A Retroreflective Sheeting Selection Technique to Provide Consistent Sign Performance for Nighttime Drivers' Needs

A Thesis Proposal
by
Susan C. Paulus

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INTRODUCTION

Appropriate traffic control devices must be present to guide drivers all the time as the transportation system must function day and night. Approximately 90 percent of the information drivers use is visual (1), arguably making traffic control signs the most important source of information. Traffic control signs notify roadway users of regulations and provide guidance and warnings. Sign visibility and maintenance is an important issue and is addressed in many areas of the Manual on Uniform Traffic Control Devices (MUTCD) (2), specifically Section 2A.08 states, “Regulatory, warning, and guide signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night, unless specifically stated otherwise in the text discussion in this Manual of a particular sign or group of signs.” The MUTCD also provides minimum retroreflectivity values that shall be maintained by agencies to ensure the signs are visible.

Additionally, nighttime operation is challenging because driver response happens with fewer visual cues. The lack of visual cues helps explain why the nighttime crash rate is three times higher than the daytime rate (3). Further, while only 25 percent of travel is at night, 55 percent of fatal crashes occur during this period (4). In the dark, the only visual cues seen at a distance are those that are illuminated or retroreflective. Retroreflectivity is the material characteristic that reflects light back to the source and is widely used on signs due to cost-effectiveness when compared with sign lighting.

The performance of retroreflective sheeting in real-world driving conditions depends on the vehicle characteristics, the location of the sign, and the relative position of the sign with respect to the vehicle. Retroreflective sheeting has been used for over 60 years on traffic signs and the most common specification is published by the American Society of Testing and Material (ASTM). ASTM groups retroreflective materials based on their retroreflective properties at specific viewing geometries into different “types” of sheeting. Within these types, the performance of individual sheeting can vary over other geometries not defined in the specification. These differences cause varying in-service performance for drivers as drivers view signs at more geometries than those specified. The relative position of the headlamps, sign, and driver define the viewing geometry.
The viewing geometries are easily quantified in static conditions. The challenge comes when evaluating the viewing geometries in a dynamic environment. Most current research focuses on static conditions where a driver will read the word on a traffic sign on a tangent section. Although these studies have produced meaningful results, signs are typically viewed in dynamic conditions on roadways with a range of geometrics. There have been a few studies using dynamic conditions and no studies evaluating retroreflectivity on curves (besides curve guidance signs).

With the large array of research results and a lack of understanding of drivers’ needs for viewing traffic signs at night, most agencies have resorted to a one size fits all policy in regards to retroreflective sheeting selection. With this policy, the same retroreflective sheeting type is applied to all traffic signs regardless of the sign location or sign use. Usually this retroreflective sheeting type is based off a specific situation, such as overhead signs. Although this strategy reduces costs for the agency, the retroreflective sheeting can provide variable performance based on the placement of the sign. Given the possible performance range of a specific sheeting type, the retroreflective sheeting may not provide enough luminance for the driver to properly read or recognize the sign at the appropriate distance. Retroreflective sheeting selection should be determined from drivers’ needs while still trying to minimize cost to the agency.

**PROBLEM STATEMENT**

This thesis will develop a retroreflective sheeting selection technique to provide consistent retroreflective sheeting performance for traffic signs. The selection technique will define the luminance needed by drivers (demand) and the luminance supplied by signs (supply). The luminance needed by drivers will be determined by reviewing previous studies. The luminance supplied for various retroreflective sheeting types will be calculated based on real-world driving conditions including roadway geometrics, sign placement, and the current vehicle mix. The luminance supply of different retroreflective sheeting types will be compared to the different demand levels to determine the performance for various sign placements.
BACKGROUND

Retroreflective traffic signs reflect light back to the driver. The retroreflective properties of the sheeting type determine how the light is reflected. The retroreflectivity varies with the angles by which the light reaches the sign. These angles vary with the sign placement and type, vehicle type, and roadway geometrics. First, an understanding of retroreflectivity is needed to comprehend how the other factors affect the retroreflective properties.

The evolution of retroreflective sheeting began in 1930’s. The tiny glass beads originally used in sheeting were actually developed for use on the cinema’s “silver screens” to produce a brighter image. These glass beads lead to experiments to reflectorize road markings by sprinkling the glass beads onto wet paint or adhesive. In 1937, retroreflective tape was developed using the glass beads but after durability issues, the development was switched to road signs with exposed bead sheeting. After performance issues, a layer of plastic film was added over the glass beads and the first retroreflective enclosed bead sheeting product was introduced in 1939. The market remained relatively stable for 15 years until 1963 when the development of the first prismatic retroreflective sheeting began. Through the 1970’s new companies entered the market and in 1971, High Intensity Sheeting was introduced. In 1973, the first microprismatic sheeting entered the market. Again the industry remained stable until 1989 with the introduction of Diamond Grade Sheeting. The most recent advance was in 2006 with the introduction of Diamond Grade Cubed Sheeting (6, 7).

Retroreflectivity

Retroreflective sheeting performance is partly defined from three light components, luminous intensity, illuminance, and luminance and the angular relationships between them. Luminous intensity is the amount of light emitted from a source (the vehicle’s headlamp). Illuminance is the light received by the viewing surface (the sign). The amount of illuminance reaching the surface depends on the distance between the light source (the vehicle’s headlamp) and the surface (the sign) and the atmospheric conditions (fog, rain, snow, air pollution, etc.). Luminance, commonly referred to as the sign brightness, is the amount of light that is reflected off the surface (the sign) and viewed by the receptor (the driver) and is also affected by the atmospheric conditions. This thesis will not consider the effects of atmospheric conditions.
Retroreflectivity is the ratio of luminance to luminous intensity. This ratio depends on the retroreflective sheeting, the viewing angles between the light source (headlamp), the viewing surface (sign), and the receptor (driver’s eyes).

There are four geometrical systems to describe the angles for viewing signs (8). The systems are the CIE goniometer system, intrinsic system, application system, and road marking system. The application system is described further. The application system defines four angles, which define the retroreflective properties of a traffic sign. The two angles with most importance are the entrance angle and the observation angle and are required by ASTM. The entrance angle ($\beta$) is the angle formed by the headlamp and perpendicular to the sign face and the observation angle ($\alpha$) is formed by the headlamp and the driver’s eye, as shown in Figure 1. The other two angles are the orientation angle and the rotation angle. There are two sets of these angles for each scenario, as the angles are measured for each headlamp to the driver’s eyes. The minimum retroreflectivity levels in the MUTCD are measurements taken at an observation angle of 0.2° and an entrance angle of -4.0° (5). However, many agree these standards do not represent on-road driving conditions (9).

As you can imagine, the entrance angle and the observation angle change based on the vehicle type as the location of the headlamps and driver changes. Sign placement (offset, twist, and height) also affects the entrance angle and the observation angle. Finally, drivers need to view specific signs by a given distance based on speed to make the appropriate decisions for a given sign. This viewing distance affects when drivers need the luminance to read a traffic sign. There
have also been various viewing models developed to help explain how drivers view signs in dynamic conditions.

**Vehicle Trends**

As vehicle trends in the US continue to change, it is important to consider different vehicle types. The amount of illumination a sign receives varies depending on the vehicle size and type of headlamps. Therefore, it is important to understand what types of vehicles are on the roadways within the US. However, the proportion of the vehicle types at night is currently unknown.

**Registration**

Vehicle registration trends in the US increased 1.27 percent from 2006 to 2007; see Table 1. As shown, automobiles and trucks make up the majority of the vehicle mix in the U.S. The truck classification includes truck tractors, farm trucks, pickups, vans, and sport utility vehicles (SUVs). Within the truck classification, truck tractors make up only 1 percent while the combination of vans, pickups, and SUVs make up 95 percent.

<table>
<thead>
<tr>
<th></th>
<th>Automobiles*</th>
<th>Buses*</th>
<th>Trucks*</th>
<th>Total</th>
<th>Motorcycles*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 (10)</td>
<td>135,399,945</td>
<td>821,959</td>
<td>107,943,782</td>
<td>244,165,686</td>
<td>6,674,958</td>
</tr>
<tr>
<td>2007 (11)</td>
<td>135,932,930</td>
<td>834,436</td>
<td>110,497,239</td>
<td>247,264,605</td>
<td>7,138,475</td>
</tr>
<tr>
<td>2007 Percent of Total</td>
<td>55%</td>
<td>0.3%</td>
<td>44.7%</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Includes both privately and commercially, and publicly owned vehicles

**Headlamps**

There have been many headlamp variations over the years and now, there is a large mix of headlamps on the roadways. The headlamps available include (12):

1. **Incandescent**: Light is created by a tungsten filament. This is the oldest headlamp type.

2. **Halogen**: Light is created by a thin tungsten filament surrounded by halogen gas. The light is brighter and whiter than incandescent bulbs.
3. Xenon: Light is created by an electrical charge traveling between two electrodes and is three times brighter than halogen. HID (high-intensity discharge) is a common type and has been available in the US for over 10 years.

The types of headlamps on vehicles can be determined by sales data; however this may not be representative of the types of headlamp on the roadways at nighttime. Flannagan, et al. (13) found the proportion of HID headlamps varied from 1.5 percent to 20 percent depending on the location of the site. Although the HID headlamps do not appear to have a large proportion on the roadway at night, the headlamps provide less light to signs as found by Vivak, et al. (14).

Signing Requirements

The MUTCD (2) divides traffic signs into three main categories: regulatory signs, warning signs, and guide signs. Each category has separate principles for sign placement. Therefore, the individual types have different requirements as to when drivers need to be able to read the signs. The requirements of the signs are outlined below.

1. Regulatory Signs. Regulatory signs, such as Speed Limit or Stop sign, shall be installed at or near where the regulation begins (2). Given these signs are located at the point of regulation; drivers need to be able to read and react to the sign before reaching them.

2. Warning Signs. Warning signs bring attention to hazards that drivers may not be aware of. These signs are placed either before the hazard or at the point of the hazard (2). For signs placed before the hazard, the MUTCD defines the PIEV time as the sum of the times necessary for perception, identification, emotion, and volition needed to perceive and complete the reaction to the hazard. Placing signs so drivers have enough PIEV time should provide enough time after the sign to respond to a hazard and therefore can be read at a closer distance than a regulatory sign. For warning signs placed at the hazard, the sign must be visible enough to provide drivers enough time to respond before reaching the hazard.

3. Guide Signs. Guide signs are considered separately for conventional roadways and for freeways and expressway and include destination and street name signs. The placement of guidance signs varies based on speed and advance notice of the intersection or exit.
Sign Viewing Models

With the large variety of signs on the roadway, many studies have tried to determine how drivers view signs and have developed various sign viewing models. The most common models include legibility index, minimum required visibility distance, and the two-look model. Some studies have also looked at how the surround environment effects the viewing conditions.

Legibility Index (LI)

Legibility index is an important concept that applies to text based signs. The legibility index is the proportion between the distance which a sign is read and the legend height. The legibly index is important as 2003 edition of the MUTCD (2) recommends a legibility index of 40 ft/in. However, recent studies have shown a legibility index of 40 ft/in may not be adequate for the aging population and the Notice of Proposed Amendment (NPA) for the MUTCD reduces the LI to 30 ft/in which approximates a Snellen visual acuity of 20/40 (15).

A concept derived from the LI is threshold legibility, which is the longest distance at which an individual can read a sign. This distance may vary based on luminance, legend font and size, and color. This distance is usually measured in experiments and does not always represent the distance drivers actually read signs.

Minimum Required Visibility Distances (MRVD)

Signs need to be view at the minimum required visibility distance to allow drivers to respond to the message provided. The MRVD includes the distance a driver travels while viewing and reacting to a traffic sign. McGee et al. (16) determined the decision sight distances (or MRVD) to include the distances it would take a driver to 1) detect the object or situation, 2) recognize the object or situation, 3) decide an appropriate course of action, 4) initiate a control response, and 5) complete the required maneuver. These actions were considered to be sequential and are easily modified for retroreflective traffic control devices by revising the detection and recognition phases. It is important drivers are able to decipher a sign at or before this distance. For some alphanumeric signs, the distance traveled during the perception, reaction, and response time could be longer than the distance provided at a legibility index of 40 ft/in.
Two Look Model

Although people typically can view a sign at a specific legibility distance, the sign viewing behavior proposed by Zwhalen and Schnell (17) suggests drivers look multiple times at a sign before they complete the viewing task. Zwhalen and Schnell’s two-glance model describes the last glance and next-to-last glance while viewing a sign. The two-glance model is shown in Figure 2. The first look distance is the distance measured from the sign to the driver’s eyes when the driver begins to focus on the sign (Glance1). The last look distance is the distance between the sign and the driver’s eyes the last time they look at the sign before reaching it (Glance0). Between Glance1 and Glance0, Zwhalen and Schenell found drivers fixate on the roadway.

Figure 2. Two Glance Model

Legibility Studies

Studies have looked at how the legibility of a sign is affected by the surround environment and the sign design. Schieber and Burns (18) found drivers read signs at legibility indices less than 40 ft/in depending on the surrounding environment. The legibility indices ranged from 32 to 36 ft/in for rural settings and from 30 to 38 ft/in for the suburban setting. Another study recommends a legibility index of 33 ft/in (19).

Holick and Carlson (20) found that all microprismatic traffic signs (types VII, IX, and X) can increase legibility up to 60 feet for shoulder mounted guide signs when compared with beaded sheeting. Traffic signs with mixed sheeting (microprismatic legend on high intensity) create an additional 30 feet of legibility. They also found the font type affects the legibility distance.
RESEARCH OBJECTIVES

The goal of thesis is to develop a retroreflective sheeting selection technique to ensure appropriate nighttime sign performance for drivers. The demand luminance will be determined by reviewing previous studies. The supply luminance for the retroreflective sheeting types will be based on real world driving conditions including roadway geometrics, sign placement, and the current vehicle mix. Luminance supplied by the retroreflective sheeting types will be compared to the drivers’ demand luminance to determine the performance level for various sign placements. The objectives to complete thesis include:

1. Determine demand luminance.
   a. Use published research results to determine luminance categories based on driver needs. The luminance categories will represent different performance levels.
   b. Determine different viewing distances for reading traffic signs. Viewing distances will be determined by looking at previous research and determining a range of distances in which traffic signs need to be read.

2. Determine supply luminance.
   a. Obtain geometric data for roadways. A database of Texas state highways will approximate the highways in the US. The geometric elements will include horizontal curve information, cross sections, and functional classification. Vertical curves and ambient lighting will not be considered. Roadway scenarios will be developed based on the geometric elements and will represent the typical on-road viewing conditions for traffic signs.
   b. Choose vehicle types and headlamp types representative of vehicle types in the US. Current measurements of the top selling vehicles in the US will be made and averaged to obtain recent trends in vehicle dimensions.

3. Develop a framework for calculating the luminance for the various conditions.
   Determine the luminance supplied by the retroreflective sheeting types and compare to
the luminance demanded. Develop a retroreflective sheeting selection tool based on luminance needed by drivers and the typical roadway scenarios.

RESEARCH STUDY DESIGN

Task 1: Literature Review
In addition to the literature review above, further research will be conducted to determine the state-of-the-art. A thorough literature review will be completed for a variety of topics related to this proposal. Retroreflective sheeting materials perform differently depending on their reflective properties, sheeting orientation, and the viewing conditions. The viewing conditions are affected by the sign placement, roadway type and geometry, vehicle type, and headlamp type. These aforementioned variables will be reviewed.

Task 2: Determine Demand Luminance
The luminance needs of drivers will be determined by using the results from previous research and a TxDOT funded sign evaluation in June 2009. The luminance needs will be categorized into three ranges of luminance values to represent different performance levels. The performance levels will be minimum, adequate, and desired. The performance levels will be determined by from research on alphanumeric signs. Each performance level will represent performance in a rural, low complexity environment with adequate sign contrast. Performance modifiers will need to be applied when looking at signs in other environments or with less than adequate contrast.

Subtask 2.1 Previous Research
Previous studies on luminance will be evaluated for various sign types. The studies will be divided to determine luminance levels for signs based on two categories, 1) Alphanumeric signs and 2) Recognition signs. Alphanumeric signs include those signs that have numbers or text that needs to be read directly by the driver, such as a guide sign. For recognition signs, a driver either needs to recognize a symbol on the sign, such as Intersection Ahead sign or recognize the entire sign, such as a Stop sign. Since there are few existing studies on luminance needed for recognition, the existing research will be reviewed, but recommended demand luminance levels will not be determined for recognition signs.
The previous studies will also identify the distance drivers need to read a sign to be able to respond properly. This distance will vary depending on the speed of the roadway, the size of the sign, the sign type, and reaction time of the drivers. Signs will be grouped together based on the type of response needed, such as a reduction in speed or lane change.

Subtask 2.2 TxDOT Study

The TxDOT experiment was designed to evaluate how different retroreflective sheeting types and the orientation of the sheeting types affect the legibility distance drivers need to read a sign. The data collected for this thesis was part of a larger research project conducted by the Texas Transportation Institute (TTI) for TxDOT to evaluate the effects of sheeting orientation on performance. This thesis will look at the luminance at which the various signs were read and relate the luminance available to the legibility index of the sign. After the study was complete, luminance measurements were taken from all the retroreflective materials at legibility indices of 20 and 40 ft/in. Using the luminance measurements and the recorded legibility distances, the luminance at each observation can be determined.

Using these results and previous research, the luminance levels will be categorized based on performance, a possible outcome is shown in Table 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>Luminance Level (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0.3 to 4</td>
</tr>
<tr>
<td>Adequate</td>
<td>8 to 15</td>
</tr>
<tr>
<td>Desirable</td>
<td>75 to 100</td>
</tr>
</tbody>
</table>

Task 3: Determine Supply Luminance

To determine the luminance supplied by a retroreflective sheeting on a traffic sign various factors need to be considered. These factors include: roadway geometrics, sign type and placement, and vehicle mix.
Subtask 3.1 Geometric Data

To determine the typical roadways in the US, geometric data will be obtained from a database of Texas state highways. From this database, geometrics will include roadway location, speed limit, cross section data, and horizontal curve data.

Vertical curves are not included in this database and therefore will not be considered. The effects of vertical curvature will be discussed by looking at how traffic signs receive illumination as drivers travel through crest and sag curves.

Cumulative distributions for shoulder width, curve radius, number of lanes, and speed limit will be determined. These distributions will create the basic geometric data to create typical viewing scenarios. With the sign type and placement, described below, typical sign viewing conditions will be developed.

Subtask 3.2 Sign Type and Placement

With the roadway types determined from the geometric data, typical signs located on each roadway will be determined. Signs to be included will be regulatory sign, warning signs, and guide signs. Due to the variety, placement, and use of temporary traffic control signs, these signs will not be considered. The typical placement of these signs will be determined using the MUTCD, the TxMUTCD, and TxDOT standard detail drawings. Important aspects of the sign placement include: sign height, sign offset, sign twist, and sign tilt.

Subtask 3.3 Vehicle Mix and Headlamp

Using vehicle sales and registration data, the vehicle mix in the US will be estimated. For actual vehicle dimensions, the market weighted average dimensions for the top-selling models will be determined for passenger cars and light trucks (pickups, vans, and SUVs). The effects of using a heavy vehicle will be discussed by looking at a right shoulder sign. For the headlamp, the 2004 market weighted average developed by UMTRI will be used (21).

Subtask 3.4 Viewing Scenarios

With the data from above, viewing scenarios will be determined. The scenarios will represent the typical on-road viewing conditions for traffic signs. A possible viewing scenario is shown in
Figure 3. Signs will be evaluated when the viewing is on a tangent section and when viewing entirely within a curve.

![Figure 3. Example Sign Location – Cross Section View](image)

*Subtask 3.5 Predicted Luminance Values*

Once the viewing scenarios are developed, luminance values will be calculated using the application geometry system for various retroreflective sheeting types. The luminance values will be based on the viewing scenarios, vehicle type, and sign type. For each sign type, the luminance will be calculated for various distances to the sign to represent the typical distance needed for a driver to be able to read or recognize a particular type of sign.

**Task 4: Reconciliation of Demand and Supply**

The data results from the luminance supplied and luminance demand categorization will be developed into a selection tool agencies can use to determine the appropriate retroreflective sheeting to use on a sign to provide similar in-service performance for various sign locations. The selection tool will be the combination of decision trees and selection tables for specific sign types.

The decision trees will provide guidance on what to consider when selecting a sheeting type for a certain sign type. The selection tables will provide the sheeting type recommended for a specific sign for each performance category. The selection tables will be developed based on a few common signs, such as a Stop sign and No Passing Zone sign. The selection tables will be developed to provide a simple decision making tool for sheeting application based on roadway geometrics, location of the sign, and vehicle type. Figure 4 shows what the graphic may look
like. D, A, and M represent the desirable, adequate, and minimum performance levels, respectively. The sheeting selection represents performance over the entire distance the sign needs to be recognized.

<table>
<thead>
<tr>
<th>Speed</th>
<th>24-19 ft LT</th>
<th>18-12 ft LT</th>
<th>2-6 ft RT</th>
<th>7-12 ft RT</th>
<th>13-24 ft RT</th>
</tr>
</thead>
</table>

Figure 4. Possible Stop Sign Sheeting Requirements

Task 5: Thesis Preparation

The data collected and analyzed will be used to develop a retroreflective sheeting selection technique for signing on roadways. Roadway curvature, cross section, and vehicle type will be considered. The findings will be documented and presented as a Master’s Thesis in accordance with Texas A&M University Policies.

POTENTIAL STUDY BENEFITS

The results of this thesis will create a technique for installing retroreflective sheeting on traffic signs. The technique will provide a simple tool for decision making and may eliminate the one sheeting fits all methodology currently used by many agencies. The results would provide similar viewing luminance conditions on all signs regardless of placement.
REFERENCES


