Evaluation of Sign Retroreflectivity Measurements from the Advanced Mobile Asset Collection (AMAC) System

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EVALUATION OF SIGN RETROREFLECTIVITY MEASUREMENTS FROM THE ADVANCED MOBILE ASSET COLLECTION (AMAC) SYSTEM

INTRODUCTION

Roadway traffic signs are a primary means of communicating and conveying critical information to roadway users. The MUTCD provides the basic principles that govern the design and use of traffic control devices for all roadways that are open to public travel. There are five main principles in the MUTCD (1) that traffic control devices must follow:

- Fulfill a need,
- Command attention,
- Convey a clear simple meaning,
- Command respect from road users, and
- Give adequate time for proper response.

Sign information can be conveyed through the legend, which can be compromised of words, symbols, and arrows. Roadway users can also extract information from a sign's unique appearance as size, color, and shape are critical components. In addition to the specialized design criteria, road users need to detect signs and comprehend the message content in a timely manner in both daytime and nighttime. At night, signs not internally illuminated must be fabricated with retroreflective materials. Retroreflective materials return light back to the original source. Light from a vehicle's headlamps is reflected from the sign's surface back to the driver giving the sign an illuminated appearance.

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." The goal of the new minimum retroreflectivity requirements was to improve safety on our nation's streets and highways. It was meant to ensure that drivers, especially the aging population, could detect, comprehend, and react to traffic signs accordingly and help to facilitate safe, uniform, and efficient travel. To satisfy the Congressional directive, the Federal Highway Administration (FHWA) has added a table containing minimum sign retroreflectivity values to the MUTCD (section 2A.08 of the 2009 MUTCD). In addition, several methods are identified that agencies can implement to maintain traffic signs at or above the minimum retroreflectivity requirements.

The 2009 MUTCD states that an agency "shall use an assessment or management method" to maintain sign retroreflectivity. The manual does not dictate the method, but provides agencies flexibility to implement one or more method(s) that best suits their needs, expertise, and level of resources. The intent of the methods and guidance outlined in the MUTCD is to provide support to the agencies and offer them systematic procedures to maintain traffic sign retroreflectivity.

Section 2A.08 of the 2009 MUTCD offers five traffic sign methods for maintaining nighttime sign visibility and an "Other" method, which must be supported by an engineering study. The five methods are categorized as either assessment or management methods. Assessment methods evaluate the retroreflectivity of individual signs and include Visual Nighttime Inspection and Measured Sign Retroreflectivity. Management methods incorporate an expected retroreflective life period of individual sheeting materials. The management methods include Expected Sign Life, Blanket Replacement, and Control Signs. Assessment and management methods may be combined in many different ways to accommodate an agency's needs and objectives. The MUTCD description of each method is contained below.

- Visual Nighttime 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.
- Measured Sign Retroreflectivity—Sign retroreflectivity is measured using a retroreflectometer. Signs with retroreflectivity below the minimum levels should be replaced.
- 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 Signs—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.

The FHWA provided an array of different sign maintenance methods at the request of agencies (2). The various methods provide agencies a way to customize their sign maintenance policies to best fit their needs while still being in compliance with the new regulations. A recent national survey has shown that all of the methods listed above are already being used, and many are being combined as agencies determine how they can best meet the new regulations (3).

Measured Sign Retroreflectivity with Handheld Devices

Of all the maintenance methods listed in the MUTCD, the most objective method to maintain traffic sign retroreflectivity is measuring sign retroreflectivity. Many agencies prefer this method because it is thought to be the most protective in terms of potential tort that may result from the new MUTCD regulations (3). However, given the current technology to measure sign retroreflectivity, some agencies have deemed this method unacceptable. The disadvantages of measuring sign retroreflectivity with handheld devices are listed below:

- The devices cost $10,000 to $15,000 per unit and require adequate care and annual recalibration (i.e., sending the device back to the manufacturer).
- The devices must be in contact with the sign surface to take measurements.
- The devices make measurements at a prescribed geometry that is not always representative of the actual driving geometries.
- Measurements from twisted and leaning signs can result in retroreflectivity levels above the minimum MUTCD levels. However, the luminance of the sign under nighttime conditions may be less than needed for the drivers because of the non-standard geometry.
- Measuring signs is time consuming. Shoulder mounted signs can be measured at a rate of about 80 to 160 signs per day using a two-person crew.
- Measuring sign retroreflectivity exposes maintenance crews to the risk associated with working near traffic and on the roadside.
- Overhead and even some shoulder mounted signs can be out of reach, even with an extension pole connected to the handheld device.
- Each reading with a handheld device measures a maximum of a 1-inch diameter area of the sign. As signs age, the variability of readings across the sign face can increase as a function of dirt and grime on the sign face. Therefore, making handheld readings on older signs can decrease the repeatability of the measurements and ultimately add bias.
- When handheld devices are used, many agencies calibrate them with using a reducer ring, which reduces the size of the measurement aperture from 1-inch diameter to 0.5-inch diameter. The reduced ring is used to measure the legend of positive contrast signs (because of the relatively narrow stroke width). To be more efficient in the field, maintenance crews typically leave the reducer ring on to make all their measurements and avoid having to recalibrate the handheld device each time the reducer ring is used. Using the reducer ring adds measurement bias to retroreflectivity readings, especially on signs made with prismatic retroreflective materials.
- There are two types of handheld devices on the market as of fall 2011. They are typically referred to as point and annular devices (see ASTM E1709). Making measurements with these devices can lead to different results. The results can be as large at 25 percent or

more, depending on the type of retroreflectivity sheeting material and the orientation in the handheld device. Some materials are called orientation-sensitive, meaning that as they are rotated around an axis perpendicular to the face of the sign, the performance can vary. This is important because point devices are sensitive to the orientation of measurement and annular devices are not. The sensitivity varies with different as a function of the geometries. An example of the 360 degree orientation sensitivity of different ASTM D4956 materials is shown in Figure 1.

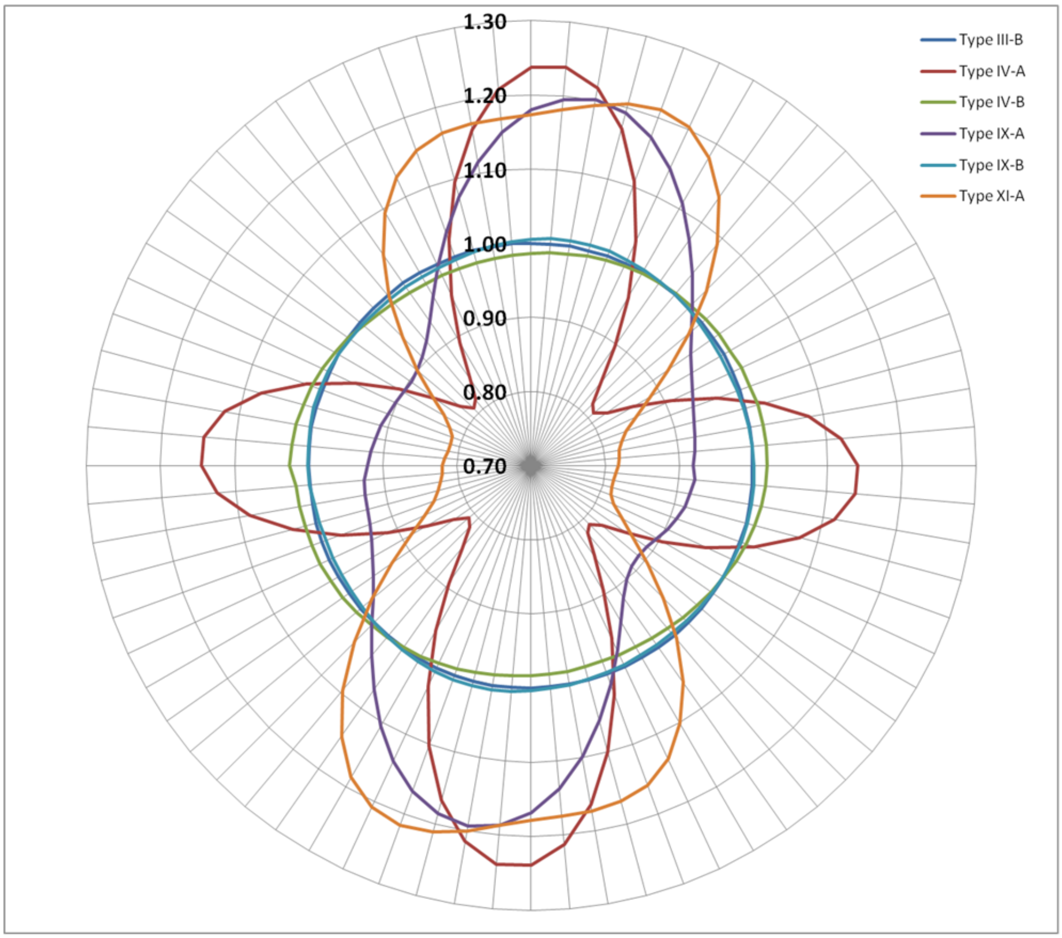

Figure 1. Rotational Sensitivity (Alpha=0.2°, Beta=4.0°)

There is practically no official information regarding the measurement bias and repeatability of handheld retroreflectometers. The Retroreflection Subcommittee of ASTM E12 (Color and Appearance) has been working on developing a precision and bias statement for two years, but nothing has officially been published yet.

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 (white and red). Here is what they found:

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

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.

Measured Sign Retroreflectivity with Mobile Technology

Almost all of the concerns associated with the handheld measurement devices (as listed above) can be alleviated or eliminated with the ability to measure sign retroreflectivity from digital images recorded at highway speeds. In other words, using technology from a mobile platform could provide the following advantages:

- Measurements could be made while driving down the highway and therefore no equipment would have to be in contact with the sign.
- Measurements would be made at real roadway geometries rather than prescribed geometries that do not always represent the real world.
- Twisted and leaning signs would be measured as seen from the roadway perspective and can be easily identified as needing routine maintenance (straightening rather than replacement).
- Images of signs could be recorded at highways speeds, although post-processing the images would be needed. This would minimize the exposure and risk of the technicians.
- All signs can be measured, including overhead and difficult-to-reach shoulder mounted signs.
- Using image analysis, the entire retroreflective area of the sign can be measured rather than a few 1-inch diameter areas. This includes the legends and backgrounds of positive contract signs.

Over 10 years ago, the first mobile sign retroreflectivity technology was introduced. As the FHWA was working to develop minimum sign retroreflectivity levels, they were also developing the first mobile sign retroreflectivity technology. The Sign Management and Retroreflectivity Tracking System (SMARTS) van was a fully functional prototype for a mobile sign retroreflectometer van. The SMARTS van was developed by the Naval Research Laboratory (NRL) for the FHWA. A total of four units were produced (but are no longer in operation). A photo of one of the FHWA vans is shown in Figure 2.

Figure 2. One of the Four FHWA Mobile Sign Retroreflectivity Vans (circa 2002)

While the FHWA's van was an ambitious project, it was ahead of its time in many ways. The van was promoted as a prototype and in a 2001 evaluation, it was deemed too inaccurate to be useful (http://www.dot.state.ak.us/stwddes/research/assets/pdf/fhwa_ak_rd_01_01.pdf). However, the purpose of the effort was to demonstrate that technology could be implemented to measure sign retroreflectivity, and in an unpublished Highway Innovation Technology Evaluation Center (HITEC) report, the van's results were not unreasonable (note that the HITEC program is no longer in operation).

Over 10 years have passed since the FHWA's van was introduced. Since that time, the MUTCD has adopted minimum sign retroreflectivity levels and implementation dates for that language is approaching. As the pending compliance dates inch closer, there has been an increased amount of activity regarding the development of mobile sign retroreflectivity measurements.

SCOPE

In 2011, TTI was approached by DBI/Cidaut Technologies LLC, a joint venture between the United States' DBi Services and Spain's CIDAUT Foundation, to evaluate their technology that was built to measure sign retroreflectivity, among other things. This business is called Advanced Asset Management Collection (AMAC) and was built by a team of engineers, physicists, psychologists, and statisticians and is composed of three components (1) a mobile system for data and image acquisition, (2) detection, performance, and positioning software, and (3) management and analysis software. In the late summer of 2011, TTI evaluated their system, including the accuracy and repeatability of the retroreflective sign measurements. The AMAC system records images during the nighttime and then processes the images to determine retroreflectivity. The remainder of this report describes the testing that was performed and the test results.

Testing Protocol

There is neither any national specification for a mobile sign retroreflectometer nor a national test method. The testing protocol that was set up for the AMAC system was derived from a combination of factors. TTI has been testing retroreflectivity measurement technologies for 15 years and has experience testing the FHWA van as well as several other mobile technologies. In addition, among the unique features of the AMAC van is the ability to measure signs in a static condition. Therefore, the testing protocol that was established included the following:

- Static measurements of a variety of retroreflective signs on a closed-course facility.
- Dynamic measurements of a variety of retroreflective signs on a closed-course facility.
- Dynamic measurements along an open-road test route.

The closed-course facility was the Texas A&M University's Riverside Campus. At this location, signs were mounted in all types of typical positions such as left-shoulder, right-shoulder, overhead, and far-right-shoulder. The signs consisted of an array of new sign material as well as older signs. A variety of different colors were used as well. The general goal was to have signs representative of what a driver encounters on any given drive. Another general goal was to include signs with very high retroreflective performance as well as signs with very poor retroreflective performance (in order to test the dynamic range of the system).

The static testing on the closed-course facility was conducted at a distance of 90 m, which was based on the test vehicle's equipment location. This testing was done with an array of different materials.

The dynamic testing on the closed-course facility was conducted to determine both the measurement bias of the system as well as the repeatability of the system. Since the closed-course testing was conducted in a dark rural environment, additional testing was conducted on the open-road to investigate the measurement bias with all the random factors that one would expect during measurements (such as interference lighting from roadway luminaires, platooned vehicles, opposing vehicles, and roadside development).

Static Test Results

The static testing was straightforward. The test van was positioned along a straight roadway with signs position 90 m downstream on both the right and left sides. The sign retroreflectivity was instantaneously measured by the van. Each reading required less than one minute.

Immediately after the van's readings were recorded, the signs were measured with a calibrated handheld retroreflectometer. The entire operation required less than an hour of testing.

Table 1. Results of Static Testing.*

Type of Material (ASTM D4956)	Color of Material	Average Handheld Measurement (n=4), cd/lx/m^2	Van Measurement, cd/lx/m^2	Actual Difference in Measurements, cd/lx/m^2
Type I	blue	6	7	1
Type I	green	13	14	2
Type I	red	21	13	−8
Type I	yellow	58	56	−2
Type III	blue	29	23	−6
Type III	red	47	38	−9
Type III	green	55	56	2
Type III	yellow	205	190	−15
Type III	white	244	293	50
Type XI	white	865	719	−146

* These signs did not have legends

The static measurements demonstrate the capability of van's dynamic range. While the apparent error in the last reading was high, the retroreflectivity levels were also high—on the order of 700 to 800 cd/lx/m^2, much above the minimum levels in the MUTCD. More interestingly, at least from a compliance point of view, is how the van did when measuring signs on the low end of retroreflectivity, or near the minimum levels in the MUTCD.

During the static testing, the sensitivity of the beta angle became apparent. The beta angle is more commonly called the entrance angle. In the prescribed geometry of handheld devices, beta is set at 4 degrees. However, the combination of an alpha angle of 0.2 degrees and a beta angle of 4 degrees is rarely seen in the field. The van testing distance is based on achieving the alpha of 0.2 but measures retroreflectivity at the resulting beta, depending on the sign offset and twist. During static measurements, it was interesting to watch the real-time retroreflectivity levels drop as a technician would slowly add twist to the sign face. The sensitivity of the entrance angle effect can vary with the type of sign sheeting as seen in Figure 3.

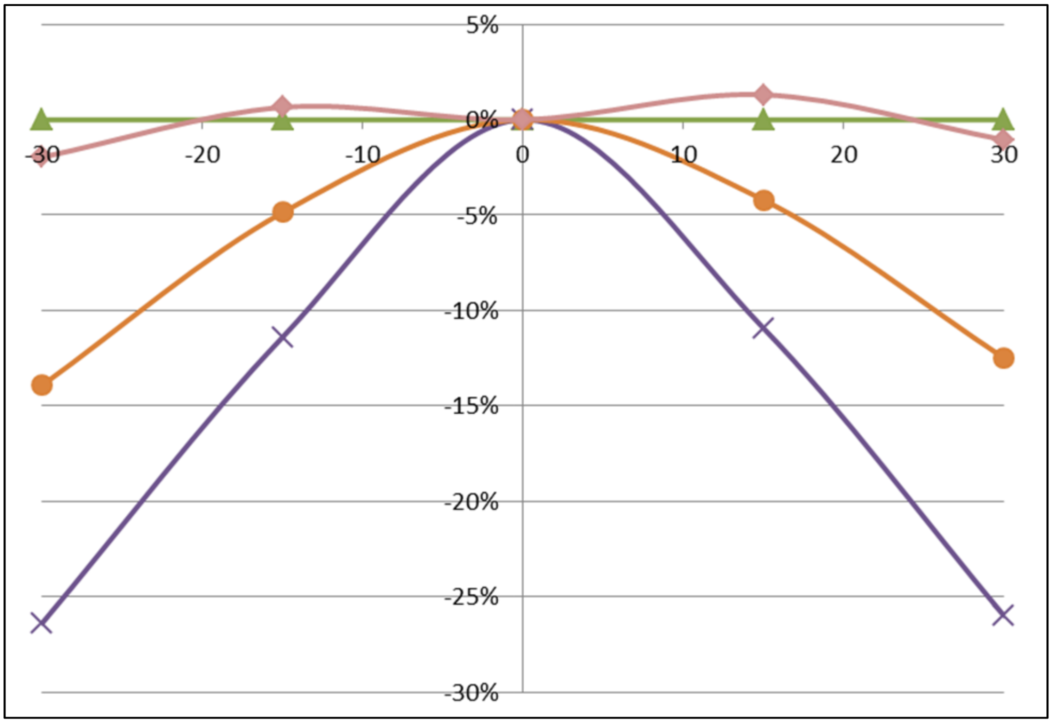

Figure 3. Sensitivity of the Beta Angle as a Function of Sign Twist

Overall though, for the signs with measured handheld retroreflectivity levels less than 100 cd/lx/m^2, the results were all within 10 cd/lx/m^2. The white Type III material has a difference of 50 cd/lx/m^2, but that is only 10 cd/lx/m^2 higher than the handheld error range reported earlier. Overall, the static results were impressive and showed promise but the technology was really built on the ability to measure signs in a dynamic situation.

Comparisons of static results, as well as the dynamic results, were made at similar epsilon angles. As indicated in Figure 1, the effect of the epsilon angle can be significant for some retroreflective materials. Therefore, rather than using handheld measurements averaged from readings of 0 and 90 degrees, the comparisons were made with handheld readings corresponding to the same epsilon angle as produced by the combination of the location of the equipment in the mobile system and the position of the van with respect to the sign. It is also important to note that two handheld retroreflectometers were used in this study. Both handheld retroreflectometers were of the “point instrument” type, as described in ASTM E1709. These types of handheld retroreflectometers are needed in order to be able to fairly compare the measurements from the mobile system.

Dynamic Closed-Course Test Results

The dynamic closed-course testing consisted of 26 different but typical signs one would normally encounter. A list of the signs, their sheeting type, and the average handheld retroreflectivity readings are shown in Table 2. For these signs, we assessed measurement bias and repeatability. In this study, the signs were measured at least four times with a handheld retroreflectometer conforming to ASTM E1709. The average of these measurements was assumed to be the true retroreflectivity of the sign. This averaged handheld value was used as a baseline to compare the van measurements. The repeatability as used herein is the ability of the AMAC van to obtain identical readings of the signs making multiple passes. Repeatability shows whether the AMAC van produces consistent readings when the conditions of the measurement are unchanged. A simple comparison of the sign background measurements is shown in Figure 4.

Table 2. Sign Used for Dynamic Closed-Course Testing.

Sign Legend	ASTM Type	Optics	Color	Average Handheld Measurement (n=4), cd/lx/m^2		
				Background	**Legend**	**Legend**
ONLY	III	Beaded	Yellow/Black	211.0		
Speed Limit 55	III	Beaded	White/Black	272.7		
Signal Ahead	III	Beaded	Yellow/Green/Red	213.7	55.3	68.7
Night Speed Limit 46	VIII	Prismatic	Black/White	745.3		
STOP	VIII	Prismatic	White/Red	174.3	843.3	
GEAR	VIII	Prismatic	Green/White	179.0	773.0	
YEILD	III	Beaded	White/Red	250.0	55.3	
NARROW BRIDGE	I	Beaded	Yellow/Black	57.0		
Speed Limit 40	XI	Prismatic	White/Black	875.3		
STOP	VIII	Prismatic	White/Red	125.7	585.0	
H	III	Beaded	Blue/White	21.3	302.3	
Honors	IX	Prismatic	Brown/White	41.7	390.3	
Sha	IV	Prismatic	Green/White	72.3	549.3	
VOICES	IX	Prismatic	Green/White	64.8	377.7	
BURNER	IX	Prismatic	Blue/White	30.2	365.8	
Speed Limit 55	I	Beaded	White/Black	58.3		
ALPNIE	III	Beaded	Green/White	8.7	33.7	
STOP	III	Beaded	Red/White	35.7	254.7	
Speed Limit 55	IX	Prismatic	White/Black	541.8		
YIELD	I	Beaded	White/Red	62.3	12.7	
LEFT	III	Beaded	Green/White	47.0	267.3	
STOP	I	Beaded	Red/White	12.0	54.3	
Night Speed Limit 73	III	Beaded	Black/White		292.3	
NO CENTER STRIPE	III	Beaded	Orange/Black	93.0		
Speed Limit 45	I	Beaded	White/Black	114.0		
BOAT	IX	Prismatic	Orange/Black	183.8		

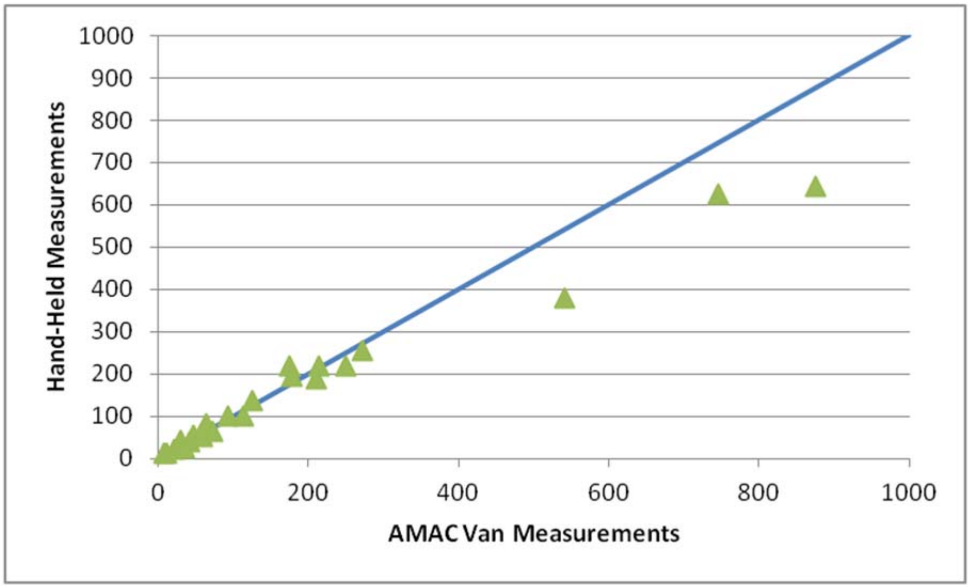

Figure 4. Comparison of Background Retroreflectivity Measurements (cd/lx/m^2)

Overall, the average percent difference between the measurements was 0.1 percent and the average actual difference was 21.2 cd/lx/m^2. Similar to the static testing results, the largest differences were observed on for the signs with very high retroreflectivity (e.g., greater than 500 cd/lx/m^2). Since these values are much higher than the minimum MUTCD retroreflectivity levels, the larger differences on the high end are not deemed to be major issues.

In many ways, measuring the sign background is easier than the sign legend (with positive contrast signs) because there are many additional pixels of information in a digital image to analyze. In fact, measuring the legend is so difficult that some mobile technologies only offer services to measure sign backgrounds. However, the AMAC system claims to be able to measure the legend retroreflectivity of positive contrast signs. Figure 5 shows a comparison of the sign legend measurements from the handheld retroreflectometer and the AMAC van.

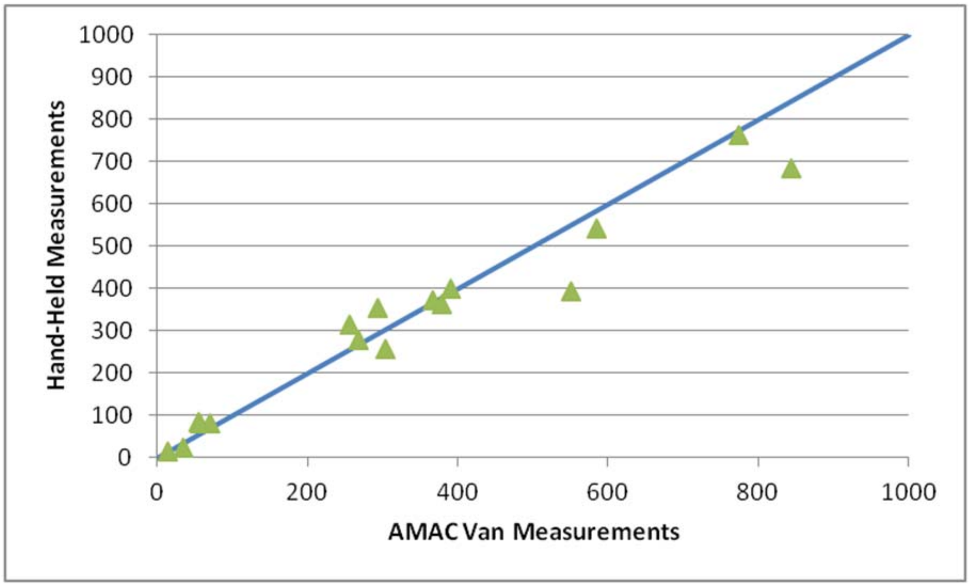

Figure 5. Comparison of Legend Retroreflectivity Measurements (cd/lx/m^2)

Overall, the average percent difference between the measurements was 5.5 percent and the average actual difference was 13.2 cd/lx/m^2. The two signs with the largest differences were both made of prismatic retroreflective materials. In general, the prismatic retroreflective materials appear to be associated with the largest differences in measurements regardless of whether the measurements were of the sign background or legend. It is possible that the signs were twisted during the mobile measurements. They were initially installed to be perpendicular to the testing path, but high winds were present during testing, which required technicians to constantly monitor and maintain the test signs.

As mentioned, the repeatability of the AMAC system was also tested on the closed-course. Three sets of dynamic data were recorded in order to test the repeatability of the mobile system. Figure 6 shows the cumulative distribution of the results graphically. The median COV 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 were about 6.5 percent and 15 percent, respectively. Therefore, based on the results reported herein, the repeatability of the AMAC van measurements is even more repeatable than handheld measurements. The differences can be explained by the potential caveats of using handheld devices as described starting on page 3.

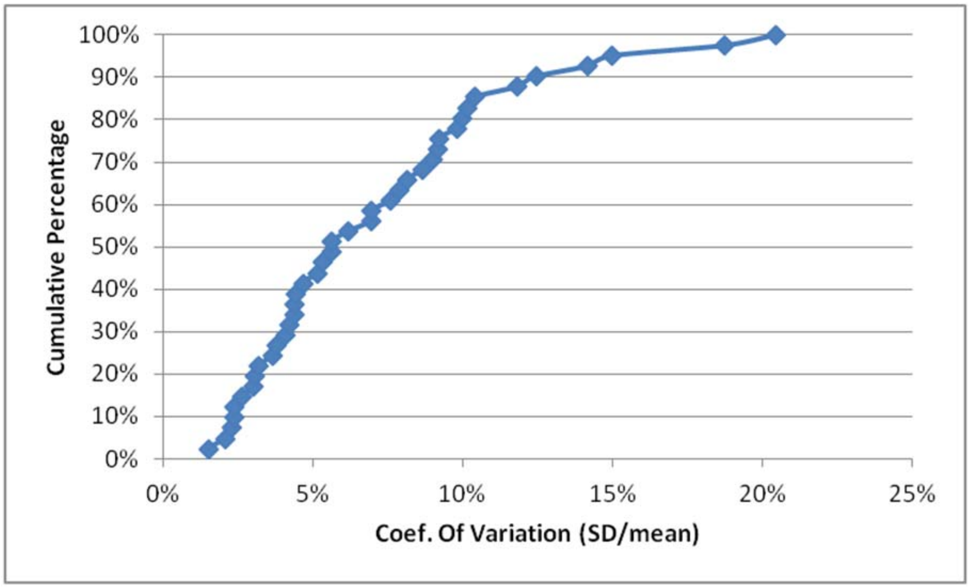

Figure 6. Cumulative Percentage of COV of Mobile Measurements

The COV for each sign and each type of measurement (i.e., background versus legend) is shown in Figure 7. The highest COV for a background was on a YIELD sign made with non-prismatic retroreflective material. The background of this sign was considered the white smaller triangle inside the red triangle. The white triangle has the word YIELD written across the top portion of triangle. In this case, the 36-in YIELD sign had a legend using 3-inch Series C font with a stroke width of less than 0.3-inch. Perhaps the legend inside the white triangle was difficult to account for within the measurements. The highest COV for a legend was on small prismatic guide sign with the word LEFT. This sign was part of a previous research study and was made with 8-inch tall letters with a stroke width of approximately 1 inch. The next highest legend COV was the same YIELD sign with the high background COV. This sign had a 15 percent COV for the legend, which can be explained by the very narrow font (0.3-inch in this case). In contrast to the reported COV from handheld retroreflectometers, these mobile COV are similar, and even slightly better. This is a promising finding given the challenges of measuring sign legends.

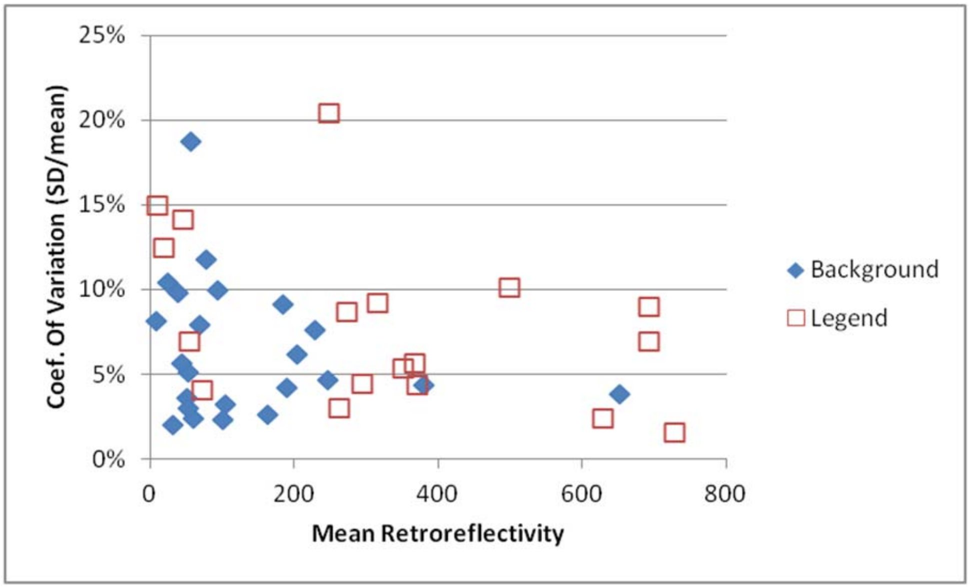

Figure 7. COV of Mobile Legend and Background Measurements

Open Road Test Results

AMAC drove a 12-mile route starting from the interchange of SH21 and SH6. They traveled west-southwest on SH21 then turned left on Silver Hill Road, a county-maintained road). Then they turned left on SH47. The last sign they measured was at the gore of the Villa Maria Rd. The route is shown below with images of the 110 signs that were measured.

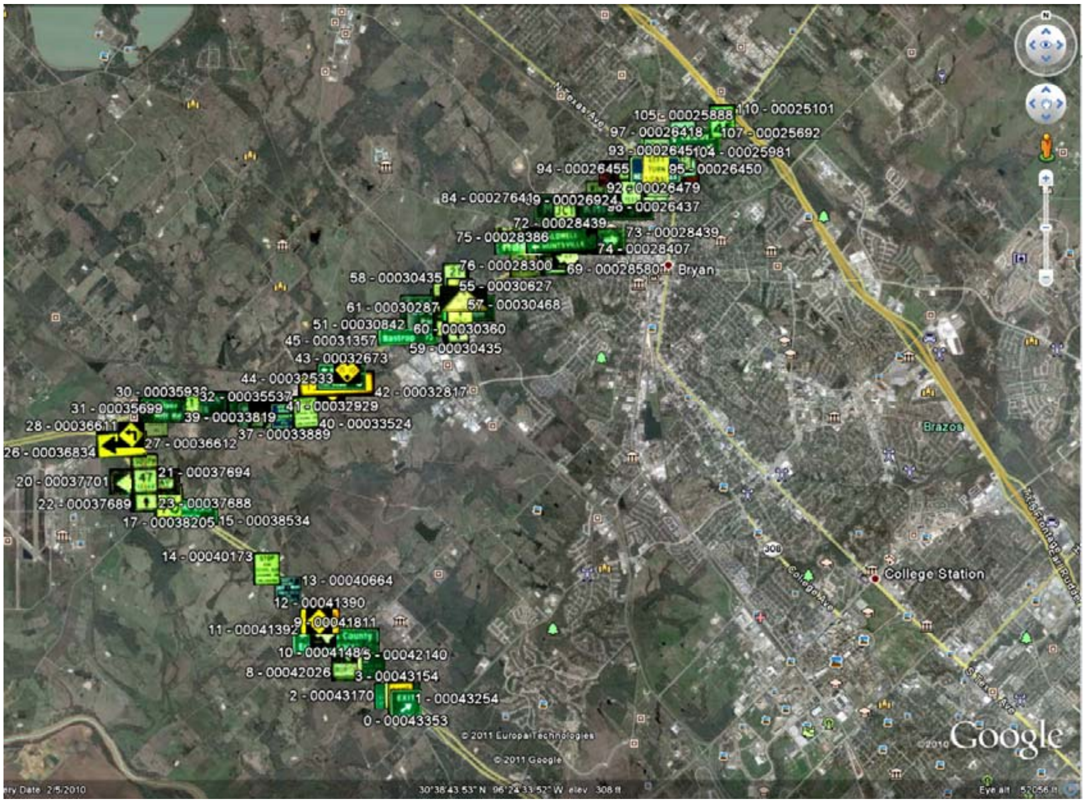

Figure 8. Route of Open-Road Testing

The data from the AMAC measurements included background and legend retroreflectivity levels as well as sign color. TTI research assistants measured the same signs with a calibrated handheld retroreflectometer, in accordance with ASTM E1709. The mobile and handheld retroreflective measurements were then compared.

Overall, the results from the mobile system were lower than the handheld device. However, this is not surprising since the mobile system measures signs in-situ rather than at a *standard* geometry. The mobile system is designed to make retroreflectivity measurements at an observation as close to 0.2 degrees as possible, but the entrance angle can be different from 4 degrees, depending on the roadway geometry, sign position, lean, and twist. One way to think about this difference is that the mobile system measures signs as drivers experience them while the handheld devices measure signs in accordance to a standardized test method.

The mobile background measurements were, on average, 13 percent lower than the handheld measurements, while the mobile legend measurements were 21 percent lower than the handheld measurements. Figure 9 shows for each sign background color how the mobile and handheld measurements compared. Overall, the fit is good with an R-squared value of 0.9375 and a slope of 1.2 (forcing a linear fit through the intercept). However, the MUTCD minimum retroreflectivity levels for sign backgrounds do not go above 75 cd/lx/m^2, so Figure 10 was created to better show the comparisons at these lower retroreflectivity levels.

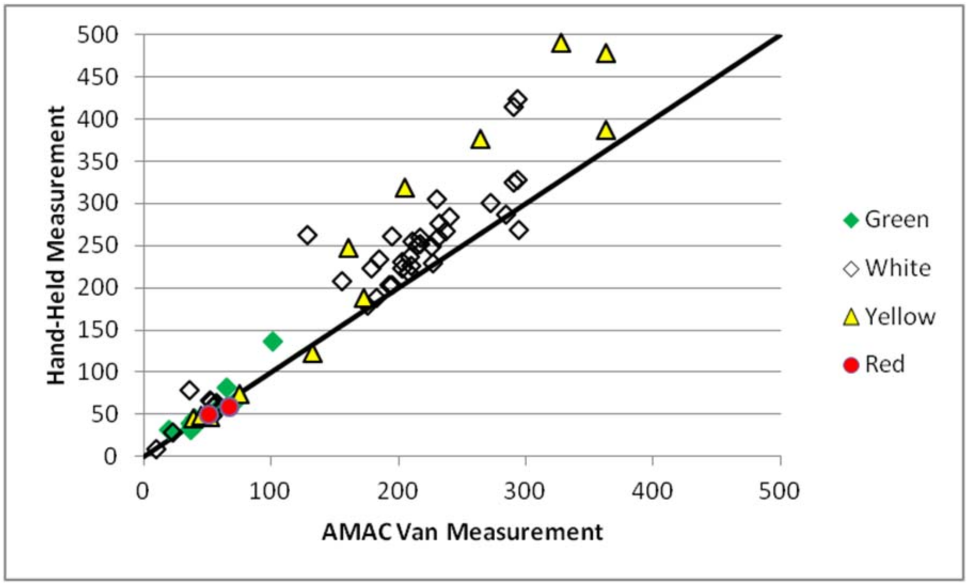

Figure 9. Comparison of Background Measurements (cd/lx/m^2)

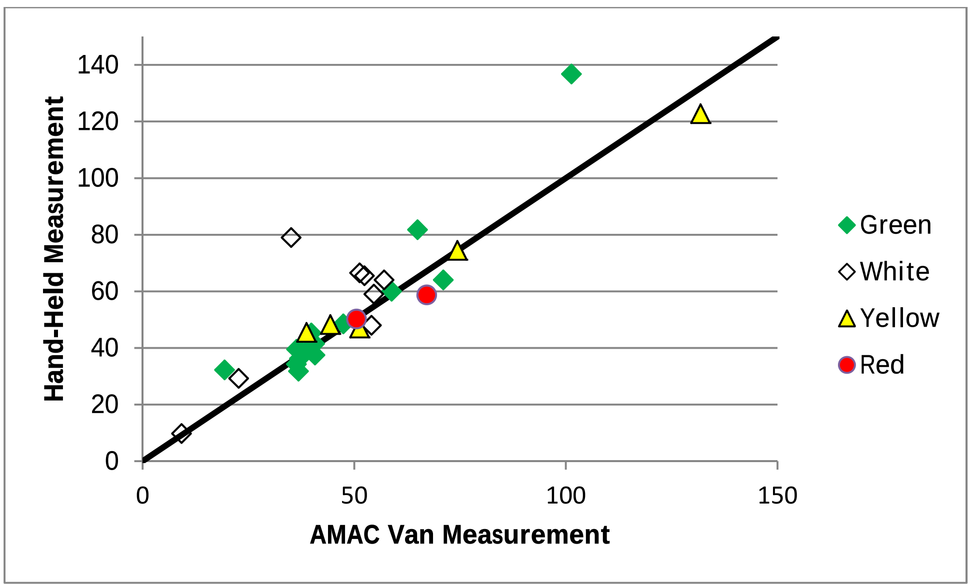

Figure 10. Close-Up of Comparison of Background Measurements (cd/lx/m^2)

Figure 11 shows a comparison of the legend measurements. The linear R-squared fit for the legend measurements is 0.6012 with a slope of 1.36 (forcing a linear fit through the intercept). The graph is truncated at 500 cd/lx/m^2 because this lower range is of more interest in terms of the minimum MUTCD levels established by the FHWA.

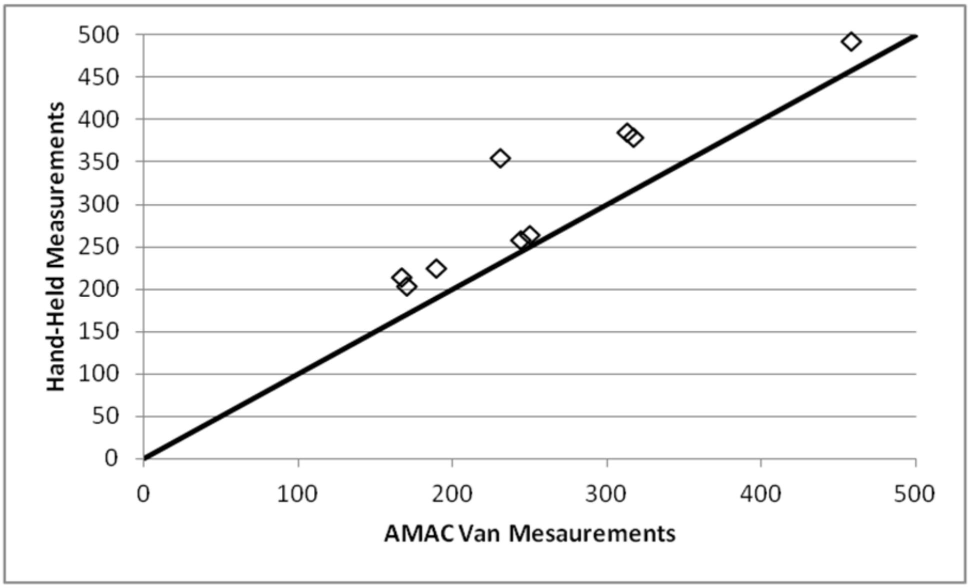

Figure 11. Comparison of Legend Measurements (cd/lx/m^2)

FINDINGS

This report includes a description of the testing of AMAC mobile sign retroreflectivity measurement capabilities. Other features of the AMAC's service such as measuring sign size and accurately locating sign position were not assessed within this effort. This effort assessed the measurement bias and repeatability of sign retroreflectivity measurements made on a closed-course testing facility and along an open-road route.

The static test results were conducted on a closed-course facility to determine the accuracy of the real-time retroreflectivity measurements. The van includes this feature as a demonstration mode only. The results of the static testing showed that at the lower end of retroreflectivity, where FHWA has set the minimum maintained retroreflectivity levels in the MUTCD, the static measurements provide a range that one would expect taking measurements with a handheld device. As the retroreflectivity increases, the range of reported retroreflectivity from the van increases, but the difference is not as critical since these retroreflectivity levels are much higher than the FHWA minimum maintained levels.

Dynamic testing along a closed-course route was 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 was about 5 percent, and the 85^{th} percentile COV was about 10 percent. In earlier reported research, the median and 85^{th} 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.

The open-road testing is what really counts, however. Over 100 signs were evaluated along an open-road test route through Brazos County. While the mobile background measurements were 13 percent lower than handheld measurements and the mobile legend measurements were 21 percent lower than handheld measurements, these differences were most evident on the signs with high retroreflectivity 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.

The two areas that were consistently a challenge for the AMAC mobile system were signs with small and narrow legends and signs made with prismatic retroreflective materials. However, these challenges are not isolated to the mobile systems. Signs with narrow legends that are retroreflective are harder for handheld measurements too. A reducer ring is needed on the handheld devices, which requires recalibrating the device and accepting higher levels of measurement uncertainty (although they have not been formally documented). In addition, signs made with prismatic retroreflective materials can provide a somewhat misleading perspective on the performance of the sign because of the sensitivity of these materials to measurement geometries (as illustrated in Figure 1 and Figure 3). Measurements made from the roadway, such as those made from the AMAC system, can provide a better realization of how the sign is seen from the perspective of the nighttime driver.

Closing Remarks

By establishing minimum retroreflectivity levels in the MUTCD, the FHWA set minimum visibility criteria for traffic signs. Ideally, the FHWA would not have used retroreflectivity as the metric but luminance. However, measuring luminance in the field is not an easy effort and until recently required quite specialized equipment. Retroreflectivity was chosen by the FHWA as a convenient way to set the minimum visibility standards. While convenient, it has limitations such as the geometry under which it needs to be measured. A much more robust way to measure and assess nighttime sign performance is using luminance. The luminance or brightness of the traffic sign is how the nighttime drivers are able to see and use the information contained on the signs. Most mobile technologies generate retroreflectivity by actually measuring the luminance of the traffic signs as seen from the drivers' perspective. Post processing of the luminance data is how the retroreflectivity levels are generated. At some point in the future, the FHWA should consider developing minimum luminance levels to supplement or even replace the minimum retroreflectivity levels that are used in the MUTCD.

REFERENCES

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