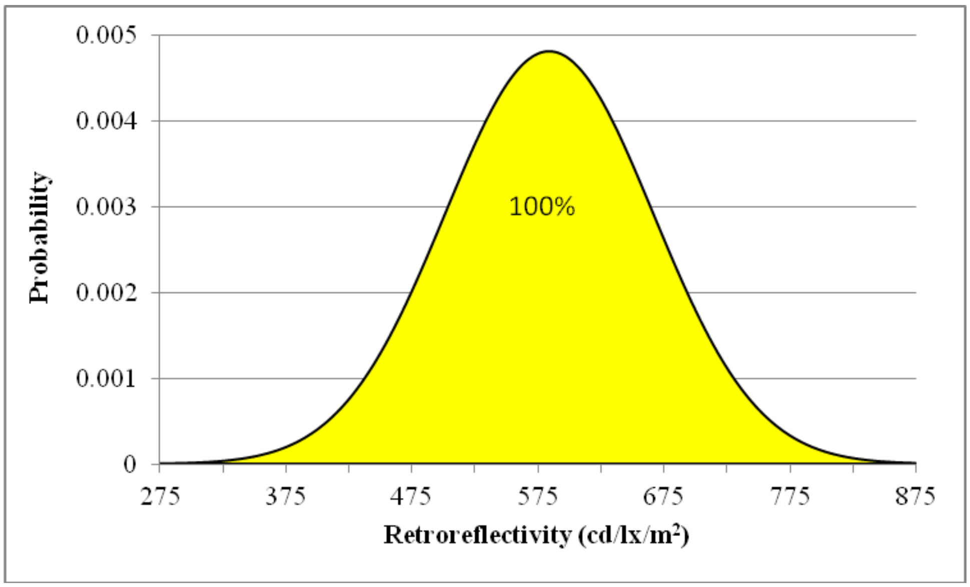

Figure B.32 Probability of Type XI Yellow Exceeding the Minimum Levels

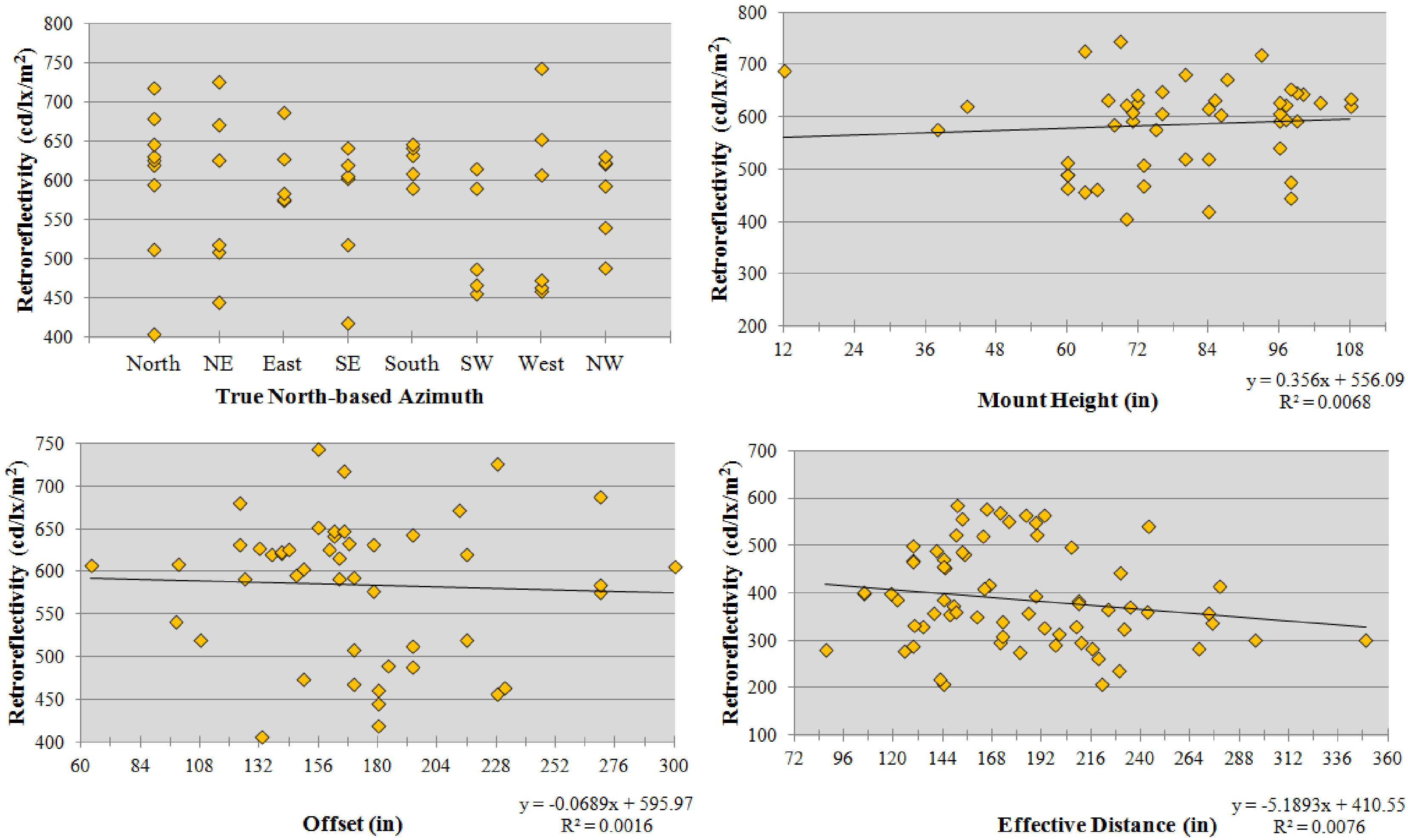

Figure B.33 Type XI Yellow Performance Trends

UDOT ASTM Type XI Green

Minimum Maintained Retroreflectivity Level Background 15 (cd/lx/m2)

Legend 120 (cd/lx/m^2)

General Sample Information	
Sample Size	57
Failures	0
Estimated Population	3,156
Estimated Failures	0

Traffic Sign Information (cd/lx/m^2)	
Mean:	99
Standard Deviation:	21
First Quartile:	85
Third Quartile:	113
Avg. Contrast Ratio:	6

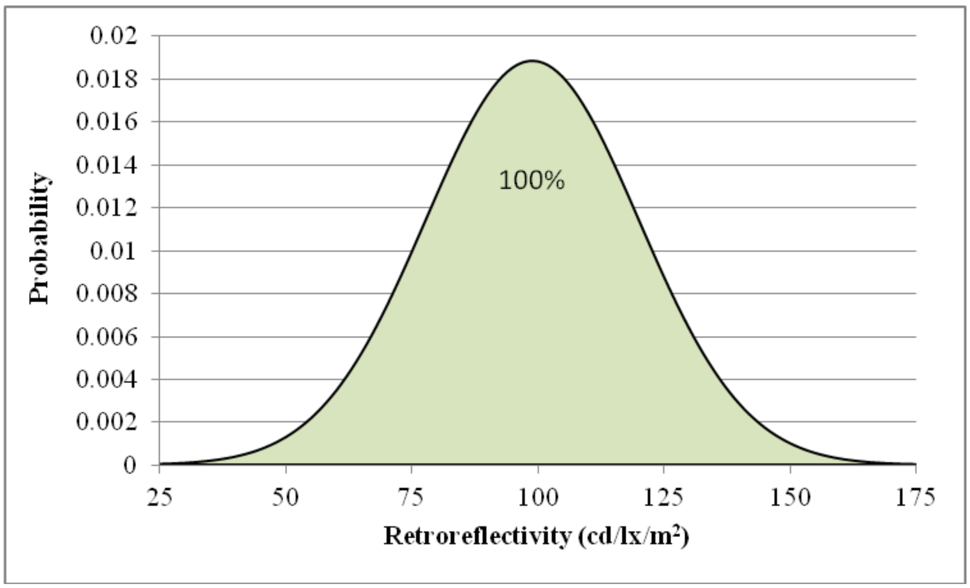

Figure B.34 Probability of Type XI Green Exceeding the Minimum Levels

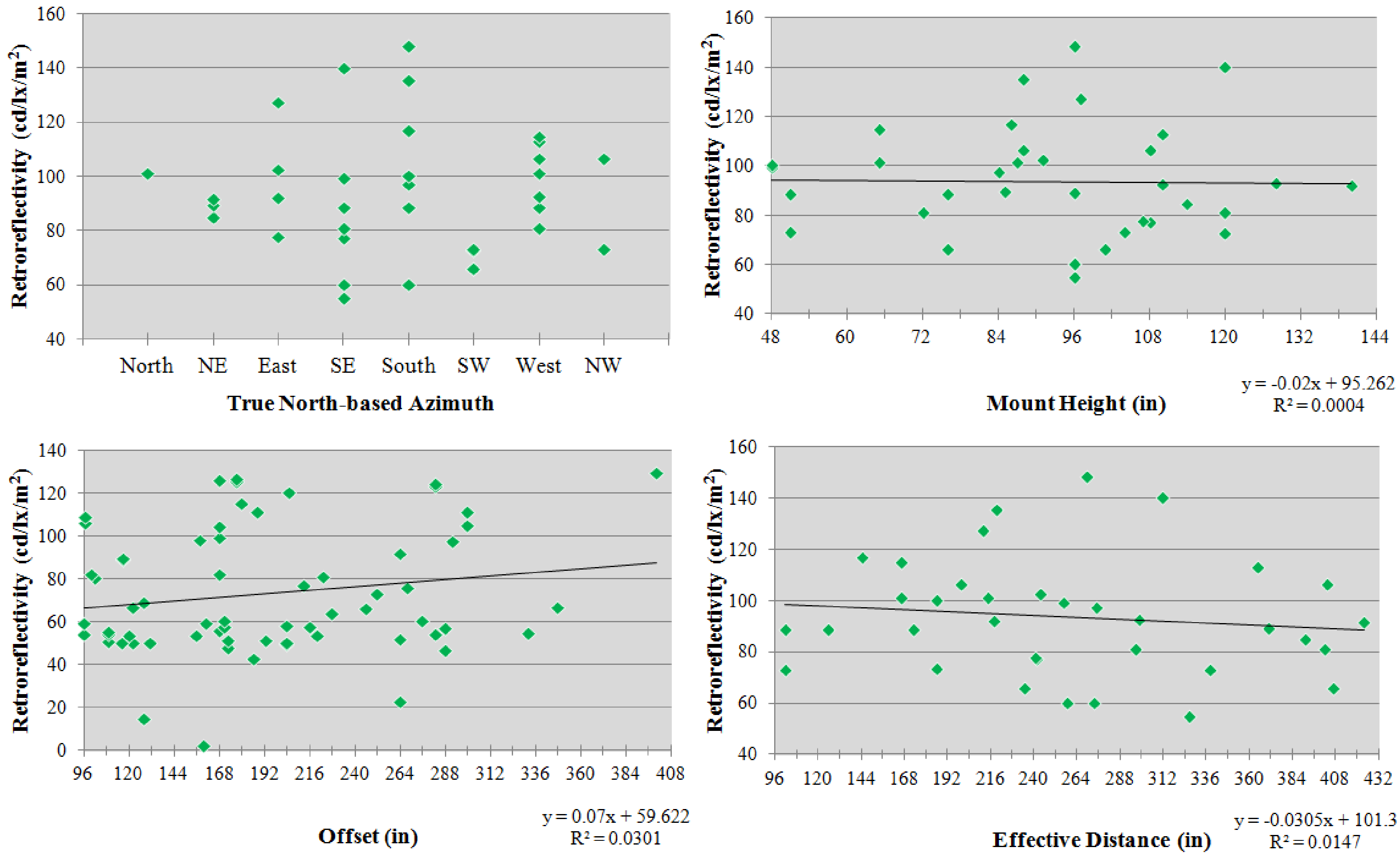

Figure B.35 Type XI Green Performance Trends

Table B.9 Distribution of Type XI Signs by Color and Maintenance Region

Region	Red	White	Yellow	Green	Total
One	3	14	12	8	37
Two	1	19	10	16	46
Three	3	13	16	15	47
Four	13	19	10	18	60
Total	20	65	48	57	190

Table B.10 ASTM Type XI Descriptive Statistics

Color	Min	Max	Mean	STDV
Red	39	204	130	47
White	472	1,045	709	127
Yellow	406	743	584	83
Green	55	148	99	21

Table B.11 Descriptive Statistics Summary

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

APPENDIX C: DETERIORATION TRENDS FOR UDOT TRAFFIC SIGNS

Within this appendix are the deterioration trends for each sheeting type and color. During the collection effort only 294 of 1,716 traffic signs had observed or known installation dates, therefore only the deterioration trends for sheeting type and color combinations with adequate population size are shown. Due to the poor fit of all deterioration curves it is recommended that no service life estimates be made off of this analysis.

The only ASTM Type III color that had an adequate sample size for deterioration analysis was green. The majority of Type III green installation dates were provided by UDOT's milepost database and had no installation designation observed in the field. Figure C.1 displays the deterioration trend for Type III green background and white legend sheeting. In total there were 104 Type III green installation dates. Form this sample it appears that the Type III green retroreflective performance is increasing, rather than decreasing over time. This could be a product of the limited installation data spread or the fading of the darker overlay over time. The trend exhibited by the legend of these signs follows a more realistic trend. Since the background has an unrealistic retroreflectivity trend with service life, the estimated service life will be estimated off of the legend requirement for green post-mount traffic signs. The minimum retroreflectivity for the legend is 120 cd/lx/m^2, which produces an estimated service life of 21 years.

Figure C.1 Type III Green Deterioration Trends

Similar to Type III green, the majority of installation dates for green Type III HIP were obtained from UDOT. By the completion of the sample survey a total of 24 Type III HIP installation dates were known. As discussed in Section 0 the legend on over half of Type III HIP green signs was ASTM Type III sheeting. The difference in the performance of the two legend types is evident in Figure C.2. Only one sign observed during the sample survey had Type III HIP legend and recorded a measured retroreflectivity twice as high as the Type III legends. The practice of using a lower performing sheeting type for the legend on green traffic signs is a potentially dangerous one. This causes the contrast ration between the legend and background to decrease, which reduces the overall legibility of the sign and increases the required reaction time for the motorist. Even though the MUTCD has not mandated a minimum contrast ratio for green signs, it should be taking it into consideration. As seen in the minimum maintained retroreflectivity levels, for overhead signs Type III sheeting is only allowed for the background and in order to be considered compliant the legend must be prismatic. The deterioration for the green background is essentially flat, with a slight decrease over time. Since the recorded deterioration is so slight no realistic service life can be estimated. Ignoring the Type III HIP measurement produces a deterioration trend that is nearly identical to the Type III legend deterioration determined in the previous section.

Figure C.2 Type III HIP Green Deterioration Trends

By the completion of the sample survey a total of 31 ASTM Type IX green traffic signs had known installation dates. A total of 13 installation dates were obtained from UDOT milepost data. Similar to the other sheeting types the green background showed to have minor deterioration over time, shown in Figure C.3. Although 14 percent of Type IX green signs had Type III legends the retroreflective efficiency of Type III and Type IX white are similar. The flat deterioration trend of the background yields an unrealistic deterioration trend. However, utilizing the legend deterioration an estimated service of 15 years can be determined. Since this service life estimate contains Type III legend recordings it can be assumed that a slightly higher service life can be achieved by Type IX green sheeting.

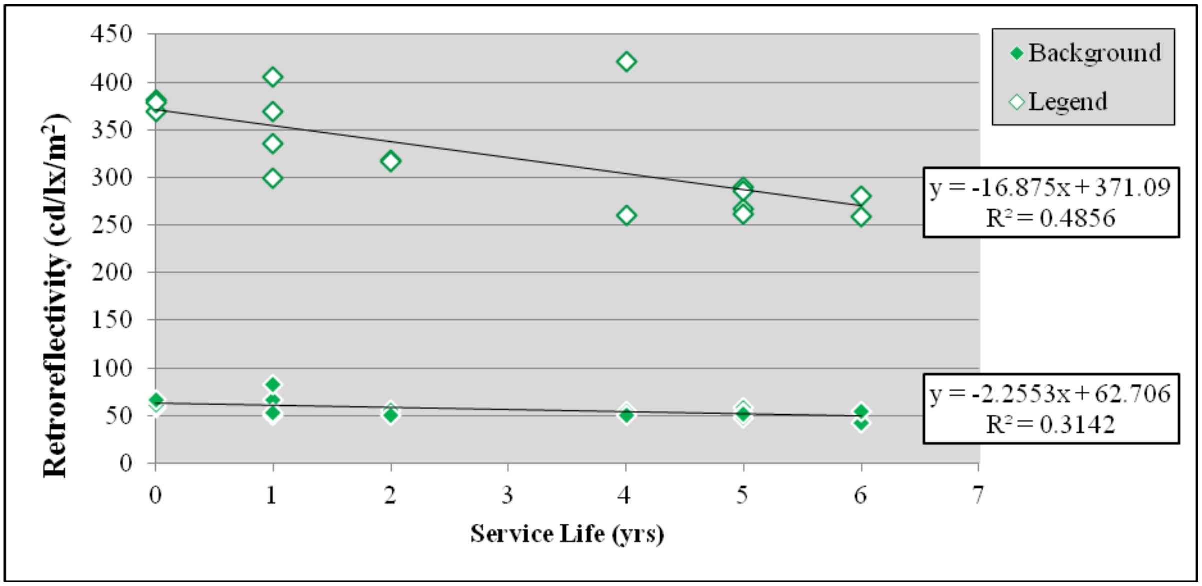

Figure C.3 Type IX Green Deterioration Trends

A total of 37 Type XI green traffic signs, with known installation dates, were observed by the completion of the collection effort. The major difference between the Type XI and the other green sheeting types is that the major of the installation dates were observed on in service traffic signs. Figure C.4 displays the performance of green Type XI with known installation dates. Similar to the other green backgrounds the deterioration of Type XI is relatively flat. Using the deterioration for the legend a service life of 20 years is calculated. Only 10 percent of Type XI green signs had Type III legend, which is evident by the high y-intercept.

Figure C.4 Type XI Green Deterioration Trends

For all green sheeting types the retroreflectivity measurements for the background were grouped very closely, with mean retroreflectivity values of 47, 100, 55, and 99 cd/lx/m^2 for Type III, III HIP, IX and XI, respectively. This is due to the way green signs are constructed. Sign legends are produced by the following methods:

- Cut-out Letters and Symbols: retroreflective sheeting is cut and applied to the sign face.
- Demountable Copy: This legend is made of retroreflective sheeting applied to a thin aluminum backing, which is then cut into the letter and legend shapes and then riveted to the sign face. This permits the sign legend to be changed or removed without having to replace the sign panel.
- Positive Silk Screen: Used for signs with legends darker than the background, such as most regulatory and warning signs. The legend is applied directly onto the colored sign face with opaque ink.
- Negative Silk Screen: Used for signs with legends lighter than the background, such as R1-1 and Interstate shields. The process begins with a white sign face, then a translucent ink is applied onto the sign face, with exception of the legend or regions of other colors. This produces a white legend on a colored background.

- Overlay Film: Also used for signs with legends lighter than the background. The process begins with a white sign face, and then the overlay film in the appropriate color is cut to remove sections where the white is to show through. This overlay film is then applied onto the sign face.

The majority of green signs under UDOT’s jurisdiction are produced using cut-out letters and symbols, negative silk screen, overlay film or a combination of these processes. The purpose of the green ink/film is to color the white sheeting, while allowing retroreflectivity of the white sheeting to shine through. Since green signs require a contrast between the legend and the background the amount of light allowed through the translucent ink/film is reduced. This is evident due to the measured retroreflectivity of green legends and backgrounds. This is the reason why even after several years in service the retroreflective measurements are near those of brand new traffic signs.

At the completion of the sample survey a total of six yellow Type III HIP traffic signs were observed with installation stickers. From the known installation data the trend line in Figure C.5 was developed. The trend line for yellow Type III HIP predicts an expected service life of 15 years. Although the expected service life is realistic the sample size is not significant enough.

By the completion of the sample survey a total of 36 Type IX yellow signs had known installation dates. From the linear analysis, shown in Figure C.6 the estimated service life would be 18 years. A total of ten Type XI yellow signs had known installation dates. Due to the limited spread of installation dates for this type of sheeting the sheeting is becoming brighter over time. As more installation dates are found for older samples this deterioration curve, shown in Figure C.7, should become more realistic

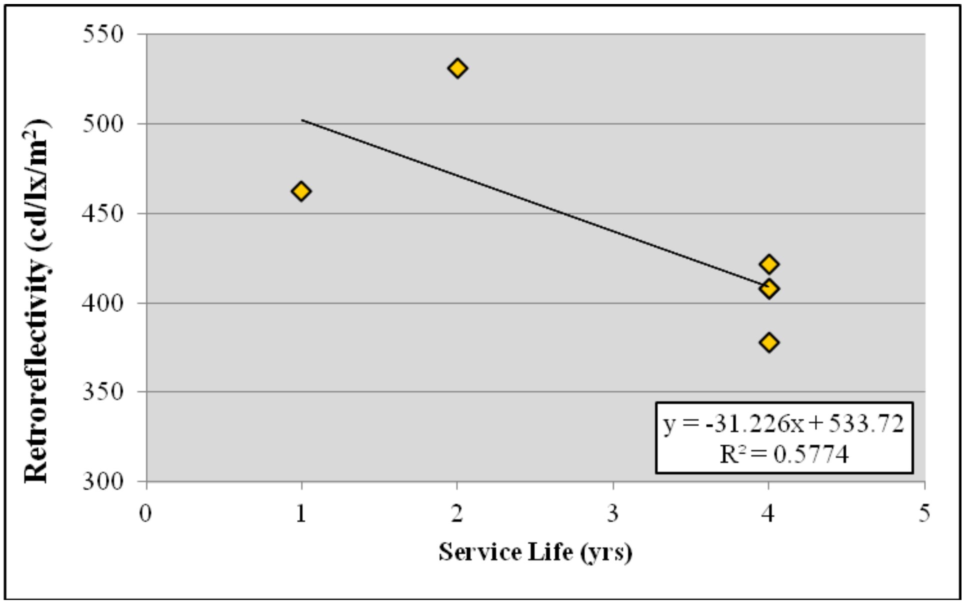

Figure C.5 Type III HIP Yellow Deterioration Trend

Figure C.6 Type IX Yellow Deterioration Trend

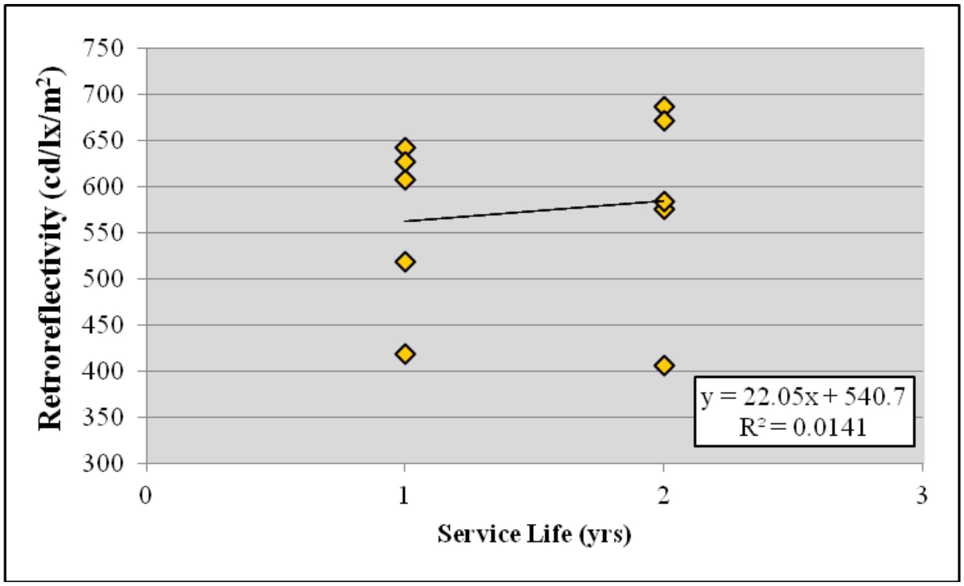

Figure C.7 Type XI Yellow Deterioration Trend

At the conclusion of the collection effort a total of 20 Type IX white signs had known installation dates. The majority of these signs were new installations with lower retroreflectivity measurements resulting from inclement weather conditions. The linear trend line for Type IX white is shown in Figure C.8 with an estimated service life of 20 years.

By the completion of the sample survey a total of 20 Type XI white signs had known installation dates. Similar to the Type XI yellow, due to the limited spread in installation dates the deterioration curve, in Figure C.9, shows an increases in retroreflectivity over time. As this sheeting type begins to age and more signs are measured the deterioration curve should begin to show a decrease in retroreflectivity.

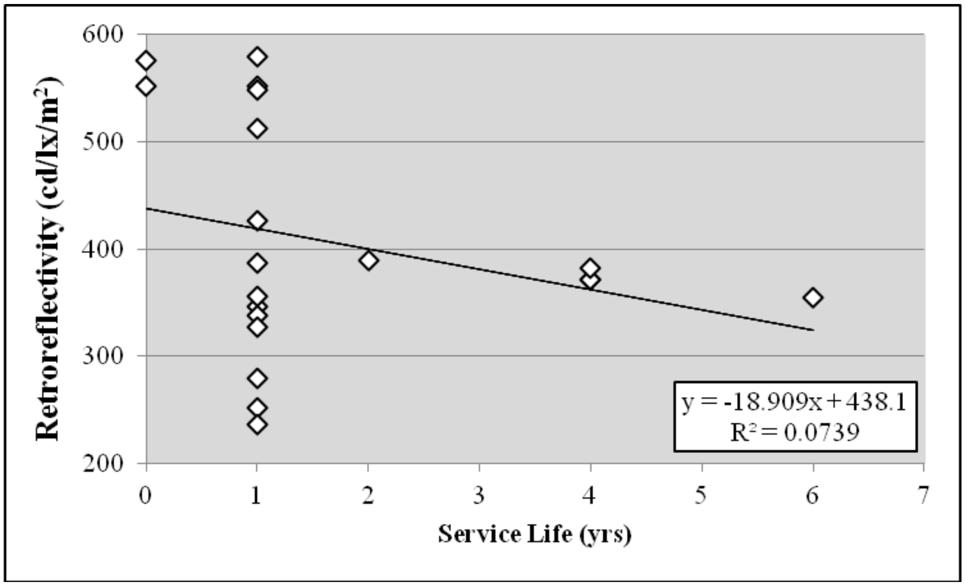

Figure C.8 Type IX White Deterioration Trend

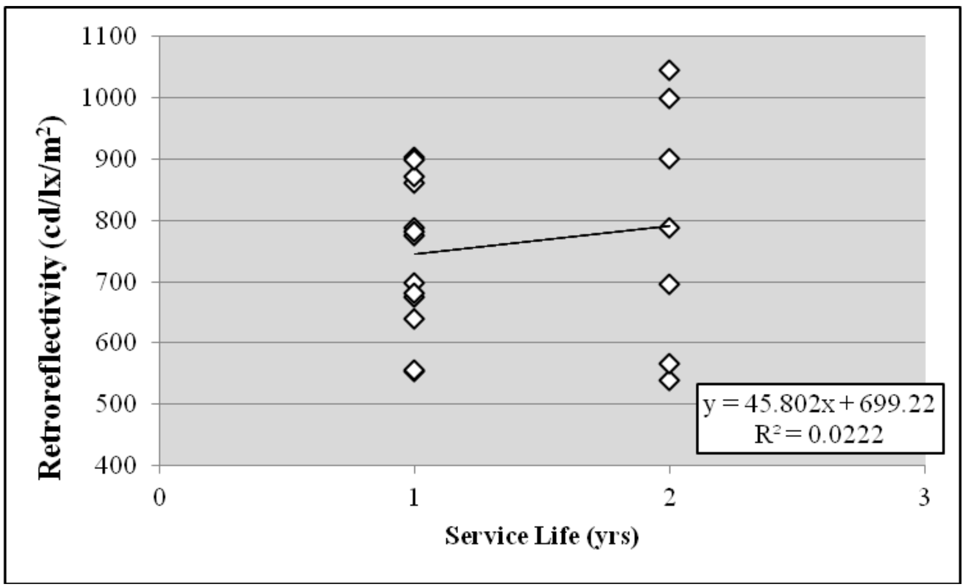

Figure C.9 Type XI White Deterioration Trend