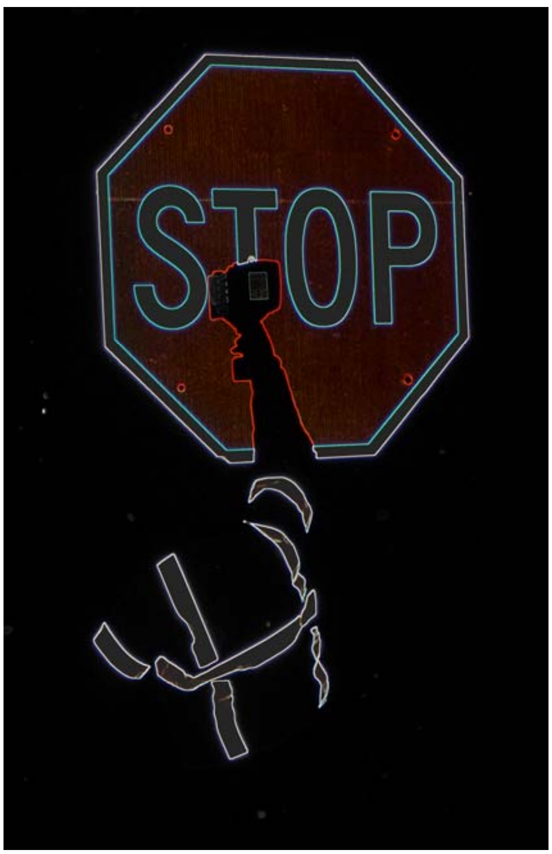
SELECTING A TRAFFIC SIGN RETROREFLECTIVITY ASSESSMENT METHOD

Accuracy and Cost Considerations



Before selecting a method to maintain sign retroreflectivity, there are key considerations an agency should consider. First, will the chosen method provide adequate protection from potential tort claims regarding marginal or inadequate retroreflectivity? Second, what will be the long-term cost to sustain the chosen method? This paper was written to provide fresh insights into these questions to assist agencies that are considering how to best comply with the MUTCD minimum sign retroreflectivity requirements.

May 2014

Paul J. Carlson, Ph.D., P.E.
Senior Research Engineer
Texas A&M Transportation Institute

Introduction

The Manual on Uniform Traffic Control Devices (MUTCD) includes minimum sign retroreflectivity levels for regulatory, warning, and guide signs (1). A compliance date of June 2014 has been set in which agencies must have a selected and starting using a sign retroreflectivity maintenance method designed to identify and replace signs before they reach the end of the service life as defined by the MUTCD minimum retroreflectivity levels. In order to provide flexibility, the MUTCD includes five different methods that agencies can use to identify and replace signs before they reach the end of the service life. The methods are listed in two basic categories: assessment methods and management methods. Assessment methods involve the inspection of signs in the field while management methods rely on techniques that limit or eliminate the need for field inspections.

Assessment Methods

- Nighttime Visual Inspection—The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels should be replaced (2).
    - Calibration Procedure—Calibration signs have known retroreflectivity levels at or above minimum levels. These calibration signs are set up so the inspector views the calibration signs in a manner similar to nighttime field inspections. A trained inspector views calibration signs prior to conducting the nighttime inspection. The inspector uses the visual appearance of the calibration signs to establish the evaluation threshold for that night's inspection. During the nighttime drive-through inspection of in-service signs, if the inspector believes a sign appears to be less bright than the calibration signs viewed earlier, the in-service sign should be replaced.
    - Comparison Procedure—Comparison panels are fabricated with retroreflectivity levels at or above the minimum levels. The trained inspector makes an initial nighttime visual inspection to identify signs obviously above or below the minimum retroreflectivity levels as well as those that the inspector considers to be marginal. Those signs designated as obviously below the minimum retroreflectivity values are scheduled for replacement. For signs considered marginal, a supplementary nighttime inspection is conducted by attaching a comparison panel to the in-service sign. With a flashlight, the inspector views the in-service sign along with the comparison panel to determine whether the in-service sign appears brighter or less bright than the comparison panel. If the in-service sign appears less bright than the comparison panel, the in-service sign should be replaced.
    - Consistent Parameters Procedure—For this procedure, nighttime inspections are conducted by a trained inspector under similar factors that were used in the research to develop the minimum retroreflectivity levels (the inspector is at least 60 years old, the inspection is conducted from a sport utility vehicle or pick-up truck, and the inspection vehicle is model year 2000 or newer). The trained inspector makes a judgment call as to

whether an in-service sign meets their nighttime driving needs. Those signs judged not to meet the visual driving needs should be replaced.

- Measured Sign Retroreflectivity—Sign retroreflectivity is measured using a retroreflectometer. Signs with retroreflectivity below the minimum levels should be replaced. Handheld or mobile retroreflectivity measurement equipment is permitted with this method.

Management Methods

- Expected Sign Life—When signs are installed, the installation date is labeled or recorded so that the age of a sign is known. The age of the sign is compared to the expected sign life. The expected sign life is based on the experience of sign retroreflectivity degradation in a geographic area compared to the minimum levels. Signs older than the expected life should be replaced.
- Blanket Replacement—All signs in an area/corridor, or of a given type, should be replaced at specified intervals. This eliminates the need to assess retroreflectivity or track the life of individual signs. The replacement interval is based on the expected sign life, compared to the minimum levels, for the shortest-life material used on the affected signs.
- Control Sign—Replacement of signs in the field is based on the performance of a sample of control signs. The control signs might be a small sample located in a maintenance yard or a sample of signs in the field. The control signs are monitored to determine the end of retroreflective life for the associated signs. All field signs represented by the control sample should be replaced before the retroreflectivity levels of the control sample reach the minimum levels.

Background

The FHWA selected the assessment and management methods for the MUTCD because they are all tied to the table of minimum of retroreflectivity in various ways. In addition to the five methods listed above, the FHWA allows other methods to be used as long as they are tied to the minimum levels too (and documented in an engineering study).

Prior to the rule-making, the most commonly practiced sign retroreflectivity maintenance activity was visual inspection—daytime or nighttime. Despite the MUTCD's longstanding sign maintenance language calling for nighttime sign inspections, many agencies did not have a formal policy for conducting and/or documenting nighttime sign inspections. In fact, some agencies simply did not perform regular nighttime sign inspections.

Regardless of previous policies and practices concerning sign maintenance, the new MUTCD regulation has raised sign maintenance awareness. More agencies are now taking a systematic look at their sign maintenance policies. The new MUTCD sign retroreflectivity regulation has provided the justification for many agencies to inventory their signs, update their supports with crashworthy equipment, and reconsider whether existing signs can be removed or other signs may be needed.

This paper was written with specific conditions in mind. Since many agencies have not been maintaining sign retroreflectivity as prescribed in the MUTCD but will soon need to, a key interest should be gaining an understanding the existing sign retroreflectivity condition. The initial assessment can be used to identify signs that need to be replaced immediately. In addition, systematic initial assessments can be used to build inventories. Depending on the details that are obtained, they can also be used to plan future sign replacements and budget needs.

The assessment methods in the MUTCD that are designed for the initial assessments are the visual inspection method and the measured sign retroreflectivity method. Depending on how agencies go about deciding which of these assessment methods is most appropriate can lead to future needs and benefits that may not be initially realized. This paper focuses on one of the most important distinctions between the assessment methods—that being the accuracy of visual nighttime inspections compared to measured sign retroreflectivity. New and previously undocumented findings are described that add concern to the visual nighttime inspection method.

Knowing that visual inspections are favored by many agencies because of their initial low implementation costs, this paper also identifies other considerations that agencies should study before making a decision regarding their chosen strategy for a sign retroreflectivity maintenance program. Examples are provided that demonstrate the value of considering initial versus long-term costs and risks associated with several sign retroreflectivity maintenance methods.

Existing Practices and Trends

When a public agency installs a sign, it owes a duty to take reasonable care in construction of the sign, properly locating the sign, and, of course, maintaining the sign. By breaching this duty of care, such as by failing to have a reasonable maintenance method in place, an agency is vulnerable to claims of negligence. To avoid or at least minimize liability associated with minimum sign retroreflectivity regulations, by June 2014 an agency will need to exercise the standard of care that is now established in the MUTCD. The manner in how an agency elects to implement a standard of care is flexible, as long as the provisions described in the MUTCD have been satisfied. That being said, the selection of a sign retroreflectivity maintenance method can have an impact on the exposure to negligence. This paper provides new findings that agencies should consider before making a final selection of their sign retroreflectivity maintenance method.

In a recent report that surveyed agencies across the US, the two most common methods that agencies were using to meeting the MUTCD retroreflectivity requirements were a form of nighttime visual inspections and expected sign life (3). This same report discovered that some of those agencies using the visual inspection method were not following one of the three procedures as outlined by the FHWA—and therefore were not technically in compliance. Furthermore, as will be described later in this paper, the visual inspection technique may not be as reliable as reported in terms of making decisions regarding adequate retroreflectivity, especially for the signs near minimum levels.

Other research has shown that many agencies do not have a documented process to identify and replace signs with low retroreflectivity levels (4). Now, in early 2014, with the MUTCD minimum retroreflectivity compliance date looming, many agencies are beginning to take stock in how they will achieve compliance with the minimum retroreflectivity requirements in the MUTCD.

This leads to a challenge facing many agencies across the country—particularly agencies that have not taken an active role in maintaining their signing infrastructure. What is the most cost effective way for an agency to be in compliance with the MUTCD, and how do they set up a maintenance program for the long haul? An agency can simply try to meet the new MUTCD requirements, or they can take the opportunity to add additional value by taking a more systematic approach, similar to asset management principle commonly used by agencies for their pavements and bridges.

In order to obtain an initial assessment of the condition an agency's signs, the options are one of the three procedures of the Visual Nighttime Inspection method or the Measured Sign Retroreflectivity method. Of course there are pros and cons to each of these methods. Accuracy of the chosen inspection method is obviously one key factor to consider. After all, a low cost inspection method that yields poor results is not likely to provide good information for planning purposes and is not likely to provide ample protection from potential tort claims. The remainder of this paper is focused on two items that agencies should consider before selecting an approach to maintain sign retroreflectivity.

- The accuracy of visual inspection methods and measured sign retroreflectivity methods
- The initial and long-term costs of operating visual inspection methods and measured sign retroreflectivity methods.

Accuracy of Sign Retroreflectivity Assessment Methods

For agencies that lack an inventory or management process to maintain sign retroreflectivity, one of the first things they could do is a condition assessment to determine the how many signs they need to immediately address. There are several methods that agencies can choose from to conduct their assessment of sign retroreflectivity. While there are additional advantages and disadvantages to each assessment method, this review is focused on the accuracy of each approach in terms of the current MUTCD minimum levels.

Nighttime Visual Inspections of Sign Retroreflectivity

There have been a few studies reporting the accuracy of nighttime visual inspections. Most of these studies report a relatively high accuracy of visual assessment decisions regarding the minimum retroreflectivity levels. A critical review of these reports is provided in the section that identifies some new findings regarding visual inspection accuracies.

The FHWA has specifically identified three distinct procedures for nighttime visual inspections: calibration procedure, comparison procedure, and consistent parameter procedures. The research summarized below included various levels of trained inspectors (starting from no training up to significant and probably unrealistic amounts of training).

The first study was published in 1987 where the Washington DOT reported on the accuracy of nighttime sign retroreflectivity assessments using trained inspectors (4). After two sessions of training, 17 inspectors evaluated 86 warning signs and 44 stop signs on two highways. All of the inspectors were 43 years or younger. The results of the nighttime visual inspections were compared to measured sign retroreflectivity levels. The primary findings are impressive—74 to 75 percent of the visual inspections resulted in correct decisions (to either keep the signs in place or remove them). However, these results are based on the median values and, as usual, the devil is in the details.

This study was conducted before the FHWA minimum retroreflectivity were generated. As a result, a decision model was developed to determine if the visual inspections resulted in correct decisions or not. A five level rating system was developed for the signs in order to assess the results of the inspectors. The adequacy of the sign retroreflectivity included whether the sign was in a rural or urban location. For rural locations, signs that were deemed in need of replacing had ratings of 0 or 1. For urban locations, signs that were deemed in need of replacing had ratings of 0, 1, or 2. Table 1 shows the retroreflectivity levels for each rating level as well as the accuracy of individual inspection ratings.

Table 1. Individual Results of Retroreflectivity Ratings

Rating Level	Warning Sign Retro	Stop Sign Retro		Accuracy of Individual Inspection Ratings	
		Type III	Type II	Warning	Stop
0	6	75	50	87%	44%
1	18	125	75	55%	21%
2	36	175	125	47%	7%
3	70	225	n/a	32%	29%
4	>70	>225	n/a	39%	12%

Regarding the results for the warning signs, the inspectors were best at identifying the signs with very low retroreflectivity levels, in other words, the dead signs (with retroreflectivity levels of 6 or less). As the sign retroreflectivity level increases, the accuracy of the ratings decreases. The MUTCD minimum levels for warning signs are either 50 or 75, depending on the size of the sign and the specific legend. The accuracy of the individual inspections for rating levels of 2 through 4 was less than 50 percent.

The inspector ratings for the Stop sign were not as strong as they were for the warning signs. However, the retroreflectivity levels used to set the rating levels were relatively high, and based on the warning sign results, the accuracy of inspector ratings decrease with higher levels of retroreflectivity. For comparison, the MUTCD minimum level for white retroreflectivity on Stop signs is only 35. The lowest rating level for Stop signs had an accuracy of 44 percent. It is likely that the accuracy would have been higher if the threshold was lower.

In 2001, another study was released comparing the results of nighttime sign inspections and sign retroreflectivity levels (5). In this study, trained TxDOT maintenance staff evaluated 49 signs on a closed course setting representing rural conditions. The results reported are based on the early FHWA minimum retroreflectivity levels that are quite different from those in the MUTCD. Therefore, the data were reanalyzed for this paper using the current MUTCD minimum retroreflectivity levels.

For the 12 warning signs that were evaluated, four had retroreflectivity levels above 100. For those four signs, the inspectors were accurate 82 percent of the time. There were 4 warning signs with retroreflectivity levels before 50. For those four signs, the inspectors were accurate 95 percent of the time. However, for the four signs with retroreflectivity levels between 50 and 100, which is where the MUTCD thresholds exist, the accuracy was only 39 percent.

For the 23 white regulatory signs that were evaluated, four had retroreflectivity levels above 100. For those four signs, the inspectors were accurate 78 percent of the time. Five of these signs had retroreflectivity levels below 50, which is the current MUTCD minimum for white regulatory signs. For these five signs, 57 percent of the inspections were correct. It should be noted that these signs were not dead signs—they had retroreflectivity levels ranging from 38 to 47.

In 2003, the FHWA reported on national sign retroreflectivity workshops that included an assessment of nighttime visual inspections (6). During the four workshops held around the country, the 99 workshop attendees participated in nighttime sign retroreflectivity inspections. For these workshops, the FHWA had completed research to set the minimum retroreflectivity levels. Therefore, the signs used for the workshops were chosen to represent specific thresholds similar to those in the MUTCD. Overall, the results indicate that the 76 to 78 percent of the visual inspections were correct for the warning signs and 59 percent correct for the Stop signs.

In early 2005, researchers in North Carolina collected sign retroreflectivity data in 5 of the 14 NC DOT Districts. During the winter of 2005, the same researchers rode along with the NCDOT maintenance crews during their nighttime sign inspections. Overall, the researchers measured 1,057 signs which were also evaluated during the nighttime visual inspections. Most of the signs were constructed with Type I or Type III retroreflective material. The inspector accuracy was 67 percent for white, 51 percent for yellow, 74 percent for red, and 63 percent for green signs. Unfortunately, there in not enough details in the report to determine how the inspector accuracy rates varied by retroreflectivity (7). Signs with the very low or very high retroreflectivity levels (i.e., dead signs and brand new Type III signs), the results of the nighttime inspections were at least 83 percent accurate. However, for the signs with retroreflectivity levels closer to the MUTCD minimums, the percent correct drops to about 50 percent.

In 2006, researchers at Purdue University published accuracy rates of nighttime visual inspections (8). The overall accuracy was 88 percent. A breakdown by sign color is provided in Table 2. However, there is no breakdown of the accuracy rates as a function of retroreflectivity level.

Table 2. Overall Results from Indiana Research

Sign Group	Number of Signs	Type I or II Error	Percent Correct
White on Red	681	65	90.5
Black on White	505	66	86.9
Bold Black on Yellow	390	50	87.2
Fine Black on Yellow	162	26	84.0
Other Colors	4	3	25.0
Total	1742	189	87.9

Analysis of Literature

Conducting nighttime sign inspections reveals many interesting insights. First of all, some signs that look perfectly adequate during the daytime may have a completely different appearance at night. Also, it is easy to recognize new and bright signs as well as old and dead signs. However, there are many signs that are difficult to judge their adequacy, especially in terms of the minimum thresholds in the MUTCD. In many cases, it becomes somewhat of a coin-flip as to the determination of adequate or inadequate retroreflectivity. Therefore, the published literature was re-analyzed in order to understand the relationship between the accuracy of nighttime visual inspections as a function of the retroreflectivity levels. When accuracy is studied as a function of retroreflectivity level, revealing and somewhat surprising results are exposed.

In an attempt to develop a relationship between accuracy of visual inspection and level of retroreflectivity, the data from the reports reviewed above were extracted and analyzed by sign type. Only some of the reports had adequate details to conduct such analyses. Those reports with enough data are referenced in the legends of the graphs showing the findings. The warning sign data provide the largest data set for analysis. The basic results are presented in Figure 1 while best fit curves are presented in various forms in Figures 2 through 4.

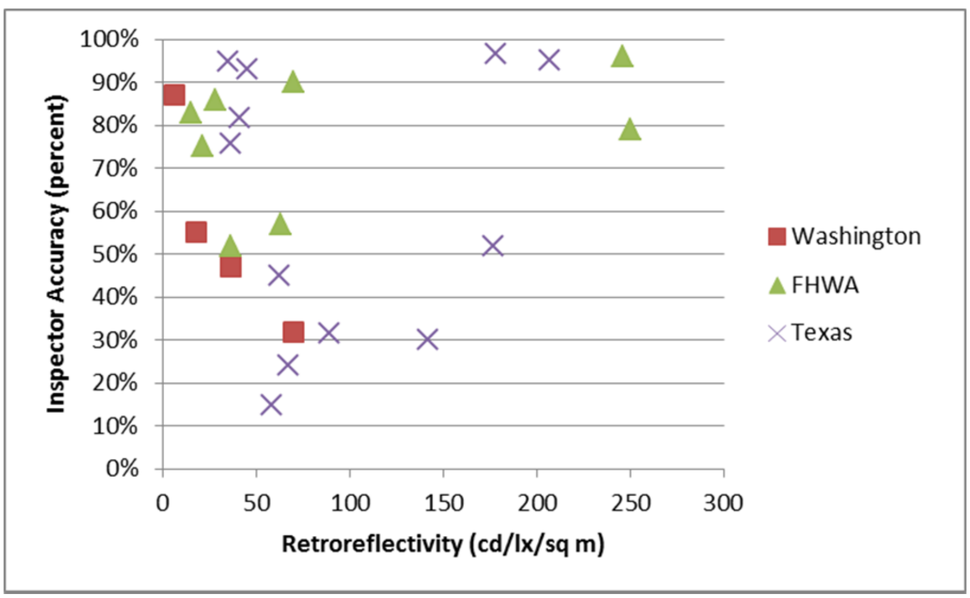


Figure 1. Accuracy of Nighttime Inspections of Warning Signs for Three Studies

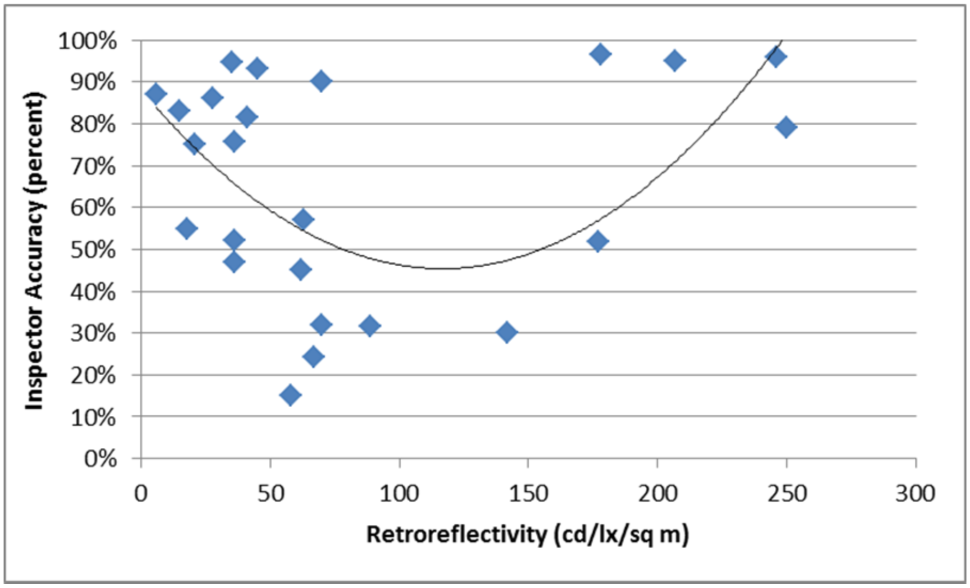


Figure 2. Accuracy of Nighttime Inspections of Warning Signs (Combined Data)

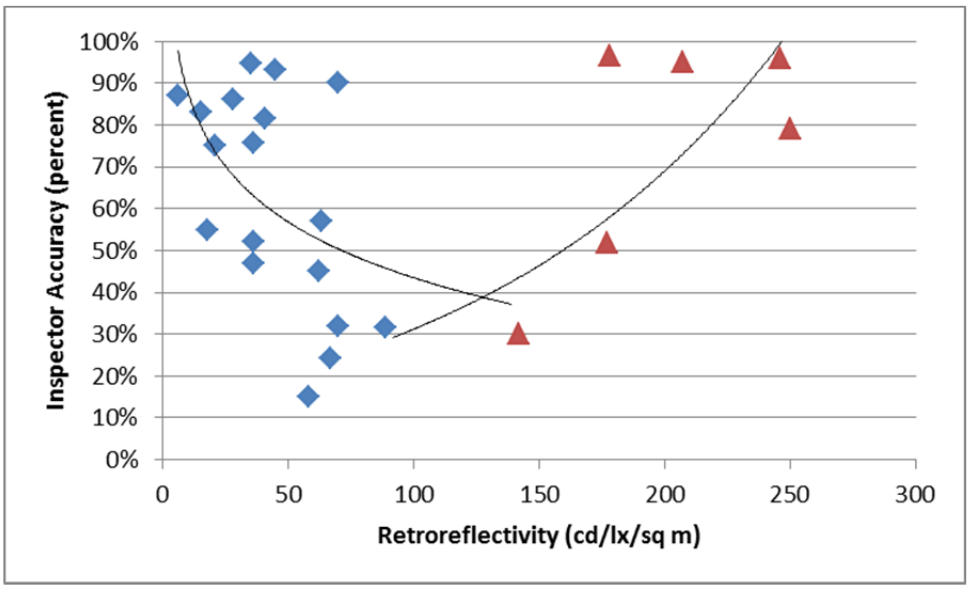


Figure 3. Accuracy of Nighttime Inspections of Warning Signs (Partitioned Data with non-Linear Fits)

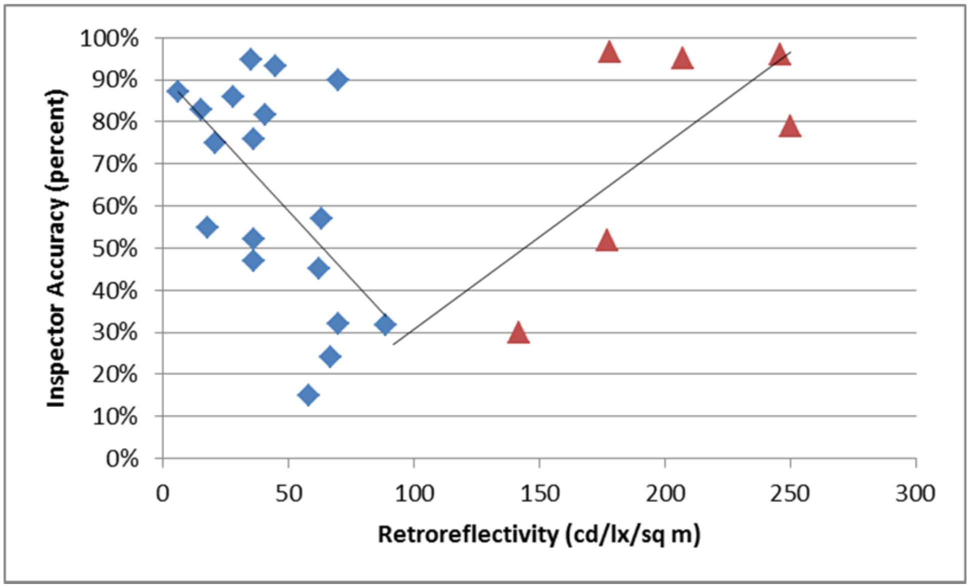


Figure 4. Accuracy of Nighttime Inspections of Warning Signs (Partitioned Data with Linear Fits)

Figures 1 through 4 all show the same data—and the same general findings—accuracy of nighttime inspections depends on retroreflectivity levels. In other words, dead signs (signs with very low retroreflectivity levels) are easy to identify and so are bright signs (signs with very high retroreflectivity levels). However, somewhere between retroreflectivity levels described as dead signs and bright signs, there is a drop in performance regarding the accuracy of visual inspections. The exact low point and the exact shape of the diminished performance is difficult to precisely quantify with the available data, however it does appear that the most difficult levels of retroreflectivity to judge accurately in terms of replacement needs are in the range of about 90 to 125 cx/lx/sq m).

For white regulatory signs, only the data from Texas were reported with enough detail to conduct the same kind of analysis as presented above for warning signs. Using that data, the accuracy of white regulatory signs as a function of retroreflectivity levels is shown in Figure 5.

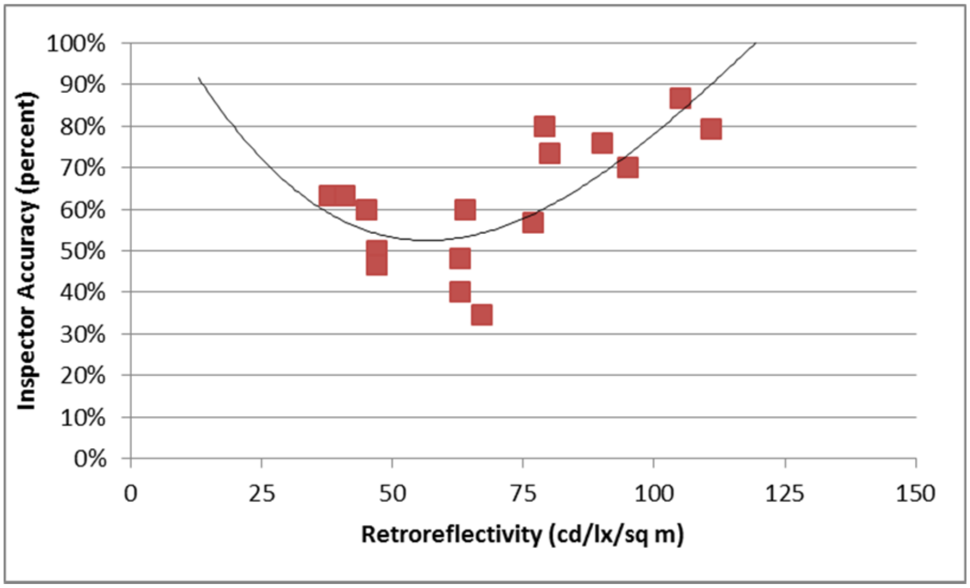


Figure 5. Accuracy of Nighttime Inspections of White Regulatory Signs

Figure 5 shows the same trends for white regulatory signs as reported for warning signs in Figures 1 through 4. However, the lowest performance shifted down to a range of about 50 to 65 cd/lx/sq m. It should be noted that the trend line shown here was extrapolated toward zero to show the trending relationship despite lack of data below about 35 cd/lx/sq m.

Compared to the warning sign analyses, the white regulatory sign analyses had much less data available for analyses. Unfortunately, even less data were available for the white on red regulatory sign analyses, which are perhaps the most interesting from at least a couple perspectives. First, these are arguably the most critical signs on the roads and second, there are three different criteria for these types of signs (legend retroreflectivity, background retroreflectivity, and contrast). Because these types of signs are perhaps the most interesting to study in terms of inspector accuracy ratings, the data from the Washington study were analyzed to understand how visual inspectors rated these types of signs with respect to legend retroreflectivity, background retroreflectivity, and contrast. The univariate relationships are shown in Figures 6 through 8 (the blue diamonds represent signs located in rural locations while the red squares represent signs located in urban areas). The sign rating from the Washington study ranges from 0 (needs replaced) to 5 (like new).

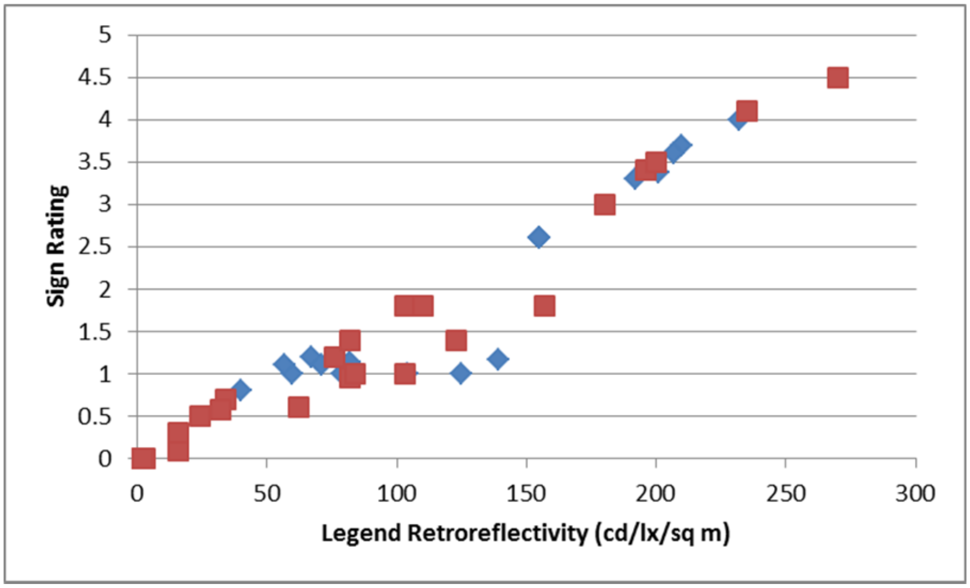


Figure 6. Nighttime Inspections Ratings for White on Red Signs (by Legend Retroreflectivity)

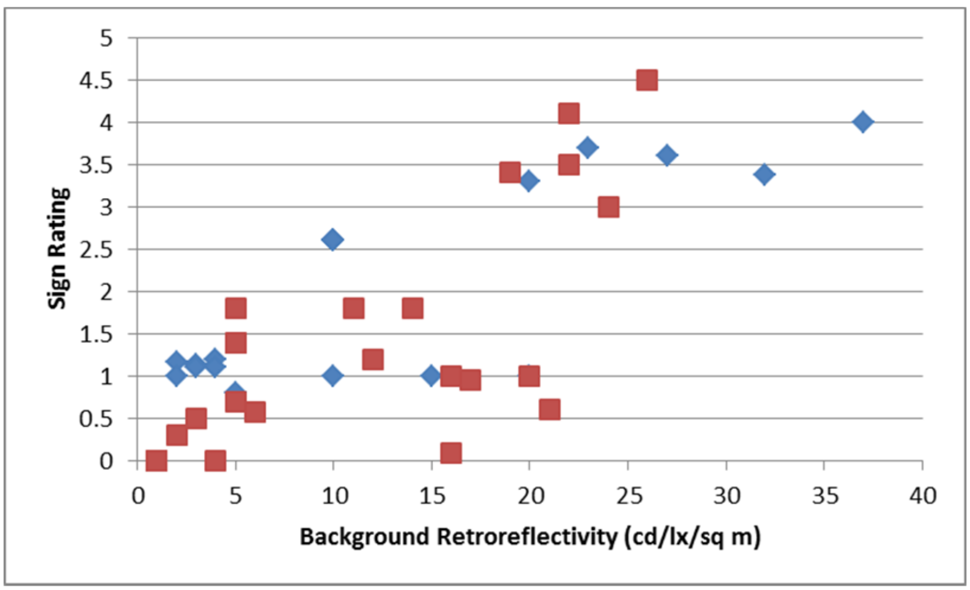


Figure 7. Nighttime Inspections Ratings for White on Red Signs (by Background Retroreflectivity)

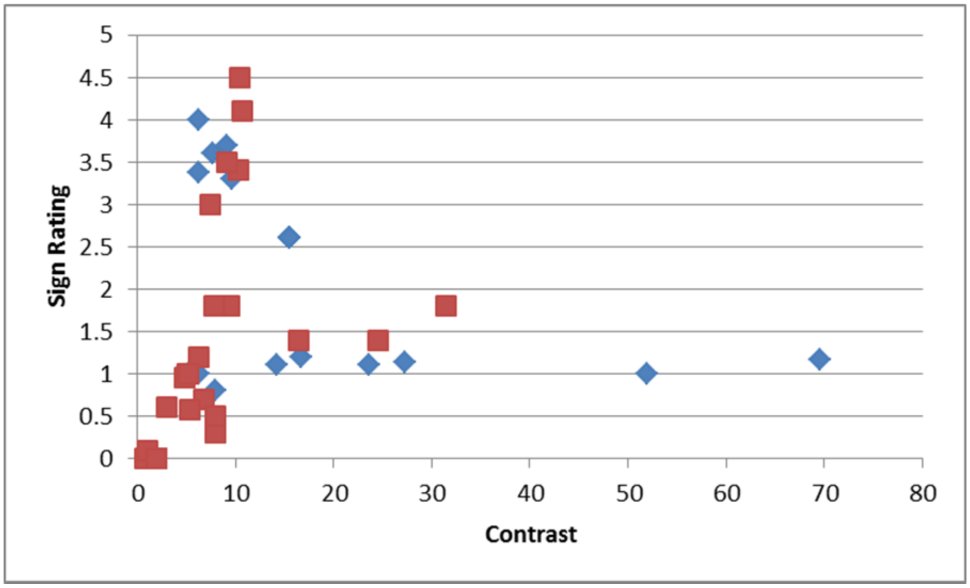


Figure 8. Nighttime Inspections Ratings for White on Red Signs (by Contrast)

A multivariate analysis of the white on red regulatory signs confirmed the visual inspections of Figures 6 through 8—nighttime inspectors rely on the brightness of the white retroreflectivity (the legend) to judge the adequacy of these sign types. Neither the sign background retroreflectivity nor the contrast was deemed to be statistically related to the inspector rankings. Furthermore, the sign environment, rural versus urban, did not impact this finding in a statistically meaningful way. With these relationships better understood, one can expect that the visual nighttime inspection of white on red regulatory signs such as Stop signs has similar inaccuracies as white regulatory signs shown in Figure 5.

Measurements using Handheld Retroreflectivity Equipment

Many agencies consider the handheld retroreflectometer to be the most accurate way to assess sign retroreflectivity. However, there is practically no reported information regarding the accuracy of handheld equipment in terms of measurement bias and repeatability. The Retroreflection Subcommittee of ASTM E12 (Color and Appearance) has been working on developing a precision and bias statement for handheld equipment for years but no results are available (as of April 2014).

In March 2011, a paper was published in the ITE Journal of Transportation that included research from Indiana used 22 stop signs and three different retroreflectometers in a laboratory test to determine the range of median bias for Type I and Type III sheeting for both the legend and background (9). Their median bias findings are listed below.

- Type I background (red) ranged from 1 to 3 cd/lx/sq m;
- Type III background (red) ranged from 2 to 4 cd/lx/sq m;
- Type I legend (white) ranged from 3 to 12 cd/lx/sq m; and
- Type III legend (white) ranged from 15 to 40 cd/lx/sq m.

They also made field measurements with the handhelds. They concluded that it is reasonable to assume that the coefficient of variation (COV) for an individual sign will be between 4 and 14 percent when using a handheld device. However, this study did not include prismatic materials and did not include the impact of using the reducer rings, which is commonly used when many field measurements are necessary.

Measurements using Mobile Retroreflectivity Equipment

A variety of mobile sign retroreflectivity measurement equipment is entering the market. It is not all created equal. Some of it has not been tested, and there is no standard test or certification that mobile equipment needs to satisfy. The results summarized below are from a specific technology called the Advanced Mobile Asset Collection (AMAC) System (10).

In 2001, an open-road test was performed using the AMAC system. Over 100 in-service signs were measured with the AMAC system and calibrated hand-held retroreflectometers. The AMAC background measurements were 13 percent lower than handheld measurements and the AMAC legend measurements were21 percent lower than handheld measurements. These differences were most evident on the signs with very high retroreflectivity levels (many multiples higher than the MUTCD minimum levels).

Regarding the differences in the mobile and handheld measurements, the open-road findings with lower mobile measurements is actually an indication that the system is probably functioning as it should. Theoretically, it is really not possible for a mobile system to produce the exact same retroreflectivity levels as a handheld device. The key difference is that the handheld devices are built to specific geometries but those geometries are not simultaneously common with typical roadway cross-sections, roadway alignments, and sign positions. In most cases, non-contact measurements from in-situ will provide slightly lower results than contact devices measuring the same signs. However, if working properly, a mobile measuring system will provide a better representation of how the signs are working at night, and this is ultimately the most important item here.

Dynamic testing along a closed-course route was also performed to assess the van's measurement bias and repeatability. The measurement bias regarding background measurements was less than 1 percent, meaning that the measurements from the van were on average less than 1 percent from the handheld measurements. The legend measurements from the van were on average about 5.5 percent from the handheld measurements.

The median COV for the AMAC system was about 5 percent, and the 85th percentile COV was about 10 percent. In earlier reported research, the median and 85th percentile COV for handheld readings on in-service signs was about 6.5 percent and 15 percent, respectively. These numbers show that the variability of measurements can be even lower with the AMAC mobile system compared to handheld measurements.

Additional Implementation Considerations

Implementing a sign retroreflectivity program requires additional considerations besides the accuracy of the inspection method. In this section, other factors are explored that also provide useful information that an agency can use to select a sign retroreflectivity maintenance method.

Building an Inventory

While not required, having a sign inventory provides many additional benefits for a highway agency. Both the visual inspection method and the measured sign retroreflectivity provide opportunities to build a sign inventory. Some visual inspection technologies allow GPS-referenced inventories, however and sign size, height, and offset are more difficult to obtain with visual inspection techniques. On the other hand, mobile retroreflectivity technologies can not only obtain retroreflectivity data, but they can also provide sign dimensions, sign positioning regarding GPS data, sign height and sign offset, and in some cases, sign legend letter size, which is useful for determining compliance with changes in the MUTCD regarding accommodation of older drivers. An example of a geo-coded sign inventory is shown below in Figure 9. In this example, the inventory includes GPS coordinates, retroreflectivity measurements, sheeting type, substrate materials, sign dimensions, sign height, support type, breakaway equipment presence, and an image. This is the type of inventory that can be quickly built when sign retroreflectivity measurements are made but not all of these details can be obtained with the visual inspection method.

Figure 9. Geo-Coded Sign Inventory with Retroreflectivity Measurements

Frequency of Inspections

Besides the initial condition assessment, visual inspections are typically conducted every year or every other year. However, measured sign retroreflectivity provides a level of data that allows less frequent inspections. The data provided from measured sign retroreflectivity can be combined with service life estimations and used to plan sign replacement for the upcoming years. Depending on where an agency sets their maintenance threshold levels compared to the MUTCD minimum retroreflectivity levels, it is reasonable that measured sign retroreflectivity may be eventually needed every 7 years. However, more frequent inspections may be initially needed as an agency develops reliable service life estimates for their specific conditions.

Combining Methods

Visual inspection methods tend to lead to the need for continued visual inspection methods. Agencies conduct visual inspection methods as much as twice per year and as little as once every three years, however, annual visual inspection methods are probably the most commonly used visual inspection frequency.

On the other hand, after measuring sign retroreflectivity, an agency can easily move to managing their sign retroreflectivity with the expected service life method if they have some knowledge of how long the retroreflectivity material will list in their geographic area. The Texas A&M Transportation Institute has been cataloging research findings pertaining to the expected service life of retroreflectivity materials all over the US. They are a good resource for learning more about the durability of signs. For instance, Figure 10 shows how Type III warning signs older than 14 years are performing in the Northeast. Similar data and predictive equations are available for many parts of the US. Some Type III warning signs have been in the field for more than 30 years and are still performing above the MUTCD minimum retroreflectivity levels.

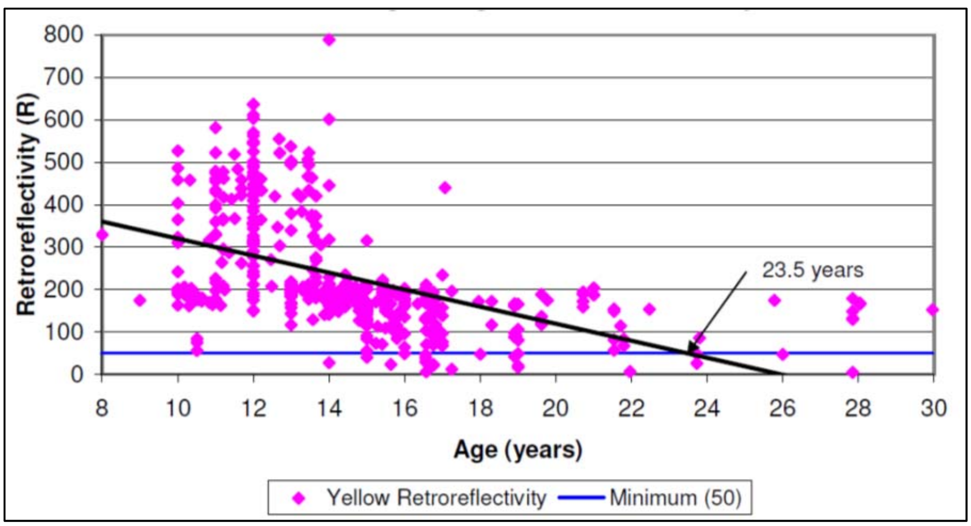


Figure 10. Type III Yellow Signs in PA (11)

Tort Liability

Tort liability is the most cited state transportation agency concern regarding the MUTCD minimum retroreflectivity levels. While implementation and documentation of an agency's chosen maintenance method can minimize liability, the subjectivity of the visual inspection procedures, particularly when the retroreflectivity levels are between about 50 and 125 cd/lx/sq m, leaves some unknown concerns that most likely will not be resolved until a case reaches the courtroom. The risk associated with the poor accuracy of visual inspection method has yet to be quantified. However, of all the MUTCD sign retroreflectivity maintenance methods, including the management methods, the measured sign retroreflectivity method provides the most objective data to use to be in compliance and therefore the most robust maintenance method for agencies concerning about the potential of tort liability.

In a national study of agencies already maintaining sign retroreflectivity, those not using the visual inspection method chose a different method because of their concern related to the potential of the tort liability with the visual inspection method (3). In addition, agencies were not using the visual inspection method because of the issues associated with staffing, overtime pay, and schedule modifications.

Minimizing Exposure

Exposure of personnel is another concern worth considering. The visual inspection method has three different procedures but they all must be completed during nighttime hours. The comparison panel procedure even requires inspection personnel to on the roadside during nighttime conditions.

The sign retroreflectivity measurement method employed with handheld equipment exposes personnel to the hazard of roadside data collection, as shown in the adjacent image. While handheld retroreflectivity measurements can be made during daytime conditions, many signs are high enough that a ladder is needed to measure the sign. Mobile sign retroreflectivity eliminates these concerns and is the most attractive method in terms of minimizing the exposure of inspectors.

Cost Considerations

To determine the cost associated with visual nighttime inspections versus either handheld measured sign retroreflectivity or mobile measured sign retroreflectivity, several assumptions were made based on a typical scenario. First, the costs considered here do not include the cost of replacing signs, only the costs of conducting the inspections, and the long-term management of a sign retroreflectivity maintenance program that complies with the MUTCD. It was assumed that the cost of replacing inadequate signs would be relatively equal across the various assessment methods (notwithstanding the inaccuracies of the visual inspection method). The assumptions are listed below.

- Sign density varies from rural to urban roadways. For this example, a mid-range density of 15 signs per centerline mile was assumed.
- A total of 5000 centerline miles was assumed, equating to 10,000 miles of needed sign inspections.
- Therefore, the total sign count in this example is 15×5,000=75,000 signs.
- Nighttime sign inspections cover 4 hours of actual inspection time per night, or 220 miles. Therefore, 45 nights are needed for sign inspections assuming one crew.
- Handheld sign retroreflectivity inspections are made at a rate of 16 signs per hour. With 6 hours of actual inspections per day, 781.25 days are needed assuming one crew.

- Mobile sign retroreflectivity inspections cover 4 hours of actual inspection time per night. Like visual inspections, 45 nights would be needed.
- A crew of two is needed to conduct nighttime inspections. The loaded rate of the inspectors is $25/hr. The vehicle cost is $25/hr. A premium of 25 percent is applied to the hourly rate because of the nighttime work. Hotel costs are assumed to be $125 per night and per diem is assumed to be $25 per night. Another fee of $3 per sign is added to produce the retroreflectivity report and provide a GPS-coded inventory.
- A crew of two is needed to conduct do the handheld retroreflectivity measurements. The loaded rate of the inspectors is $25/hr. The vehicle cost is $25/hr. Hotel costs are assumed to be $125 per night and per diem is assumed to be $25 per night. Another fee of $3 per sign is added to produce the retroreflectivity report and provide a GPS-coded inventory.
- The cost to conduct mobile retroreflectivity inspections is $140 per centerline mile. This covers all costs associated with the measuring and reporting the retroreflectivity, and a GPS-coded inventory.

The assumptions above were used to generate the costs associated with conducting an initial sign retroreflectivity condition assessment, with a GPS-coded inventory. The final costs are shown below

- Visual nighttime inspection method: $270,455
- Handheld measured retroreflectivity method: $853,125
- Mobile measured retroreflectivity method: $700,000

From this example, the lowest cost option to conduct the initial condition assessment is the visual inspection method. However, as pointed out earlier, the visual inspection method provides levels of subjectivity and inaccuracies that may not be acceptable for some agencies. There is an unknown but potentially high level of risk associated with leaving inadequate signs in service when using visual nighttime inspections. The use of a handheld retroreflectometer has the highest cost in this example. In addition, the visual inspection method must be conducted at regular intervals.

In order to better understand the on-going costs of a sign retroreflectivity maintenance program, the next step considers the costs over a 20 year period. In this case, the following assumptions are made:

- Visual nighttime inspections are conducted every other year.
- Measured sign retroreflectivity measurements are repeated gradually increasing schedule. The first interval is 5 years, the second interval is 6 years, and the final interval is 7 years.
- The annual cost adjustment is set at 4 percent.
- Over the 20 year period, the total costs are:
  - Visual nighttime inspection method: $4,500,000 ($3.03/sign/year)
  - Handheld measured retroreflectivity method: $5,050,000 ($3.37/sign/year)
  - Mobile measured retroreflectivity method: $4,150,000 ($2.67/sign/year)

After considering the long-term costs of maintaining sign retroreflectivity, the low cost method ends up being the mobile measured retroreflectivity inspections. The cost of the visual nighttime inspection is only slightly higher but the mobile measured retroreflectivity method provides additional benefits of offering more protection from tort claims as well as a more accurate GPS-coded inventory and more detailed sign information such as sign dimensions, sign offset, and sign height. The mobile measured retroreflectivity method also has another key advantage over the visual nighttime inspection method—the mobile measured retroreflectivity method provides actual retroreflectivity levels that can be used ro budget planning purposes.

Conclusions

Implementing a cost-effective sign retroreflectivity maintenance program requires more than just consideration of the initial cost. The long-term costs of the options to maintain sign retroreflectivity need to be considered along with the additional benefits that can be realized as a result of the various options.

Long-term costs need to be considered since both nighttime visual inspections and measured retroreflectivity need to be adopted as long-term approaches. With a visual inspection method, there is a need for somewhat frequent inspections (usually every year or every other year). Measured sign retroreflectivity allows longer intervals between inspection periods (for example, 5 to 7 years). While the less frequent inspections impact costs, they also reduce the risk exposure of maintenance personnel on the highway. Measured sign retroreflectivity also provides an option to transition to a management method such as the expected sign life method, which may provide the lowest overall long-term cost (ignoring the additional benefits of measured sign retroreflectivity).

Besides the costs, the accuracies of the options are another key consideration for agencies. Visual nighttime sign inspections are most accurate for identifying signs with very low retroreflectivity levels (e.g., dead signs), and signs with very high retroreflectivity levels (e.g., new prismatic signs). For the minimum levels required for warning and regulatory signs, nighttime visual inspections produce relatively poor results (only about 50 percent accurate in a range of about 50 to 125 cd/lx/sq m).

On the other hand, measured sign retroreflectivity provides an accurate numeric result that can be used to directly assess a sign's condition relative to the MUTCD minimum retroreflectivity levels. Handheld measurements and mobile measurements are both very accurate and repeatable, compared to visual nighttime inspections. Measured sign retroreflectivity also provides the highest level of protection from potential tort claims. However, mobile technology offers several advantages over handheld equipment such as:

- Measurements are made while driving down the highway at highway speeds and therefore no equipment has to be in contact with the sign and no personnel are exposed to the hazards of roadside work.
- Measurements are made at real roadway geometries rather than prescribed geometries that do not always represent the real world.
- Twisted and leaning signs are measured as seen from the roadway perspective and can be easily identified as needing routine maintenance (straightening rather than replacement).

- Images of signs are recorded.
- All signs can be measured, including overhead and difficult-to-reach shoulder mounted signs.
- The entire retroreflective area of the sign is measured rather than a few 1-inch diameter areas. This includes the legends and backgrounds of positive contract signs and provides a more representative result.

When the costs of conducting various types of sign retroreflectivity assessment methods were analyzed, the results revealed that while the visual inspection method produces the lowest initial cost, the long-term cost analyses favored the mobile retroreflectivity measurement method. It also turns out that this method provides the lowest risk of inspector exposure and the highest level of protection from potential tort liability concerns.

References

1. *Manual on Uniform Traffic Control Devices*, US DOT, FHWA, Washington DC, 2009.
2. *Maintaining Sign Retroreflectivity*. US DOT, FHWA, FHWA-SA-07-020, Washington DC, 2007, Revised 2013.
3. Re, J. and P.J. Carlson. Practices to Manage Traffic Sign Retroreflectivity: A Synthesis of Highway Practice, NCHRP Synthesis 431, Transportation Research Board, Washington, DC, 2012.
4. E.A. Lagergren. Traffic Sign Retroreflectivity Measurements Using Human Observers. WA-RD 140.1, Washington DOT, Olympia, Washington, December 1987.
5. Hawkins, H.G. and P.J. Carlson. Sign Retroreflectivity-Comparing Results of Nighttime Visual Inspections with Application of Minimum Retroreflectivity Levels. In Transportation Research Record 1754, Transportation Research Board. Washington, DC. 2001.
6. Hawkins, H.G., P.J. Carlson, G.F. Schertz, and K.S. Opiela. Workshops on Nighttime Visibility of Traffic Signs: Summary of Workshop Findings. US DOT, FHWA, FHWA-SA-03-002, Washington, DC., February 2003.
7. Pavan V.K., W.J. Rasdorf, J.E. Hummer and C. Yeom. Field Investigation of Highway Sign Damage Rates and Inspector Accuracy, Public Works Management Policy Volume 11, Edition 266, 2007.
8. Kilgour, M. D., J. D. White, and D. M. Bullock. Sign Retroreflectivity: Fiscal Impact of Proposed Minimum Retroreflectivity Values on Local Governments in Indiana and Investigation of the Accuracy of Nighttime Inspections. Transportation Research Board 86th Annual Meeting. No. 07-0387, 2007.
9. Remias, S.M., S.M. Hubbard, E.A. Hulme, G.D. Farnsworth, and D.M. Bullock. Bias and Uncertainty in Traffic Sign Retroreflectivity. Journal of Transportation, Institute of Transportation Engineers, March 2011.
10. P.J. Carlson. Evaluation of Sign Retroreflectivity Measurements from the Advanced Mobile Asset Collection (AMAC) System. Texas A&M Transportation Institute, College Station, TX, October, 2011.
11. Clevenger, K., K. Colello, and J. Quirus. Retroreflectivity of Existing Signs in Pennsylvania. FHWA-PA-2012-003-E01041-W09, PennDOT, April 2012.