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16. Abstract

This study evaluated TxDOT's current sign retroreflectivity maintenance practices, assessed their effectiveness, and recommended statewide sign retroreflectivity maintenance practices that could be easily and effectively implemented to ensure that TxDOT would be in compliance with the new MUTCD language related to minimum sign retroreflectivity. The researchers measured the retroreflectivity of almost 1400 signs across the state to assess the effectiveness of TxDOT's current practices, evaluated a mobile sign retroreflectivity measurement technology, visited district and maintenance offices across the state, studied the effectiveness of using the calibrated sign and comparison panel procedures of the visual nighttime sign inspection maintenance method, developed a standardized form for making and documenting nighttime inspection, and made recommendations for changes in TxDOT's current sign retroreflectivity maintenance practices. Researchers concluded that TxDOT's current practices are quite effective compared to the minimum retroreflectivity levels in the 2011 Texas MUTCD. Three specific recommendations are provided that will bring TxDOT's current practices into compliance with the 2011 Texas MUTCD. First, TxDOT should provide calibration signs to the maintenance sections. Second, a standardized form should be used to conduct inspections and document inspections. Finally, a training program should be implemented to educate the inspectors on how to conduct the inspections and the importance of sign retroreflectivity.

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RESEARCH AND RECOMMENDATIONS FOR A STATEWIDE SIGN RETROREFLECTIVITY MAINTENANCE PROGRAM

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The engineer in charge of this project was Paul J. Carlson, P.E. #85402.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1: INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA), there were fewer than 31,000 fatal crashes in 2009 (*1*). While only a quarter of travel occurs at night (*2*), about one-half of the traffic fatalities occur during nighttime hours (*1*). This translates to a nighttime fatality rate that is approximately three times greater than that of daytime. While fatigue and alcohol are probable factors to the unbalanced day/night fatality ratio, no one factor can be singled out. It is reasonable to expect that critical traffic signs be visible to drivers at night to facilitate safe night driving.

Maintaining traffic sign retroreflectivity is an important consideration to improving safety on the nation's streets and highways. Safety and operational strategies are dependent on sign visibility that meets the needs of drivers. One can expect that improvements to nighttime visibility of traffic signs will help drivers better navigate the roads at night and thus promote safety and mobility. Improvements in sign visibility will also support TxDOT's efforts to be responsive to the needs of older drivers whose visual capabilities are declining. This is important because the number of older drivers is expected to increase significantly in the coming years. Currently, 26.2 million drivers are 65 or older, and by 2010 an estimated 33.7 million drivers will be 65 or older (*3*).

The opening statements of the *Manual on Uniform Traffic Control Devices* (MUTCD) in Section 1A.01 define the purpose of traffic control devices and the principles for their use to be the promotion of highway safety and efficiency by providing for the orderly movement of all road users (*4*). Those devices notify road users of regulations, provide warning, and give guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. Requirements for nighttime sign visibility have been included in every version of the MUTCD since the first edition in 1935. The latest edition of the MUTCD, the 2009 edition, continues to address the visibility of signs but in an escalated way with the introduction of minimum retroreflectivity levels in Section 2A.08.

The FHWA developed minimum maintained traffic sign retroreflectivity levels in response to a Congressional directive in the Department of Transportation and Related Agencies Appropriations Act, 1993 (*5*). Section 406 of this Act directed the Secretary of Transportation to revise the MUTCD to include a standard for minimum levels of retroreflectivity that must be maintained for traffic signs and pavement markings, which apply to all roads open to public travel. As part of the FHWA's plan to meet the Congressional directive described above, the FHWA has outlined methods that agencies can implement to maintain minimum traffic sign retroreflectivity levels in conformance with the MUTCD requirements. As a result of rulemaking, agencies will need to implement sign maintenance methods that incorporate the consideration of minimum retroreflectivity levels to provide for nighttime visibility of signs.

The MUTCD includes a list of approved methods to maintain traffic sign retroreflectivity. TxDOT already implements several processes that are intended to maintain traffic sign retroreflectivity. This study evaluated TxDOT's current sign retroreflectivity maintenance practices, assessed their effectiveness, and recommended statewide sign retroreflectivity maintenance practices that could be easily and effectively implemented to ensure that TxDOT would be in compliance with the new MUTCD language related to minimum sign retroreflectivity.

CHAPTER 2:
STATE-OF-THE-PRACTICE

There have been numerous retroreflective sign sheeting and maintenance studies in the last decade as a result of the FHWA's mandated minimum retroreflectivity standards. Included in this literature review are a background discussion of retroreflectivity and the development of minimum requirements.

RETROREFLECTIVITY

Drivers need to be able to view and comprehend traffic signs in both daytime and nighttime conditions. Signs that are not illuminated are manufactured from retroreflective materials. Retroreflective signs reflect light from the vehicles' headlights back toward the driver. At night, these signs appear to be illuminated. The efficiency of a sign to retroreflect light back toward the driver is partly dependent on the coefficient of retroreflection (R_A). The R_A value is the ratio of light reflected by a surface (luminance measured in candelas per meter squared) to the initial amount of light hitting the surface (illuminance measured in lux). The ratio is expressed in units of candelas per lux per meters squared ($cd/lx/m^2$).

The luminance of the sign is dependent on the light source intensity, the retroreflective material, and the context of angularity. In simple terms, the context of angularity consists of the entrance angle and the observation angle. The entrance angle is the angle between the incoming light source and the normal axis from the surface of the sign. The observation angle is the angle between the illumination path of the headlights and the observation path of the driver. The location of the sign and vehicle determines the entrance angle while the distance between the drive's eye and headlights determines the observation angle. Both angles affect the amount of returned luminance. For retroreflective measurements, the *Manual on Uniform Traffic Control Devices* calls for an observation angle of 0.2° and an entrance angle of −4° (*4*).

Types of Retroreflective Sheeting

Retroreflective sign materials are comprised of either spherical optics or prismatic optics. Spherical optics employ glass spheres or beads with a reflective mirror backing. Light enters the glass sphere and is directed to a focal point where it is returned to its original direction via the mirrored surface. Prismatic optics provide retroreflection when light is reflected off microscopic mirrored surfaces and redirected back to the source. The exact orientation of the mirrored surfaces is unique to each manufacturer. Both types of retroreflective optics are common and are widely manufactured.

The three common types of manufactured sign sheeting consist of enclosed beads, encapsulated beads, and prismatic sheeting. Enclosed bead sheeting consists of glass beads imbedded in a layer of transparent plastic that is protected by a metallic reflective shield. Encapsulated bead sheeting is similar except that there is a thin layer of air between the glass beads and plastic layer. The layer of air helps to enhance sheeting durability and the retroreflective capabilities. Prismatic sheeting is made up of many small cube corners molded into transparent plastic film. The color of prismatic sheeting is either imprinted into the film or on the reflecting surface. The ASTM International assigns a roman numeral to each specific type of sheeting (*6*), and TxDOT denotes them with a letter (*7*). Table 1 contains common types of sign sheeting and the ASTM and TxDOT nomenclature.

Table 1. Common Sign Sheeting Nomenclature.

Sign Sheeting Naming	ASTM D4956 (*6*)	TxDOT DMS8300 (*7*)
Engineering Grade (Enclosed Beads)	Type I	A
Super Engineering Grade (Enclosed Beads)	Type II	B
High Intensity Grade (Encapsulated Beads)	Type III	C
High Intensity Grade (Prismatic)	Type IV	C
Non-Fluorescent Prismatic	Type VIII, IX, XI	D
Fluorescent Prismatic	Type VIII, IX, XI	E

MINIMUM RETROREFLECTIVE REQUIREMENTS

In 1993, Congress required the Secretary of Transportation to revise the MUTCD to include "a standard for a minimum level of retroreflectivity for pavement markings and signs, which apply to all roads open to public travel" (*5*). Several research efforts helped to establish minimum retroreflective values for traffic signs. Paniati and Mace were the first researchers to determine minimum requirements for regulatory, warning, and guide signs (*8*). The researchers developed a program called the Computer Analysis of the Retroreflectance of Traffic Signs (CARTS) to generate the values. The CARTS model incorporated various driver, vehicle, and roadway parameters such as headlight height, sign location, vehicle offset to sign, etc. The

CARTS models computed the minimum required visibility distance (MRVD) based on the input parameters. The MRVD was the shortest distance that a driver can safely detect, recognize, comprehend, and react to a sign. The researchers generated minimum retroreflective values for white, yellow/orange, red, and green colored sign sheeting. Paniati and Mace also identified that signs should maintain a minimum background and legend color contrast ratio of 4:1.

In 1995, Mercier et al. tested if Paniati and Mace's minimum requirements would sufficiently meet the needs of an aging driving population (*9*). Paniati and Mace estimated that their minimum values would be adequate for 75 to 85 percent of the driving public. Following the initial research, there was more of an emphasis to accommodate older or more vulnerable drivers. Mercier et al. measured the luminance thresholds for various traffic signs in a laboratory setting and determined what percentage of the driving population were accommodated by the proposed minimum values. In the laboratory, subjects viewed "scaled" traffic signs at simulated viewing distances to replicate the MRVD. Traffic sign luminance was increased for each sign until the subjects could correctly respond to the signs' content. Overall, the analysis determined that 85 percent or more of all drivers would be accommodated by the proposed minimum retroreflective values, which the researchers referred to as "fairly conservative" (*9*).

Carlson and Hawkins established the final FHWA minimum retroreflective values (*10*). This study utilized the previous concepts developed in Paniati and Mace's CARTS program. Carlson and Hawkins conducted their analysis to reflect recent developments in vehicle headlamps, vehicle types/sizes, drivers' nighttime needs, and the latest sheeting materials. The researchers also employed a new analysis tool that computed retroreflectivity requirements for traffic signs in various positions (right, left, and overhead) on the roadway. The final minimum requirements were adopted by the FHWA and are contained in Table 2A-3 of the 2009 MUTCD (*4*). Table 2 contains the MUTCD minimum requirements and the specific applications.

Table 2. MUTCD Minimum Maintained Retroreflectivity Levels.[1]

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

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

Body Systems

- 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.

Note: This table is a replica of Table 2A-3 in the 2009 MUTCD (*4*)

RETROREFLECTIVITY MAINTENANCE METHODS

The MUTCD states that "Public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels" (*4*). Traditionally, each state and local agency managed and maintained their traffic sign inventory in a manner that best suited their specific conditions, resources, and priorities. For this reason, the MUTCD allows the flexibility to select and modify one or more methods to best fit the resources and capabilities of each individual agency. Section 2A.8 in the MUTCD offers five traffic sign maintenance methods and an "Other" method (*4*). The Other method provides additional flexibility but it must be supported by an engineering study.

The MUTCD will require each state and local agency to formally document their maintenance strategy. Agencies should also be able to show that they are actively engaged in maintaining retroreflective sign compliance. The MUTCD acknowledges that "an agency or official having jurisdiction would be in compliance if there are some individual signs that do not meet the minimum retroreflectivity levels at a particular point in time" (*4*). Conformance does not require or guarantee that every individual sign will exceed minimum retroreflectivity levels at every point during its lifecycle. The fundamental key to the MUTCD compliance is documenting the maintenance procedure and being able to verify implementation. The following subsections outline each of the five optional traffic sign maintenance methods and different approaches for implementation.

ASSESSMENT METHODS

This section describes the assessment or evaluation methods for maintaining traffic sign retroreflectivity. The two methods are the nighttime visual inspections and measured sign retroreflectivity. Both methods require physical or tangible assessment of individual signs to verify compliance with the minimum requirements.

Nighttime Visual Inspections

The visual inspection method is already the most common and easily implemented traffic sign maintenance method. The MUTCD states "The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions" (*4*). If an inspector deems that a sign falls below minimum levels, then that sign will be replaced. Besides retroreflectivity, both nighttime and daytime sign inspections can identify sign damage, message obstruction, inadequate placement, and compromised sign appearance. This method typically requires a visual inspector and a driver, an illumination source or vehicle, and a record system to document the evaluation. The simple procedure and lack of equipment makes visual inspections a practical and inexpensive option. Visual inspection may also reduce unnecessary fiscal waste by replacing only failed signs as opposed to replacing all signs in a specific area or time period. While the visual inspection is simplistic and practical, this method is subjective and tied less to retroreflective benchmark values. One way to minimize the subjective nature of visual inspections is with standardization and training.

One of the first research studies to assess and document the accuracy of visual sign inspection was conducted in the State of Washington in 1987 (*11*). The first part of the study surveyed other state DOT agencies to identify current maintenance strategies. Forty-four states completed the survey and the responses revealed that only six states maintained performance standards for retroreflective sheeting. At the time, 35 states conducted visual inspections in both daytime and nighttime. The practices varied between DOTs, but all states replaced signs if there were physical defects (i.e., peeling, delaminating, or vandalism) or retroreflectivity defects (i.e., faded colors or insufficient retroreflectivity).

The second part of the Washington study evaluated the accuracy of 17 trained sign observers (*11*). The researchers trained the observers to rate Stop and warning signs in two environmental settings: a controlled gymnasium and a stationary car on a simulated road. After training, the observers were driven on two highway courses where they rated a total of 130 traffic signs. Overall, the observers made correct ratings for 75 percent of the signs. Within the total incorrect responses, observers were more likely to replace an adequate sign as opposed to accepting a sign with insufficient retroreflectivity. Despite the incorrect responses, replacing signs that are questionable or borderline is a more conservative and preferable approach for drivers. The researchers concluded that "trained observers can make accurate and reliable decisions to replace traffic signs" (*11*).

In 1996, Hawkins et al. conducted a similar study that further built upon the Washington study's survey (*12*). In a statewide survey of TxDOT district sign maintenance offices, the researchers found that 80 percent of the districts conducted nighttime visual inspections and 65 percent also performed daytime inspections. Approximately 83 percent of the districts would implement visual inspection training when the proposed FHWA requirements took effect. The researchers also conducted a cost/benefit analysis of several different sign maintenance methods and determined that visual inspection was one of the least expensive methods and led to the lowest levels of sign waste.

In 2001, Hawkins and Carlson evaluated the accuracy of experienced TxDOT sign personnel (*13*). In the study, TxDOT staff subjectively assessed 49 signs during nighttime conditions and rated them as acceptable, marginal, or unacceptable. TxDOT observers viewed test signs on a closed-course test track at speeds of 30 to 40 mph. Evaluation scenarios varied the vehicle type and headlight intensity. The results determined that TxDOT observers rejected 26 signs despite that only one sign failed to meet the MUTCD minimum requirements. The researchers determined that overall appearance and uniformity of the sign face were as important as the retroreflectivity levels in sign assessment. The TxDOT observers identified sign inconsistencies and blemishes that rendered the sign unacceptable despite meeting the retroreflective minimums. The researchers concluded that "visual nighttime sign inspections should be a critical component of any process that evaluates the nighttime visibility of traffic signs" (*13*).

One of the more recent visual sign inspection studies was conducted in North Carolina in 2006 (*14*). Rasdorf et al. evaluated the accuracy of North Carolina Department of Transportation (NCDOT) staff during roadway inspections. The researchers monitored the NCDOT staff during inspection and documented each sign evaluation. Later, researchers measured the retroreflectivity of the evaluated signs to determine inspector accuracy. In total, the data measurements included 1057 signs on various types of state roadways in five different counties. Overall, the analysis determined that the NCDOT sign inspectors were effective in identifying and removing signs that were below the minimum values and accuracy ranged from 54 to 83 percent. Unlike the incorrect response rate in the Washington study, NCDOT sign inspectors were more likely to accept a sign with insufficient retroreflectivity levels than replace a sign with adequate levels. Despite the higher rate of false positive responses, the researchers concluded that the NCDOT inspectors were proficient and that nighttime visual inspection was reliable.

Measured Sign Retroreflectivity

The measured sign retroreflectivity method directly measures the retroreflective values with specialized equipment. Sign measurements remove the subjectivity by obtaining a specific retroreflectivity value. Repeatable and adequate measurements require both a reliable instrument and a knowledgeable operator. Devices require calibration and routine maintenance to achieve accurate and repeatable measurements. There are two types of devices that measure sign retroreflectivity in the field: contact instruments and non-contact instruments. Contact instruments require the operator to place the device in direct contact with the sign face. Non-contact instruments can measure sign retroreflectivity from a distance and devices can be either handheld or vehicle based systems. Similar to the visual sign inspection, a standard operating procedure needs to be established and operators acquire proper training.

In a 2004 draft report, the Texas Transportation Institute (TTI) evaluated six different types of retroreflectometer instruments (*15*). The objectives were to document performance, provide input to aid device developers, and offer information to help potential device users. The researchers evaluated four contact instruments and two non-contact instruments. Of the two the non-contact instruments, one was a vehicle based system and the other was a handheld device. The study assessed performance based on measurement bias, repeatability of a single instrument, and reproducibility of a specific type of instrument. The researchers tested the instruments in a controlled laboratory setting and on a closed-course test track. Overall, the contact instruments achieved more favorable repeatability and reproducibility results than the non-contact devices. The non-contact vehicle-based system was very sensitive when prismatic sheeting was rotated at different angles and measurements exhibited high variability. Despite these two shortcomings, the vehicle-based system showed potential.

In 1994, the Michigan Department of Transportation (MDOT) evaluated one of the first non-contact vehicle-based systems (*16*). The project was a feasibility study for the FHWA and built upon technology from the National Cooperative Highway Research Program (NCHRP) project HR 5-10 (*17*). The MDOT vehicle system operated during the daytime and the system consisted of a van equipped with two video cameras, flash tubes, roof mounted laser, and two video monitors. The system required a driver and an operator who focus the video camera and laser on the targeted sign. The laser measured the distance between the van and the sign. At 62 m (203 ft), the flash tube illuminated the sign and the cameras captured the image. Computer software calculated the retroreflectivity of the sign from the intensity of the black-and-white digital image. The researchers estimated that the system could measure between 200 and 300 signs per day at an expense of approximately $3.70 per sign. MDOT turned the technology and equipment over to the FHWA for further refinement and testing.

The FHWA ultimately developed the Sign Management and Retroreflectivity Tracking System (SMART) van (*18*). Alaska Department of Transportation & Public Facilities conducted the research in 2001. The FHWA system operated similarly to the MDOT system but with Global Positioning System (GPS) capabilities and a computerized database for storing sign information. The SMART van was evaluated along 10 miles of rural and 1.2 miles of urban roadway. The analysis compared SMART van sign measurements to handheld contact instrument measurements. The SMART van's sign readings deviated considerably from the handheld device. The operators had additional problems with the vehicle-based system. The automatic sign tracking lock did not function properly, and many targeted signs were missed. Sign capture rates were sporadic and ranged from 27 to 68 percent depending on environmental conditions. The researchers concluded that the SMART van's performance was not acceptable.

In 2003, researchers Maerz and Niu took a different approach. Their vehicle-based system captured relative luminance of traffic signs during nighttime conditions as opposed to the previous studies that calculated retroreflectivity during the day (*19*). The new system consisted of imaging equipment, an illumination source, and image analysis software. The feasibility study assessed the luminance of 32 signs in a controlled environment. The researchers found that the system had "fairly good" reproducibility and performance improved with high beam illumination conditions (*19*). The researchers demonstrated that their vehicle system was viable for estimating relative sign luminance.

Similar to the Maerz and Niu project, a research institute in Spain developed a vehicle-based system to measure luminance (*20*). The Cidaut Foundation created a program called SIGES or automated inspection system for traffic signs. The SIGES vehicle utilized state of the art cameras and advanced software to acquire sign attributes, measure retroreflectivity, and document critical sign management information. The vehicle operates during nighttime conditions, and it can collect data up to speeds of 70 mph (110 km/h). The sign management features can calculate sign height and roadway offset, and the measurements can be associated with GPS position data on a Google® Earth database. The SIGES vehicle has shown promise, and the Cidaut Foundation deemed it suitable on all types of roadways.

Another system was developed by Mandli Communications, Inc. (*21*). The Mandli system utilizes technology from the RetroView™ system, which is current technology used to measure pavement markings while driving. The system utilizes a multi-wavelength, active-sensor system to measure retroreflectivity. This system was tested as part of this research and is further explained in a subsequent section of this report.

SIGN MANAGEMENT METHODS

This section contains the information on the sign management methods for maintaining traffic sign compliance. The three methods are Expected Sign Life, Blanket Replacement, and Control Sign Method. Management methods are based on expected service life of the overall sign inventory, which are based on warranties or control sign assessment.

Expected Sign Life

The expected sign life documents and tracks vital sign information to allow individual signs to be replaced before the expected service life expires. This method employs a scientific system and advanced technology to track individual sign replacement. The level of complexity and sophistication depends on an agency's needs and available resources.

One of the simplest expected sign life systems or strategies is utilizing sign stickers. A sign sticker typically contains the fabrication/installation dates, sheeting type, and other agency specific information. They are placed on the back of signs, and maintenance crews utilize sign sticker information to determine replacement. Wyoming Department of Transportation (DOT) prints the fabrication year on the front of the sign, and Minnesota DOT places a colored sticker on the back to help maintenance personnel and expedite the replacement process (*22*). The sticker information can be stored at regional offices in either a paper or computer-based inventory system to help predict and schedule sign replacement.

There are many different computer programs designed to facilitate and improve sign inventory efficiency. There are many commercial vendors of sign management software such as SignIT & Datalink by TAPCO, TES Information Technology Limited, Roadway Maintenance Services by 3M, and CartéGraph. Apart from the software, some of the programs required additional equipment such as field laptops, digital cameras, bar-code readers, and GPS receivers. Many public and state agencies have developed in-house computer programs that have shown promise. The Pennsylvania Department of Transportation (PENNDOT) (*23*) created an in-house program called the Sign Inventory Management and Ordering System (SIMOS), which was estimated to save a total of $1,730,000 in labor and reduced sign order errors. Researchers from Iowa State University demonstrated the practical application of simple GPS technology for Iowa DOT by mapping out route and milepost signs (*24*). Ultimately, all systems for tracking individual signs are still based on the expected service life.

The expected service life represents the longest length of time that a sign will be used in the field while remaining compliant with the minimum retroreflective values (*12*). The retroreflectivity of a sign will degrade and deteriorate over time as it is exposed to the elements. Using manufacturers' warranty values as expected service life is practical and accepted. Each manufacturer estimates a warranty year as assurance of adequate sign performance under certain acceptable conditions. TxDOT's warranty period and expected service life for Type III high-intensity beaded sheeting is 10 years (7). However, warranty values incorporate a factor of risk on the part of the manufacturer and are inclined to be fairly conservative. Signs may last longer than the warranty. Subsequently, states such as Delaware, Kansas, Maine, Missouri, and North Dakota are exploring the use of a 12-year service life for Type III sheeting (*22*). The conservative warranty values and the desire to maximize sign service life have spurred research in sign deterioration rates and prediction models.

In 1992, Black et al. conducted one of the first reports to assess deterioration rates for FHWA (*25*). The study determined factors that contributed to sign retroreflective degradation and formulated models based on significant factors to accurately estimate retroreflectivity. The researchers collected retroreflective readings from 5722 signs in 18 different locations throughout the United States. Along with measurements, the collection process identified sheeting color, type, contrast ratio, sign direction, ground elevation, area type, and sheeting age. The measurements revealed that Type III signs performed adequately for up to 12 years. Within the generated scatter plots, there was high variability and a large dispersion of data points. For example, values for white Type III sheeting at five years ranged between 150 and 390 cd/lx/m^2, and red Type III values were between 10 and 90 cd/lx/m^2. The analysis determined that sheeting age, ground elevation, and temperature were significant factors in sign deterioration. The analysis also showed that the sign direction and solar radiation variables were not found to be acceptable predictors of in-service sign retroreflectivity. With the significant factors, researchers created linear prediction models for each Type III sheeting color. The linear prediction models estimated the retroreflectivity of a specific sheeting type based on the installation age. The researchers deemed the equations to be reasonable predictors of retroreflectivity, but model correlation was poor and the R-squared values ranged from 0.20 to 0.50.

Ten years later the Louisiana Department of Transportation and Development (LDOTD) produced another study that generated retroreflectivity deterioration models (*26*). The Wolshon et al. study assessed current compliance rates, determined influential factors, and created statistical models to predict retroreflectivity relative to age. The data collection effort measured a total of 237 signs in Louisiana and identified key environmental factors that may affect sign deterioration. The LDOTD results showed that 92 percent of the signs under the 10-year warranty were performing above the minimum requirements. Within the signs past the warranty period, 43 percent were in compliance. The researchers generated linear deterioration models for each type and color of sign sheeting. The Type III models tended to be relatively "flat," and the analyses showed that sign orientation and the offset distance to the road were not statistically significant factors for contributing to retroreflective deterioration (*26*). The correlation between the models and field data varied enough for the authors to caution that these models should only be applied with local and site specific data.

At Purdue University, Bischoff and Bullock applied a similar approach as Wolshon et al., but their main objective was to determine if Indiana's current Type III 10-year service life needed to be shortened or could be extended (*27*). In total, 1341 Type III roadway sign retroreflectivity measurements were recorded and sheeting colors included red, yellow, and white. Many of the signs exceeded the 10-year warranty period and installation ages went up to 16 years. Overall, the analysis found that only seven signs were not in compliance with the minimum requirements, and signs past 10 years were performing adequately. The researchers created linear prediction models that showed that red Type III sheeting produced the highest R-squared value at 0.32 and white Type III sheeting displayed the lowest at 0.02. There was a great deal of disparity in the regression models and differences became more evident as sign age increased. In the end, researchers could not fully support the prediction models, but they did recommend that the service life of white and yellow Type III sheeting could be extended to 12 years and red Type III sheeting should remain at 10 years.

The last and most recent expected service life study was conducted in 2006 by Rasdorf et al. for the North Carolina Department of Transportation (NCDOT) (*14*). There were similar objectives and a comparable approach to the previous studies. Measurements were compiled from 1057 Type I and Type III signs in North Carolina and included the four different colors. Models were generated from linear, logarithmic, polynomial, power, and exponential functions. The majority of the models exhibited poor correlation and the R-squared values ranged from 0.01 to 0.48. Within the sign sheeting types, white had the weakest relationship while red showed the strongest, which was similar to the Bischoff and Bullock study. Despite the poor correlation, the majority of the Type III signs performed well, and the models projected long-term retroreflective compliance beyond 10 years.

Blanket Replacement Method

The blanket replacement method replaces a large group of signs at a specified time interval. The blanket replacement is similar to the expected sign life method, but the fundamental difference is targeting a large group of signs opposed to identifying an individual sign in an inventory. The replaced signs can be based upon spatial or strategic data.

The spatial sign replacement removes all signs in a certain geographic area. The scale of the spatial area can vary widely between agencies. The area could be limited to a single road or as large as replacing all signs in the agency's jurisdiction. The strategic approach replaces all signs of a common characteristic such as sheeting type, sign classification, and sign content. Upgrading sign sheeting from Type I to Type III is an example of strategic replacement. Stop signs are a major concern and have a higher priority for replacement over warning and guide signs. The blanket replacement could incorporate both spatial and strategic characteristics by removing specific sign types in a certain area. Despite its simplistic nature, the blanket replacement method can be wasteful and labor intensive. Retroreflective performance is not the driving factor, and many adequately performing signs could be replaced before the end of their expected service life.

Hawkins et al. conducted one of the reviewed studies that addressed blanket replacement issues in 1996 (*12*). The researchers surveyed TxDOT sign personnel and performed a cost/benefit analysis of several different sign maintenance strategies. The TxDOT survey projected that up to 50 percent of the signs were replaced for reasons other than retroreflective performance. Responses also indicated that vandalism was one of the most common difficulties for sign maintenance and replacement. In conclusion, the researchers determined that blanket replacement was the most costly method and other maintenance methods were more cost effective.

The previously reviewed NCDOT study also established sign vandalism and damage rates (*14*). The field data showed that 2.37 percent of the inspected signs were replaced due to human vandalism, natural damage, or both. Of the total signs replaced, vandalism accounted for approximately 40 percent, and natural damage contributed to 30 percent. Typically vandalism included paintballs, eggs, and bullet holes. Researchers examined past NCDOT signs budgets and determined that sign replacement outside of retroreflectivity was 4.7 percent per year in the past. The NCDOT percentage may seem low, but it is still a considerable loss in sign materials and expenditure in labor. When equated to a 10-year blanket replacement, the 4.7 percent vandalism/damage rate would replace a great deal of the signs before they reached the full service life.

In 2009, Hurt et al. reported on the traffic sign replacement and operational cost in national wildlife refuges (*28*). The research team collected data from 104 national wildlife refuges in 11 states in the Midwest. There were 3861 signs evaluated and the researchers reasoned that 935 signs required repairs or replacement. Approximately 35 percent of the repair/replacement signs were for reasons other than low retroreflectivity. Conversations with refuge staff revealed that sign maintenance strategies were not in place to comply with the MUTCD requirements. The study provided the cost assessment for a 15-year blanket replacement strategy for Type III signs.

Control Sign Method

The control sign method is the third sign management strategy, and it may utilize both sign assessment and management techniques to maintain sign compliance. The MUTCD states that sign replacement in the field is based on the performance of a sample set of control signs (*4*). Specific sheeting types in the controlled sample set represent the retroreflective values of a sign population. The control signs may be a small sample in a maintenance yard or selected signs on the roadway. The control signs are assessed and monitored to determine retroreflective performance. Once the control signs start to near the retroreflective requirement thresholds, then all the corresponding signs in the field are replaced. The control sign method requires means of establishing a creditable sample set, sign evaluation techniques, and a system to manage sign inventory information.

The first step is establishing an acceptable and effective sample size. An agency should select a sample size that they deem is appropriate and justifiable. The National Transportation Product Evaluation Program (NTPEP) conducts sign deterioration studies for new sheeting products for the American Association of State Highway and Transportation Officials

(AASHTO). The NTPEP tests two panels for each new sheeting type in an accelerated experiment to determine minimum levels of outdoor durability (*29*). Carlson and Lupes recommended testing a minimum of three signs per sheeting type (*22*). On the other hand, Harris et al. designed an elaborate and complex experimental sign retroreflectivity measurement facility (ESRMF) (*30*). The researchers called for 16 signs sheeting type. The ESRMF layout also tested signs in all four directions.

Control signs should be established at the same time as large field sign deployments. Ketola determined that retroreflectivity of control signs varied when installed at different times of the year (*31*). The comparison revealed that the percent reduction in initial luminance between installation periods could differ by approximately 15 percent. This study illustrated that agencies need to exercise caution and eliminate factors that may contribute to discrepancies between control and field sign performance. Carlson and Lupes recommended that control signs be continually installed at strategic intervals to account for aging material and turnover in personnel (*22*). The researchers reason that too little time between control sign deployment misuses labor to monitor unnecessary signs and too much time may lead to inaccuracies in predicting service life of signs in the field (*22*).

Another aspect of the control sign method is determining adequate sign sample locations and arrangements. Sample signs can be placed at either a protected environment like a maintenance yard or an unprotected roadway. The unprotected arrangements are liable and exposed to vandalism, knockdowns, and premature damage. A protected facility greatly decreases the likelihood of the control signs being corrupted. However, protected signs may provide a limited and biased sample that does not fully represent roadway conditions. Unprotected sample signs can encompass a large demographic area and cover a wide range of roadway conditions.

CHAPTER 3:
IN-SERVICE SIGN ASSESSMENT

This chapter contains a description of the work that was conducted to better understand the current condition of signs on TxDOT roadways. The findings of this effort played a key role in developing the report recommendations.

OVERVIEW

In order for policymakers to develop an effective sign maintenance strategy, they must first understand the conditions of their traffic signs. Each MUTCD sign maintenance method utilizes different approaches at various degrees of resource allocation. One method may be more economically sustainable depending on the current level of sign compliance. Researchers anticipated that the in-service sign assessment would evaluate the current conditions and help to establish the most appropriate and efficient sign maintenance method for TxDOT.

Objective

The overall objectives of the in-service sign assessment were to establish how traffic signs in Texas compared to the MUTCD minimum retroreflectivity requirements and to determine any specific factors that should be taken into consideration when developing a sign maintenance program. Researchers established four main objectives, which were to:

- Acquire a sufficient sample of sign measurements within the State of Texas.
- Assess sign retroreflectivity compliance and TxDOT warranty periods.
- Identify influential sign and environmental factors.
- Estimate expected service life.

DATA COLLECTION METHODOLOGY

This section explains the methodology that was employed to collect retroreflective sign measurements. For this study, researchers utilized effective techniques from past studies while incorporating modifications that addressed their specific needs. Overall, the researchers' goals were to ensure reliable and representative sign measurements while ensuring worker safety by minimizing roadway exposure.

Sign Measurements

The data collection utilized a handheld contact retroreflectometer to measure traffic sign retroreflectivity. Measurements were collected at an observation angle of 0.2° and an entrance angle of −4.0° as noted in the 2009 MUTCD (*4*). Data collectors only measured signs with TxDOT installation/fabrication stickers. If a sign did not have a TxDOT sticker or if a sticker was not legible, then measurements were not taken for that sign.

Originally, there was some deliberation about whether to collect washed or unwashed sign measurements for this study. Dirt and dust buildup could vary from sign to sign and comparing washed measurements may lead to a more direct comparison. The Wolshon et al. study determined that there was about a 25 percent increase in retroreflectivity when Type III signs were washed (*26*). In contrast, the Bischoff and Bullock study concluded that sign washing does not significantly affect the retroreflectivity (*27*). In the end, the researchers decided to measure unwashed signs because this is the condition that drivers view on the roadway, and TxDOT staff evaluated unwashed signs during nighttime visual inspection.

Similar to the washed or unwashed issue, researchers debated whether signs should be classified by the fabrication process and/or by the specific manufacturing vendor. The previous FHWA study determined that silk-screen and overlay Stop signs produced different deterioration rates and measurements (*25*). It can be assumed that various manufacturing vendors fabricate slightly different sheeting products. Additionally, a single vendor may modify a product from year to year or discontinue sheeting lines. Classification by fabrication and/or vendor may be beneficial, but it could lead to complications and problems with the sign sample. Ultimately, the researchers selected the current TxDOT classification that groups sheeting into five different categories that are based on ASTM and material type (beaded or prismatic).

Data collectors also assessed the visual condition of measured signs, which included daytime appearance, message integrity, and general condition. Assessing the daytime visual condition relied on the data collectors' personal judgment and categories were:

- Good: The sign's color, surface, message integrity, and overall appearance showed no notable damage, vandalism, weathering, or distress.
- Adequate: The sign showed moderate weathering or distress that did not affect the message integrity.

- Poor: The sign's message integrity and overall appearance were compromised by damage or distress and the sign should be replaced in a timely manner.

Study Regions and Sampling

Data collection needed to obtain a diverse and broad cross-section of signs that varied in sign type, location, and installation age. In 1996, Hawkins et al. (*12*) estimated that there were approximately 2.3 million traffic signs on the TxDOT roadway system. Acquiring a sign sample that was distributed in every TxDOT district would prove costly and difficult.

For this study, researchers focused on several different and distinctive regions. Study regions needed to exhibit unique characteristics that would differentiate it from other parts of the state. These unique characteristics may affect sign performance and accelerate deterioration rates. Researchers reasoned that if sign performance was adequately addressed in regions with harsh or intense conditions, then signs in other regions should be performing at a similar or better level. Climate, land-use, precipitation, and geography were some of the characteristics that researchers took into consideration when making the final selection. Figure 1 depicts the locations of the seven selected regions, which were Panhandle (PAN), Central Texas (CT), Houston (HOU), Corpus Christi (CC), South Padre (SP), Laredo (LRD), and West Texas (WT).

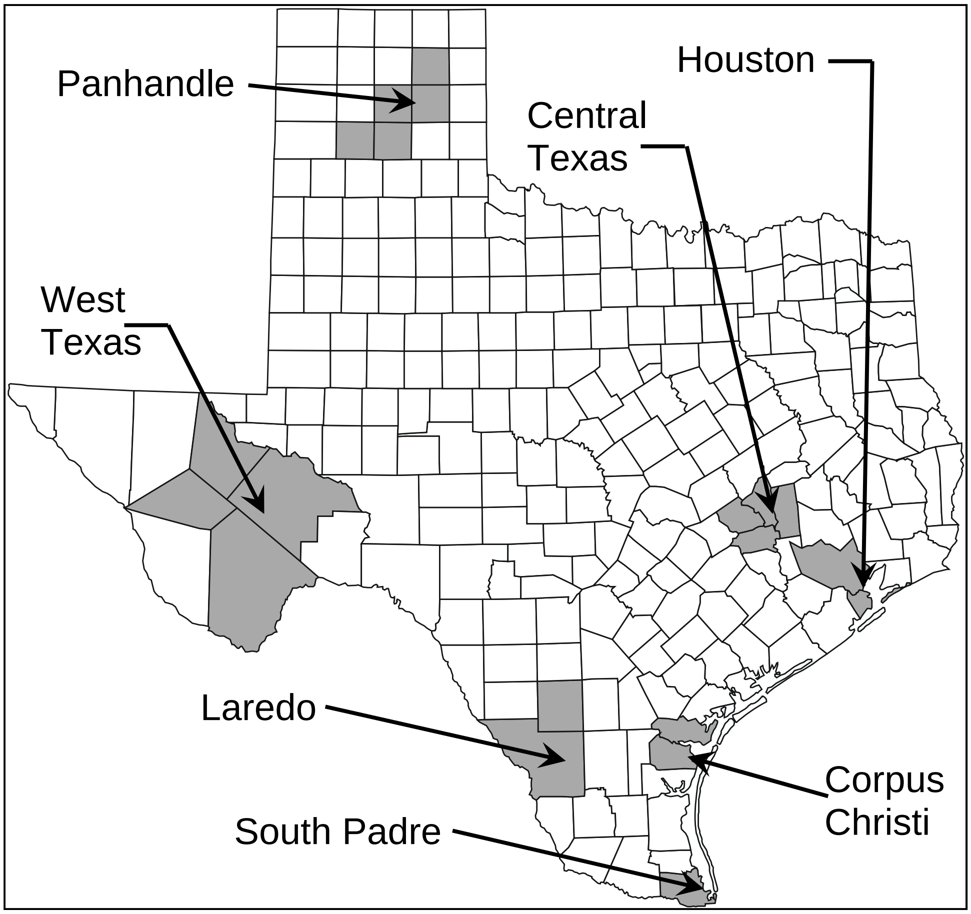

Figure 1. Study Regions in Texas.

Table 3 contains annual and average data for each selected region. In the table, the high and low temperature values were averages from the three hottest and three coldest months and the snow and precipitation were cumulative annual amounts. Regions were diverse and included conditions such as tropical storms, intense sunshine, high temperatures, powerful winds, constant exposure from petrochemical exhaust, etc. The WT Region's summer high and winter low temperatures fluctuated by 69°F. Most of the regions exhibited little snowfall, but the PAN Region had about 15 inches of snow per year. Also, the National Climatic Data Center determined that a city in the PAN Region exhibited the third highest annual average wind speed of all major cities in the contiguous United States (*32*). The difference in total precipitation between the HOU and WT Regions was about 39 inches per year. Relative humidity also varied greatly, and the CC and SP Regions exhibited the highest rates at 74 percent while the WT Region had the lowest at 50 percent. Land use ranged from urban industrial to very remote. The distance between the two farthest data collection points was approximately 700 miles, which is about the same distance as from Indianapolis, IN, to Jacksonville, FL. It was not feasible to collect data in every part of Texas, but studied regions covered an extensive area and included many different conditions.

Table 3. Annual and Average Regional Data.

Regions	**PAN**	**CT**	**HOU**	**CC**	**SP**	**LRD**	**WT**
Basic Description	Plains & Prairie	Forest & Plains	Urban & Industrial	Gulf Coast	Gulf Coast	Brush & Plains	Desert & Mts.
High Temperature (°F)	89	93	89	93	93	97	97
Low Temperature (°F)	23	40	43	47	51	45	28
Total Precipitation (in)	20	38	48	31	26	19	9
Total Snowfall (in)	15.4	0.2	0.4	0.0	0.0	0.0	4.6
Probability of Sunshine	73%	60%	58%	61%	60%	60%	78%
Relative Humidity	56%	72%	72%	74%	74%	62%	50%
Wind Speed (mph)	13.5	8.5	7.6	12.0	11.3	9.5	11.1

Notes: Sources (*32*) provided the data for the table.

Minimizing roadway exposure and ensuring data collectors' safety were top priorities in sign sampling. Poor shoulder conditions and unapproachable sign supports made some sign measurements precarious. Ultimately, data collectors were free to measure signs that offered safe and favorable stopping locations. A team of two data collectors was able to measure between 10 to 15 signs per hour.

FINDINGS

The sample crossed 21 different counties, 83 roadways, and 1013 centerline miles. This study measured a total of 1385 traffic signs from seven different regions in Texas. Table 4 shows the basic sign sample information. Overall, 87 percent of all infield signs were less than 10 years old, and there was a 95 percent compliance rate with the MUTCD minimum requirements. There were 70 signs that failed to meet compliance which consisted of 56 Type I, 12 Type III, and 2 prismatic signs. The mean age for the failure Type I signs was 12 years, and TxDOT has stopped using Type I materials. The two failed prismatic signs were considered to be outliers as a result of accelerated deterioration from the elements (they were located along the beach in the SP Region) Besides the two failed prismatic signs, most of the prismatic installation ages were less than 6 years old, and signs generally exhibited high retroreflective values.

The most notable trends came from the Type III failed signs data. Type III sample sign compliance with the minimum requirements was high with a rate of 99 percent. There were 12 failed signs out of 994 Type III signs in the sample and the mean age for the failures was 12 years. The observed likelihood of failure for signs between the installation ages of 10 to 12 years was 2 percent, and it was 8 percent for signs that ranged from 12 to 15 years. Excluding the Type I signs and 2 prismatic outliers, the sample produced a high compliance rate, and Type III signs were remaining compliant past 10 years of installation. For a more in-depth analysis, the researchers analyzed the retroreflectivity measurements using an Analysis of Variance (ANOVA) statistical model.

Table 4. Basic Sign Sample Information.

Sign Category		PAN	CT	HOU	CC	SP	LRD	WT	Total
Sample Size		221	204	193	155	191	203	218	1385
Age < 10 yrs		88%	93%	84%	88%	93%	91%	81%	87%
MUTCD COMPLIANT		96%	99%	91%	94%	94%	95%	96%	95%
Sign Type	Regulatory	37%	34%	55%	37%	34%	35%	31%	38%
	Warning	29%	35%	23%	21%	28%	22%	33%	27%
	Guide	34%	31%	22%	41%	38%	43%	36%	35%
Background Color	Red	29%	20%	15%	13%	14%	11%	16%	15%
	White	15%	31%	56%	52%	51%	54%	36%	47%
	Yellow	38%	35%	23%	21%	28%	22%	33%	27%
	Green	18%	14%	6%	14%	7%	13%	15%	11%
Sheeting Type	Type I	5%	1%	9%	6%	5%	1%	6%	5%
	Type III	68%	67%	74%	79%	71%	73%	71%	73%
	Prismatic	27%	32%	17%	15%	24%	26%	23%	23%
Visual Condition	Poor	8%	2%	4%	2%	1%	0%	4%	2%
	Adequate	32%	27%	12%	19%	12%	20%	24%	19%
	Good	61%	70%	84%	79%	87%	79%	72%	78%
Sign Direction	North	26%	32%	20%	48%	21%	21%	33%	29%
	East	13%	22%	24%	20%	28%	35%	23%	26%
	South	34%	18%	31%	19%	26%	11%	26%	22%
	West	27%	28%	25%	12%	25%	33%	18%	23%

The ANOVA model was used to determine significant factors that affected sign retroreflectivity. The dependent variable was sign retroreflectivity and the independent variables were region, visual condition, sign direction, and age. A confidence interval of 95 percent was used to determine variable significance. The analysis included a model for all sign data, and seven models for each individual sheeting type and color. Table 5 contains the ANOVA results and shows which independent variables were significant. Both the direction and visual condition variables were only significantly different in one of the seven models. While the previous findings related to sign direction have been mixed, for these data sign direction was not a significant factor. Daytime visual condition assessments were not a good indicator for retroreflectivity. The 12 Type III and 2 prismatic signs that did not meet the minimum retroreflectivity levels appeared in good or adequate visual condition during daytime hours. Data collectors acknowledged this trend and added that many poor or distressed signs exhibited high retroreflectivity levels.

Table 5. ANOVA Analysis Results.

Sign Category		Region	Visual Con.	Direction	Age
All Signs		**0.00**	**0.00**	0.53	**0.00**
White	Type I	0.97	0.49	0.36	0.14
Red	Type III	0.16	0.79	0.92	**0.00**
White	Type III	**0.00**	0.32	**0.00**	**0.00**
Yellow	Type III	**0.00**	0.21	0.50	**0.00**
Green	Type III	**0.01**	0.54	0.19	**0.02**
White	Prismatic	N/A	0.27	0.85	**0.00**
Yellow	Prismatic	**0.00**	0.20	0.89	0.23

Note: Significantly different independent variables have P-values that are less than 0.05 and are denoted by bold text and gray shading.

The ANOVA results did determine that sign age was a significant factor in six of the models and the region variable was significant in five of the models. The region variable was not significant in the red Type III sign sheeting model. The majority of the white Type I signs were older than 10 years and exhibited low retroreflective values. Most of the yellow prismatic were less than 6 years with consistently high retroreflective measurements. Both the white Type I and yellow prismatic signs may have had limiting sign distributions. All things considered, sign installation age significantly affected sign retroreflectivity and signs were performing differently among each region. Researchers utilized linear regression models to obtain a better understanding of how some sign types were performing over time in each region.

Researchers focused on red, white, and yellow Type III sign sheeting for a more in-depth analysis of deterioration rates and regional differences. These sheeting types were selected because of the large sample size for each color. Table 6 contains the linear regression equations and R-squared values for red, white, and yellow Type III sign models, and Appendix A shows the scatter plots. The top row of the table shows the results from all of the Type III data. Deterioration rates for white sheeting ranged from about −2 to −8 cd/lx/m^2 per year while yellow rates were between −1 to −12 cd/lx/m^2 per year. The PAN and WT Regions typically exhibited the lowest rates while LRD Region had the highest rates.

The R-squared values in Table 6 were low. The R-squared values from the all regions model ranged from about 0.10 to 0.20. The regional model R-squared values were also similar. The red and white correlation values ranged from 0.01 to 0.30. The yellow R-squared values were higher, which may be contributed to a smaller sample size in some of the regions. Regardless, the linear relationships were consistently weak, which indicates large disparity between the predicted and measured values. The poor correlation and high variability in the measurements also adds more uncertainty when projecting expected service life. Some of the projected service life values were considerably lengthy and ranged between 15 to up to 155 years (probably unrealistic). This trend was similar to the projections generated from past research.

Table 6. Regional Linear Prediction Models and R-Squared Values.

Reg.	Red			White			Yellow		
	R^2	Equation	SL*	R^2	Equation	SL	R^2	Equation	SL
All	0.09	y = −1.0x + 52	44	0.08	y = −6.2x + 265	35	0.19	y = −6.8x + 251	26
PAN	0.02	y = −0.4x + 53	129	0.07	y = −3.6x + 285	34	0.62	y = −11.2x + 315	21
CT	0.02	y = −0.3x + 50	112	0.28	y = −6.9x + 281	65	0.4	y = −9.2x + 281	23
HOU	0.01	y = −0.6x + 55	28	0.14	y = −6.2x + 271	104	0.02	y = −1.5x + 194	80
CC	0.41	y = −2.0x + 51	86	0.07	y = −5.4x + 253	35	0.19	y = −5.4x + 208	24
SP	0.04	y = −0.4x + 36	76	0.02	y = −2.2x + 323	82	0.31	y = −7.8x + 243	21
LRD	0.06	y = −1.0x + 50	42	0.06	y = −7.7x + 236	24	0.57	y = −12.3x + 258	15
WT	0.26	y = −2.0x + 63	22	0.04	y = −2.2x + 279	38	0.01	y = −1.0x + 225	155

Note: * SL is the abbreviation for service life projections, which were generated from the most conservative MUTCD minimum requirements.

Figure 2 shows an example of the deterioration rates and predicted values for yellow Type III sheeting for each region. The figure depicts the predicted values in 5-, 10-, and 15-year intervals, and the deterioration rates can be visually assessed between the intervals. The WT

Region's predicted values were the highest and had the lowest rate of change while the LRD Region exhibited the highest deterioration rate. The CC, SP, and LRD Regions were relatively close in geographic location, but the 15-year predicted values deviated by about 60 cd/lx/m^2. The LRD Region illustrated that there were regional differences, and a comprehensive or all-inclusive state model may not be representative for certain regions.

In spite of the variation in regional data, the differences were not practically sizeable to implement different sign management and maintenance programs for specific regions. Figure 2 depicts that all retroreflectivity estimations would be compliant at the end of a 10-year period, and the majority of 15-year projections would also be incompliance. The only retroreflective forecast that was close to the MUTCD minimum requirements was the 15-year projection for region LRD. Despite this one questionable projection, all of the 12-year service life retroreflectivity values were above the minimum requirements. Similar to findings in past research, a 12-year service life for Type III signs could be a reasonable and practical benchmark for a sign management strategy.

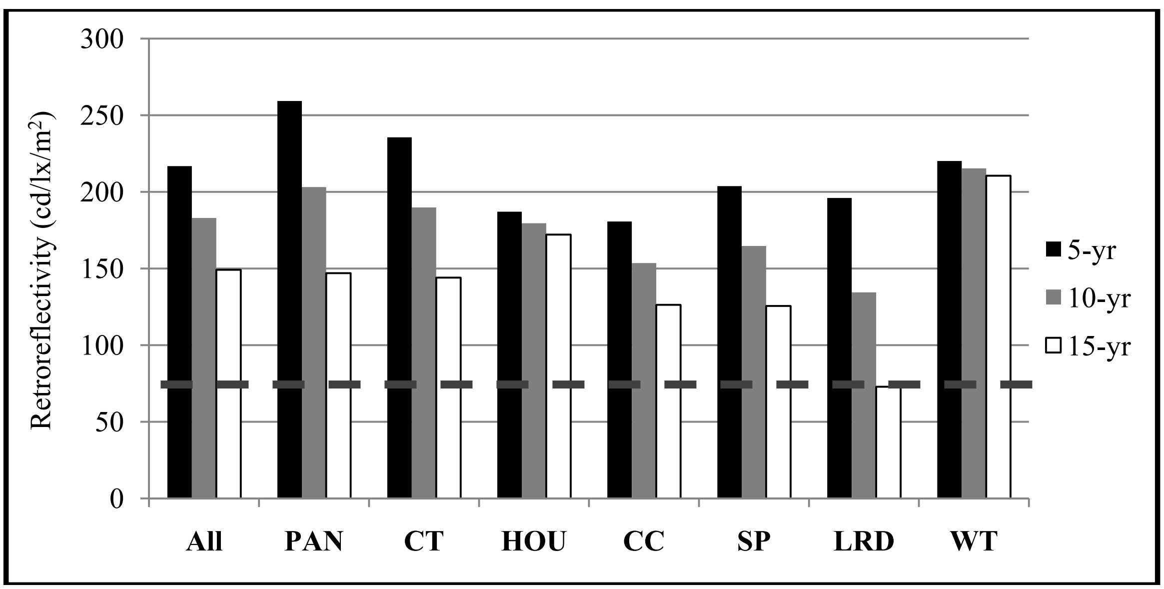

Figure 2. Region Model Predictions for Yellow Type III Sheeting.

Note: The dashed gray line is the MUTCD minimum requirement (75 cd/lx/m^2) for black on yellow signs.

SIGN QUANTITY ESTIMATION

TxDOT does not have an inventory of their signs or a firm estimate of the total number of signs on their system. A previous TxDOT study estimated 2,324,756 signs with 29 signs/mile for urban and 11 signs/mile on rural roads (*12*). A North Carolina study quantified that the State of North Carolina maintains about 986,000 signs on the 78,000 miles of state roadway, which is a sign density of 6.32 signs/mile (*14*). One of the tasks the researchers conducted during the statewide assessment of sign retroreflectivity was measuring sign density along stretches of various roadway types in urban and rural environments to obtain empirical data that could be used to generate an updated estimate of TxDOT's sign inventory.

Sign density counts basically required data collectors to count the number of traffic signs over a defined distance. Data collectors counted signs during their efforts to measure sign retroreflectivity. Researchers also utilized the Google Earth Street View function to collect additional data. The roadway classification (freeway, arterial, collector, and local) and land-type (rural and urban) were identified in the counts. In total, sign density counts covered approximately 850 miles and included 9872 signs. Sign densities were averaged and rounded up to the nearest whole integer, and Table 7 contains the final values. The table also contains an overall value that was not used in this study but was inserted for general knowledge. The distribution for each sign color was determined and incorporated into the model. The next step in the sign quantity estimation was to generate total number of TxDOT signs from the sign density and roadway mileage values.

Table 7. Sign Density Values (Signs/Mile).

	Freeway	Arterial	Collector	Local	Overall Average
Rural	9	13	11	7	14
Urban	13	25	30	8	

Researchers utilized the RHiNo database to generate the total number of TxDOT directional centerline miles. RHiNo is a TxDOT database that presents roadway characteristic and geometric data in a comprehensive spreadsheet. In total, the database contains 134 different characteristic variables for approximately 280,000 roadway segments. Using the database, researchers extracted directional centerline miles for each of the 8 different roadway types in the 25 TxDOT districts. Both two-way and one-way mileage was determined. The total directional centerline mileage was generated by doubling the two-way mileage and adding in the one-way miles. The final estimate used in this study was around 2,119,110 traffic signs on 155,676 directional centerline miles in Texas.

SUMMARY

The research showed that TxDOT's current traffic sign maintenance practices were effective regarding the new minimum retroreflectivity levels in the MUTCD. An analysis of 1385 signs showed that 87 percent of all in-service signs were less than 10 years old and 95 percent of all signs were compliant with the minimum requirements. Type I signs accounted for most of the sign failures in the sample, and if they were excluded, then there was a 99 percent MUTCD compliance rate. There were 2 failed prismatic signs that could be considered outliers and 12 failed Type III signs. Within the Type III sign sample, the observed likelihood of failure for signs between the installation ages of 10 to 12 years was 2 percent and it was 8 percent for signs that ranged from 12 to 15 years. Excluding the Type I signs and 2 prismatic outliers, the sample produced a high compliance rate, and Type III signs were remaining compliant past 10 years of installation.

The ANOVA testing determined that sign age and region variables were significant. The research also demonstrated that visual daytime assessment of signs was not a reliable method to assess retroreflectivity and sign direction was not a significant factor affecting sign retroreflectivity. The linear prediction models revealed that there were differences in deterioration rates among the regions. However, the differences between regions were not practically significant to justify different sign management and maintenance programs for specific regions.

Furthermore, the majority of the R-squared values were relatively low, ranging from 0.10 to 0.30. The low R-squared values limit the confidence for projecting sign service life. Some of the projected service life values were considerably lengthy and ranged between 15 to 155 years. However, the data indicated that the service life for Type III beaded sign sheeting could exceed the typical 10-year period. The data indicated that Type III signs may meet the MUTCD minimum requirements for up to 12 years of installation, but this may not always be true for all signs. A 12-year service life for Type III signs may provide the basic estimation, but it may be beneficial to also implement robust maintenance practices and periodic nighttime visual inspections to replace signs that do not meet the projection.

In addition, the researchers also made sign counts along various stretches of highway to determine a statewide estimate of TxDOT's sign inventory. Researchers estimated that TxDOT has about 2,120,000 traffic signs along its system.

CHAPTER 4: EVALUATION OF MOBILE SIGN RETROREFLECTIVITY MEASUREMENTS

An element of this research included investigations of new technology that might be used to measure signs from a vehicle driving at highway speeds. The FHWA had developed a prototype system over 10 years ago to demonstrate proof of concept. As this project was being developed, it was discovered that at least one technology had since been developed and was being offered to measure sign retroreflectivity. This chapter contains a discussion of the procedures and results from an evaluation of a vehicle-based sign retroreflectivity measurement system.

OVERVIEW

The 2009 MUTCD minimum sign retroreflectivity requirements have placed greater importance on techniques and strategies for measuring sign retroreflectivity. Taking retroreflective measurements may be labor intensive and time consuming if employing a handheld contact retroreflectometer on a large sign population. Sign maintenance and assessment strategies need to be conducted in a reliable and efficient manner. One area of emerging technologies is with non-contact sign measurement equipment fitted on a vehicle platform.

The non-contact instruments possess the ability to measure sign retroreflectivity from a desirable distance while in motion. This emerging technique offers greater flexibility and offers the potential for expediting the data collection process. Mandli Communications, Incorporated and Facet Technology Corporation developed a vehicle that is equipped with sign retroreflective measuring instrumentation and software to collect sign retroreflectivity while driving at typical roadway speeds. At the time of this phase of the research, the Mandli technology was the only system that the researchers could identify as being market ready. Since then, other mobile sign retroreflectivity measurement technologies have been introduced. Only the Mandli system was tested and reported here.

Objective

This evaluation examined the capabilities and explored the benefits of the mobile data collection technology. Researchers conducted a demonstration and evaluation of the technology at a closed-course facility and an open-road course. The data collection vehicle measured retroreflectivity of various signs under different conditions. The objectives of the data collection vehicle testing were to determine:

- Accuracy of retroreflectivity measurements.
- Features and attributes that are beneficial to a sign maintenance program.
- Limitations and areas for improvement.

VEHICLE BACKGROUND

The data collection vehicle measures sign retroreflectivity during daytime hours. The specialized equipment is mounted on top of a vehicle, and the driver operates the system with a computer from within the vehicle. Once the driver initiates the system, the data will continuously be collected until the system is disengaged. The optimal operating range stated by the developers is collecting data below 55 mph and measuring signs within 50 to 200 ft of the data collection vehicle. Figure 3 shows an image of the data collection vehicle and the assembled equipment.

Figure 3. Mandli Collection Vehicle.

The retroreflective measuring equipment consists of specialized digital cameras, orthogonal LiDAR scanners, retroreflectivity sensors, and an LED light source. There are up to eight cameras that are mounted at different positions on the roof. The cameras collect right-of-way imagery to be used in the post-processing of sign data, and other relevant roadway information. Similar imaging technology has been employed to create Google Map Street View application, which provides a near continuous 360 degree view of the roadway. The cameras are high resolution and capture color images. Orthogonal LiDAR scanners are mounted in the left, center, right side of the front of the vehicle. The scanners are able to collect in excess of 80,000 points per second and acquire spatial sign information such as GPS location, sign face direction, mounting height, face size, roadway offset, etc. Similarly, the retroreflectivity sensors are positioned in the left, center, and right sides of the vehicle to capture signs on both sides of the roadway and signs overhead. The retroreflectivity sensors consist of precision-aligned cameras that are synchronized to a full-spectrum LED light source. The LED lights exceed 70,000 lumens and strobes at a rate of 15 times per second. Each retroreflectivity sensor captures 45 frames per second.

The system does not measure retroreflectivity directly, but it is later obtained in a post-processing phase with the aid of specialized software. In post-processing, a technician focuses on a targeted sign and clicks the mouse for a single data event. The mouse click will identify the pixel intensity of the selected portion of the sign. An assessment of the color characteristics generates an estimate of sign luminance. Retroreflectivity is then generated from the luminance. The entrance and observation angles are determined from the LiDAR sensors.

Each sign measurement utilizes a minimum of 21 data events to generate sufficient data to produce the RetroCurve® for both the background and legend colors. The RetroCurve® is a proprietary program developed by the vehicle operators. The program plots retroreflective measurements at different observation angles, which allows the post-processing to determine the sign's material type and projected service life. The sign service life estimate is based on the sign's sheeting type, its measured retroreflectivity, facing direction, latitude, and the minimum allowed retroreflectivity values from the MUTCD. The sign information and projected service life projections are then stored in a sign management database to assist with the sign replacement schedule.

METHODOLOGY

This study evaluated the data collection vehicle in two different settings: a closed-course facility at Texas A&M Riverside Campus and an open-road course throughout the Bryan-College Station area. In both settings, the operator measured the retroreflectivity of various traffic signs under different roadway conditions.

Closed Course

The evaluation of the data collection vehicle began at the Texas A&M Riverside campus. The Riverside campus is a retired U.S. Air Force base that enabled the TTI researchers used to test the data collection vehicle in a controlled environment without outside interference. Figure 4 depicts an aerial image of the Riverside campus.

Figure 4. Riverside Campus.

At the start of the exercise, vehicle operators were allowed to setup and calibrate the data collection vehicle. A company representative conducted an informal presentation and discussion of the mobile measurement technology, which included a description of individual components and how the system generates sign retroreflectivity. Following the setup and presentation, the data collection vehicle was driven to measure various signs on the closed course that was setup by the research staff.

The closed course encompassed two runways that were closed off to facility through traffic, and it was designed to simulate a typical rural roadway. The course was not a circular loop but extended from a beginning point to a turnaround point. The data collection vehicle started at the beginning point and measured signs on one side of the course. When the driver reached the turnaround point, the vehicle reversed 180 degrees and headed back toward its start while measuring signs on the opposite side of the roadway. The distance between the beginning and turnaround point was approximately one mile, and it included two horizontal curves. The course replicated a two-lane, undivided roadway delineated with centerline and edge line pavement markings and travel paths were 12 ft in width.

Researchers placed a total of 22 different traffic signs on the closed course. Most signs had a mounting height of 7 ft and were located at a 12-ft offset from the nearest travel lane. Some signs were set at a farther offset distance to simulate measurements on a multilane roadway. The distance between consecutive signs was typically 500 ft or greater. One section of the course contained three signs that were spaced 50 ft apart to replicate a high density sign area. Typically, sign post assemblies held one sign to be measured at a time but there was one assembly that displayed four signs of differing retroreflective values. Researchers installed the four sign assembly to test if measurements of one sign would be compromised by adjacent signs.

Figure 5. Closed-Course Test Signs.

The 22 closed-course signs differed in color, contrast, material, and retroreflectivity. There were six red, eight white, four yellow, two green, and two orange signs. Material type was split among engineer grade (Type I), high-intensity beaded (Type III), and prismatic materials. Among the 22 signs, the handheld retroreflective measurements ranged from 6 to 698 cd/lx/m^2. There were 16 signs that met the MUTCD requirements and six signs that fell below the minimum levels. Signs were placed to vary the viewing order. For example, a noncompliant white Type I regulatory sign followed a high performing yellow prismatic warning sign. The four sign assembly was also a mixture of different sign types; one prismatic, one Type III, and two Type I signs that all varied considerably in retroreflectivity and visual condition. Table 20 in Appendix B contains all of the closed-course sign information and handheld retroreflective measurements.

Instructions to the data collection vehicle driver were simple and brief. The driver was instructed to follow pavement markings while maintaining a favorable vehicle speed, which was between 25 and 40 mph. Upon reaching the turnaround point, the driver would return to the beginning point while collecting data on the opposite side of the course.

The data collection vehicle conducted a total of five passes along the closed course. The first three passes measured signs on the right side of the runway and the last two measured signs on the left side. The vehicle was not able to measure signs on both sides of the road. The first and fourth passes replicated normal two-lane conditions. In the second and fifth passes, the offset distance between the vehicle's travel lane and the signs increased by 12 ft to test the measuring capabilities on multi-lane roadways. The third pass utilized the original offset distances in the two-lane conditions, but several of the signs were rotated toward or away from the travel path by approximately 45°. The third pass evaluated if the directional rotation of the sign considerably affected the vehicle's measurements. Table 8 shows a summary of the different scenarios used during the testing.

Table 8. Closed-Course Summary.

Passes	Road Side	Scenario
1	Right	Typically Two-Lane Road
2	Right	Multi-lane Road
3	Right	Rotated Signs w/ Two-Lane Road
4	Left	Typically Two-Lane Road
5	Left	Multi-lane Road

Open-Road Course

The open-road course portion immediately followed the closed course evaluation. This evaluation examined the data collection vehicle under actual road conditions. The driver followed a fixed course and had to encounter obstacles such as stopped traffic at signalized intersections, interference from tall vehicles, changes in roadway speed, etc. The open-road route spanned a length of approximately 30 miles, which started at the Riverside campus entrance. The course included nine different roads that were comprised of high-speed divided highways, urban arterials, and connector streets. Appendix B shows a map of the open-road course and driving instructions.

Researchers instructed the vehicle operator to drive at a safe speed that was favorable to data collection and close to the flow of traffic. The data collection vehicle finished three complete passes on the open-road course measuring signs on the right and left side of the road and signs overhead. Researchers tasked the vehicle operators with acquiring as many sign measurements as possible. Targeted signs included regulatory speed limit signs, signs in the median of a divided roadway, overhead guide signs, route marker assemblies, etc. In addition to retroreflective measurements, it was important to obtain information that would be beneficial to a sign management and inventory program. Such additional information included GPS location, face size, sign height, color, material type, digital images, etc.

Ultimately, the vehicle's retroreflective readings were compared to handheld measurements. The purpose of the comparison was to test the accuracy of the new mobile technology. Researchers created an inventory of the traffic signs on the open-road course and measured their retroreflectivity. The following section contains a comparison between the handheld retroreflectometer measurements and those from the data collection vehicle for the closed-course and open-road course.

COMPARISON

This section contains the researchers' analysis of the data set for both the closed-course and open-road evaluations. The final data set was delivered and enclosed in a zip folder that was approximately 26 megabytes. The folder contained one Excel® spreadsheet and 382 sign image files. Each sign image file was labeled with a sign ID number that corresponded to the appropriate sign information contained in the spreadsheet. The spreadsheet columns included sign ID number, color, message content, size, location, post and support information, face direction, GPS data, sheeting type, entrance angle, and computed retroreflectivity. The retroreflective measurements included only sign background measurements (no measurements were made of the signs' legends) and were at an observation angle of 0.2° and an entrance angle of −4.0°. The spreadsheet and sign images provided sufficient information to cross-reference the information. Figure 6 shows one of the sign images that were included in the zip folder.

Figure 6. Example of Image File.

The company representatives later confided that they were having difficulty and issues with the "post-processed guidance solution." The post-processed guidance solution aided with the data refinement and greatly expedited the data formatting process. For the closed-course signs, this problem corrupted some sign measurements, but it did not render all the data unusable. Some retroreflective values could be obtained, but it did add a great deal of time consuming manual formatting and manipulation. For the open-road course, the vehicle operators collected data the following, day but they were only able to measure signs on the right side of the roadway before rain halted further measurements for overhead and left side signs. In the end, the final zip folder contained limited closed-course readings and only right side signs on the open-road course.

Closed Course

In the closed-course portion, the vehicle operators provided 24 measurements, which included 12 of the 22 signs. There were eight signs positioned on the right side of the roadway and four signs on the left side. The closed-course portion was designed to challenge the data collection vehicle's capabilities. Although the overall sign capture rate was low (12 of 22), it is difficult to make any conclusion or inference from the closed-course capture rate because of the issues with the post-processing. Taking the technical problems into consideration, researchers focused on the data that were provided and evaluated the data collection vehicle based on those measurements.

Table 9 shows side-by-side comparisons of the mobile measurements and the handheld measurements. The data collection vehicle reported two different values where one value was from a two-lane roadway arrangement and the other was from a multi-lane setup. The two-lane and multi-lane measurements were similar, and the average difference was around 8 cd/lux/m^2. The difference between two- and multi-lane arrangements was greater when the sheeting retroreflective values were higher. For example, sign number 9a values were between 333 and 306, and the 9b values were between 36 and 33, which were differences of 27 and 3, respectively. All in all, the measurements from the two- and multi-lane arrangements were comparable, and this demonstrated that the vehicle can collect data from either the inside or outside position of a multi-lane roadway.

When the material types were compared in Table 9, it was determined that the vehicle falsely identified the sheeting type for six of the 12 signs. The mobile data collection vehicle mislabeled all Type III signs as Type I signs, and only one of three prismatic signs was accurately identified.

Table 9. Closed-Course Measurement Comparisons of Sign Background.

Sign Number	BKGD Color	Reported R_A by Vehicle			Handheld R_A		Percent Error
		Sheeting	Two-Lane	Multi-Lane	Sheeting	Actual	
1a	White	Type I	4	2	Type I	24	88%
2a	Green	Type I	2	2	Type I	24	92%
4a	White	Type I*	2	2	Type III	255	99%
4b	White	Type III*	209	185	Prism.	559	65%
6a	White	Type I*	30	27	Type III	115	75%
8b	Yellow	Type I*	23	21	Type III	191	88%
9c	White	Type I	51	34	Type I	92	54%
9b	White	Type I	40	31	Type I	61	42%
9d	White	Type I*	36	33	Type III	257	87%
9a	White	Prism.	333	306	Prism.	631	49%
11b	Black	Type I	0	0	Vinyl	0	0%
11a	Red	Type I*	16	11	Prism.	104	87%

Note: R_A values are expressed with an observation angle of 0.2° and an entrance angle of −4.0° and in units of cd/lx/m^2.

Table 9 also shows that all of the sign retroreflective measurements reported by the vehicle, both two- and multi-lane values, were lower than the handheld measurements. The far right column in the table depicts the percent error, which is the magnitude of the absolute difference between the mobile and the handheld values. The percent error ranged from 42 to 100 percent. The mean percent error for all 12 signs was 75 percent, and Type III signs exhibited the highest percent error among the three sheeting materials. Overall, reported retroreflectivity values by the vehicle were substantially different from the handheld values.

The lower sign measurements by the data collection vehicle had a considerable effect on the projected MUTCD sign compliance. The handheld measurements revealed that only one of the 12 signs failed to meet the minimum MUTCD requirements while the vehicle projected that five other signs were not in compliance.

Open-Road Course

The mobile measurements taken on the open-road included only signs on the right side of the roadway. There were a total of 402 signs on the right side of the roadway along the 30-mile course. The vehicle did not collect data for orange construction signs, so if those signs are excluded, then the capture rate for signs on the right-side was approximately 89 percent (a total of 370 signs were captured by the mobile system).

A random selection of 29 signs along the test route was chosen to make comparisons between the mobile and handheld retroreflectivity measurements. Appendix B shows the measurements. Overall, the mobile measurements were, on average, 86 cd/lx/m^2 lower than the handheld measurements. The average error was 70 percent. Of the 29 signs that were evaluated, only 6 signs had the correct retroreflective sheeting type identified.

SUMMARY

Mobile sign retroreflectivity measurements offer many promising features and advantages over handheld measurements. However, the FHWA's demonstration vans were not generally believed to be accurate enough, and since they have been out of service, there has been little activity in this area. The only exception (as of the 2009 when this project was initiated) was Mandli Technologies. Because of the size of Texas and the expected costs to measure all of the signs by hand, the concept of measuring sign retroreflectivity from a vehicle was promising. Researchers at TTI evaluated the mobile technology to determine if it was accurate enough to include within a management plan to satisfy the MUTCD minimum retroreflectivity levels.

Once the results were post-processed and delivered, researchers were able to cross-reference the sign data quickly as a result of the spreadsheet format and image files. Most of the sign attribute data were accounted for in the spreadsheet such as sign color, message content, size, location, post and support information, etc. The information spreadsheet presented the data in an organized and logical manner. The sign image files, ID numbers, and GPS information could allow an agency to easily and efficiently correlate the inventory data with the physical sign locations. The data collection vehicle acquired most of the necessary information, and it could be an effective tool in an inventory program.

On the other hand, the comparison of the retroreflectivity measurements was less than impressive. The retroreflective measurements differed considerably in both the closed-course and open-road course evaluations. The closed-course mean percent error was 75 percent. It was 70 percent on the open-road. In both conditions, the assessment of the retroreflective sheeting type was mostly incorrect.

While it might be considered safe to err on the side of caution, the lower measurements and inaccurate material identifications could lead to excessive and unnecessary sign replacement. For the closed-course signs, the vehicle projected that seven signs would fail to meet the MUTCD requirements while the handheld measurements determined that only one sign needed to be replaced. The false identifications and lower values could ultimately lead to a great deal of waste in both resources and capital.

Ultimately, the system tested herein failed to satisfy the expectations of accurately measuring sign retroreflectivity and being able to identify the type of retroreflective sheeting material used on each sign. In addition, the capture rate was less than expected, and the system could not provide the retroreflectivity measurements of the legends of positive contrast signs. The minimum retroreflectivity levels in the MUTCD are for both background and legends.

While there was only one mobile sign retroreflectivity technology available when this study was conducted, as of November 2011 there is at least one more mobile sign retroreflectivity technology available in the United States (Advanced Mobile Asset Collection) and others under development (*33*).

CHAPTER 5:
TXDOT DISTRICT VISITS

Visits to TxDOT district and maintenance offices were conducted to learn specifics regarding how TxDOT maintenance technicians inspect and evaluate traffic signs. TTI researchers observed one nighttime visual inspection and met with maintenance technicians, maintenance supervisors, and engineers at a total of eight district and maintenance offices across the state. The discussions were focused on each district's or maintenance section's sign inspection practices. Topics included the number of nighttime (and daytime, if any) sign inspections each office generally conducts each year, the number of inspectors that ride in each vehicle, the number of nights and number of hours per night needed to complete each inspection, and whether or not the district has a training program in place for its sign inspectors. Table 10 summarizes this information for the districts visited.

Table 10. Sign Inspection Data from TxDOT District Visits.

Agency	Nighttime Inspection	Inspectors per Vehicle	Hours per Night	Nights per Inspection	Training Program	Daytime Inspections
Washington Co., Bryan	2	2	3 to 4	5 to 6	No	1
Milam Co., Bryan	2	1	3 to 4	5 to 6	No	2
Bryan & Grimes Co., Bryan	2	2	6 to 8	2 to 3	No	1
Williamson County, Austin	1	2	6 to 8	2 to 3	Yes	1
Atlanta District	2	1 or 2	6 to 8	2 to 3	No	0
Grayson Co., Paris	2	2	4 to 5	5 to 6	No	2
Hockley Co., Lubbock	1	2	3 to 4	1	No	1
Amarillo District	2	1	3 to 4	3 to 4	Yes	0

NIGHTTIME VISUAL INSPECTION

Nighttime visual inspections are the sign inspection method preferred by the maintenance staff members who participated in the discussions. The eight TxDOT offices visited follow similar but not identical procedures for nighttime inspections. Inspections most often occur during early fall and/or late spring, times of year when nightfall is relatively early but frost and dew are not likely to interfere with the visual inspections. The maintenance personnel select nights that do not conflict with daytime maintenance activities. Offices that conduct two nighttime inspections per year try to space those inspections six months apart.

Inspection routes are selected to minimize travel paths for maximum efficiency; the total region to be inspected is typically divided into geographic areas identified by direction: e.g., southwest region, northern region, and so forth within the jurisdiction. Inspectors usually drive the roadways on the inspection routes at normal roadway speeds, although they may slow down on roadway sections that have high sign densities. On average, inspectors inspect approximately 200 to 300 signs (40 to 50 miles of roadway) per hour.

Sign Inspecting and Replacement

Nighttime inspections focus on the retroreflectivity of signs; inspectors may also look for evidence of sign vandalism, obstructions, and the condition of sign supports. Some maintenance offices also inspect pavement markings, pavement markers, delineators, and other retroreflective devices, as well as general roadway conditions, on the same inspection runs. Any failed, damaged, or obstructed signs are documented (location, sign type, defect) so that they can be replaced or repaired as needed. Visual sign inspection is largely a matter of the inspector's individual judgment. Most of the sign inspectors stated they tend to replace signs with marginal or questionable retroreflectivity or with moderate damage/distress, rather than leave a potentially failed or failing sign on the road until the next inspection. Some questionable signs may be examined by more than one inspector in order to reach a decision.

Inspectors and Inspection Training

Most of the offices that were visited use two inspectors per vehicle. One experienced inspector is usually paired with a maintenance technician/novice inspector who drives the vehicle. TxDOT sign inspectors typically have 5 to 15 years of experience; they observe road signs throughout the year and during routine maintenance in addition to the scheduled inspections. Maintenance technicians may have less specialized experience but still need to be knowledgeable about retroreflectivity. Most inspector and technician training is conducted on the job, with novice inspectors paired with more experienced ones on the inspection runs.

The Amarillo and Austin Districts are using more formal inspection training efforts. Opinions about inspection training (in addition to the on-the-job training that is currently the norm) were mixed. The engineers and maintenance supervisors interviewed tended to be in favor of additional training; the experienced sign inspectors did not think formal training is necessary.

Documentation of Inspections

Documentation methods differ among the districts and maintenance offices; some inspectors use pre-printed forms for this purpose and others document sign failures and other comments on an ordinary notepad. The forms or written reports document the names of the inspected roadways, the inspection dates, the names of the inspectors and information about any failed signs. Some of the offices have written/formalized procedures for following through with sign replacements and other work orders, based on any needs identified in the inspection documentation. However, there is no universal or uniform form for sign inspection and replacement.

Peer Review Inspections

Most of the offices employ peer reviews by maintenance supervisors, district or area engineers, and other authorities. Another peer review method involves inspectors from one area or section inspecting signs in another area/section. Roadways or roadway segments are selected for peer inspection at random within a given area or section. The peer reviews help to monitor road sign quality and the proficiency of the sign inspectors. Opinions of the peer review process are generally positive and the process is considered helpful by inspectors. The purpose of the reviews is additional quality assurance; peer reviewers should not expect that all signs in the selected sections will be perfect but should find that signs are generally in compliance.

In addition, a more formal peer review of the districts is conducted by the Traffic Operation Division. This program involves day and night inspections of random roadway sections. Sign retroreflectivity is one of many factors included in these reviews. These reviews are tied to district engineer annual evaluations, and the maintenance crews and inspectors appear to be aware of the importance of having their signs in good condition.

DAYTIME INSPECTIONS

Daytime inspections are conducted using a similar procedure as that used in nighttime inspections. Inspectors examine each sign’s message, color, support system, and hardware for vandalism, peeling legends, and brush/tree obstructions and identify knocked down or missing signs. Daytime inspections can take longer, on average, than nighttime inspections. Six of the eight offices that were visited schedule dedicated daytime sign inspections; offices that do not employ dedicated daytime sign inspections include regular observation and periodic localized inspections during routine daily maintenance. Daytime inspections, whether formal or conducted as part of maintenance, generally detect more sign defects and result in more sign replacements than nighttime inspections.

SIGN INVENTORY SYSTEMS

Of the visited TxDOT offices, only the Grayson County office currently maintains a complete sign inventory. Descriptions and location information (based on roadway mileage) about all of the TxDOT-maintained signs in the county are recorded in a spreadsheet. The inventory took some time to complete but is now used to help plan sign maintenance activities.

Sign inventories were discussed with the other TxDOT offices during the visits with mixed responses. There was greater acceptance of the idea of developing a sign inventory system in the Atlanta and Paris Districts, both of which use a centralized approach to sign maintenance activities. Meeting participants commented that an inventory system would need to be in a format that is user-friendly for maintenance technicians, would need to expedite the sign work-order process, and would provide for documenting missing signs. One suggestion received was for the development of a smart-phone application or similar mobile technology that would allow direct updating of the inventory by technicians in the field.

Not all of the meeting participants were in favor of sign inventories. Some of the older, more experienced technicians are concerned that maintaining an up-to-date inventory will add more work than it will save. Creating an initial inventory will require significant resources and personnel time, and continued time to maintain. Inventory maintenance would be more difficult in areas with high sign densities. There was also concern that not every office will have personnel with the types of computer software expertise needed.

SIGNING MATERIALS AND EQUIPMENT

Related topics discussed during the visits included experiences to date with the newer sign sheeting materials, sign substrates, and support/base materials. Overall, maintenance crews have been satisfied with both the high-intensity (HI) and prismatic sheeting materials. Both of these have been found to have a longer service life than engineering grade (EG) sheeting, which leads to fewer sign replacements over time. Within these sheeting types, red-colored signs were reported to degrade in both retroreflectivity and color more quickly when facing south or west; blue and brown signs also fade more quickly than other colors. Comments were also made that prismatic signs have a tendency to appear too bright at night, and to exhibit some glare. Some problems have been encountered with the black vinyl tape used for sign legends shrinking and peeling off of the signs.

Aluminum sign substrates have proven to be much longer-lasting than plywood, which would often cause signs to fail structurally before the HI and prismatic sheeting materials failed for retroreflectivity levels. The maintenance offices recycle aluminum substrates from removed signs periodically throughout the year.

Maintenance crews are generally content with the triangle slip-base sign support; there have been some instances of bolts at the bottom of the slip-base rusting, which causes the bolts to be difficult to remove when it is time to replace or repair a sign. Wind can push signs out of alignment, particularly in the districts in the western half of the state (Lubbock, Amarillo). These districts have added wind washers and fender washers to the assemblies to help keep signs straight on their bases. Another reported adaptation is due to soil type: the maintenance office in Grayson County has made some changes to the sign bases to help them stay anchored more securely in the soft soil that is prevalent in the region.

FOLLOW-UP VISITS

Visits to three additional TxDOT maintenance offices were conducted after the initial visit described above. The researchers made these follow-up visits to further discuss different sign retroreflectivity maintenance methods, as well as ideas for a statewide form for documenting sign inspections and follow-up activities. TTI researchers also demonstrated two of the MUTCD visual nighttime inspection procedures (calibration signs and comparison panels) for TxDOT personnel during these meetings.

Sign Inspection Supporting Methods

The MUTCD visual nighttime inspection procedures—calibration signs, comparison panels, and consistent parameters—were described to the TxDOT maintenance technicians, sign inspectors, and supervisors. Of the three methods, the TxDOT participants felt that “consistent parameters,” which requires that one inspector in each vehicle be 60 years of age or older, was the least feasible method for most maintenance offices, since it would be difficult to guarantee that each office will have one or more inspectors of that age at any given time.

The use of calibration signs prior to starting an inspection run was received favorably by inspectors and supervisors, and several participants commented that this method could also be a useful training tool for new inspectors. Numerous suggestions were received regarding the implementation of this method. Supervisors commented that calibration signs could be outfitted with brackets that would allow them to be quickly and easily hung at an appropriate height on the maintenance yard fence prior to an inspection run; the signs would be stored inside during the rest of the year. One supervisor thought it might be helpful to have calibration signs posted on a dedicated sign post at the start of each roadway to be inspected. Another suggested using examples of good, marginal, and failed signs as calibration signs.

Comparison panels received mixed responses. Some of the participating maintenance personnel commented that the panels could be useful for some decisions regarding marginal signs. However, most participants reiterated the comments heard at the earlier district visits regarding the tendency among TxDOT inspectors to replace near-failing signs; in most cases, they would be more likely to remove and replace a sign that exhibited retro levels low enough to merit the use of a comparison panel.

Sign Inspection Documentation

The variety of methods for documenting sign inspection results and follow-up actions was a discussion topic in the first round of district visits and was confirmed in the follow-up meetings. Appendix C provides samples of inspection documentation from two of the offices visited as well as an inspection form drafted by the research team that was distributed and discussed during the follow-up meetings. Most of the participants agreed that the form included the necessary information regarding the inspection routes and dates, locations and description of failed signs, and follow-up actions. However, not all of the crews felt that a single standardized form would work for every inspector and every office. It was suggested that instead of requiring every office to use the same form, TxDOT establish standards for the types of information that need to be ultimately recorded and kept on file about the inspections and results.

SUMMARY

The researchers made 11 visits to district and maintenance offices across the state to assess the current sign retroreflectivity maintenance practices and discuss potential changes to current practices to be in compliance with the MUTCD language related to minimum sign retroreflectivity levels. We learned that most nighttime inspections were conducted annually and most inspections included paired inspectors—consisting of a young and inexperienced maintenance personnel with a more experienced maintenance personnel. While some areas have started their own training programs, it was generally agreed that the calibration sign technique of the visual nighttime inspection method as described in the MUTCD would be the most accepted and most helpful change to current practices. We also learned that there are various ways to record and document the results of nighttime visual inspections. We drafted a standard form and solicited comments and suggestions for improvements. Appendix C includes the final version of that form.

CHAPTER 6:
SUPPORTING STUDY

Researchers conducted a study at TTI's Riverside test facility to assess the usability and the effectiveness of calibration signs and of comparison panels—two of the proposed tools for improving a sign inspector's consistency in identifying marginal and poor signs during nighttime roadway inspections.

Calibration signs are a tool intended to be used prior to a nighttime visual inspection of roadway signs, as a way to train or "calibrate" an inspector's eyes to recognize signs that are just at or below the minimum retroreflectivity level. The signs that were used as calibration signs for this study were TTI-constructed signs that were made with a variety of off-the-shelf films. Table 11 lists the retroreflectivity levels of the calibration signs. The comparison panels were manufactured by Avery Dennison and are fabricated to be at the appropriate minimum retroreflectivity depending on the criteria in Table 2A-3 of the MUTCD (more information about the Avery Dennison comparison panels can be found here: http://www.reflectives.averydennison.com/PDFs/MRS_Kit_PDB.pdf).

Table 11. Retroreflectivity of TTI-Produced Calibration Signs.

Calibration Signs	Color		Researchers' Measured Values	
	Background	Legend	Background	Legend
White on Green	Green	White	17	118
Black on Yellow	Yellow	Black	81	-
White on Red	Red	White	5	29
Black on White	White	Black	47	-

TEST COURSE

The runway system on Texas A&M's Riverside Campus served as the test roadway for data collection. Along the selected route, 23 sign posts were spaced about 500 ft apart (see Figure 7). The signs were located at offsets typical of two-lane highways. The route was laid out as two different laps, each with a different set of 23 signs. Two signs were mounted back-to-back on each sign post and the posts were rotated between laps.

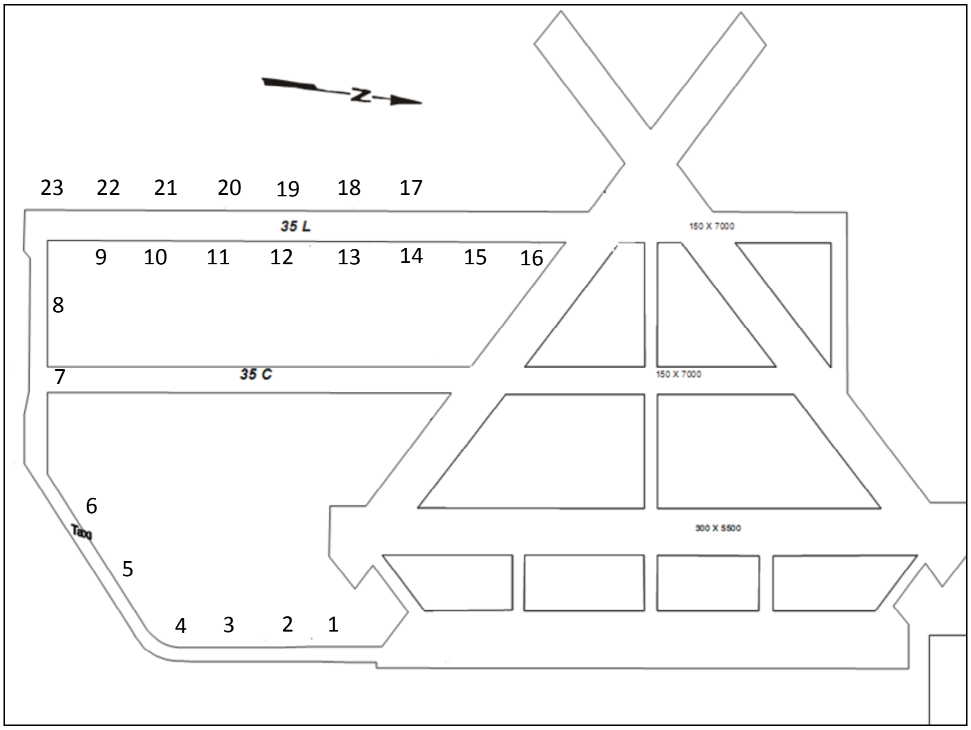

Figure 7. Map of Riverside Runways Showing the Positions of Signposts 1 through 23.

The 46 signs selected for the course were a mixture of "good" condition signs with adequate-to-good levels of retroreflectivity, "marginal" signs with retroreflectivity levels just above or below the minimum levels required in the MUTCD, "failed" signs with low retroreflectivity levels, and a few signs that could be classified as marginal or failing because of discoloration or damage.

Tables 17 and 18 list the signs used in each lap of the course with their measured retroreflectivity values. The tables also list the research team's evaluation of each sign's condition, based on a combination of its measured retroreflectivity and any other visible flaws. The evaluation categories—good, marginal, and poor—were defined as follows:

- Good (G) – the sign's retroreflectivity is within 20 percent of the ASTM values for a new sign of its type and is mostly free from scratches, damage, or discoloration. Many manufacturers set the warranty period for signs at the 20 percent reduction in retro. Fourteen of the signs on the test track met these criteria.

- Marginal (M) – the sign's retroreflectivity is at least 20 percent lower than the ASTM values for a new sign of its type but is more than 15 percent above the MUTCD's minimum retroreflective requirements; a sign that is considered good based on retro values can be considered marginal for minor scratches or other damage to the appearance or sign surface. Fifteen signs on the test track fell into this category.
- Poor (P) – the sign's retroreflectivity is less than or equal to 15 percent above the minimum retroreflective requirements and/or is significantly discolored or damaged. Seventeen signs on the test track were in this category.

Table 12. Signs Shown on Lap A of Test Course.

Pos.	Color	Message	Measured Retroreflectivity ($cd/lx/m^2$)		Sign Condition
			Background	Legend	
1	White	55	82	-	M
2	Yellow	SCHOOL CROSSING	82	-	M
3	Red	STOP	23	208	G
4	Yellow	Right Arrow	35	-	P
5	Green	RETRO	28	216	M
6	White	ROUTE MARKER	60	-	P
7	White	55	86	-	M
8	Red	YIELD	60	254	G
9	Yellow	SCHOOL CROSSING	167	-	G
10	Red	STOP	10	73	P
11	White	H8	251	-	G
12	Green	ALASKA	52	254	G
13	White	B3	193	-	M
14	Red	DO NOT ENTER	35	231	M
15	Yellow	PAVEMENT ENDS	90	-	P
16	White	ONE WAY	90	-	M
17	Yellow	Right Arrow	198	-	G
18	Green	PHILLIPS	8	88	P
19	Red	YIELD	12	30	P
20	White	ROUTE MARKER	169	-	M
21	White	45	31	-	P
22	Yellow	NARROW BRIDGE	34	-	P
23	Red	STOP	15	87	G

Table 13. Signs Shown on Lap B of Test Course.

Pos.	Color	Message	Measured Retroreflectivity (cd/lx/m^2)		Sign Condition
			Background	Legend	
1	White	60	73	-	M
2	Yellow	Right Arrow	84	-	M
3	Red	STOP	4	28	P
4	Yellow	Right Arrow	238	-	G
5	Green	RETRO	18	108	P
6	White	ROUTE MARKER	225	-	G
7	White	Y2	265	-	G
8	Red	YIELD	9	67	M
9	Yellow	NO PASSING	76	-	P
10	Red	STOP	13	112	G
11	White	55	103	-	M
12	Green	MONTANA	56	260	G
13	White	F4	34	-	P
14	Red	DO NOT ENTER	5	39	P
15	Yellow	LOOSE GRAVEL	203	-	G
16	Green	AUSTIN	4	19	P
17	Yellow	NARROW BRIDGE	20	-	P
18	Green	LAKEWOOD	37	254	M
19	Red	YIELD	15	53	M
20	White	ROUTE MARKER	63	-	P
21	White	55	191	-	G
22	Yellow	WATER OVER ROAD	216	-	M
23	Red	STOP	4	37	P

PARTICIPANTS

In the original work plan, sign inspectors from TxDOT maintenance offices were proposed as study participants. Because of budgetary restrictions, TxDOT was unable to fund travel of its personnel to College Station for this purpose. Because the project budget did not include compensation for study participants, 20 TTI personnel were recruited as volunteer participants. In addition, a visiting class of TxDOT young engineers, as well as three local-area TxDOT employees, participated in a portion of the Riverside study.

PROCEDURES

Calibration signs and comparison panels were demonstrated over three nights at the Riverside campus. The first night, scheduled to take advantage of a visiting class of TxDOT's young engineer program, served as a demonstration and partial pilot test of the study procedures. Some of the study procedures were modified after the first night, specifically the procedures for viewing the calibration signs and the driving speed through the test course. Additionally, the first nine participants received a brief demonstration of the comparison panels; the other 20 study participants were given an additional scoring sheet and each scored eight signs using the comparison panels.

Participant Intake and Instructions

Participant intake was performed at the TTI offices (Building 7091) on the Riverside Campus. This location was selected because it was near the driving route, had public parking available, included a large conference room and restroom facilities, and was available for nighttime use during the data collection period. The intake procedures were performed with the entire group of pilot-test participants at one time. After reviewing the informed consent documentation, participants were given an overview of the study. The overview included a slide presentation containing a summary of nighttime sign inspection procedures, including criteria for determining if a sign should be replaced and a description of the use of calibration signs and comparison panels in inspection procedures. The presentation included photographs of road signs with each of the following characteristics to help illustrate the inspection criteria:

- Low retroreflectivity when viewed with vehicle headlamps.
- Faded or uneven color.
- Damaged surface.
- Distressed or obscured sign legend.

Participants were each given a score sheet (see Appendix D) and instructed to score each sign on the course with a "P" (pass), "FR" (fail because of low retroreflectivity), "FO" (fail because of other reasons such as discoloration or damage), or "FRO" (fail because of low retroreflectivity as well as other reasons).

Nighttime Sign Inspection Testing (with and without Calibration Signs)

Following the instructional presentation, participants were driven from Building 7091 to the test course. Two to three participants were passengers in each of the test vehicles, which were driven by researchers. Participants who were in the "calibration training" group viewed the four calibration signs, which were set up close to the test course entrance; participants in the "non-trained" group did not view the calibration signs.

All participants were then told which lap of the course they would be viewing first (A or B) and were driven through the test course past each of the 23 signs. A separation of approximately 1500 ft was maintained between test vehicles.

Once all vehicles had completed the first lap, the field crew turned each of the sign posts around to display the remaining 23 signs. Participants in the "calibration training" group viewed the calibration signs again (this time with stationary vehicles), and all participants were driven through the test course a second time.

Comparison Panels Testing

Eight road signs, two each of four sign types (white regulatory sign, yellow warning sign, red Stop sign, green guide sign) were displayed on portable stands at approximately eye level. One or two comparison panels were clipped to each sign: one panel that corresponded to a minimum retroreflectivity value for the sign's background color, and for the Stop and guide signs, an additional panel to compare to the sign's legend.

Participants were provided with flashlights and instructed to shine light on each comparison panel and on the sign background or legend adjacent to it. If the sign background and (where applicable) the sign legend both looked brighter than the corresponding comparison panels, participants were instructed to score the sign as "passing." If either the background or the legend looked dimmer than the corresponding comparison panel, the sign was scored as "failing." Appendix E shows the scoring sheet used by participants.

Survey

Following the comparison panels test, participants were driven back to Building 7091 and were given a brief written survey to gather their feedback regarding the sign inspection process and the calibration signs.

RESULTS

The first night of the Riverside study was June 29, 2011. The nine participants were TxDOT employees, including three local TxDOT employees and six members of TxDOT's young engineer program in Atlanta, Texas, who were visiting TTI's College Station offices.

Unlike the TTI participants on the two subsequent study nights, the TxDOT participants were not split into calibration training and non-trained groups; all nine of these participants viewed the calibration signs prior to scoring signs on the test track. Over the entire participant sample (TxDOT and TTI participants), 19 viewed calibration signs and 10 did not.

Scoring Signs with and without Calibration Signs

Table 14 and Table 15 list the scoring results for the 46 signs across the three participant groups. Figure 8 and Table 16 summarize the percentages of participants who failed the signs that were classified as good, marginal, and poor based on retroreflectivity measurements and surface condition. The "Fail" columns in the tables and figure represent signs that participants marked as failing on their sheets based on their visual perception of a given sign's retroreflectivity (entered as FR on the score sheet), on other flaws such as discoloration (entered as FO), or for both retroreflectivity and other flaws (entered as FRO). Appendix F contains the complete tables showing the breakdown of FR, FO, and FRO scores.

Table 14. Lap A – Participant Sign Scores.

Pos.	Color	Message	Sign Condition	TxDOT – w/ Calibration Signs		TTI – w/o Calibration Signs		TTI – w/ Calibration Signs	
				Pass	Fail	Pass	Fail	Pass	Fail
1	White	55		8	1	7	3	10	0
2	Yellow	SCHOOL CROSSING	M	6	3	9	1	6	4
3	Red	STOP	M	9	0	9	1	9	1
4	Yellow	Right Arrow	G	0	9	3	7	2	8
5	Green	RETRO	P	8	1	5	5	5	5
6	White	ROUTE MARKER	M	5	4	2	8	3	7
7	White	55	P	8	1	3	7	8	2
8	Red	YIELD	M	8	1	8	2	8	2
9	Yellow	SCHOOL CROSSING	G	8	1	9	1	8	2
10	Red	STOP	G	2	7	1	9	2	8
11	White	H8	P	6	3	5	5	7	3
12	Green	ALASKA	G	6	3	5	5	3	7
13	White	B3	G	5	4	7	3	5	5
14	Red	DO NOT ENTER	M	5	4	5	5	5	5
15	Yellow	PAVEMENT ENDS	M	1	8	0	10	0	10
16	White	ONE WAY	P	7	2	5	5	4	6
17	Yellow	Right Arrow	M	9	0	10	0	9	1
18	Green	PHILLIPS	G	4	5	1	9	5	5
19	Red	YIELD	P	1	8	1	9	0	10
20	White	ROUTE MARKER	P	2	7	7	3	6	4
21	White	45	M	3	6	0	10	1	9
22	Yellow	NARROW BRIDGE	P	2	7	0	10	0	10
23	Red	STOP	P	9	0	10	0	10	0

Table 15. Lap B – Participant Sign Scores.

Pos.	Color	Message	Sign Condition	TxDOT – w/ Calibration Signs		TTI – w/o Calibration Signs		TTI – w/ Calibration Signs	
				Pass	Fail	Pass	Fail	Pass	Fail
1	White	60	M	8	1	8	2	8	2
2	Yellow	Right Arrow	M	9	0	10	0	8	2
3	Red	STOP	P	1	8	1	9	1	9
4	Yellow	Right Arrow	G	8	1	10	0	7	3
5	Green	RETRO	P	2	7	3	7	4	6
6	White	ROUTE MARKER	G	7	2	4	6	5	5
7*	White	Y2	G	7	2	4	6	3	7
8*	Red	YIELD	M	3	6	5	5	2	8
9	Yellow	NO PASSING	P	0	9	0	10	0	10
10	Red	STOP	G	9	0	10	0	9	1
11	White	55	M	8	1	5	5	7	3
12	Green	MONTANA	G	8	1	4	6	3	7
13	White	F4	P	0	9	1	9	1	9
14	Red	DO NOT ENTER	P	1	8	1	9	0	10
15	Yellow	LOOSE GRAVEL	G	9	0	6	4	7	3
16	Green	AUSTIN	P	0	9	1	9	0	10
17	Yellow	NARROW BRIDGE	P	0	9	0	10	0	10
18	Green	LAKEWOOD	M	6	3	4	6	3	7
19	Red	YIELD	M	0	9	7	3	3	7
20	White	ROUTE MARKER	P	3	6	3	7	2	8
21	White	55	G	9	0	9	1	10	0
22	Yellow	WATER OVER ROAD	M	4	5	0	10	0	10
23	Red	STOP	P	4	5	4	6	5	5

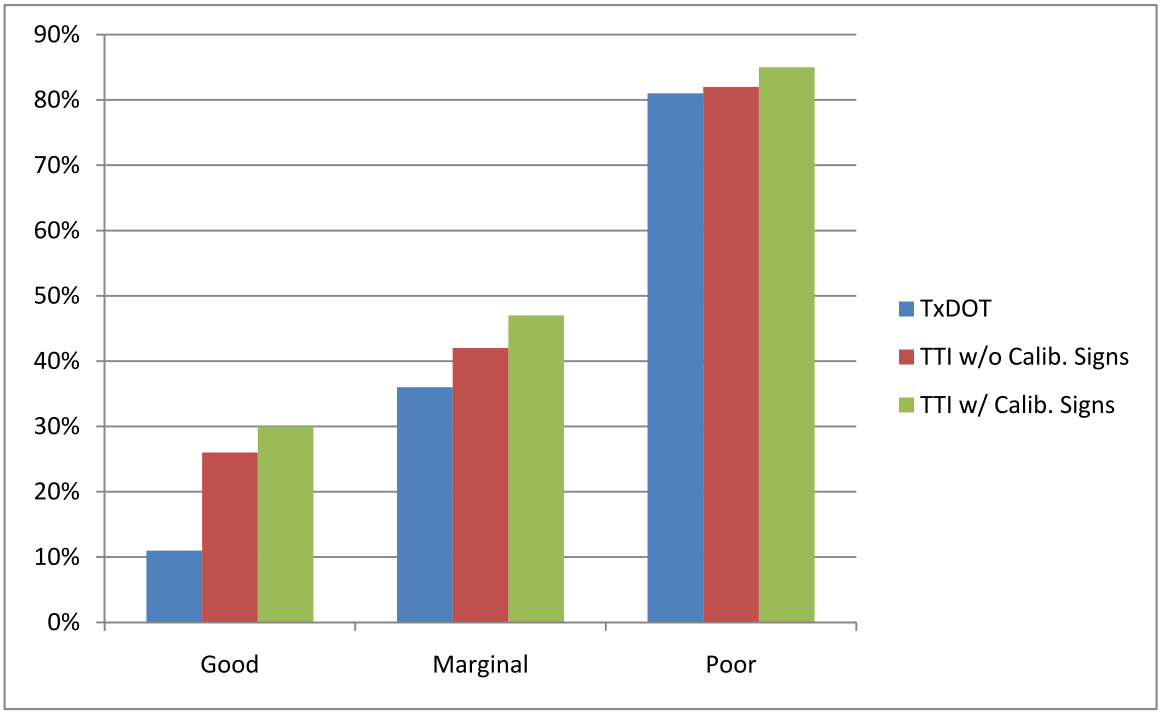

Figure 8. Percent of All Test-Track Signs that Were Failed by Participants, by Sign Category (All Colors).

Table 16. Percent of Test-Track Signs Failed by Participants.

Sign Classification	Percent of Signs Failed		
	TxDOT Participants	TTI Participants (without Calibration Sign Training)	TTI Participants (with Calibration Sign Training)
Good	11%	26%	30%
Marginal	36%	42%	47%
Poor	81%	82%	85%

As shown in Figure 8 and Table 16, the percentage of participants scoring signs as failing for perceived retroreflectivity levels, discoloration, or other surface flaws was highest for poor-quality signs, decreased for marginal-quality signs, and was lowest for good-quality signs. Additional analyses were attempted to look for trends within sign types/colors, but the sample sizes within each color group were too small to yield reliable results; individual variation among participants was higher than variation between groups when analyzing the smaller subsets.

A Pearson's chi-square test for independence indicated no significant differences in scoring across the three participant groups. Again, because of the small total sample size, variability within each participant group was high.

Scoring Signs with Comparison Panels

Participants were asked to judge visually whether each sign background and legend reflected more or less light, i.e., looked brighter or dimmer, than the corresponding comparison panel when viewed using an LED flashlight as a light source. If they thought that either the sign background or the sign legend (for red and green signs) was less retroreflective than the corresponding comparison panel, they were instructed to score the sign as failing. Table 17 shows how each of the eight signs were scored by participants, as well as the average measured retroreflectivity of the signs and of the comparison panels that were used with each sign's background and legend.

Table 17. Retroreflectivity Values and Participant Scores for Signs Viewed with Comparison Panels.

Sign #	Type & Message	Measured Retroreflectivity (cd/lx/m^2)				Sign Score based on Measured Retro	Scores from Participants (%)	
		Background Avg.	Panel Avg.	Legend Avg.	Panel Avg.		Pass	Fail
1	Speed Limit 45	38	61			Fail	20%	80%
2	Warning - Curve	71	94			Fail	95%	5%
3	STOP Sign HI	49	9	245	37	Pass	85%	15%
4	Guide sign - TEST	20	23	57	126	Fail	55%	45%
5	Speed Limit 45	69	61			Pass	75%	25%
6	Warning - CHURCH	66	94			Fail	70%	30%
7	STOP Sign EG	8	9	47	37	Pass	80%	20%
8	Guide sign - RETRO	20	23	103	126	Fail	70%	30%

Sign 1, a white speed limit sign, had a measured retroreflectivity of 38 cd/lx/m^2, which was lower than the comparison panel's retro of 61. Sixteen out of the 20 participants (80 percent) correctly failed this sign. The other speed limit sign (Sign 5) had a measured retroreflectivity of 69, and 15 participants (75 percent) correctly passed this sign.

Signs 2 and 6 were both yellow warning signs, and both had measured retro levels lower than the corresponding comparison panel's 94 cd/lx/m^2; Sign 2's retroreflectivity was 71, and Sign 6's retroreflectivity was 66. However, a majority of participants passed both signs; 95 percent gave Sign 2 a passing score and 70 percent passed Sign 6. This may be due largely to the difference in color between the signs and the comparison panel. The panel was an unfaded yellow, while both signs had faded to a light yellow, which looked brighter than the panel, despite their respective retroreflectivity levels.

The two red Stop signs both received passing scores from a majority of participants. Sign 3's background and legend were both considerably brighter than their respective comparison panels—49 cd/lx/m^2 for the sign background and 247 cd/lx/m^2 for the legend, compared to 9 and 37, respectively, for the comparison panels. This sign received a passing score from 85 percent of participants. Sign 7's background retroreflectivity was almost identical to the red comparison panel (8 cd/lx/m^2 for the sign versus 9 for the panel), and its legend was slightly brighter than the corresponding white comparison panel (47 for the sign versus 37 for the panel). Despite the small retroreflectivity difference, 80 percent of participants gave this sign a passing score.

The green backgrounds of the guide signs (Signs 4 and 8) happened to have identical retroreflectivity levels (20 cd/lx/m^2), which was also very close to the retroreflectivity level of the green comparison panel (23 cd/lx/m^2). The two sign legends had different retroreflectivity levels (57 for Sign 4 and 103 for Sign 8) that were both lower than that of the corresponding white comparison panel. Even though the Sign 4 legend had a lower retroreflectivity than the Sign 8 legend, more participants failed Sign 8 out of this pair: 55 percent failed Sign 4, compared to 70 percent who failed Sign 8. Again, color—this time the color of the sign legend rather than the background—may have played a part in participant perceptions of these two signs. While the green backgrounds were virtually identical in color to each other and to the green comparison panel, the white sign legends were slightly different in shade. Sign 8's legend was visibly yellowed next to the white of the comparison panel, while Sign 4's legend color was much closer to that of the panel even though its retroreflectivity level was lower.

Survey Results

Two different versions of the survey were created. The survey for participants in the calibration training group included four questions that were not included in the survey for the non-trained group; additionally, one question was worded slightly differently for each group. Table 18 compares the questions that were presented to the two participant groups.

Table 18. Survey Questions Following Sign Inspections.

Survey Questions – Calibration Training Group	Survey Questions – Non-Trained Group
1. How difficult was the on-road sign inspection task in this evaluation without prior experience or training? *(Not difficult, Somewhat difficult, Difficult)*	**1.** How difficult was the on-road sign inspection task in this evaluation without prior experience or training? *(Not difficult, Somewhat difficult, Difficult)*
2. How often were you unsure if a sign passed or failed? *(Rarely, Sometimes, Frequently)*	**2.** How often were you unsure if a sign passed or failed? *(Rarely, Sometimes, Frequently)*
3. I was confident in my ability to inspect signs and to determine if they were passed or failed. *(Agree, Neutral, Disagree)*	**3.** I was confident in my ability to inspect signs and to determine if they were passed or failed. *(Agree, Neutral, Disagree)*
4. I believe that I would need additional experience and training if I was going to inspect traffic signs on a professional level for a roadway agency. *(Agree, Neutral, Disagree)*	**4.** I believe that I would need additional experience and training if I was going to inspect traffic signs on a professional level for a roadway agency. *(Agree, Neutral, Disagree)*
5. Viewing the calibration signs helped to improve my accuracy and bolster my confidence when inspecting traffic signs in this evaluation. *(Agree, Neutral, Disagree)*	**5.** Would viewing calibration signs near the pass or fail threshold before starting the sign inspection task have been helpful in this evaluation? *(Agree, Neutral, Disagree)*
6. How often should the calibration signs be viewed and utilized for visual nighttime inspection? *(Nightly, Monthly, Yearly)*	
7. Which calibration signs technique did you prefer? *(In-motion, Stationary)*	
8. Overall, the calibration signs were effective with aiding the inspection task of traffic signs in this evaluation. *(Agree, Neutral, Disagree)*	

Question 1. How difficult was the on-road sign inspection task in this evaluation without prior experience or training? The answers to this question were similar in both participant groups. In the group of 10 participants using the calibration signs, six rated the task "not difficult" and four as "somewhat difficult." In the group that had not used calibration signs, five rated the task "not difficult," four rated the task as "somewhat difficult," and one rated it as "difficult." Figure 9 compares the Question 1 answers from the two participant groups.

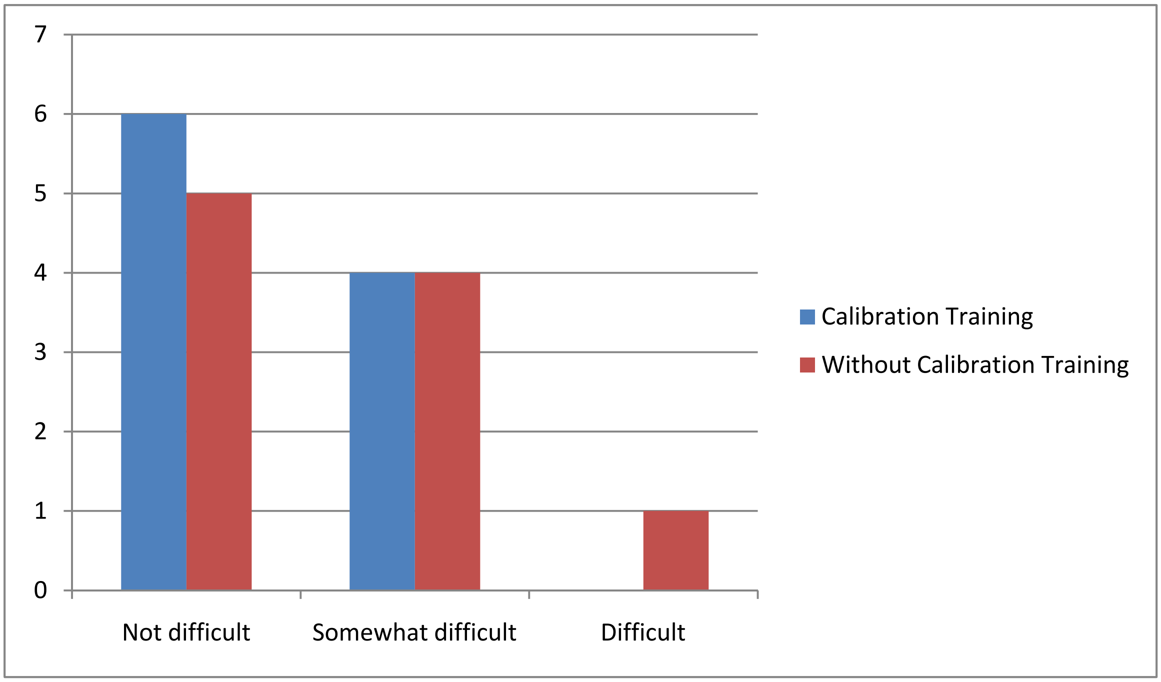

Figure 9. Answers to Question 1: How Difficult Was the On-Road Inspection Task in This Evaluation without Prior Experience or Training?

Question 2. How often were you unsure if a sign passed or failed? In the group using the calibration signs, two indicated that they were "rarely" uncertain, five that they were "sometimes" uncertain, and three that they were "frequently" uncertain. In the group that had not used calibration signs, eight indicated that they were "sometimes" uncertain and two indicated they were "frequently" uncertain.

Figure 10 compares the Question 2 answers from the participant groups.

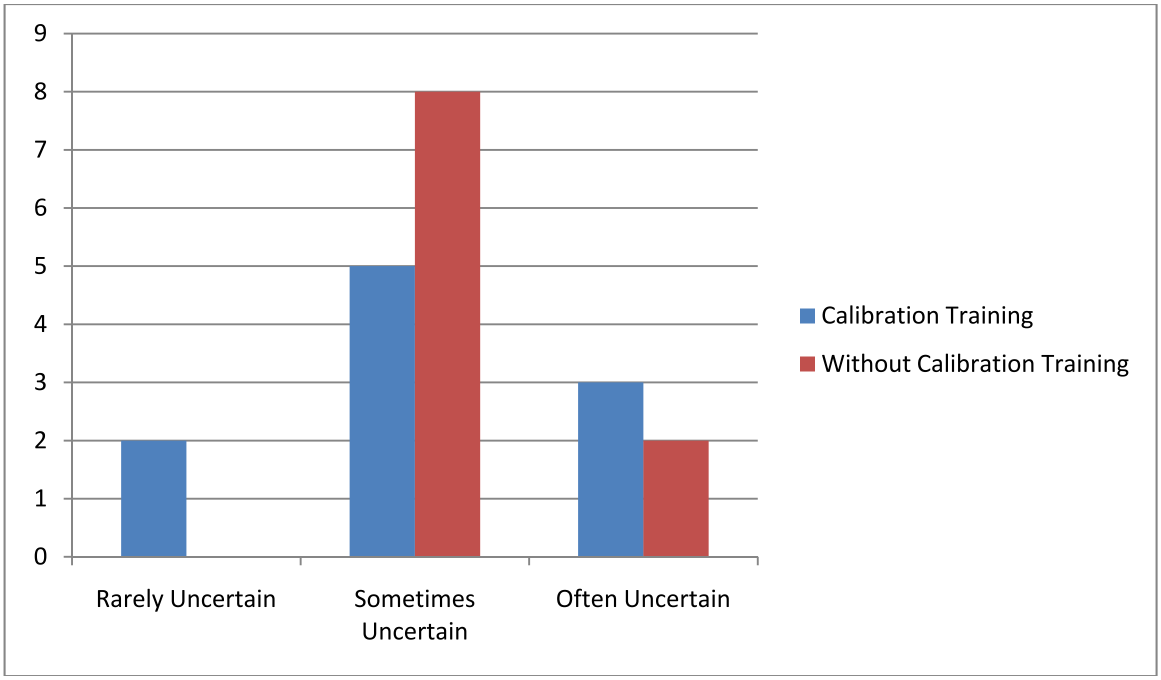

Figure 10. Responses to Question 2: How Often Were You Unsure if a Sign Passed or Failed?

Question 3. I was confident in my ability to inspect signs and to determine if they were passed or failed. In the group using the calibration signs, four out of 10 indicated that they agreed with the statement presented (were confident in their ability to inspect and grade the signs on the test course); the other six indicated that they were neutral (neither agreeing or disagreeing). In the group that did not use the calibration signs, three out of 10 agreed that they were confident in their ability to inspect the signs on the test course, three were neutral, and four disagreed with the statement. Figure 11 compares the answers to Question 3 from the participant groups.

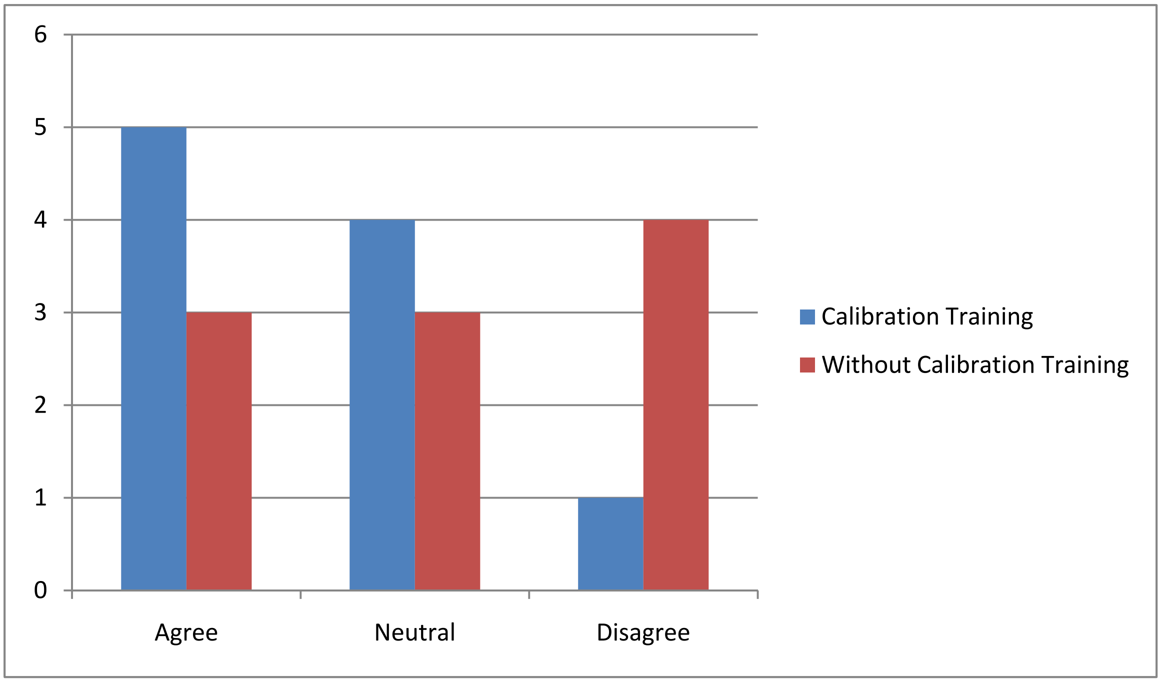

Figure 11. Responses to Statement in Question 3: I Was Confident in My Ability to Inspect Signs and to Determine if They Were Passed or Failed.

Question 4. I believe that I would need additional experience and training if I was going to inspect traffic signs on a professional level for a roadway agency. In the group using the calibration signs, five agreed with the statement presented, indicating that they believe they would need additional experience and training to inspect traffic signs for a roadway agency. Four were neutral about the statement and one disagreed. In the group that had not used the calibration signs, nine believed they would need additional training; one did not. Figure 12 compares the answers to Question 4 from the two participant groups.

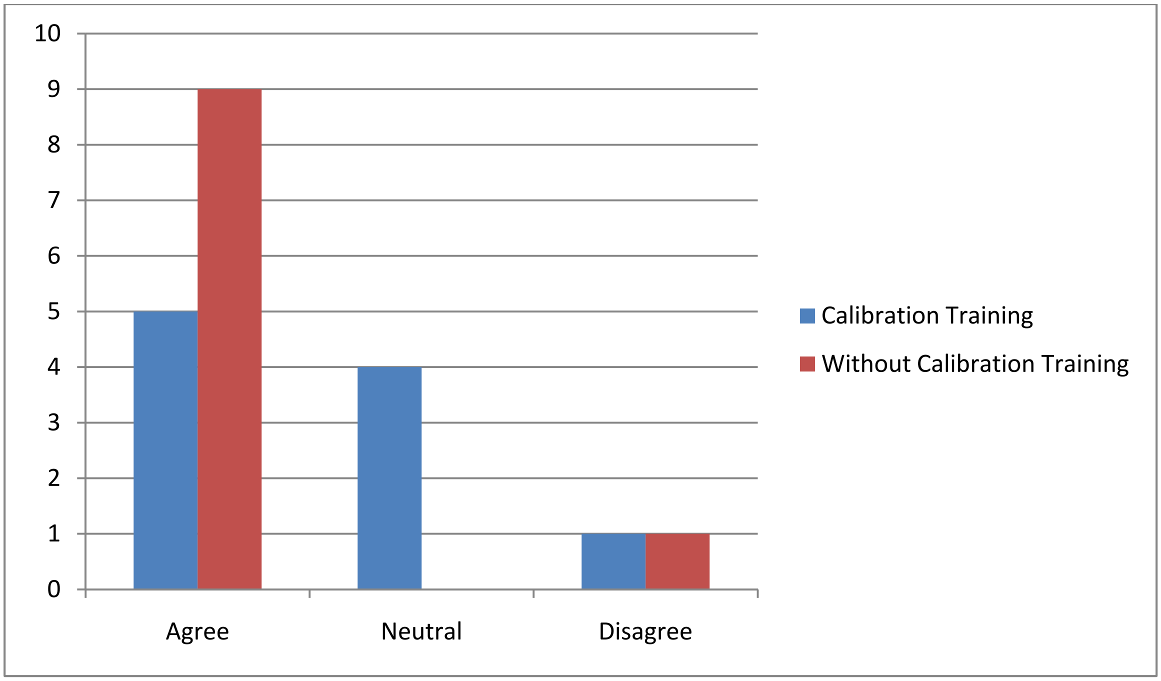

Figure 12. Responses to Statement in Question 4: I Believe that I Would Need Additional Experience and Training if I Was Going to Inspect Traffic Signs on a Professional Level for a Roadway Agency.

Question 5. Helpfulness of calibration signs. For the group that had used the calibration signs, this question was worded as the statement "Viewing the calibration signs helped to improve my accuracy and bolster my confidence when inspecting traffic signs in this evaluation." Nine of the 10 participants in this group agreed with the statement; one was neutral.

The statement for the group that had not used the calibration signs was worded "Would viewing calibration signs near the pass or fail threshold before starting the sign inspection task have been helpful in this evaluation?" Five of the 10 participants in this group agreed, four were neutral, and one disagreed.

Question 6. How often should the calibration signs be viewed and utilized for visual nighttime inspection? This question was asked only of participants who had viewed the calibration signs. Four of these 10 participants responded that calibration signs should be viewed nightly prior to sign inspections, four that the calibration signs should be viewed monthly, and two believed that they should be viewed yearly.

Question 7. Which calibration signs technique did you prefer? Six of the participants in the calibration signs group preferred viewing the calibration signs by driving past them. The other four preferred viewing the signs in a stationary vehicle.

Question 8. Overall, the calibration signs were effective with aiding the inspection task of traffic signs in this evaluation. Nine out of 10 of the participants who had viewed the calibration signs felt that the signs were an effective aid for conducting nighttime sign inspections; one was neutral.

SUMMARY

In the visual sign inspections on the Riverside test track, the scoring of signs as passing or failing was similar across all three groups of participants. As a whole, participants were fairly conservative in their evaluations, more likely to reject a passing sign than to incorrectly pass a failing sign. This is consistent with previous research regarding visual sign inspections.

There was no obvious improvement in the percentage of correct pass or fail scores based on whether participants had used calibration signs prior to starting the inspections. However, the participants who had used the calibration signs regarded them favorably as a training tool and expressed more confidence about the sign inspection task.

The comparison panels produced somewhat inconsistent results. Differences in color between a given sign's background and/or legend and the corresponding comparison panel could make the sign look brighter (more retroreflective) or darker (less retroreflective) than it actually was.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

This study evaluated TxDOT's current sign retroreflectivity maintenance practices, assessed their effectiveness, and recommended a statewide sign retroreflectivity maintenance practices that could be easily and effectively implemented to ensure that TxDOT would be in compliance with the new MUTCD language related to minimum sign retroreflectivity. The timing of the study was planned so that the recommendations would be available before the MUTCD's January 2012 compliance date to have selected and started using a sign retroreflectivity maintenance method (although the current January 2012 compliance date is subject to change as a result of on-going FHWA rule-making activities) (*34*).

CONCLUSIONS

In this study, researchers identified that TxDOT currently has a nighttime visual inspection requirement but practices and documentation vary across the state. Some areas conduct visual nighttime inspection twice per year and other areas conduct them annually. None of the current practices that were identified would meet the intent outlined by FHWA in terms of the three available procedures for conducting nighttime visual inspections. In addition, researchers tested a new mobile retroreflectivity technology, but the results are not accurate enough to recommend its use as a way to remove the subject nature of visual nighttime inspections (although newly available technologies may have the accuracy needed to further consider mobile sign retroreflectivity measurements as a viable element of a sign retroreflectivity management program).

A statewide inspection of in-service signs revealed that almost all were above the MUTCD minimum retroreflectivity levels. TxDOT has a formal quality control process in place to help ensure that sign retroreflectivity maintenance, among other items, remains a top priority. In many areas around the state, self-imposed quality checks are also in place. These varying levels of quality control help ensure that sign retroreflectivity maintenance remains a top priority. The statewide condition assessment results are proof that the current system is working.

Despite the existing evidence of a successful sign retroreflectivity maintenance program, there is the issue that the visual inspection processes used throughout the state are not well documented and not compliant with the three different procedures the FHWA has outlined for visual nighttime inspections. One recommendation might be that TxDOT use this study and the results to support their current processes. However, as currently practiced, the visual nighttime inspections lack a direct tie to the minimum retroreflectivity levels in the MUTCD, which is the basis for the methods FHWA has listed in the MUTCD. In addition, the inspectors must be trained as per the MUTCD language. Currently, TxDOT inspectors acquire their inspection skills through experience rather than training.

RECOMMENDATIONS

Considering the MUTCD requirements and through the discoveries learned during this study, researchers recommend three specific items that TxDOT should implement to improve their sign retroreflectivity maintenance program and be in compliance with the MUTCD's minimum sign retroreflectivity language.

- In order to have a direct link between the visual nighttime inspection method and the MUTCD's minimum retroreflectivity levels, researchers recommend that TxDOT begin using calibration signs prior to nighttime inspections. The calibration signs can be mostly made with ASTM D4956 Type I beaded materials except for guide signs, which should be made with a combination of ASTM D4956 Type I beaded materials (for the backgrounds) and ASTM D4956 Type II beaded materials (for the legends of shoulder-mounted signs).
- Researchers also recommend that TxDOT implement a standardized inspection form that can be used during the inspection to document the activities and help facilitate safe inspection procedures (such as the one shown in Appendix D). The form should have the same fields for all inspections but may include optional or supplemental fields for maintenance section or districts opting to include more fields in their nighttime inspections. There should also be a repository for the forms to help TxDOT protect itself from potential tort cases concerning sign retroreflectivity.
- Finally, in order to meet the requirement of having trained inspectors, we recommend that TxDOT establish a training program for all inspectors. The training program should include, at a minimum, how to use and care for the calibration signs, how to conduct safe nighttime visual inspections, and how to use the standardized inspection forms.

FUTURE RESEARCH NEEDS

Although the testing of the mobile sign retroreflectivity technology resulted in subpar results, it is likely that this technology will continue to evolve and improve as time goes on and the market for mobile sign retroreflectivity measurements grow. As this occurs, it is likely that there will be a need to evaluate these technologies again. If they prove to be an accurate way to measure sign retroreflectivity, they may also prove to be a viable way to manage sign retroreflectivity. If so, there is a strong likelihood that there will be concerns about their accuracy and repeatability, much in the same way as today's mobile pavement marking retroreflectivity measurements come with concern. In addition to evaluating future mobile sign retroreflectivity measurement technologies, the researchers also see a possible need to develop a specification and establish a certification program for such technologies.

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APPENDIX A:
IN-SERVICE SIGN DATA

Table 19. Regional Sign and Route Information.

Routes	Signs	Miles Traveled	Roadways	Counties
Region A - Route 1	102	80	FM 2386, FM 282, FM 2880, FM 293, FM 294, TX-152, TX-207, US-287, US-60, I-40	Armstrong, Carson, Gray, Randall
Region A - Route 2	123	90	FM 1321, FM 2375, FM 2857, FM 398, FM 748, FM 749, SL-171, TX-152, TX-273, TX-291, TX-70, US-60	Gray, Roberts
Region B - Route 3	24	25	FM 2038, FM 974, TX-21	Brazos
Region B - Route 4	49	46	FM 1361, FM 166, FM 1687, FM 2155, FM 50, FM 60	Brazos, Burleson
Region B - Route 5	52	38	FM 149, FM 244, FM 429, TX-30, TX-6, TX-90	Brazos, Grimes
Region B - Route 6	79	48	FM 1155, FM 159, FM 2154, FM 390, TX-105	Brazos, Washington
Region C - Route 7	66	16	TX-134, TX-225	Harris
Region C - Route 8	76	8	FM 1765, FM 519, TX-146, TX-197	Galveston
Region C - Route 9	51	38	FM 3005	Galveston
Region D - Route 10	51	25	TX-35, FM 1069, TX-188, FM 3512	Aransas
Region D - Route 11	79	49	TX-361, PP-22	Nueces
Region D - Route 12	25	12	FM 2444	Nueces
Region E - Route 13	78	40	FM 1419, FM 511, TX-4	Cameron
Region E - Route 14	113	58	FM 510, TX-100, TX-48	Cameron
Region F - Route 15	102	114	FM 1472, TX-255, TX-83, TX-44, FM 3338	LaSalle, Webb
Region F - Route 16	101	127	TX-59, FM 2895, FM 2050, TX-359, FM 649	Webb, Jim Hogg
Region G - Route 17	104	114	FM 1837, TX-118, US-385, US-67, US-90	Bewster, Jeff Davis, Pecos
Region G - Route 18	114	85	FM 2448, FM 1832, FM 869, TX-17, I-10, I-20	Jeff Davis, Reeves

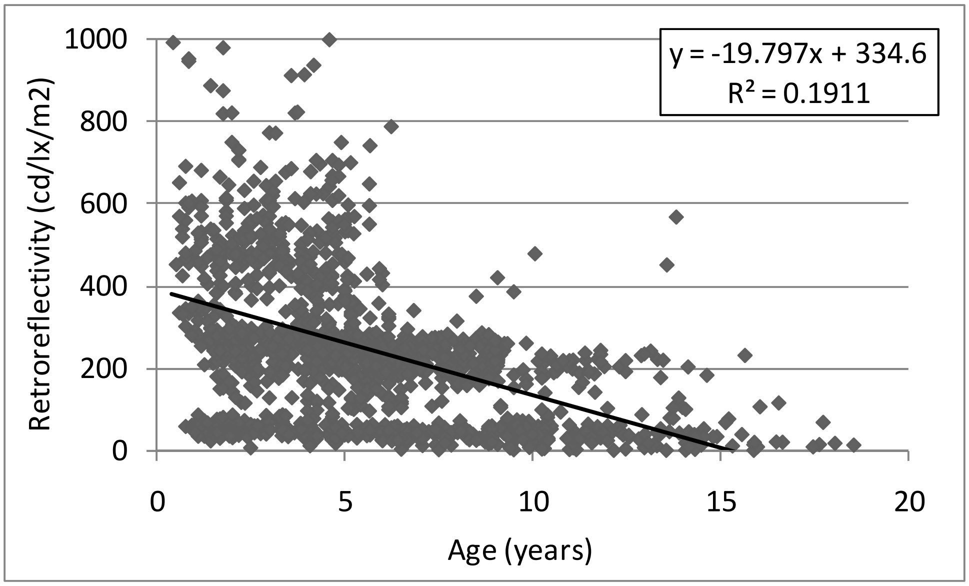

Figure 13. All Sign Measurement Data.

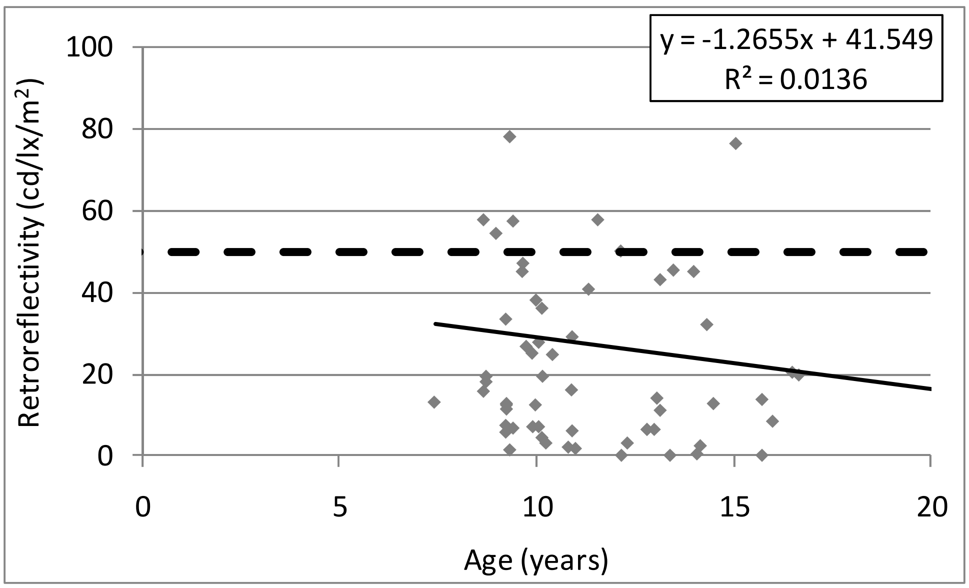

Figure 14. White Type I Sign Measurement Data.

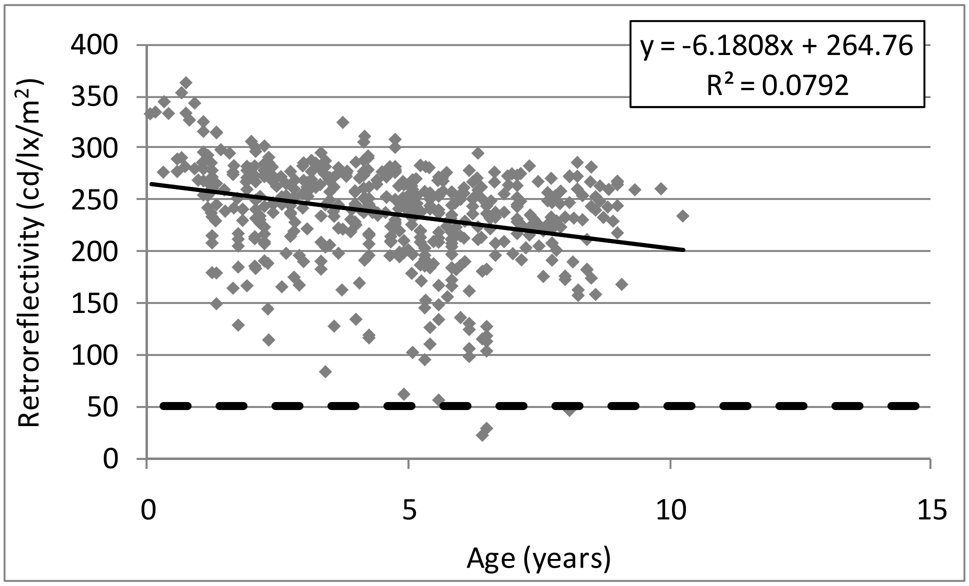

Figure 15. White Type III Sign Measurement Data.

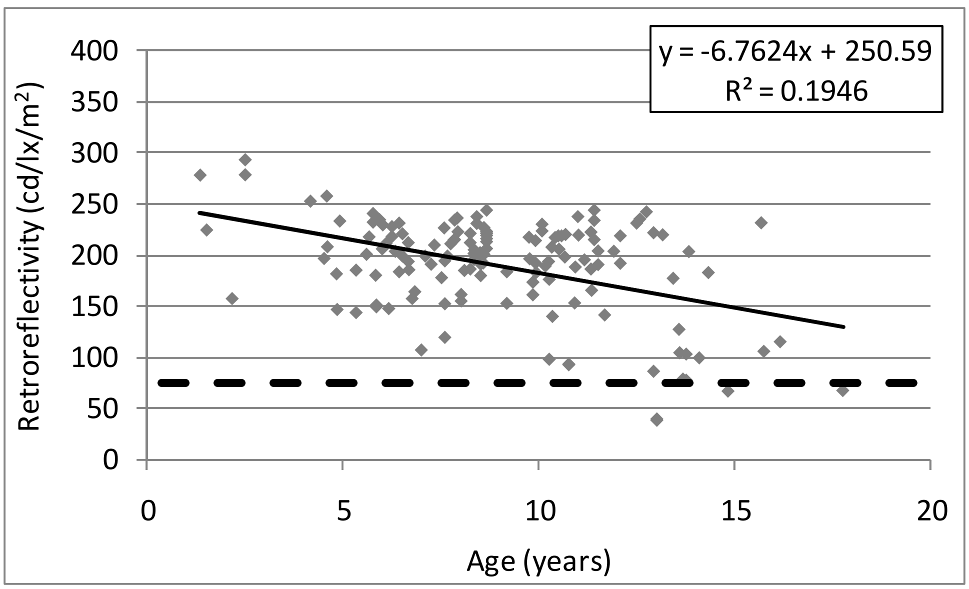

Figure 16. Yellow Type III Sign Measurement Data.

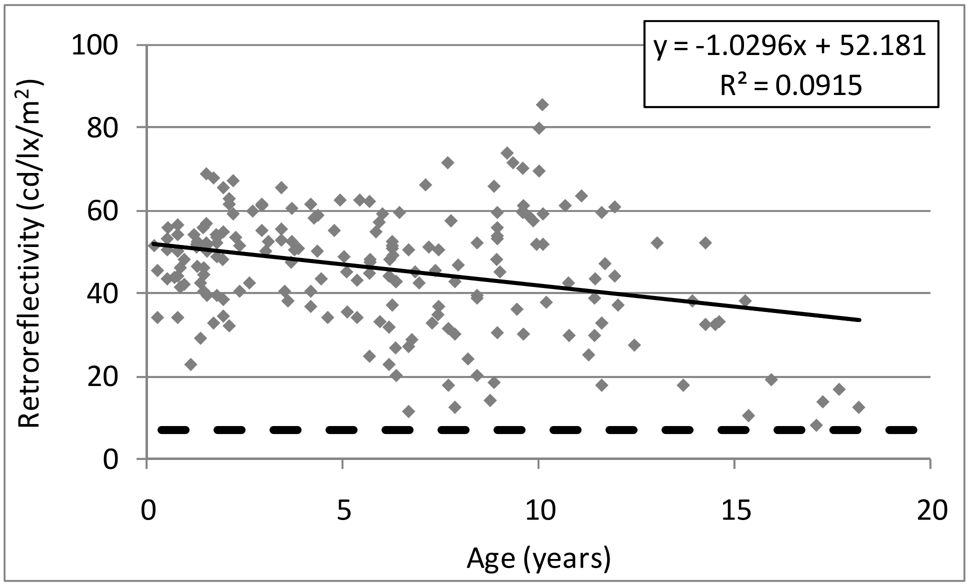

Figure 17. Red Type III Sign Measurement Data.

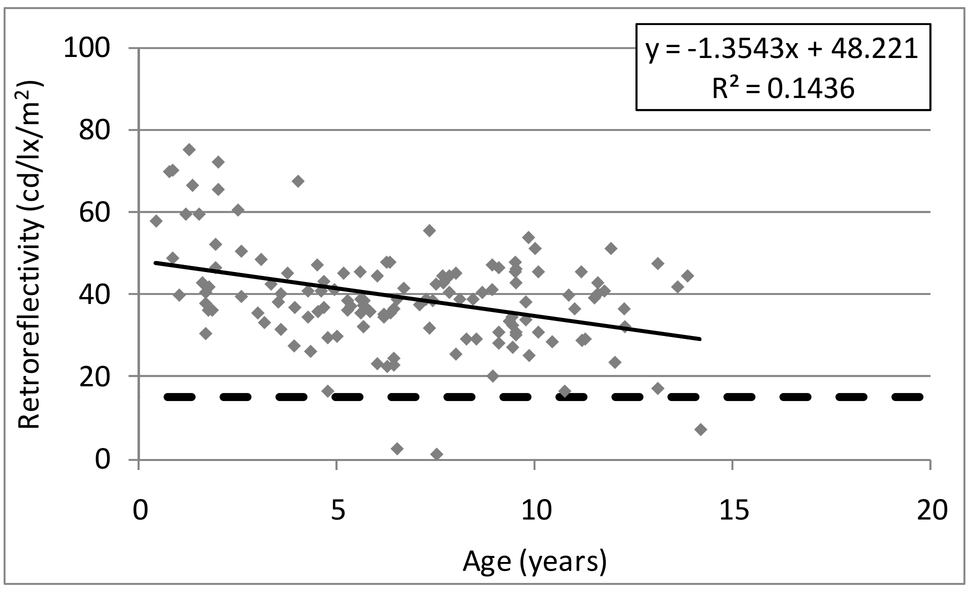

Figure 18. Green Type III Sign Measurement Data.

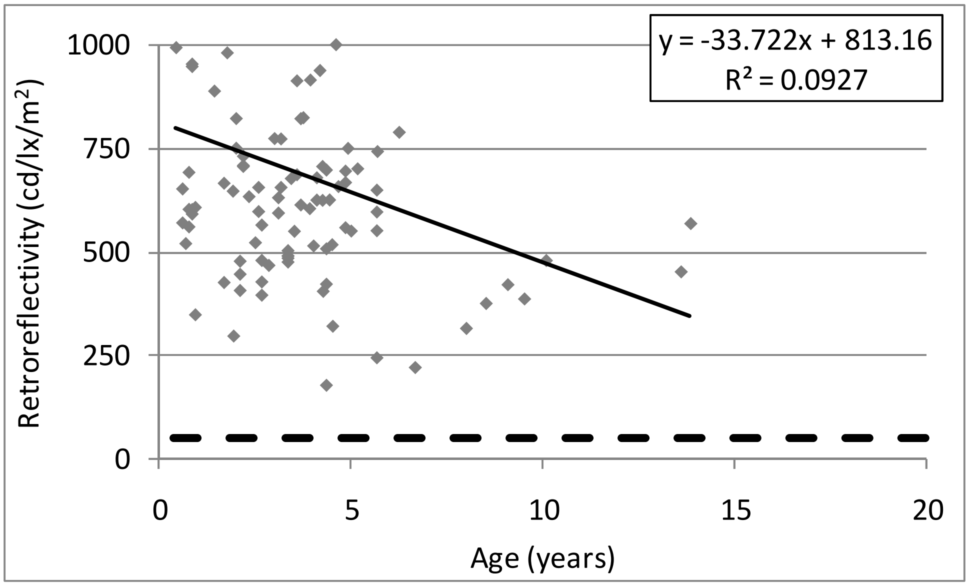

Figure 19. White Prismatic Sign Measurement Data.

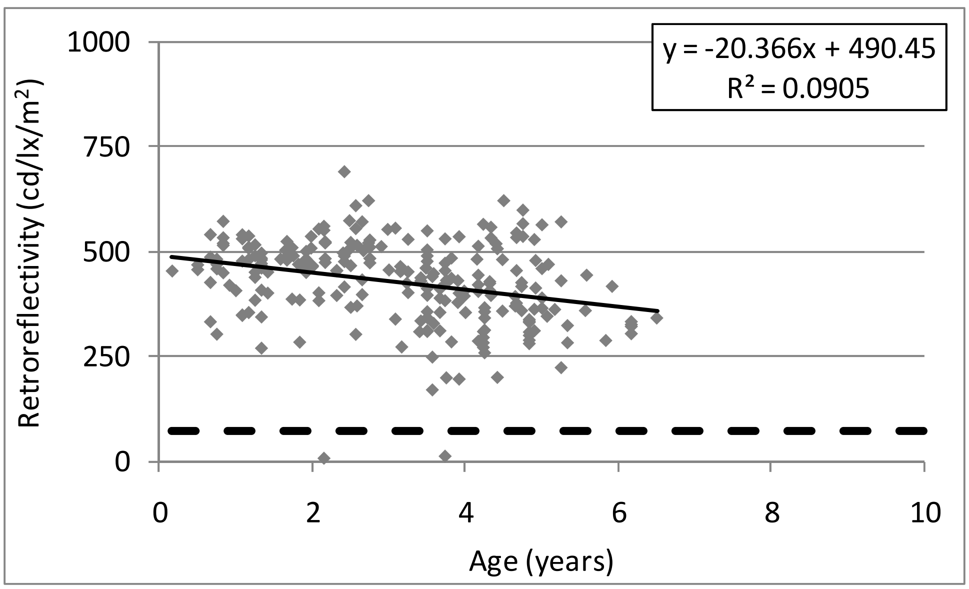

Figure 20. Yellow Prismatic Sign Measurement Data.

APPENDIX B:
DATA COLLECTION VEHICLE EVALUATION DATA

Table 20. Closed Course Sign Information.

Number	Sign	Bkgd.	Leg.	Material	Message	Bkgd	Leg
1a	Regulatory	White	Black	Type I	Speed Limit 45	24	
1b	Regulatory	Red	White	Type III	Stop	19	169
2a	Guide	Green	White	Type I	Test	24	66
2b	Construction	Orange	Black	Type I	Detour	38	
3a	Construction	Orange	Black	Prism.	Here	273	
3b	Guide	Green	White	Prism.	Test	153	691
4a	Regulatory	White	Black	Type III	F4	255	
4b	Regulatory	White	Black	Prism.	F5	559	
5a	Warning	Yellow	Black	Type III	Narrow Bridge	222	
5b	Warning	Yellow	Black	Prism.	Narrow Bridge	269	
6a	Regulatory	Red	White	Type III	Do Not Enter	115	246
6b	Regulatory	Red	White	Type I	Stop	6	53
7a	Regulatory	Red	White	Type III	Stop	53	279
7b	Regulatory	Red	White	Prism.	Stop	169	698
8a	Warning	Yellow	Black	Type I	Narrow Bridge	47	
8b	Warning	Yellow	Black	Type III	School Crossing	191	
9a	Regulatory	White	Black	Prism.	Speed Limit 46	631	
9b	Guide	White	Black	Type I	FM 153	61	
9c	Regulatory	White	Black	Type I	One-Way	92	
9d	Guide	White	Black	Type III	East	257	
10a	Regulatory	White	Black	Type I	Reduced Speed	41	
11a	Regulatory	Red	White	Prism.	Stop	104	531
11b	Regulatory	White	Black	Type I	Night 55		56

Note: Retroreflective values are in cd/lx/m^2.

Table 21. Open-Road Course Measurement Comparison.

Sign Type	BKGD Color	Legend Color	Mobile		Handheld		Difference in R_a	Percent Error
			Sheeting	R_a	Sheeting	R_a		
Regulatory	White	Black	Type I	124	Type III	249	−125	50%
Regulatory	Black	White	Type I	0	Type III	229	−229	100%
Warning	Yellow	Black	Type IX	438	Prism	495	−57	12%
Guide	Green	White	Type III	36	Type III	43	−7	17%
Guide	White	Black	Type I	133	Type III	225	−93	41%
Guide	White	Black	Type I	132	Type III	246	−114	46%
Warning	Fl. Yellow	Black	Type IX	119	Type IX	328	−209	64%
Regulatory	White	Black	Type I	49	Type I	6	43	708%
Regulatory	White	Black	Type I	0	Type I	8	−8	99%
Regulatory	White	Black	Type VIII	680	Prism	929	−249	27%
Regulatory	White	Black	Type III	199	Type III	333	−134	40%
Guide	White	Black	Type I	103	Type III	208	−105	51%
Regulatory	White	Black	Type I	137	Type III	238	−101	42%
Regulatory	White	Black	Type I	141	Type III	268	−127	47%
Warning	Yellow	Black	Type IX	516	Prism	471	45	10%
Guide	Green	White	Type VIII	153	Prism	76	77	101%
Regulatory	White	Black	Type I	117	Type III	205	−89	43%
Warning	Yellow	Black	Type IX	449	Prism	395	54	14%
Information	Blue	White	Type I	8	Type III	18	−9	53%
Information	Brown	White	Type III	11	Type III	31	−20	65%
Regulatory	White	Black	Type I	120	Type III	222	−102	46%
Regulatory	White	Black	Type I	136	Type III	252	−116	46%
Regulatory	White	Black	Type III	150	Type III	249	−99	40%
Regulatory	White	Black	Type I	113	Type III	256	−143	56%
Regulatory	White	Black	Type III	253	Prism	519	−265	51%
Regulatory	White	Black	Type I	116	Type III	144	−27	19%
Regulatory	White	Black	Type I	133	Type III	246	−113	46%
Guide	White	Black	Type I	87	Type III	204	−117	57%
Warning	Yellow	Black	Type I	122	Prism	194	−72	37%

Note: R_a values are expressed in units of $cd/lx/m^2$.

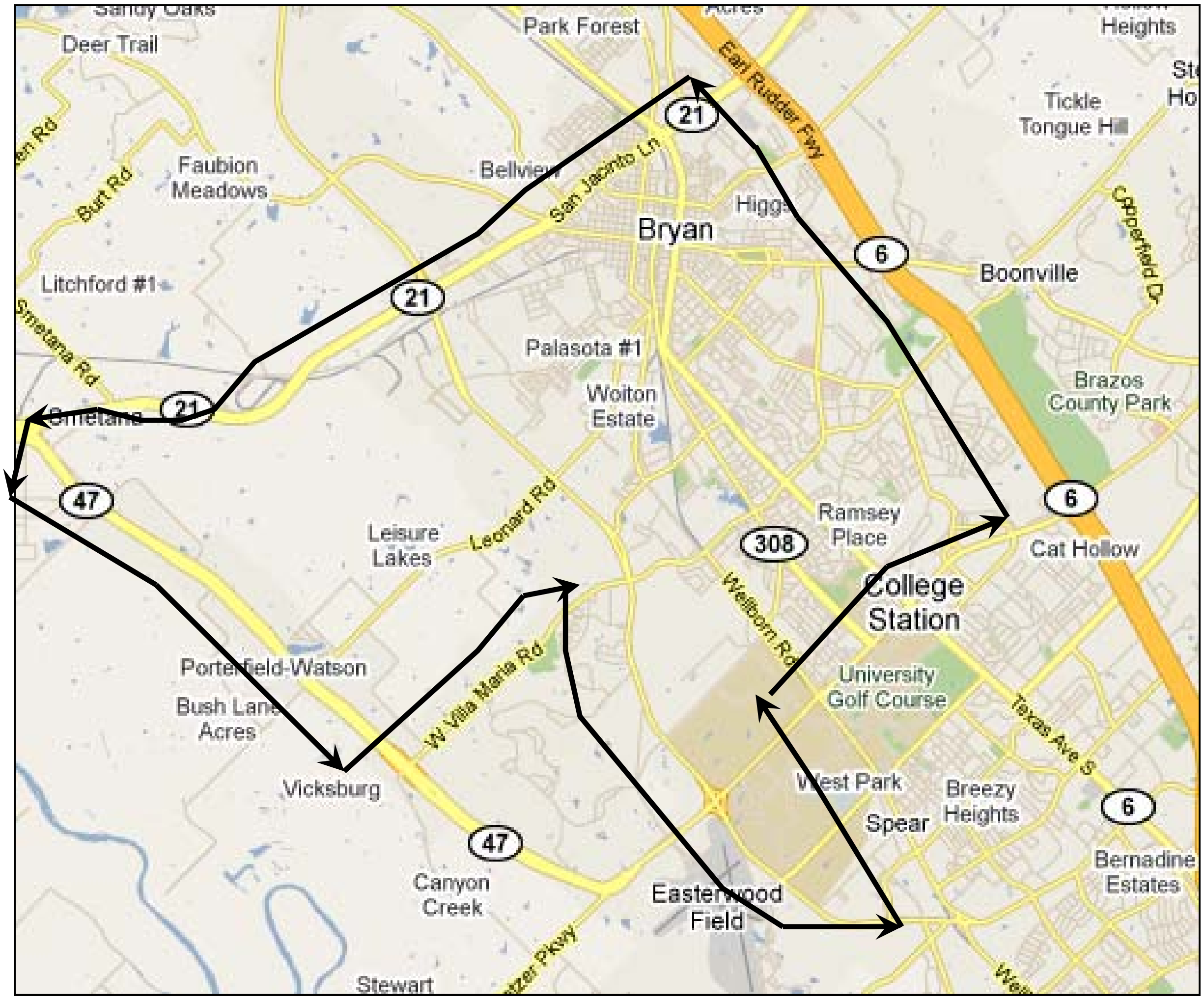

Figure 21. Open-Road Course.

Open-Road Course, 30 miles

1. Turn right onto Highway 47 exiting the Riverside Campus and head southeast for 3.5 miles.
2. Merge right onto Villa Maria (FM 1179) exit ramp for 0.5 mile.
3. Turn left onto Villa Maria Road (FM 1179) from ramp and head east for 2.7 miles.
4. Turn right onto Harvey Mitchell Parkway (FM 2818) and head southeast for 4.8 miles.
5. There will be roadway construction signs prior to reaching the Wellborn Road (FM 2154) intersection.
6. Turn left onto Wellborn Road (FM 2154) and head northwest for 2.3 miles.
7. Merge right onto the University Drive (FM 60) ramp and head east on University Drive for 3.0 miles.
8. Turn left onto frontage road of Earl Rudder Freeway (Highway 6) and merge onto freeway. Head northeast for 4.8 miles.
9. Merge right onto Highway 21 exit.
10. Turn left onto Highway 21 and head west for 6.9 miles.
11. Turn left onto Silver Hill Road (after Smetana Road).
12. Veer left on Silver Hill Road and turn right at P4-747 Road and head straight into Riverside Campus.

APPENDIX C: SIGN INSPECTION FORMS

Hockley Co. Annual Night Time Sign, Striping and Delineator Inspections

Section:	Roadway:	Inspection Date:
Limits of Segment:		

	Type of Sign	Location of Sign	Condition of Sign	Date Action Taken
Signs				

	Location	Condition	Date Action Taken
Delineators, Chevrons Object Markers Barrier Reflectors			

Striping Review	Reflectivity of Long Line Striping?	☐ Good	☐ Fair	☐ Poor
	Comments:			
	Reflectivity of Specialty Markings?	☐ Good	☐ Fair	☐ Poor
	Comments:			

Good: 6 or more centerline dashes visible, Fair: 4 or 5 centerline dashes visible, Poor: 3 or less centerline dashes visible

Note: The Signs, Delineators, Object Markers and Reflectors listed above have deficiencies that are to be corrected by the Maintenance Section. The Striping Review is information collected for inclusion in the district wide striping contract or regional striping callouts.

Inspector's Signature: ______________________ Date Corrections Completed:

Supervisor's Signature: ______________________ Date: ______________

SIGN AND STRIPING INSPECTION REPORT

NIGHT RIDE

Maintenance Section: Burleson Co 04 **Inspection Date:** 12-18-06

Supervisor: [redacted]

FM696

Reported by: [redacted] [redacted]

Roadways Checked & Findings: Buttons missing, Striping faded an in some spots edge has been reworked so in some spot line has been covered up/weathered Sign post need to be taped Buttons are dead an also sunk in in pavement / Curve sign leaning in 60 different areas / Highway intersection Ahead an also Stop Ahead need to be replaced going toward Highway 21 / Some button missing

Immediate Action:

Action Needed: Signs replaced / will order signs / Buttons need to be replaced / Will have buttons replaced / Striping needs to be replaced / Will have it restriped

Comments: Have ordered for FM696 we are upgrading signs

Copy to: [redacted] 2/1/07

Sheet ___ of ____

Nighttime Traffic Sign Visual Inspection Form

District: ________________ Maintenance Section: ________________________________

Inspector's Name: _______________________ Driver's Name: _______________________

Inspection Date: _______________ Start Time: ______________ End Time: ____________

Calibration Signs: _________ Vehicle: _____________________

Starting Mileage: ___________________ Ending Mileage: ___________________

Name of Roadway	Number of Signs to be Replaced	Comments

Sheet ___ of ____

Texas Department of Transportation

Signs to be Replaced by Roadway

Roadway Name: ________________________________ Direction: ___________________

Starting Point: ___________________________ Starting Mileage: ___________________

Ending Point: ____________________________ Ending Mileage: ____________________

Sign Type	Latitude	Longitude	Comment

APPENDIX D: PARTICIPANT SCORE SHEET FOR TEST TRACK SIGNS

Date:__________ Participant #:_____

TxDOT Sign Inspection Project 0-6408 Riverside Study
Sign Score Sheet – Lap A

Scores: **P** = Pass **FR** = Failed retro **FO** = Failed, other reason

Sign #	Message	Score
1	55 mph	
2	School Crossing	
3	STOP	
4	Right arrow	
5	RETRO	
6	FM 1291	
7	55 mph	
8	YIELD	
9	School Crossing	
10	STOP	
11	H8	
12	ALASKA	

Sign #	Message	Score
13	B3	
14	DO NOT ENTER	
15	PAVEMENT ENDS	
16	ONE WAY	
17	Right Arrow	
18	PHILLIPS	
19	YIELD	
20	Hwy 6	
21	45 mph	
22	NARROW BRIDGE	
23	STOP	

Date:_________ Participant #:_____

TxDOT Sign Inspection Project 0-6408 Riverside Study

Sign Score Sheet – Lap B

Scores: **P** = Pass **FR** = Failed retro **FO** = Failed, other reason

Sign #	Message	Score
1	60 mph	
2	Right arrow	
3	STOP	
4	Right arrow	
5	RETRO	
6	Hwy 6	
7	Y2	
8	YIELD	
9	NO PASSING	
10	STOP	
11	55 mph	
12	MONTANA	

Sign #	Message	Score
13	F4	
14	DO NOT ENTER	
15	LOOSE GRAVEL	
16	AUSTIN	
17	NARROW BRIDGE	
18	LAKEWOOD	
19	YIELD	
20	FM 153	
21	55 mph	
22	WATER OVER ROAD	
23	STOP	

APPENDIX E: PARTICIPANT SCORE SHEET USING COMPARISON PANELS

TxDOT Sign Inspection Project 0-6408 Riverside Study
Sign Score Sheet: Comparison Panels

Scores: **P** = Pass (sign brighter than comparison panel)
F = Fail (sign less bright than comparison panel)

Sign #	Message	Score
1	Speed Limit 45	
2	Curve Warning	
3	STOP Sign	
4	TEST	
5	Speed Limit 55	
6	CHURCH	
7	STOP Sign	
8	RETRO	

When scored (check one):
___ Night/after dark
___ Day/sunlight

Light source:
___ Flashlight
___ Avery spotlight

APPENDIX F: RIVERSIDE STUDY PARTICIPANT SCORES

Participant Scores for Roadside Sign Inspection, Lap A.

					Participant Scores															
					TxDOT				TTI w/o Calib. Signs				TTI w/ Calib. Signs				Total			
Pos.	Color	Cond.	Bkgd. Retro	Leg. Retro	Pass	FR	FO	FRO	Pass	FR	FO	FRO	Pass	FR	FO	FRO	Pass	FR	FO	FRO
1A	White	M	82		8	1	0	0	7	3	0	0	10	0	0	0	86%	14%	0%	0%
2A	Yellow	M	82		6	3	0	0	9	1	0	0	6	3	0	1	72%	24%	0%	3%
3A	Red	G	23	208	9	0	0	0	9	0	1	0	9	1	0	0	93%	3%	3%	0%
4A	Yellow	P	35		0	3	5	1	3	2	1	4	2	3	1	4	17%	28%	24%	31%
5A	Green	M	28	216	8	1	0	0	5	3	1	1	5	5	0	0	62%	31%	3%	3%
6A	White	P	60		5	3	0	0	2	7	0	1	3	6	1	0	36%	57%	4%	4%
7A	White	M	86		8	1	0	0	3	6	1	0	8	2	0	0	66%	31%	3%	0%
8A	Red	G	60	254	8	1	0	0	8	0	2	0	8	1	0	1	83%	7%	7%	3%
9A	Yellow	G	167		8	1	0	0	9	0	1	0	8	1	1	0	86%	7%	7%	0%
10A	Red	P	10	73	2	6	0	1	1	8	1	0	2	8	0	0	17%	76%	3%	3%
11A	White	G	251		6	1	2	0	5	4	1	0	7	2	1	0	62%	24%	14%	0%
12A	Green	G	52	254	6	2	0	0	5	4	1	0	3	6	1	0	50%	43%	7%	0%
13A	White	M	193		5	0	4	0	7	2	0	1	5	1	1	3	59%	10%	17%	14%
14A	Red	M	35	231	5	3	1	0	5	2	2	1	5	2	3	0	52%	24%	21%	3%
15A	Yellow	P	90		1	5	2	1	0	0	3	7	0	4	2	4	3%	31%	24%	41%
16A	White	M	90		7	0	2	0	5	5	0	0	4	5	1	0	55%	34%	10%	0%
17A	Yellow	G	198		9	0	0	0	10	0	0	0	9	1	0	0	97%	3%	0%	0%
18A	Green	P	8	88	4	5	0	0	1	8	0	1	5	5	0	0	34%	62%	0%	3%
19A	Red	P	12	30	1	6	0	2	1	7	1	1	0	6	0	4	7%	66%	3%	24%
20A	White	M	169		2	5	2	0	7	3	0	0	6	4	0	0	52%	41%	7%	0%
21A	White	P	31		3	6	0	0	0	9	1	0	1	9	0	0	14%	83%	3%	0%
22A	Yellow	P	34		2	7	0	0	0	8	1	1	0	9	1	0	7%	83%	7%	3%
23A	Red	G	15	87	9	0	0	0	10	0	0	0	10	0	0	0	100%	0%	0%	0%

Participant Scores for Roadside Sign Inspection, Lap B.

Pos.	Color	Cond.	Bkgd. Retro	Leg. Retro	Participant Scores: TxDOT				TTI w/o Calib. Signs				TTI w/ Calib. Signs				Total			
					Pass	FR	FO	FRO	Pass	FR	FO	FRO	Pass	FR	FO	FRO	Pass	FR	FO	FRO
1B	White	M	73		8	1	0	0	8	2	0	0	8	2	0	0	83%	17%	0%	0%
2B	Yellow	M	84		9	0	0	0	10	0	0	0	8	2	0	0	93%	7%	0%	0%
3B	Red	P	4	28	1	7	1	0	1	8	1	0	1	6	1	2	10%	72%	10%	7%
4B	Yellow	G	238		8	0	1	0	10	0	0	0	7	3	0	0	86%	10%	3%	0%
5B	Green	P	18	108	2	6	0	1	3	5	2	0	4	5	1	0	31%	55%	10%	3%
6B	White	G	225		7	1	1	0	4	5	1	0	5	4	1	0	55%	34%	10%	0%
7B	White	G	265		7	2	0	0	4	6	0	0	3	5	1	1	48%	45%	3%	3%
8B	Red	M	9	67	3	4	2	0	5	4	1	0	2	7	0	1	34%	52%	10%	3%
9B	Yellow	P	76		0	7	1	0	0	8	1	1	0	6	2	2	0%	75%	14%	11%
10B	Red	G	13	112	9	0	0	0	10	0	0	0	9	1	0	0	97%	3%	0%	0%
11B	White	M	103		8	0	0	0	5	5	0	0	7	3	0	0	71%	29%	0%	0%
12B	Green	G	56	260	8	0	1	0	4	6	0	0	3	5	1	1	52%	38%	7%	3%
13B	White	P	34		0	6	2	0	1	7	2	0	1	8	1	0	7%	75%	18%	0%
14B	Red	P	5	39	1	8	0	0	1	3	3	3	0	0	4	6	7%	38%	24%	31%
15B	Yellow	G	203		9	0	0	0	6	2	2	0	7	3	0	0	76%	17%	7%	0%
16B	Green	P	4	19	0	8	0	0	1	9	0	0	0	10	0	0	4%	96%	0%	0%
17B	Yellow	P	20		0	8	0	0	0	8	1	1	0	8	0	2	0%	86%	4%	11%
18B	Green	M	37	254	6	2	1	0	4	4	2	0	3	5	1	1	45%	38%	14%	3%
19B	Red	M	15	53	0	6	2	1	7	2	1	0	3	6	1	0	34%	48%	14%	3%
20B	White	P	63		3	5	0	0	3	5	2	0	2	6	1	1	29%	57%	11%	4%
21B	White	G	191		9	0	0	0	9	1	0	0	10	0	0	0	97%	3%	0%	0%
22B	Yellow	M	216		4	1	3	1	0	1	6	3	0	1	5	4	14%	10%	48%	28%
23B	Red	P	4	37	4	5	0	0	4	5	1	0	5	3	2	0	45%	45%	10%	0%