CAN TRAFFIC SIGNS BE TOO BRIGHT ON LOW-VOLUME ROADS?

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ABSTRACT

The objective of this study was to investigate a concern that signs along rural highways can be so bright that they cause reduced legibility and/or glare to the point of being a safety concern. The researchers recruited participants and conducted visibility studies on a closed-course facility to assess how various levels of brightness of Speed Limit signs can impact nighttime participants’ ability to read the Speed Limit signs and detect various types of potentially hazardous objects along the edge of the traveled way. Based on the findings, considerations are provided for low-volume rural highways with average daily traffic of 5000 vehicles per day or less. To avoid glare and reduced object detection distances, ASTM Type III or IV materials should be specified for regulatory and nonfluorescent warning signs on these low-volume roads. Also, because of reduced object detection distances, recommendations are made to avoid the installation of unnecessary signs. Not only do unnecessary signs provide a potential hazard for errant vehicles, they also add to the overall maintenance responsibility, breed disrespect for traffic signs, and reduce the visibility of potentially hazardous objects along the roadside.

INTRODUCTION

The Federal Highway Administration has completed a series of research projects to develop recommended minimum traffic sign retroreflectivity levels. Based on the research results, minimum maintained traffic sign retroreflectivity levels have been added to the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD minimum retroreflectivity levels were derived from conditions representative of rural highways with low visual complexity. In the meantime, industry has continued to develop sign sheeting materials with higher levels of retroreflectivity (such as those meeting the ASTM D4956 Type XI criteria).

The new retroreflective sign material technologies are progressively more efficient in returning light to the driver’s eyes and are particularly useful in disadvantaged sign locations in urban environments with high visual complexity. Based on the coefficient of fractional retroreflection, the Type XI materials are twice as efficient as previous generations of microprismatic materials. However, all retroreflective materials can have a wide range of performance depending on the conditions under which they are viewed, and there is no single measure that ubiquitously defines their performance. This is why many specifications include retroreflectivity requirements at various combinations of measurement geometries.

On rural roadways with low traffic volumes, no roadside lighting from commercial, retail, or residential areas, and no overhead signs, certain retroreflective materials may be overpowering, leading to decreased legibility distances and discomfort or even disability glare. Anecdotal evidence from several agencies across the United States suggests that signs in rural environments can be too bright and may be distracting to the driving task or, even worse, cause a safety concern because of glare. In addition, the newest, most efficient materials are also the most expensive.

Because of the nationwide efforts to replace signs due to minimum retroreflectivity requirements in combination with industry’s push to market their “brightest” materials, managers and traffic
engineers are in need of guidance on what types of sign sheeting materials or what upper levels of retroreflectivity should be used for signs along rural highways.

OBJECTIVE

The objective of this study was to determine if signs along rural highways can be so bright that they cause reduced legibility and/or glare to the point of being a safety concern.

A key factor of this study is the thought that the brightest signs are typically white and yellow shoulder-mounted signs located on rural two-lane highways where nighttime drivers may be using their high beam headlamps. The typical background of this environment is dark with practically no visual complexity besides roadside signs.

IMPACTS OF SIGN BRIGHTNESS

The study of sign brightness (or, more technically correct, luminance) has almost exclusively focused on the lower end of the scale—in other words, the minimum amount of brightness needed for nighttime drivers to see, read, and react to the sign message in a safe manner. This study investigates the other side of the spectrum in term of sign brightness—the effects of signs being very bright.

There is a general belief that increasing luminance increases legibility up to a point, and beyond that point, signs overglow where irradiation begins to blur the edges of letters and ultimately degrades legibility. The loss of legibility has been difficult to document, and previous research has not found a clear point at which legibility begins to decrease.

Sivak and Olson published work in 1983 looking at the optimal luminance for traffic signs. They computed the geometric mean of findings from previous research and used the crest of an inverted U-shaped luminance function derived from those previous studies. They identified an optimum value of 75 cd/m² using the published results ranging from 24 to 343 cd/m². The loss of legibility at the higher luminance levels was actually quite small.

In addition to the meta-analysis conducted by Sivak and Olson, applied research has also been carried out with different combinations of retroreflective sheeting materials used on white legends on green background guide signs. Mace et al. performed a study with guide signs to assess legibility of various sheeting combinations, letter styles, and letter spacing. The highest contrast combination of materials was ASTM D4956 Type VII legends on ASTM D4956 Type I backgrounds. The researchers found this combination with a narrowed stroke width to perform the best during the nighttime conditions, but the daytime performance was compromised.

In 2005, Carlson and Holick published applied research findings related to mixed combinations of retroreflective sheeting on guide signs. They found that combinations of microprismatic materials (ASTM D4956 Type VIII and Type IX) on ASTM D4956 Type III backgrounds provided the best all-around performance.

It should be pointed out that the applied research reviewed above used guide signs as the type of sign in the study. Guide signs are made with mostly white legends on green backgrounds.

Everything else being equal, guide signs generally have lower luminance levels than white
regulatory signs or yellow warning signs. In addition, guide signs are typically installed at 
disadvantaged locations (overhead and right shoulder mounted with large offset distances).
Therefore, guide signs are not typically thought of as being too bright. In addition, guide signs
are not as common on two-lane rural highways as they are on urban divided highways.
Therefore, while the results presented above offer some indication of legibility performance by
sheeting type, they may not be the most representative research studies in terms of the objectives
of this study.

HIGH BEAM USAGE

One of the factors that can significantly impact sign luminance is the amount of illumination
reaching the sign. While the illuminance varies with distance (and other factors), a key factor
controlling illuminance is the headlamp of the vehicle. Almost all headlamps have either a low
beam position or a high beam position. Because of the nature of this study, the research team
wanted to explore the trends in high beam usage.

A recent study in Texas evaluated high beam usage on low-volume roadways using photometric
readings of passing vehicles and compared the results to previous studies.(10) The results showed
moderate use of high beams on low-volume, rural two-lane highways, with 42 percent of the
free-flow drivers using high beams. There was a wide variation in high beam use between sites.
Overall, as vehicle volume decreases, the percent of high beam usage increases. Analyses of the
Texas data showed that vehicle speed and presence of horizontal curves are statistically
significant factors that contribute to the probability of high beam use.

Figure 1 shows a comparison of vehicle per hour results obtained from this Texas study with
other studies on high beam usage.(11,12) The figure shows that the volumes at the sites used in
this Texas study were generally lower compared to the other studies. For the 279 hours of data
available at the Texas sites, the maximum “clear” volume was only 45 vehicles per hour.
Sullivan et al. had data for a volume as high as 236 vehicles per hour.(12) Each study shows an
overall trend of decreasing high beam usage with increasing traffic volume; however, the
variability of the data increases as the vehicles per hour decrease.

STUDY DESIGN

This nighttime visibility study investigated the impacts of sign presence and sign brightness on
object detection distance and sign legibility distance. For the object detection task, the
researchers used three targets: a small gray wooden box, a full-sized deer decoy, and a pedestrian
dressed in blue medical scrubs, shown in figure 2. These targets consist of relatively uniform
diffuse, low-contrast surfaces. The gray wooden box and the pedestrian in blue medical scrubs
have been used in a previous study.(13) The deer target is a standard deer that can be purchased
for archery practice and is meant to represent a low-contrast animal.

A two-lane road course was marked at the Texas A&M University Riverside Campus with white
edge lines and a double yellow center line. All the detection targets were located approximately
1 m from the edge line, outside the travel path. The signs were located approximately 2 m off
the edge line. The detection targets were located at relative positions with respect to the sign:
200 ft in advance of the sign, at the sign, and 200 ft beyond the sign.
For the sign legibility task, researchers used Speed Limit signs of different speeds with 10-in-tall numbers, as shown in figure 2d. Researchers recorded the distance at which the participants could read the speed limit. The Speed Limit signs were changed throughout the course of the study from 30 to 55 mph (the participants were instructed to drive approximately 35 mph throughout the study course).

In all conditions, one of the three types of targets was used. However, in some conditions, no sign was used in order to establish a baseline visibility distance for the targets. When a sign was present, it was made with retroreflective sheeting material classified as either ASTM D4956 Type III or ASTM D4956 Type XI.

A total of 23 participants contributed to the study, with 11 between the age of 18 and 36 years and 12 over the age of 60 years. All participants had a valid driver’s license and visual acuity of at least 20/40. The participants drove a Texas A&M Transportation Institute (TTI)–owned Toyota Highlander during the study. The vehicle was equipped with a data acquisition system (DAS) that was used to record the object detection distance and legibility distance. The study was conducted at night with high beam illumination only.

PROCEDURE

The participants were met at the entrance to the Riverside Campus by TTI staff and then escorted to an office where they completed an informed consent form, a demographics questionnaire, and a Snellen visual-acuity test. Each participant was given some brief instructions about what was required of them. Provided the participant did not have any reservations about conducting the required tasks, an experimenter escorted him or her to the instrumented vehicle. Once in the vehicle, each participant was given an opportunity to familiarize him- or herself with the controls of the vehicle and adjust the vehicle seat to his or her preferences. The participant was instructed to wear a seat belt at all times during the testing and to alert the researcher to any concerns throughout the study. The participant was also instructed to stop the vehicle at any point that he or she felt it was necessary. Once the pretesting process was completed, the participants drove through a closed-course route at the Texas A&M University Riverside Campus at night.

Researchers designed the on-course study tasks to be similar to typical night driving activities, such as identifying speed limits for speed adjustments and detecting potential objects along the roadway that could affect the intended drive path. Prior to starting the study, each participant was instructed to alert the researcher the instant that he or she detected an object. For the Speed Limit signs, the participant was instructed to state the speed limit once it became clear. The participant was instructed to correct him- or herself as soon as possible if he or she incorrectly stated an observation.

To minimize confusion and response time between the participant and the researcher, the researcher suggested terms for each object that the participant could consistently use throughout the data collection: “wood” or “box” for the wooden plaque, “pedestrian” for the pedestrian in blue medical scrubs, and “55” for the sign. Participants used “box” most often because many of them thought the wooden plaque resembled a gray electrical box like the ones used in buildings. On the first lap, the participant used either a portion or the entire lap to become familiar with the procedure.
The in-vehicle researcher guided each participant throughout the driving course. For the majority of the data collection, the researcher remained silent and allowed the participant to follow the directions of the pavement markings. Red, retroreflective raised pavement markers were also placed throughout the course at key turning points and stop locations. Cones marked an 80-ft radius U-turn. At the end of each lap, the researcher asked the participant to indicate if he or she had any general or specific comments about the visibility of any of the objects or signs along the study course during the previous lap. During this downtime, the research team prepared the course for the next lap in accordance with a predetermined balanced design—changing any or all of the signs, the sign positions, and the detection targets. The study was completed when eight laps were made. The study design was balanced with randomization so that each lap was unique in that not all objects were present on each lap and different sign locations were used on each lap.

DATA ANALYSIS

Among the 1178 recorded detection distances, 393 were for the deer, 381 were for the pedestrian, and 404 were for the wooden box; 496 records involved Speed Limit signs with Type XI sheeting material, 507 included Speed Limit signs with Type III sheeting material, and 175 had no sign present (in order to set a baseline condition). For those observations involving signs, 337 had objects located 200 ft before the sign, 351 observations had objects at the sign, and 315 had objects 200 ft after the sign. In terms of drivers’ age, 518 observations were made with young drivers, and 660 were made with older drivers.

The average detection distances for the detection targets in terms of different sign types, object locations, and drivers’ ages are shown in figure 3, figure 4, and figure 5, respectively. The x-axis represents different categories of data. The y-axis represents detection distance, and the I-bars represent the 95 percent confidence intervals of detection distances in each category.

Some expected findings are evident in figure 3. For instance, the average detection distances of the deer and pedestrian were longer than those of the wooden box. Figure 3 also shows an interesting trend regarding the effect of sign presence and sign sheeting material. When there was no sign, the average detection distances for deer and pedestrian were longer than when a sign was present with Type III sheeting material, which was also longer than when a sign was present with Type XI sign sheeting material. This indicates that the presence of a sign (and the material used on signs) has an effect on target detection distance. For the wooden target, the presence of a sign and/or the materials used on the sign appeared to have little impact on the detection distance.

When a sign was present, the average detection distance varied with the relative location of the object with respect to the sign. For the deer and pedestrian, the average detection distances were longest when the target was 200 ft behind the sign. The shortest detection distance for the deer and pedestrian were when they were located at the sign. The detection distance of the wooden box does not appear to be affected by its location relative to the sign.

As expected, figure 5 shows that the younger participants had longer detection distances for all three target types. The difference is larger for the deer and pedestrian.
Figure 6 shows similar findings as figure 5 in that the younger participants were able to detect the objects at greater distances than the older participants. For both groups of participants, the trend in sign material/sign presence was similar.

In order to study the data further, statistical testing was implemented using analysis of variance (ANOVA) with repeated measures. The ANOVA results for detection distances using object type, sign type, object location, drivers’ age, and their respective interaction terms are shown in table 1. The numbers of observations in each category are not the same, which leads to the unbalanced ANOVA. Therefore, Type III sums of squares (SS) are used in testing effects because they test a function of the underlying parameters that is independent of the number of observations per treatment combination.

The main effects of sheeting type, object type, drivers’ age group, and object location are all significant (factors in bold are significant with a p-value < 0.05), with three two-way interaction terms (sheeting*object, object*age, and object*location) and a three-way interaction term (sheeting*object*location) significant. With respect to the objective of this study, the sheeting type and relative object location are two key factors, and they are both significant. The average detection distance of the three objects with no sign was 371 ft. When there was a sign with Type III sheeting, the detection distance decreased to about 302 ft. When the sign sheeting was Type XI material, the detection distance decreased even more to 258 ft.

In terms of relative object location to a sign, when the object was placed 200 ft in advance of the sign, the average detection distance of the three objects was about 279 ft. When the object was moved at the same longitudinal position as the sign, the detection distance decreased to 253 ft. When the object was further moved 200 ft behind the sign, the detection distance increased to 314 ft.

ANALYSIS OF SIGN LEGIBILITY DISTANCE

In all, 1130 valid legibility distances were recorded throughout the project. These legibility distances represent two sheeting types (Type III and Type XI sign sheeting materials), three different objects (wooden box, pedestrian, and deer) and three relative locations to the sign (200 ft in front of the sign, at the sign, and 200 ft after the sign) for drivers in two age groups (young for an age between 18 and 34, and old for an age greater than 60). Among the 1130 recorded legibility distances, 563 records included Type XI sheeting material, and 567 included Type III sheeting material; 333 records included the deer, 327 included the pedestrian, 343 included the wooden box, and 127 had no object present. There were 493 records with young drivers and 637 with old drivers.

In the initial statistical analyses, it was determined that the main effects of object type location were not statistically significant in terms of the legibility distances. Therefore, researchers ran an unbalanced ANOVA using sheeting type and drivers’ age grouping as the main effect variables. The result is shown in table 2.

The main effects of sheeting type and drivers’ age group are significant (factors in bold are significant with a p-value < 0.05). The average legibility distance for signs with Type III sheeting was 444 ft. When the sign sheeting was Type XI material, the legibility distance
decreased to 432 ft. The young group had an average legibility of 484 ft, while the old group had an average legibility distance of 401 ft.

DISCUSSION OF RESULTS

Even though the sheeting type was deemed statistically significant in terms of legibility distance, the average difference was only 12 ft (with longer legibility distances being recorded with signs made from Type III material versus Type XI material). The impacts of the type of sheeting material used to construct the sign had less influence on legibility than target detection distance (the average detection distance from a condition with no sign to signs made with Type III material decreased about 70 ft and then decreased almost another 50 ft with signs made with Type XI material).

In terms of legibility, it is quite possible that the luminance of the sign was near optimal for both types of sheeting material. Based on researchers’ past experience, legibility would be expected to fall off rapidly when luminance was too low (e.g., less than 1 cd/m²), and possibly fall off rapidly when luminance became too high (e.g., greater than 1000 cd/m²). However, the data from the previous studies demonstrate that there is likely to be a relatively large range of luminance where sign legibility performance is likely to be relatively flat. It is quite possible that the sign luminance levels observed in this study were mostly included in the range where performance, in terms of legibility, is not affected. The maximum luminance of the Type III material was measured near 200 cd/m² and over 500 cd/m² for the Type XI material.

That being said, within the relatively large luminance range of relatively flat legibility performance, there can be other factors worth consideration. In this case, glare is one of those factors. Depending on the sign luminance, and the complexity and ambient luminance of the surrounding area, glare can narrow the band of ideal sign luminance (compared to considering only legibility). Because glare depends on factors that are tied to urban and rural conditions (i.e., complexity and ambient luminance of surrounding area), it may be reasonable to have varying sign performance criteria based on conditions such as urban versus rural areas.

In this case, rural conditions were studied. The impacts in terms of sign legibility alone indicate that sign sheeting material is not a key factor in terms of performance. However, considering the impacts of object detection, the effects of sign presence and sheeting material become more pronounced.

The largest difference in object detection was over 100 ft. More specifically, a white sign made with Type XI sign sheeting material decreased the average object detection distance versus no sign present by over 100 ft. For a sign made with Type III sign sheeting materials, the impact was almost 70 ft. For perspective, the braking distance of a contemporary vehicle (one having antilock brakes and maintained tires) on a typical pavement going about 45 to 50 mph is 95 to 120 ft.

One of the more interesting recommendations from the object detection task is that unnecessary signs should be removed because even signs made with Type III material impact (decrease) target detection. In addition, removing unnecessary signs also eliminates objects that might be hit by vehicles and eliminates the need to maintain those assets.
Regarding the development of guidelines for sign sheeting criteria in rural areas, the findings from the object detection task provide evidence that detection distance can be reduced when white shoulder-mounted signs are viewed with high beam illumination. In developing recommendations as a result of this finding, researchers also considered the following factors:

- The most recent data on high beam usage show that about 10 percent of nighttime drivers use their high beams when the nighttime hourly volume is 250 vehicles per hour (vph) or less. About half of nighttime drivers use their high beams when the nighttime hourly volume is 50 vph or less. The average daily traffic (ADT) represents the total traffic for a year divided by 365, or the average traffic volume per day. Because most travel occurs during daytime hours, ADT is not the same as the hourly volumes referenced above. Traffic volumes fluctuate by time of day, and nighttime traffic volume on rural two-lane highways can range from 5 percent to less than 1 percent of the ADT. For conversion of the hourly volumes referenced above, and using 2 percent, the 50 vph would be equivalent to an ADT of 2500 vehicles per day (vpd), and the 250 vph would be equivalent to an ADT of 12,500 vpd.

- The MUTCD minimum retroreflectivity standard for white regulatory signs requires a minimum maintenance level of 50 cd/lx/m². Per ASTM D4956 requirements, new Type I material is required to have an initial retroreflectivity level of 70 cd/lx/m². Initial levels for Type III and Type IV are 250 and 360 cd/lx/m², respectively. The difference between the initial requirements of ASTM and the maintained requirements of the MUTCD provides an indication of the amount of degradation of retroreflectivity that is allowed by each sign type (in other words, a surrogate for expected service life). While higher initial retroreflectivity provides for possibly longer life of the sign in terms of minimum retroreflectivity, it also reduces nighttime target detection as shown in this study.

- In the United States, Type I and Type II materials are not used as much as they were in the past. Some companies have stopped making these materials. Type III and Type IV materials are commonly used as equals even though their construction is quite different. Type III materials are made with microsized glass beads, and Type IV materials are made with microsized prisms. Type III and Type IV materials are priced about the same.

- Research has shown that Type III materials can be expected to last at least 15 years before they need to be replaced (because of inadequate retroreflectivity). Type IV materials have not been available long enough to estimate expected sign life; however, the available data indicate at least similar expected sign life as the Type III materials.

- Neither Type III nor Type IV materials come in fluorescent colors (as of November 2014). However, there are fluorescent Type IV materials being tested through the American Association of State Highway and Transportation Officials National Transportation Product Evaluation Program. Type VIII, Type IX, and Type XI materials include fluorescent colors, but they also have the higher retroreflectivity levels that could cause glare and reduce object detection.
RECOMMENDATIONS

Based on the findings from this study, there is evidence that shoulder-mounted signs can be too bright in rural areas with low or no visual complexity. While there was no measured reduction in legibility, there was a large reduction in the overall ability to detect potentially hazardous objects near the roadway. In other words, the detection distances were shorter when signs were within 200 ft of the targets. More specifically, the average detection distance of the three objects with no sign was 371 ft. When there was a sign with Type III material, the detection distance decreased to about 302 ft. When the sign sheeting was Type XI material, the detection distance decreased even more to 258 ft.

The following recommendations have been derived for sign sheeting material to be used on low-volume rural highways (roads with an ADT of 5000 vpd or less):

- Avoid installing unnecessary signs. When assessing signs in reference to the MUTCD minimum retroreflectivity levels, consider removing unnecessary signs as well. Not only do these signs provide a potential hazard for errant vehicles, they also add to the overall maintenance responsibility, breed disrespect for traffic signs, and reduce the visibility of potentially hazardous objects along the roadside.

- Specify Type III or Type IV materials for regulatory signs and warning signs. Although warning signs were not tested in this project, object detection was diminished with Type III white regulatory signs compared to no signs at all. Therefore, this recommendation was extended in an effort to minimize the impact of potentially over-bright warning signs.

- If an agency chooses to use fluorescent signs such as fluorescent yellow and fluorescent yellow green, the only options (as of November 2014) are to use the sheeting material Types VIII, IX, or XI. While there are positive benefits to using fluorescent warning signs, agencies should use these signs sparingly to avoid the potential hazards of reducing nighttime drivers’ ability to detect objects such as deer and pedestrians along the rural highway. Preferably, manufacturers will begin to produce a Type IV fluorescent sheeting material in the near future. If so, then agencies should begin to specify fluorescent Type IV materials for rural applications.

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REFERENCES


Figure 1. Graph. High beam usage by vehicles per hour.
Figure 2. Photos. Detection targets.
Figure 3. Graph. Detection distance for detection targets.
Figure 4. Graph. Detection distance for three objects by object location.
Figure 5. Graph. Detection distance for three objects by drivers’ age.
Figure 6. Graph. Detection distance for age group by sign material/presence.
Table 1. ANOVA results for detection distance.

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Table 2. ANOVA results for legibility distance.

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