A REVIEW OF KDOT OVERHEAD GUIDE SIGN LIGHTING POLICY

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Abstract

Before year 2012 the US States must implement and continue using an assessment or management method to maintain traffic signs' retro-reflectivity at or above the minimum levels adopted by FHWA. Overhead guide signs are a particular problem because past research has shown that with available sheeting types, external illumination may still be necessary. Newer sheeting types and more energy efficient and cost-effective lighting systems are currently available. Over the next several years there is potential for savings of tens of thousands of dollars if the states don't have to use external illumination for their overhead guide signs, or, if more energy efficient, low cost lighting systems are used when necessary.

A detailed literature review was conducted on minimum retro-reflectivity values for overhead guide signs, the legibility distance under reduced sign luminance and the lighting systems available for external illumination. There is no agreement found in the previous research studies as to what is the optimum or minimum luminance of the guide signs. In addition, a survey was sent to all state DOTs. This survey was focused on finding states' policies regarding the use of sheeting type and external illumination requirement, and methods and lighting systems for maintaining minimum values for overhead guide sign luminance. The total response rate was 56% (28 out of 50 state DOTs responded). Out of 28 respondents 19 said that they have usage policy for the type of sheeting material used for overhead guide signs and 18 of them provided details about their policy. An equipment to control the illumination levels from vehicle headlamps was built and pilot tests were conducted in the laboratory. A pulse-with-modulation dimming circuit designed around the Atmel ARM-based microcontroller board and power MOSFETs was used to control the brightness of the headlights for the high- and low-beams. Field tests were conducted in the later stages during nighttime to evaluate three different types of sheeting materials using 10 human subjects from age group 18-34. The materials DG3 and Type IV were found to perform better than Type I material for nighttime visibility but they were not significantly different from each other.

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Chapter 1 - Introduction

The purpose of traffic signs is to communicate information to the road users. Therefore, the signs need to be visible during the day and nighttime conditions. For the sign to serve its purpose effectively, the sign has to have different colors, shapes, etc. In addition to this, different sheeting materials are used for different traffic signs. During nighttime the sign is visible to road users because of the retro-reflective sheeting materials. Retro-reflection is ability of the material to redirect the light back to the light source even if the surface is not perpendicular to the light. Considerable research has been done in the past few decades to find the minimum levels of retro-reflectivity that will satisfy the requirements set by Federal Highway Administration (FHWA). (MUTCD, 2009)

Before year 2012 the US States must implement and continue using an assessment or management method to maintain traffic signs' retro-reflectivity at or above the minimum levels adopted by FHWA. Overhead guide signs are a particular problem because past research has shown that with available sheeting types, external illumination may still be necessary. Newer sheeting types and more energy efficient and cost-effective lighting systems are currently available. Over the next several years there is potential for savings of tens of thousands of dollars if the states don't have to use external illumination for their overhead guide signs, or, if more energy efficient, low cost lighting systems are used when necessary.

Chapter 2 - Literature Review

During nighttime the sign is visible to road users because of the retro-reflective sheeting materials. Retro-reflection is ability of the material to redirect the light back to the light source even if the surface is not perpendicular to the light. Considerable research has been done in the past few decades to find the minimum levels of retro-reflectivity that will satisfy the requirements set by Federal Highway Administration (FHWA).

2.1 Research on Retro-reflectivity

1. Lagergren (1987) performed a study of measuring retro-reflectivity of traffic signs by using human observers. As a part of this study human observers were trained to rate the signs first in a dark gymnasium and then by using a stationery car on a straight level section of the road. The observers rated the signs on a scale of 0 to 4 (by whole numbers) and the signs were placed on sign posts from 100 to 300 feet away. The scale was explained to the observers as 0 being the worst a sign could be and 4 being a brand new sign.

   After this they were driven on two highway courses at night where they rated 130 signs. The experiment included establishing categories of retro-reflectivity and having the observers rate the signs into these categories. The retro-reflectivity of these signs was also tested by a retro-reflectometer. The rating done by the observers was compared with the value obtained by using a retro-reflectometer. The research showed that a very high percentage of signs were rated correctly by the observers.

   The study also suggested some recommendations for future research which included:

    1. The observers, after going through the training, should undergo full evaluation before participating in the research.
    2. The agencies should develop a training program for the people who make sign replacement decisions.
    3. While replacing signs, sign criticality should be considered because many states use different levels of retro-reflectivity for different classifications of highway.

   This research was limited to STOP sign and warning signs.

2. Paniati et al., (1993) carried out research to define the minimum nighttime visibility required for traffic control devices and come up with measurement devices and computer management

tools to effectively implement these requirements. They developed a model called Computerized Analysis of Retroreflectorized Traffic Signs (CARTS) that considered the time and distance required to identify and respond to a sign, the amount of luminance required for sign detection and recognition and the retro-reflectivity levels needed to ensure the required performance level. This model consisted of the following three components:

1. The Minimum Required Visibility Distance (MRVD) sub model-

   This was developed to find out the minimum distance at which the sign must be visible so that the drivers with varying visual, cognitive and psychomotor abilities are capable of responding safely and appropriately to it. In order to use this model, the information related to driver characteristics (age), roadway characteristics (visual complexity, lane width etc.), traffic characteristics (speed, volume) and sign characteristics (MUTCD code) was provided by the user, and based on this information, the sub model calculated the MRVD for the given sign.

2. The Inverse Programmed Detect (IPDET) sub model-

   This sub model used the distance calculated by the MRVD sub model, as well as sign characteristics (MUTCD code, location), driver characteristics (age, acuity, and eye height), vehicle characteristics (headlamp type, height and spacing), roadway characteristics (number of lanes, lane width, background complexity, curvature and grade), traffic characteristics (speed, volume, glare) to find out the required luminance. The IPDET sub model calculated the required retro-reflectivity value from the luminance value and the total candlepower from the vehicle headlamp falling on the sign.

3. The Standardized Retro-reflectivity Measurement (SRM) sub model-

   This sub model performed the conversion of the R_a value at MVRD into the required R_a value at standard observation and entrance angles that they can be measured by a retro-reflectometer.

They determined the minimum retro-reflectivity values for different types of signs. They were as follows:

- Black on Yellow and Black on Orange Warning Sings- the values for this type of sign for different sign sizes, material types and legend type were found out to range from 15 cd/lx/m^2 to 120 cd/lx/m^2

- White on Red Regulatory Signs- the values for this type of sign for different traffic speeds and sign sizes were found out to range from 30 $cd/lx/m^2$ to 70 $cd/lx/m^2$ for white and 6 $cd/lx/m^2$ to 14 $cd/lx/m^2$ for red
- Black on White Regulatory and Guide Signs- the values for this type of sign for different traffic speeds, sign sizes, material types and sign placement were found out to range from 15 $cd/lx/m^2$ to 120 $cd/lx/m^2$, for ground mounted signs and 40 $cd/lx/m^2$ to 250 $cd/lx/m^2$ for overhead mounted sings.
- White on Green Guide Signs- the values for this type of sign for different traffic speeds and sign placement were found out to range from 25 $cd/lx/m^2$ to 110 $cd/lx/m^2$ for white and 5 $cd/lx/m^2$ to 22 $cd/lx/m^2$ for green.

The detailed tables showing the minimum retro-reflectivity values for the above mentioned four types of signs can be found in Appendix A.

The values from the CARTS model were found to provide a reasonable level of driver accommodation (80^{th} percentile to 90^{th} percentile) for most driving situations.

3. McGee et al., (1998) came up with an implementation guide for minimum retro-reflectivity requirements for traffic signs to help agencies in forming a cost-effective program for the replacement of ineffective signs. The report explained the principles of retro-reflectivity which included the concepts of retro-reflection, illuminance and luminance, coefficient of retro-reflection (R_A), the entrance angle and the observation angle. The report further described various types of retro-reflective sheeting materials and their difference based on the coefficient of retro-reflection provided at different entrance and observation angles. The third section of the report quoted the minimum retro-reflectivity values for four groups of signs based on early research performed by the researchers.

   The report also presented the concept of a Sign Management System (SMS) which they defined as a coordinated program of policies and procedures which ensure that the highway agency provide a sign system that meets the needs of the user cost-effectively within available budgets and constraints. They also explained the various advantages of a fully developed comprehensive Sign Management System for the activities taking place during the life cycle of the highway signs.

   The researchers further described the concept of sign inventory and the purposes it can serve like:

- targeting signs for replacement,
- identification of the problems,
- minimizing tort liability,
- planning and budgeting for sign replacement, and
- maximizing productivity.

They also suggested the seven step process for planning and development of an effective sign inventory. The steps include:

- involving key personnel,
- selecting a location reference system,
- choosing data elements,
- selecting inventory software,
- preparing for data collection,
- initial data collection, and
- maintaining the inventory.

The report also explained the Visual Sign Inspection Method and Sign Inspection by R_A measurement method and various activities which can be performed for sign maintenance. They also discussed various options that the state and local agencies can follow for sign replacement. The researchers presented minimum and desirable programs for meeting the minimum retro-reflectivity guidelines.

4. Russell et al., (1999) performed a study to determine the minimum luminance requirements for overhead guide signs and to find out whether the illuminance from vehicle headlamps on the highway was sufficient to provide drivers with this required minimum luminance.

   In the first phase they conducted an experiment in the FHWA lighting laboratory. In this experiment the observers drove towards the sign at 8 km/h and when the sign became legible, they pushed a button to turn off the lighted sign. At this stage the distance travelled by the vehicle was recorded. The observer then reported what word it was on the sign.

   The researchers also conducted two field tests as part of this study. The first field studies were performed on straight, flat level sections of Interstate 70 and Interstate 435 highways using seven photometers (five Minolta T-1 illuminance meters and two International Light IL-1700 illuminance meters). They collected illuminance values from the vehicles travelling in the right lane and making use of low beam headlamp. The researchers collected a sample of about 2500 vehicles from the field study. To find out the differences in the illuminance between vehicle types an analysis of variance (ANOVA) procedure was used. This field study showed higher illuminance values than what were anticipated by researchers. The reason for these high values was determined to be the substantial amount of light reflected from the pavements which was also included in the readings.

For this reason, a second field study was conducted in which the pavement reflections were eliminated from the illuminance readings by making use of optical occluders. The second field study was performed on 50 known vehicles along with 1500 vehicles that travelled through the data collection site at the time of data collection. Separate statistical analysis was done for the 50 known vehicles and the 1500 unidentified vehicles using the Statistical Analysis System (SAS) version 3.11.

The laboratory experiment in this study gave a minimum luminance value of 13 cd/m^2 using white letters on a green background with a contrast ratio of 8:1. From the field study it was found that there was sufficient amount of light for right and left shoulder mounted signs but insufficient light for overhead signs. It was determined that the values of minimum luminance for overhead signs were 3.7 cd/m^2 at 152 m, 3.6 cd/m^2 at 114 m and 3.4 cd/m^2 at 84 m. These values however were lower than the minimum sign luminance value of 13 cd/m^2 obtained from the laboratory study.

5. Hawkins et al., (2002, 2003) summarized four projects carried out by Texas Transportation Institute during March 2002 and October 2003 in their paper, Impact of Retro-reflectivity on Sign Management, Maintenance and Design. This study was carried out in 25 districts of Texas. The team studied issues related to retro-reflectivity of traffic signs to help the Texas Department of Transportation conduct their signing operations. They visited sign crews and maintenance supervisors; sign shop staff, area engineers, district maintenance staff, district traffic staff and district engineer to review TxDOT signing operation practices. They conducted workshops for sign crews and performed a comparative study of legibility of different sign sheeting materials. Their study also included evaluation of headlamp performance and a micro prismatic sheeting legend on a high intensity background.

   The conclusions of the study were as follows:

   1. From the district visits the team found significant variations in the signing practices among the districts.

2. They also found out that the quality of contractor installed signs is not consistent with the quality of signs installed by TxDOT.
3. The legibility indices for the signs used in evaluation were between 24 and 34 feet per inch of letter height. The legibility of the signs was dependent on the type of retro-reflective sheeting.
4. The study also concluded that with the help of the limited number of vehicles used for the test, there was no evidence to suggest that headlamp performance of real-world vehicles is different from those which were used in the experiment.
5. One more conclusion of the study was that the combination of micro prismatic legends on high intensity backgrounds provided greater legibility than high intensity on high intensity combinations.

The following recommendations were made:

- The TxDOT should continue the use of nighttime inspections to assess sign retro-reflectivity.
- A legibility index of 30 to 35 feet/inch should be used for designing signs.
- The researchers emphasized the need to aim the headlamps of the test vehicles properly and micro prismatic sheeting material should be used for the legend on overhead signs.
- TxDOT should use Type D legends in combination with a Type C backgrounds.

6. Carlson et al., (2003) performed extensive research for the Texas Transportation Institute (TTI) for finding the minimum retro-reflectivity levels for overhead guide signs and street name signs. They developed a computational model based on the relationship between the headlamps (source), sign (target) and the geometric relationship between these and driver (receptor). They developed the following equation for minimum retro-reflectivity:

$$Minimum\ R_A = New\ R_{A,SG} \times \left(\frac{Demand\ R_{A,NSG}}{Supply\ R_{A,NSG}}\right)$$

Where:

Minimum R_A = Minimum retro-reflectivity at standard measurement geometry (Observation angle =0.2 and entrance angle of -4.0)

New $R_{A,\ SG}$ = Averaged retro-reflectivity of new sheeting at standard geometry $cd/lx/m^2$

Demand $R_{A, NSG}$ = Retro-reflectivity needed to produce the minimum luminance at the Nonstandard geometry, cd/lx/m^2

Supply $R_{A, NSG}$ = Retro-reflectivity of new sheeting at the nonstandard geometry, cd/lx/m^2

They conducted a field study on thirty subjects of age 55 or older using a study vehicle and 32 different headlamp illumination levels. The field study was performed on a closed course, real world driving condition and the subjects were told to read different retro-reflective signs. The minimum amount of luminance needed to read an overhead sign was found for different legibility indices ranging from 40 ft. /inch to 20 ft. /inch in 10 ft. /inch intervals. The luminance of the signs was controlled in such a way that they were very dim initially and then the luminance was increased systematically until the drivers could read it. This study also analyzed various factors causing an impact on minimum retro-reflectivity levels for overhead guide signs. Some of these factors were distance, sign position and type of retro-reflective sheeting used, headlamp illumination, accommodation level, vehicle speed and vehicle type.

According to their research the luminance value required was 2.3 cd/m^2 , for the 50^{th} percentile accommodation level. There were three factors which raised question about applicability of the model to the real world situation. These factors were:

a. accommodation level for drivers of age 55 or older,
b. sign position relative to vehicle position, and
c. rounding the minimum retro-reflectivity level for overhead and street name signs to the nearest integer divisible by five

They performed follow up research with updated factors, like the effect of changing the assumed nighttime needs of the driver, updated vehicle headlamp profile, larger observation angles representing typical light truck/minivan/SUV that could be used to develop minimum retro-reflectivity levels and found the minimum retro-reflectivity levels for overhead guide signs were based on the luminance values of 2.3 and 3.2 cd/m^2 for 55 year old and 65 year old driver data sets respectively.

7. Carlson et al., (2007) conducted some research on methods for maintaining traffic sign retro-reflectivity. They described maintenance methods so that the agencies can decide which retro-reflectivity maintenance method or the combination of methods best suits their needs.

They divided the sign maintenance methods into two groups; assessment methods and management methods. The researchers also said that if the agencies have a method to maintain the minimum retro-reflectivity levels it will be easy for the agency to decide to spend the resources on the signs which need immediate replacement. This will also help to improve safety for the motoring public.

a. Assessment Methods

The concept behind this method was the periodic assessment or evaluation of the condition of each individual sign. The assessment methods were as follows:

i. Nighttime Visual Inspection

This method not only evaluates the retro-reflectivity but also looks for damage, obstructions and poor placement of the signs. This method makes use of trained inspectors to assess the traffic signs during the nighttime to evaluate the overall appearance of the sign and find out whether the sign meets the required retro-reflectivity level or not. The important factor for this method is to have trained sign inspectors. As there is no nationally recognized training program or the certification for this it becomes responsibility of the agencies to give some sort of training to these inspectors before the sign inspections are done.

This method makes use of the rating method defined by the agency as good, fair and poor. The signs having poor ratings should be replaced as soon as possible. The signs having fair ratings should be marked for attention during the next scheduled inspection.

Advantages

- Least administrative and fiscal burden of all the methods
- Lowest level of sign replacement and sign waste

Disadvantages

- Chances of mistakes if the driver is playing the role of both the recorder and the evaluator

ii. Measuring Traffic Sign Retro-reflectivity

The retro-reflectivity can be measured in two ways: with hand held contact instruments or with non-contact instruments. The first method requires the physical contact between the measurement device and the sign surface whereas the second method measures the retro-reflectivity from some distance. Although the use of contact instruments has less uncertainty for a given measurement, it can be time consuming. The non-contact instruments accelerate the process but there is higher level of uncertainty.

In this method with the contact instruments, four measurements should be taken of the sign background and the legend. From these four measurements for each color, an average value of the retro-reflectivity for each color is obtained. These values are compared to minimum retro-reflectivity values to determine whether or not the sign should be replaced.

Advantage:

- Removes the subjectivity that exists in other methods

Disadvantage:

- Time consuming

b. Management Methods

The management methods for maintaining the retro-reflectivity of the traffic signs are as follows:

i. Expected Sign Life

This method consists of replacing the signs before their expected service life. The factors influencing the service life of the sign can be sign sheeting warranties, test deck measurements, measurement of the sign in the field and information from other agencies. There are two ways to implement this method. One way consists of using a computerized sign management system which keeps a record of the agency's sign inventory and provides the information about the signs which need replacement. Another way to do this is use of an installment or replacement date sticker on each sign. This helps the agency crew determine which sign is to be replaced. Some agencies also make use of the warranty period provided by the sign manufacturer to find out when the sign should be replaced.

Advantages

- Use of a computerized management system helps to eliminate the need for a date sticker
- It can be executed during the day time
- The date sticker method requires no inspection or measurement of the sign.

Disadvantages

- Time consuming
- Placement of the date stickers at front or back of the sign can lead to complexity
- Little data is available related to deterioration rate of different types of sheeting materials

ii. Blanket Replacement

This method is a modified version of the expected sign life method performed with strategic or spatial basis. With the strategic basis all signs of a particular type are replaced and with the spatial basis all signs in a particular area are replaced. The agency crew replaces all the designated signs at a set time period without considering the time the sign have been in the field or the condition of the sign at the time of replacement.

Advantages

- All signs are replaced ensuring that the each sign is visible and meets the minimum retro-reflectivity levels.

Disadvantages

- This method can lead to wastage of money in some cases

iii. Control Signs

In this method the agency creates a subset of signs representing its sign inventory. This subset of the signs represents the population of the signs which are made with the same material. The actual measurements for the retro-reflectivity are performed on this subset of the signs. When the signs in this subset approach to the minimum levels of retro-reflectivity the agency takes this as an indication to begin the replacement of the entire related population. This method has not been very popular with the agencies.

Advantages

- This method is not labor intensive
- Signs are not removed prematurely

Disadvantages

- The size of subset of the signs determines the effectiveness of the method.
- The agencies need to be able to measure the retro-reflectivity of the subset of the signs accurately.

8. Zwahlen et al., (2003) performed some research related to nighttime field evaluation of four different retro-reflective overhead sign sheeting combinations. The sheeting materials used for this purpose were compared when lighted and unlighted (illuminated by low-beam headlights only) for appearance, conspicuity and legibility. The same sign sheeting material combinations were tested photometrically under low-beam illumination at selected approach distances from 200 to 1,000 ft.

   The combinations of the sheeting material used for this purpose were as follows

   a. Group A: Beaded Type III legend on beaded Type III background
   b. Group B: Type IX legend on beaded Type III background
   c. Group C: Type IX legend on Type IX background, and
   d. Group D: Type VII legend on beaded Type III background

   The research was performed in two parts

   1. Expert Panel Field Evaluation

      For this phase of the experiment 12 Ohio Department of Transportation engineers and technicians served as evaluators. Each sheeting material was used on separate sign bridge and each bridge had three signs, one over the left lane, one over the right lane and one over the exit lane. The locations for conducting the experiment were chosen for their relatively straight and flat approaches of at least 1,000 ft. The evaluation was done in a loop which was 22.3 mi long. The locations of the sign groups and the locations where the evaluators pulled off the road to fill out the evaluation forms were fixed. The evaluations were conducted for both lighted and unlighted conditions for each group of signs. For evaluation under the unlighted conditions the circuit was driven twice in which the vehicle was approaching in the right lane once and approaching in the left lane once. For evaluation under lighted condition only one loop was conducted, in which vehicle was approaching in the right lane. The vehicle used for conducting this experiment was 2002 Dodge Caravan equipped with halogen headlamps. All the evaluators were given instructions and they were given a chance to preview the questionnaire so that they will be familiar with the questions and what characteristics of the signs to look for. The evaluators had an average age of 38 years and an average experience of 12 years in traffic engineering. The average corrected visual acuity of the group was 20/21.

2. Photometric Evaluation

   For this purpose ART 920 Retro-reflectometer was used in order to verify that the sheeting materials used on the signs met the ASTM requirements and the signs used in photometric evaluation were comparable to those evaluated by expert panel.

   These photometric evaluations were done on the straight and flat test track. The signs A and B which were beaded Type III legend on beaded Type III background and Type IX legend on Type IX background were mounted on front track. The signs C and D which were Type IX and Type VII legends mounted on beaded Type III backgrounds were mounted on second track. These evaluations were done using three vehicles, one sedan, a minivan and a large semitrailer truck. The headlamps of the vehicles were set to low beam. The locations for the measurements were fixed with the vehicle to sign distance of 200, 600 and 1,000 ft. with the vehicle oriented head on towards the sign. The measurements were made using state of art ProMetric CCD Light and Color Measurement System manufactured by Radiant Imaging. This helped the researchers to get the luminance pixel maps which were stored on computer. The ProMetric program was used to find put the values of luminance at 10 points on the legend and 10 points on the background of each sign.

   Based on the results obtained from the field evaluations and photometric evaluations the researchers concluded that the practice of lighted overhead signs can be discontinued if either white Type VII or the Type IX legends are used on green beaded Type III backgrounds. The researchers also suggested that this change of practice from lighted to unlighted overhead signs with white micro prismatic legends on a green beaded Type III background will provide many benefits. These benefits will include

   a. No need to for luminaire installation
   b. Less maintenance costs
   c. Less electricity costs

9. Carlson (2001) conducted some research for the evaluation of clearview alphabet with micro prismatic retro-reflective sheeting. The main objective of this research was to find out if the legibility of the full-scale guide signs fabricated with micro prismatic sheeting could be increased by using the Clearview alphabet instead of Series E (Modified). The research was conducted using full-scale overhead and shoulder mounted guide signs. And the results obtained for the legibility of Clearview alphabet were compared with legibility of freeway guide signs constructed with Series E (Modified) alphabet. This research project also had a secondary objective which was to compare the legibility performance of guide signs fabricated with Type III sheeting and guide signs fabricated with micro prismatic sheeting.

   The researcher conducted field tests to determine the legibility distances of overhead and shoulder mounted guide signs. These signs were fabricated with Type VIII and IX retro-reflective sheeting with Clearview and Series E (Modified) legends. For conducting the field tests Series E (Modified) alphabet was treated as control alphabet and Clearview regular express typeface was treated as experimental alphabet. The field tests were done for the total of 60 subjects which were divided into three age categories. These categories were young group (18 to 34 years), middle aged group (35 to 54 years) and elderly group (55 and older). Each age category had 20 subjects with an equal gender split. All the field tests were done during nighttime and all the subjects completed these field tests while driving two different vehicles. For the field tests, the subject would start from the distance where the signs were not legible. They would accelerate to 35 mph and then put the vehicle into cruise control. This helped the subjects to concentrate more on reading the word. Once the subject read the word correctly, the researcher sitting with the subject inside the car noted down the distance.

   The results of the experiments showed that micro prismatic sheetings produced longer legibility distances than Type III sheeting for both the shoulder mounted and overhead guide signs. These improvements in the legibility distances were 44 and 41 ft. for overhead and shoulder mounted guide signs respectively.

The results also showed that the Clearview provides statistically longer legibility distances than Series E (Modified), for shoulder mounted guide signs fabricated with micro prismatic sheeting. The overall mean legibility distances were 32 ft. greater for Clearview. This also was found useful for the older drivers for whom the Clearview produced legibility distances 6% longer than Series E (Modified).

For overhead guide signs fabricated with micro prismatic sheeting, the results showed that Clearview provides statistically longer legibility distances compared to Series E (Modified). The overall mean legibility distances were 40 ft. greater for Clearview. For older drivers Clearview provided legibility distances 6.8% longer than Series E (Modified).

Based on the results obtained from this experiments researcher recommended TxDOT to use micro prismatic retro-reflective sheeting and Clearview on all new and refurbished guide signs.

10. Hawkins et al., (1999) conducted research on legibility comparison of three freeway guide sign alphabets. The objective of the project was to find out if the performance of a white high intensity legend on a green high intensity background on freeway signs can be improved by using alternative alphabet that reduces the blooming effect. The researchers used three different lowercase alphabets for comparison in this project which were Series E (Modified), Clearview and British Transport Medium. The project was conducted by using both overhead and ground mounted sings during both daytime and nighttime conditions. No external illumination was used during the nighttime conditions and the legibility and recognition distances were measured.

    For the field test conducted for this project, the subject would start at a distance where the signs were not legible. Each sign panel had three words on it with all three words in the same alphabet. The experimenter would indicate one word that test subjects had to identify the position of on the sign. This was considered as recognition task. The test subjects had to read the other two words and this was considered as legibility task. A total of 54 subjects participated in the field tests. The researchers had divided the subjects into three age groups. These age groups were young drivers (less than 35 years old), young-old drivers (55-64 years old) and old-old drivers (65+ years old).

    The results of this research indicated that Clearview was slightly more legible than Series E (Modified) in overhead position in both daytime and nighttime. The improvement was found to be in the range of two to eight percent over Series E (Modified). The greatest improvement was found for older drivers. But the Clearview ground mounted signs were less legible than Series E (Modified) in daytime conditions. For the ground mounted signs, the researchers did not find Clearview giving much better performance than Series E (Modified). For the recognition task the Clearview was found to be better in overhead position for both daytime and nighttime. The British Transport Medium was less legible than Series E (Modified).

But even though the field tests showed that Clearview performed better, the statistical analysis of mean legibility and recognition distances showed that this improvement was not statistically significant.

11. Holick et al., (2003) conducted some research on nighttime guide sign legibility for micro-prismatic Clearview legend on high intensity background. The study had two objectives. The main objective of the study was to compare the legibility of guide signs by using combinations of micro-prismatic and glass beaded sheeting. Another objective of the study was to evaluate the Clearview fonts for guide signs as compared to the standard highway fonts. The signs used for this research were mainly destination and distance signs and shoulder mounted freeway guide signs. In addition to these signs the study also included a small sample of Texas county road name signs.

    For the field tests done for this study the test subject driving the test vehicle started at a distance where the tests sign were not legible. The subject accelerated the test vehicle to 35 mph and began to concentrate on reading the test word. When the subject read the word correctly, the researcher recorded the distance traveled. The field tests were done suing 66 randomly selected words. The pattern in which the 66 words were displayed was: 24 shoulder mounted guide signs, 36 destination/distance signs and 6 were Texas county road name signs. The total 30 subjects participated in this study and they were divided into three age groups. These age groups were young (18-34 years old), middle aged (35-54) and older (55+). Each age group had 10 participants.

    The research showed that the shoulder mounted guide signs with Clearview font and micro-prismatic legend and background produced 47 to 60 ft. increase in the legibility distance.

    In addition to this the research also showed that for shoulder mounted guide signs fabricated with a combination of micro-prismatic and glass beaded sheeting, the Clearview 5WR font provided longer legibility distances than Series E (Modified). The overall mean legibility distances were found to be 26ft. greater with Clearview 5WR font.

For the destination and distance signs fabricated with a combination of micro-prismatic and glass beaded sheeting it was found that 6 inch Series D font provided the same or better legibility distances than 6 inch Clearview 3W. The overall mean legibility distances of Series D were 12 ft. greater than 6 inch Clearview 3W. But in case of 8 inch Clearview, mixed case font the results were found different. And they showed these signs produced significantly longer legibility distances than that of 6 inch Series D and 6 inch Clearview 3W. The overall mean legibility distances were 50 and 62 ft. greater respectively.

12. Manual on Uniform Traffic Control Devices (MUTCD) (2009) standards

Section 2A.07

The MUTCD 2009 standard for retro-reflectivity and illumination is as follows:

Regulatory warning and guide signs and object markers shall be retro-reflective or illuminated to show the same shape and similar color by both day and night. The requirements for sign illumination shall not be considered to be satisfied by street or highway lighting.

Light Emitting Diode (LED) units may be used individually within the legend or symbol of a sign and in the border of a sign, except for changeable message signs, to improve conspicuity, increase the legibility of the sign legends and borders or provide a changeable message.

The standard for LEDs is:

Neither individual LEDs nor groups of LEDs shall be placed within the background area of a sign.

If used, the LEDs shall have a maximum diameter of 1/4 inch and shall be the following colors based on the type of sign:

A. White or red, if used with STOP or YIELD signs.
B. White, if used with regulatory signs other than STOP or YIELD signs.
C. White or yellow, if used with warning signs.
D. White, if used with guide signs.
E. White, yellow, or orange, if used with temporary traffic control signs.
F. White or yellow, if used with school area signs.

If flashed, all LED units shall flash simultaneously at a rate of more than 50 and less than 60 times per minute.

The uniformity of the sign design shall be maintained without any decrease in visibility, legibility, or driver comprehension during either daytime or nighttime conditions.

Section 2A.08

The MUTCD 2009 standard for maintaining minimum retro-reflectivity is as follows:

Public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retro-reflectivity at or above the minimum levels in Figure 2.1 below.

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

[1] The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m² measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Bold Symbol Signs

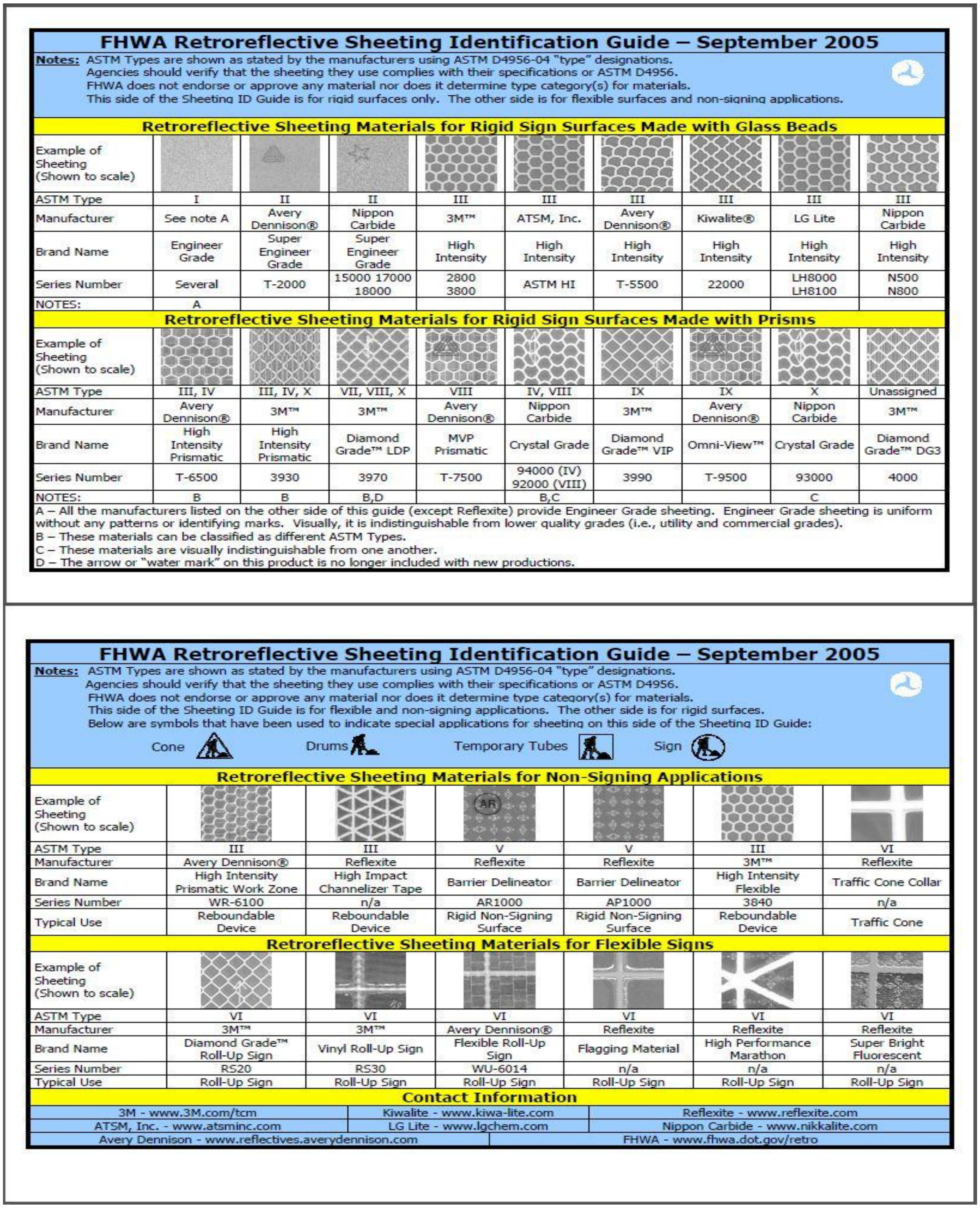
- W1-1,2 – Turn and Curve
- W1-3,4 – Reverse Turn and Curve
- W1-5 – Winding Road
- W1-6,7 – Large Arrow
- W1-8 – Chevron
- W1-10 – Intersection in Curve
- W1-11 – Hairpin Curve
- W1-15 – 270 Degree Loop
- W2-1 – Cross Road
- W2-2,3 – Side Road
- W2-4,5 – T and Y Intersection
- W2-6 – Circular Intersection
- W2-7,8 – Double Side Roads
- W3-1 – Stop Ahead
- W3-2 – Yield Ahead
- W3-3 – Signal Ahead
- W4-1 – Merge
- W4-2 – Lane Ends
- W4-3 – Added Lane
- W4-5 – Entering Roadway Merge
- W4-6 – Entering Roadway Added Lane
- W6-1,2 – Divided Highway Begins and Ends
- W6-3 – Two-Way Traffic
- W10-1,2,3,4,11,12 – Grade Crossing Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3,4,16-22 – Large Animals
- W11-5 – Farm Equipment
- W11-6 – Snowmobile Crossing
- W11-7 – Equestrian Crossing
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow
- W16-5P,6P,7P – Pointing Arrow Plaques
- W20-7 – Flagger
- W21-1 – Worker

Fine Symbol Signs (symbol signs not listed as bold symbol signs)

Special Cases

- W3-1 – Stop Ahead: Red retroreflectivity ≥ 7
- W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35
- W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7
- W3-5 – Speed Reduction: White retroreflectivity ≥ 50
- For non-diamond shaped signs, such as W14-3 (No Passing Zone), W4-4P (Cross Traffic Does Not Stop), or W13-1P,2,3,6,7 (Speed Advisory Plaques), use the largest sign dimension to determine the proper minimum retroreflectivity level.

Figure 2-1 Minimum values of retro-reflectivity (MUTCD, 2009)



FHWA Retroreflective Sheeting Identification Guide – September 2005

Notes: ASTM Types are shown as stated by the manufacturers using ASTM D4956-04 "type" designations.
Agencies should verify that the sheeting they use complies with their specifications or ASTM D4956.
FHWA does not endorse or approve any material nor does it determine type category(s) for materials.
This side of the Sheeting ID Guide is for rigid surfaces only. The other side is for flexible surfaces and non-signing applications.

Retroreflective Sheeting Materials for Rigid Sign Surfaces Made with Glass Beads

Example of Sheeting (Shown to scale)									
ASTM Type	I	II	II	III	III	III	III	III	III
Manufacturer	See note A	Avery Dennison®	Nippon Carbide	3M™	ATSM, Inc.	Avery Dennison®	Kiwalite®	LG Lite	Nippon Carbide
Brand Name	Engineer Grade	Super Engineer Grade	Super Engineer Grade	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity	High Intensity
Series Number	Several	T-2000	15000 17000 18000	2800 3800	ASTM HI	T-5500	22000	LH8000 LH8100	N500 N800
NOTES:	A								

Retroreflective Sheeting Materials for Rigid Sign Surfaces Made with Prisms

Example of Sheeting (Shown to scale)									
ASTM Type	III, IV	III, IV, X	VII, VIII, X	VIII	IV, VIII	IX	IX	X	Unassigned
Manufacturer	Avery Dennison®	3M™	3M™	Avery Dennison®	Nippon Carbide	3M™	Avery Dennison®	Nippon Carbide	3M™
Brand Name	High Intensity Prismatic	High Intensity Prismatic	Diamond Grade™ LDP	MVP Prismatic	Crystal Grade	Diamond Grade™ VIP	Omni-View™	Crystal Grade	Diamond Grade™ DG3
Series Number	T-6500	3930	3970	T-7500	94000 (IV) 92000 (VIII)	3990	T-9500	93000	4000
NOTES:	B	B	B,D		B,C			C	

A – All the manufacturers listed on the other side of this guide (except Reflexite) provide Engineer Grade sheeting. Engineer Grade sheeting is uniform without any patterns or identifying marks. Visually, it is indistinguishable from lower quality grades (i.e., utility and commercial grades).
B – These materials can be classified as different ASTM Types.
C – These materials are visually indistinguishable from one another.
D – The arrow or "water mark" on this product is no longer included with new productions.

FHWA Retroreflective Sheeting Identification Guide – September 2005

Notes: ASTM Types are shown as stated by the manufacturers using ASTM D4956-04 "type" designations.
Agencies should verify that the sheeting they use complies with their specifications or ASTM D4956.
FHWA does not endorse or approve any material nor does it determine type category(s) for materials.
This side of the Sheeting ID Guide is for flexible and non-signing applications. The other side is for rigid surfaces.
Below are symbols that have been used to indicate special applications for sheeting on this side of the Sheeting ID Guide:
Cone Drums Temporary Tubes Sign

Retroreflective Sheeting Materials for Non-Signing Applications

Example of Sheeting (Shown to scale)						
ASTM Type	III	III	V	V	III	VI
Manufacturer	Avery Dennison®	Reflexite	Reflexite	Reflexite	3M™	Reflexite
Brand Name	High Intensity Prismatic Work Zone	High Impact Channelizer Tape	Barrier Delineator	Barrier Delineator	High Intensity Flexible	Traffic Cone Collar
Series Number	WR-6100	n/a	AR1000	AP1000	3840	n/a
Typical Use	Reboundable Device	Reboundable Device	Rigid Non-Signing Surface	Rigid Non-Signing Surface	Reboundable Device	Traffic Cone

Retroreflective Sheeting Materials for Flexible Signs

Example of Sheeting (Shown to scale)						
ASTM Type	VI	VI	VI	VI	VI	VI
Manufacturer	3M™	3M™	Avery Dennison®	Reflexite	Reflexite	Reflexite
Brand Name	Diamond Grade™ Roll-Up Sign	Vinyl Roll-Up Sign	Flexible Roll-Up Sign	Flagging Material	High Performance Marathon	Super Bright Fluorescent
Series Number	RS20	RS30	WU-6014	n/a	n/a	n/a
Typical Use	Roll-Up Sign	Roll-Up Sign	Roll-Up Sign	Roll-Up Sign	Roll-Up Sign	Roll-Up Sign

Contact Information

3M - www.3M.com/tcm	Kiwalite - www.kiwa-lite.com	Reflexite - www.reflexite.com
ATSM, Inc. - www.atsminc.com	LG Lite - www.lgchem.com	Nippon Carbide - www.nikkalite.com
Avery Dennison - www.reflectives.averydennison.com	FHWA - www.fhwa.dot.gov/retro	

Figure 2-2 FHWA retro-reflective sheeting identification guide (FHWA, 2010)

Section 2E.06

The MUTCD 2009 standard for color of guide signs is as follows:

Letters, numerals, symbols, arrows, and borders of all guide signs shall be retro-reflectorized.

The background of all guide signs that are not independently illuminated shall be retro-reflective**.** FHWA also published the retro-reflective sheeting identification guide in September 2005 shown in Figure 2.2.

13. Indiana Department of Transportation conducted research on the field evaluation of the unlighted overhead guide signs. The main objective of the study was to compare selected signing materials in certain legend/background combinations to determine if there is adequate conspicuity, legibility and appearance to allow INDOT to erect and use overhead guise signs without lighting at night. Another benefit was to save electricity and maintenance cost.

    Following material combinations were used for comparison

    1. 3M DG3 on 3M DG3 (Type IX on Type IX)
    2. 3M DG3 on 3M HIP (Type IX on Type IV)
    3. Avery Dennison Type IX on Avery Dennison Type IX
    4. Avery Dennison Type IX on 3M HIP
    5. Avery Dennison Type VIII on Avery Dennison Type IV
    6. Avery Dennison Type IX on Avery Dennison Type IV
    7. 3M Type IV on 3M Type IV
    8. 3M Type IV on 3M Type IV (Sheet sign overlay)
    9. Avery Dennison Type IV on Avery Dennison Type IV (sheet sign overlay)

    The evaluators drove on test sites 30 minutes before sunset and filled out evaluation forms as they travelled through the test sites. The vehicles used were Dodge Caravan and a crew cab dump truck (1992 International). The evaluators again evaluated these signs after one month with different vehicles Ford Focus and Kia Rondo. The evaluation forms consisted of a picture of each sign and the rating scale of “Acceptable”, “Marginal”, or “Unacceptable”. All the evaluators were group of traffic engineers and technicians ranging the age from 30’s to 60’s.

    The results of the evaluations showed that the Avery Dennison Type VIII on Type IV signs were rated the highest overall. Type IX on Type XI (3M DG3 on DG3) signs performed slightly worse and Avery Dennison Type IX on Type IX performed significantly worse. It was also indicated that there would be an estimated $450,000 savings in annual energy and maintenance costs by turning off the sign lights.

In the follow up evaluation three new signs were installed at the test site. One sign was a new panel with 3M Type IV sheeting and demountable copy and the other two were sheet signs overlays one with 3M Type IV sheeting and the other with Avery Dennison Type IV sheeting.

The experimenters concluded that use of prismatic Type IX, Type VIII or Type IV legends on Type IV backgrounds on unlighted overhead guide signs should not result in any detrimental information acquisition or adverse safety effects for the majority if the driving public. They also recommended that INDOT should have statewide implementation plan to discontinue the practice of providing and maintaining luminaries for overhead guide signs and replace step by step all overhead guide signs in the state with prismatic sheeting legends on Type IV background sheeting.

2.2 Research on sensitivity of eye to light

1. American Optometric Association (www.aoa.org) has information related to good vision throughout the life. The good vision throughout the life is divided into total of six stages.
    a. Infant vision- birth to 24 months of age
    b. Preschool vision- 2 to 5 years of age
    c. School aged vision- 6 to 18 years of age
    d. Adult vision- 19 to 40 years of age- many people from this age group have healthy eyes and good vision. The main reason for having visual and eye problems for these people is visual stress and eye injuries.

        For the people in this age group it is recommended to have an eye examination at least every two years.
    e. Adult vision- 41 to 60 years of age- The people in this group face the problem for reading and performing close work activities. And this aging of eyes continues with the age. For the people in this group comprehensive eye exam is suggested every two years. The people in this age group see following age related changes in their visual ability.
        - Need for more light- This is the stage when people may feel the need of more light to see. They feel need of brighter light in their work area or next to their reading chair.

- Difficulty in reading and doing the close work- person cannot find the printed material as clear as before due to lesser flexibility of lens in the eye with time.
- Problems with glare- People may feel additional glare from headlights during nighttime or sun reflecting off of the windshields or pavement during the daytime, thus making driving more difficult. This is due to the change in the lens in eye which causes light entering the eye to be scattered instead of focusing more on retina and hence creates more glare.
- Changes in color perception- for the people in this age group the lens inside the eye starts to discolor. This hampers the visual ability of the person making it harder to see and differentiate between shades of colors.
- Reduced tear production- as the person goes on aging the tear glands in eye produce fewer tears. This may cause problem for maintaining the clear sight.

f. Adult vision- over 60 years of age- The American Optometric Association (AOA) recommends annual eye examination for everyone over the age of 60. It is this stage when driving a car can be very difficult for the people. The people belonging to this group may face difficulty in judging the distances and the speed. The headlights of oncoming traffic can impair the vision. Some of these problems are as follows:

- Not being able to see road signs clearly
- Problems seeing in low light or nighttime conditions
- Experiencing loss of side vision
- Difficulty in adapting to glare from headlights

2. Bailey et, al. (1988) briefed some papers and described the importance of visual ability of the person for driving, in their paper Vision Screening for Driver Licensure. According to the researchers 90 percent of the input the driver receives is visual. Thus as the person goes on getting older, the decrease in the visual ability can be considered to be a causal factor for the driving difficulties experienced by driver.

   The crystalline lens within the eye shows various changes with the person's age. This lens loses its elasticity. Because of this loss of elasticity the ability of the human eye to accommodate or change focus reduces considerably. This loss generally begins at the age of 40 and can be compensated by the use of reading glasses or bifocals. This loss is complete by the age of 60 to 65. The lens inside the eye becomes yellowish with the age thus contributing to changes in color vision, decreased light sensitivity and decreased visual acuity. This also increases the glare susceptibility. In addition to this the cataracts which are age related should also be removed and the optical power of the lens should be replaced by contact lenses, spectacles or implants.

The pupil of the eye gets smaller with the age and thus the ability of the pupil to dilate the dim light is reduced. Thus as the person gets older the eye admits less light. This problem gets worse in darker conditions.

The corrected visual acuity of a person remains constant from ages 20 to 50 in absence of any disease. And this corrected visual acuity starts decreasing after 50 and decreases rapidly after 60.

Thus this paper summarized research showing that decreasing visual acuity can be considered an important factor to decreasing driving ability of a person.

But this paper is more focused on effect of decreased visual acuity on accident rates.

Chapter 3 - Survey and Survey Analysis

A survey was emailed to 50 state DOTs between February and March 2011. The survey consisted of 21 questions which were divided into three sections.

A. Type of sheeting material used
B. Maintenance, inventory and other activities
C. Retro-reflectivity measurement

3.1 Results and discussion

The total response rate of this survey 28 out of 50 state DOTs which was 56%. The responses to the survey questions are discussed below.

1. *Does your agency have a usage policy or policies for the type of sheeting material used for overhead guide signs? (Yes or No) If your answer to the question above is 'Yes', please attach the policy.*

   Among the 28 respondents, 68% (n= 19) answered '*Yes*' and 25% (n= 7) answered '*No*' to this question. 7% (n= 2) respondents did not give any response to this question.

   The responses are obtained for the policies were as follows. Out of 19 respondents who answered the question as *'Yes'*, one respondent did not attach their policy with the response.

Table 3-1 Usage policy of state DOTs for the type of sheeting material used for overhead guide signs

Usage policy provided by state DOTs
See Section 712.02 of the Idaho Standards Specifications Manual and associated Supplemental at the following link http://www.itd.idaho.gov/manuals/Online_Manuals/Spec_04/Spec_04.htm
Background: ASTM Type 4, Copy: ASTM Type 9 or 11
The Ohio DOT reflective sheeting requirements are found in the ODOT Construction and Material Specifications, Section 630.04, 4th paragraph, and Sections 730.19, 730.192 and 730.193.This publication can be accessed on-line.
Type IV Sheeting
We have an approved products list for sign sheeting. It can be found at: http://transportation.ky.gov/materials/download/list%20of%20approved%20materials/lam.pdf
Currently we use ASTM type 3A on all overhead signs.
All Minnesota DOT signs shall use DG3 prismatic sheeting except for signs installed under contract. Contract specifications shall allow the use of either ASTM Type IX or DG3 prismatic sheeting.
Missouri DOT- While we do not have a written policy for our own fabrication facility, we do have specifications for sign sheeting and fabrication in our Standard Plans for Highway Construction and our Standard Specifications for Highway

Construction (which contains the material specifications). I copied the table from our standard plans that refer to guide sign fabrication. MoDOT type 3 sheeting is equal to ASTM type 4 HIP and type 7 is equal to ASTM type 7.
Kansas DOT –Type IV for all signs at this time
Florida DOT -700-2.6 Sign Background: Meet the requirements of Section 994. Use Type III, IV, V or VII sheeting for background sheeting, white legends, borders and shields on all signs, excluding STOP, DO NOT ENTER, and WRONG WAY. Use Type VII sheeting for STOP, DO NOT ENTER and WRONG WAY signs. Use Type III, IV, V or VII yellow-green fluorescent sheeting for S1-1 school advance signs and supplemental panels used with S1-1, S3-1 and S4-5 school signs. Do not mix signs having fluorescent yellow-green sheeting with signs having yellow reflective sheeting. Use fluorescent orange Type VI or VII for all orange work zone signs. Mesh signs shall meet the color, daytime luminance and non-reflective property requirements of Section 994, Type VI.
Virginia DOT -http://www.virginiadot.org/business/resources/traffic_engineering/memos/TE-337_Clearview_Highway_Font.pdf
South Carolina DOT- Yes. Current practice is to use AASHTO Type VIII or IX for overhead signs. We are considering changing this to Type IX or XI. We do not have an official written policy. Signs are placed under contract and the sheeting requirements are included as with sign layouts as part of the signing contracts.
Oregon DOT - ASTM Type IX – http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/Design_Manual.pdf, page 38 & 44
Indiana DOT – Using prismatic Type IV, Type VIII or Type IX legends on Type IV background on unlighted overhead guide signs. The results were based on the evaluations done by Indiana DOT traffic engineers and technicians ranging in age from 30's to 60's riding a minivan and dump truck.
Massachusetts DOT – Sign legends shall be fabricated either from High Intensity (Type II or IV) or Super High Intensity (Type VII, VIII, IX or X) retro-reflective sheeting. Sign backgrounds shall be fabricated from either High Intensity (Type III or IV) or Super High Intensity (Type VII, VIII, IX or X) retro-reflective sheeting.
New Mexico DOT – Type III or IV sheeting with Type VII, VIII or IX legend
For overhead guide signs legends are made up of grade A sheeting and the background is made up of grade C sheeting. Signs meeting Grade C are typically of encapsulated microscopic glass bead lens or unmetallized Microprismatic construction. Signs meeting grade A are typically of unmetallized Microprismatic construction.
Tennessee DOT – reflective sheeting for all signs with a Silver-White, Yellow, Red, Green, Brown or Blue background shall be Encapsulated Lens or Microprismatic Lens material meeting or exceeding the minimum requirements for Type III or higher as specified by AASHTO M 268

The signing policies provided by state DOTs can be found in Appendix B.

2. *What materials does your agency use for overhead guide signs (for legend and background)? If more than one material is used please mention the primary material.*

The responses are shown in Table 3.2.

Table 3-2 Materials used by state DOTs for overhead guide signs

Materials used by state DOTs for overhead guide signs
Background - ASTM D 4956 Type III, IV, VIII, IX or XI. Legend - ASTM D 4956 Type VIII, IX or XI. ASTM D 4956 Types VII and X are obsolete designations, but could be used for either background or legend.
Unlighted overhead guide signs use Type IV sheeting for background and Type VIII/IX/XI for legend. Lighted overhead guide signs use Type II sheeting for background and Type IV for legend.
Background 3M TYPE IV Prismatic Legend, Border, Symbols and Arrows are all 3M TYPE IX Prismatic.
Background: ASTM Type 4 Legend: ASTM Type 9 or 11
High Intensity
Currently experimenting with the 3M (DG3) Type XI sheeting.
Some Type III, Type IV & Some Diamond Grade VIP and DG3
We now require a type III or better prismatic material for both background material as well as the legend.
Type IX
Legend is AASHTO Type VII or IX. Background is Type III.
High Intensity for background (Type III or IV on our approved products list). Prismatic for legend (Type VIII, IX, or XI on our list).
ASTM Type 3A
Legend - encapsulated lens or micro-prismatic construction, mainly micro-prismatic Background – micro-prismatic construction.
All Minnesota DOT signs shall use DG3 prismatic sheeting except for signs installed under contract. Contract specifications shall allow the use of either ASTM Type IX or DG3 prismatic sheeting.
Type III (high intensity), DG3 on occasion.
Missouri DOT -MoDOT utilizes extruded aluminum panels for all large signs, with the background sheeting and legend directly applied, no overlay material is used. The minimum sheeting type used on any highway sign is ASTM Type IV High Intensity Prismatic (HIP) sheeting. Specifically on guide signs, the background sheeting is HIP and the legend is ASTM Type VII. 3M currently has the state bid for sign sheeting. Our sheeting bid is awarded all or nothing so only one manufacture supplies materials on any give bid/year. So far only 3M and Avery Denison have the ability to supply MoDOT with all the materials types required.
Kansas DOT -Type IV - Vendor depends upon our sheeting contract awarded. Contract projects: it depends upon who the contract uses for fabricating the signs in the project. It usually is between 3M and Avery Dennison
Indiana DOT - no response
Florida DOT - see previous questions
Wisconsin DOT -ASTM D4956 -09 Type IX or better legend and background.
Virginia DOT - Reflective sheeting used for the background on positive contrast guide signs shall conform to the requirements of ASTM D4956 for a Type III, VII, VIII, IX, or X material. Positive contrast letters, numerals, symbols, arrows, and borders used on guide signs shall be fabricated from prismatic sheeting conforming to the requirements of ASTM D4956 for a Type

VII, VIII, IX, or X material. Color shall conform to the requirements of 23 CFR, Part 655, Subpart F, and Appendix Tables 1and 1A.The maintained coefficient of retro-reflection of the sheeting after 3 years on the test deck shall conform to the requirements of ASTM D4956.
Texas DOT - Texas Type D on Texas Type D (ASTM 7,8,9,10 on ASTM 7,8,9,10)
South Carolina DOT - see previous answer. Same grade of sheeting is used for both background and legend.
Oregon DOT - ASTM type IX
New York DOT - N/R
Iowa DOT - Prismatic high intensity
Nebraska DOT - Type IV and Type XI
Mississippi DOT - Type III with green background and Type XI for legend

The materials used for background and legend and the number of DOTS using them can be seen in Table 3.3.

Table 3-3 Sheeting material used for background and legend according to number of DOTs using them

Material	Number of states using for background	Number of states using for legend
Type II	1 state for lighted overhead guide signs	0
ASTM D 4956 Type III	11	6
ASTM Type III A	1	1
ASTM D 4956 Type IV	11	1 state for lighted overhead guide signs 5
Type V	1	1
Type VII	4	6
ASTM D 4956 Type VIII	5	7
ASTM D 4956 Type IX	8	13
Type X	3	3
ASTM D 4956 Type XI	3	7
Diamond Grade DG3	3	3

3. *What is the name of the type of the material used for legend? If your answer is 'Other' please specify the brand name of the type of the material used for legend*.

The responses obtained for this question are as follows:

Table 3-4 Type of material used for legend

Brand Name	Number of DOTs using	Percentage (%)
Engineer Grade	0	0
Super Engineering Grade	0	0
High Intensity	3	5.17
High Intensity Prismatic	8	13.79
Diamond Grade LDP	2	3.45
MVP Prismatic	4	6.89
Crystal Grade	6	10.34

Diamond Grade VIP	9	15.52
Omni-view	6	10.34
Diamond Grade DG3	10	17.24
Other	7	12.07
N/R	3	5.17
Total	58	100

Other materials used – each of the following materials has been used by one DOT.

1. ASTM Type IV or XI
2. Omni Cube
3. South Carolina DOT – Diamond Grade NAP
4. Texas DOT – Competitive Bids from materials producer list
5. Wisconsin DOT – Avery Dennison Omni Cube
6. Type 3A
7. Our standard does not specify a particular brand but rather calls for a Type III or better meeting AASHTO M 268

4. *What is the name of the type of the material used for background? If your answer is 'Other' please specify the brand name of the type of the material used for background.*

The responses obtained are as follows:

Table 3-5 Type of material used for background

Brand Name	Number of DOTs using	Percentage (%)
Engineer Grade	0	0
Super Engineering Grade	1	1.67
High Intensity	5	8.34
High Intensity Prismatic	14	23.34
Diamond Grade LDP	3	5
MVP Prismatic	4	6.67
Crystal Grade	5	8.33
Diamond Grade VIP	5	8.33
Omni-view	5	8.33
Diamond Grade DG3	8	13.33
Other	7	11.66
N/R	3	5
Total	60	100

Other materials used- each of the following materials has been used by one DOT.

1. ASTM Type IV
2. Omni Cube
3. Our standard does not specify a particular brand but rather calls for a Type III or better meeting AASHTO M 268

4. Type 3A
5. Wisconsin DOT – Avery Dennison Omni Cube
6. Texas DOT – Competitive bids from materials producers list
7. South Carolina DOT – Diamond Grade NAP

5. *What type of font does your agency use for overhead guide signs?*

Table 3-6 Type of fonts used by DOTs for overhead guide signs

Type of Font	Number of DOTs using	Percentage (%)
Series E	2	5.71
Series E (Modified)	17	48.57
Clearview 5W	8	22.86
Clearview 5WR	6	17.14
Other	1	2.86
N/R	1	2.86
Total	35	100

Other fonts used

1. Clearview 4W
2. Florida DOT - Series E (Modified) used on older projects, Clearview 5W used on new projects and Clearview 5WR for replacement sign panels
3. Virginia DOT - Clearview 5WR is used only when necessary to maintain width in an overlay operation.
4. South Carolina DOT - Currently we have started using Clearview font for sign replacement projects. Clearview 5WR used on existing structures are to be retained. 5W is used for new structures. Series E (Modified) is used for spot replacements where all other signs are E Modified.
5. Clearview 5W is used for upper/lower case legends (destinations; street names). Clearview 4W is used for capital legends (cardinal direction; distance message; action message).

6. *What minimum value of retro-reflectivity does your agency use for overhead guide signs? Please mention the values used for legend and background separately*.

The responses obtained for this question were as follows:

Table 3-7 Minimum values of retro-reflectivity used by DOTs for overhead guide signs

Minimum values of retro-reflectivity used by DOTs for overhead guide signs
Ohio DOT follows the minimum levels found in MUTCD Table 2A-3. ODOT is using the blanket replacement method as described in MUTCD Section 2A.08 to assure signs remain comfortably above minimum levels. Signs are replaced every 15 years.
Based on 0.2 degree observation angle and -4 degree entrance angle: Legend (Lighted) - 250 (candelas/lux/meter2); Legend (Unlighted) - 380; Background (Lighted) - 30; (Unlighted) 35.

We use the Standards in the Retro-reflectivity Chart in Chapter 2 of the 2009 MUTCD.
Background: 25 cd/lx/m^2 Legend: 250cd/lx/m^2
We don't
As per ASTM Type XI sheeting specifications.
FHWA minimum requirements
We require that the material meets the minimums of the MUTCD.
MDOT is in compliance with the MUTCD.
ASTM D 4956-09, Table 4
Not established.
Use whatever type 3A will give us.
The minimal federal standard
We replace signs based on expected life of sheeting material (currently 12 years), therefore minimum retro values aren't used i.e. the signs are replaced along a corridor regardless of retro.
We do not have a specific minimum other than that included in the MUTCD.
Missouri DOT -MoDOT will be following MTUCD minimums specified in the retro-reflectivity requirements. Sign deficiencies are not currently judged on retro-reflectivity measurements, but on visual inspections. To address the new FHWA requirements MoDOT is currently developing a training/certification program to for a group of trained inspectors following defined sign performance expectations.
Kansas DOT - N/A - We use a 10 year blanket corridor replacement policy with nighttime reviews to manage our minimum retro-reflectivity.
Indiana DOT - N/R
Florida DOT - MUTCD minimums
Wisconsin DOT - 380 for legend and 38 for background
Virginia DOT - as per requirements of ASTM D 4956
Texas DOT - N/A
South Carolina DOT - We do not use minimum values. We use a regular replacement schedule of 10-12 years.
Oregon DOT - 2009 MUTCD requirements for both legend and background
New York DOT - N/R
Iowa DOT - No minimum value specified, would be in accordance with MUTCD minimum values
Nebraska DOT - have not obtained values
Mississippi DOT - for legend 250 and for background 45

Table 3-8 Specific values of retro-reflectivity used by DOTs for overhead guide signs

Retro-reflectivity value for background	Retro-reflectivity value for legend
Lighted- 30 Unlighted- 35	Lighted- 250 Unlighted- 380
25	250
38	380
45	250

Out of 24 remaining respondents 11 said that they use MUTCD minimum values for retro-reflectivity of overhead guide signs. The MUTCD minimum values can be seen in Figure 3.1 given below.

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

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

Bold Symbol Signs

- W1-1,2 – Turn and Curve
- W1-3,4 – Reverse Turn and Curve
- W1-5 – Winding Road
- W1-6,7 – Large Arrow
- W1-8 – Chevron
- W1-10 – Intersection in Curve
- W1-11 – Hairpin Curve
- W1-15 – 270 Degree Loop
- W2-1 – Cross Road
- W2-2,3 – Side Road
- W2-4,5 – T and Y Intersection
- W2-6 – Circular Intersection
- W2-7,8 – Double Side Roads
- W3-1 – Stop Ahead
- W3-2 – Yield Ahead
- W3-3 – Signal Ahead
- W4-1 – Merge
- W4-2 – Lane Ends
- W4-3 – Added Lane
- W4-5 – Entering Roadway Merge
- W4-6 – Entering Roadway Added Lane
- W6-1,2 – Divided Highway Begins and Ends
- W6-3 – Two-Way Traffic
- W10-1,2,3,4,11,12 – Grade Crossing Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3,4,16-22 – Large Animals
- W11-5 – Farm Equipment
- W11-6 – Snowmobile Crossing
- W11-7 – Equestrian Crossing
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow
- W16-5P,6P,7P – Pointing Arrow Plaques
- W20-7 – Flagger
- W21-1 – Worker

Fine Symbol Signs (symbol signs not listed as bold symbol signs)

Special Cases

- W3-1 – Stop Ahead: Red retroreflectivity ≥ 7
- W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35
- W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7
- W3-5 – Speed Reduction: White retroreflectivity ≥ 50
- For non-diamond shaped signs, such as W14-3 (No Passing Zone), W4-4P (Cross Traffic Does Not Stop), or W13-1P,2,3,6,7 (Speed Advisory Plaques), use the largest sign dimension to determine the proper minimum retroreflectivity level.

Figure 3-1 MUTCD minimum values for retro-reflectivity (MUTCD, 2009)

7. *Does your agency keep inventory of in-service traffic signs? (Yes or No)*

   Out of 28 state DOTs which responded to this question, 54% (n= 15) answered *'Yes'* and 39% (n= 11) answered *'No'*. 7% (n= 2) of the respondents did not give any response.

8. *Does your agency use computerized database to keep track of inventory? (Yes or No)*

   57% (n= 16) respondents answered this question as *'Yes'* and 32% (n= 9) respondents answered as *'No'*. 11% (n= 3) of the respondents did not give any response.

9. *If your answer to the question 7 above was 'Yes', how often does your agency update sign inventory?*

Table 3-9 Schedule for updating sign inventory

Schedule	Number of DOTs using	Percentage (%)
Daily	8	53.33
Weekly	1	6.67
Monthly	0	0
Quarterly	0	0
Semiannually	0	0
Annually	3	20
Other	1	6.67
N/R	2	13.33
Total	15	100

10. *Does your agency perform any activities for sign maintenance? (Yes or No)*

If your answer is 'Yes', please specify the maintenance activity.

71% (n= 20) of the respondents answered this question as *'Yes'* and 18% (n= 5) of the respondents answered it as *'No'*. 11% (n= 3) of the respondents did not give any response.

In the electronic version of the survey 10 respondents answered this question as *'Yes'* but only 9 of them mentioned about the maintenance activity thus the following table has 19 responses. The details provided by some of the respondents about the maintenance activities are as follows.

Table 3-10 Maintenance activities used by DOTs for signs

Maintenance activity
Replace, repair vehicle damage, vandalism, wind damage, standards change
Daytime sign checks when performing other sign work and annual nighttime visual inspections for retro-reflectivity.
Unsure
We handle all repair work and any needed operational changes for signs.
Overhead signs get inspected every other year.
Sign replacement program replaces signs within a ten year period.
As of today, most Districts just put fires out. Some Districts have enough staff to proactively replace signs as needed.
Nighttime sign assessments
All activities, repair, replacement, some new installation.
Missouri DOT -As stated above, an annual sign inspection is performed. Before the retro requirements the inspection was done alternating between day and night time inspections every other year. Then we adopted a 10 replacement cycle based on sheeting warranty life to comply with the new rule, however, this method had a degree of signing that was being replaced before the complete end of service life. Due to recent budgetary constraints we have now implemented

an annual night time inspection program only to assure only signs that no longer serviceable. In addition to the annual inspections, we of course perform maintenance on damaged signs throughout the year as they are identified. These repairs are prioritized into three levels..
Kansas DOT - As noted above: a 10 year blanket corridor replacement policy and an annual nighttime review to be in compliance with the MUTCD.
Florida DOT -Washing & Cleaning, bulb replacement
Wisconsin DOT -Routine Sign replacements take place on a 12 year maintenance schedule or are included as part of a roadway improvement project (reconstruction, resurfacing, etc.).
Virginia DOT - We perform limited amount of preventative and replacement maintenance.
South Carolina DOT - Overhead guide signs are replaced on a regular schedule as part of a comprehensive plan for sign replacements or interstate routes. The replacement cycle is currently 10-12 years.
Oregon DOT - repairs, cleaning and replacements
Iowa DOT - Minor maintenance, tighten connections, install overlays, etc.
Nebraska DOT - annual inspections
Mississippi DOT - we do all maintenance, replacement of sings on all MDOT maintained roadways

The majority of states perform some type of activities for sign maintenance which range from

1. Replacing signs based on their replacement policies (10 to 12 years cycle)
2. Repair damaged signs
3. Cleaning of signs
4. Installation of new signs
5. Sign Inspection (daytime, nighttime, annual etc.)

11. *How often does your agency perform the inspection of traffic signs? If your answer is ‘Other’, please specify.*

Table 3-11 Schedule of inspection for traffic signs

Schedule	Number of DOTs using	Percentage (%)
No schedule	10	35.71
Monthly	1	3.57
Quarterly	0	0
Semiannually	0	0
Annually	13	46.43
Other	3	10.71
N/R	1	3.57
Total	28	100

Other responses

1. Biannually
2. Districts are not currently required to perform sign inspections. Until we get the inventory developed, Districts will have to do routine nighttime inspections to maintain retro.
3. We have an "expected life" cycle for replacement; however crews do monitor signs (particularly south facing red series).
4. South Carolina DOT -We perform inspections as our schedule permits. Currently, there is no formal inspection program or schedule.

12. *What type of inspection activity does your agency perform? If your answer is 'Other', please specify.*

Table 3-12 Types of inspection activities used by DOTs

Inspection Activity	Number of DOTs using	Percentage (%)
Visual	5	15.15
Nighttime Visual	8	24.24
Day and night visual	10	30.30
One day and one night visual	0	0
Other	8	24.24
N/R	2	6.06
Total	33	100

Additional comments

1. We have not established a standard inspection program but are working to set one up at this time.
2. We take some retro readings of suspect signs.
3. Wisconsin DOT - None, signs are replaced either on a segment approach (for improvement projects) or through general maintenance (12 year interval).
4. Texas DOT - Each of the 25 districts performs a day and night inspection. Our division office (headquarters) does a sport day and night inspection.
5. South Carolina DOT - random day and night visual
6. Mississippi DOT - we use combination of expected sign life and blanket replacement methods to maintain retro reflectivity

13. *Does your agency use any instrument for measuring retro-reflectivity? (Yes or No)*

28% (n= 8) respondents answered this question as *'Yes'* and 54% (n= 15) of the respondents answered it as *'No'*. 18% (n= 5) of the respondents did not give any response.

14. *If your answer to the above question is 'Yes', please specify model with manufacturer name.*

Some of responses which state model name are as follows:

Table 3-13 Instruments used by DOTs for measuring retro-reflectivity

Model Name
ART 920
RoadVista Model 922, but I would not recommend it to others. It is too bulky, and the display is very hard to read. This was not our first choice but due to our purchasing rules we ended up with the low bid item.
DeltaSign 450
Missouri DOT -The equipment that we currently have is two Delta Light & Optics RetroSign retro-reflectometers, Type 4500.
Kansas DOT –Delta LTL-X
Florida DOT -Delta Retro Sign Reflectometer
South Carolina DOT -It is an older Delta Light and Optics Model DK 2800.
Mississippi DOT - ART 920 SEL Sign Master

15. *If your agency does not use any instrument for measuring retro-reflectivity, what method do you follow to measure retro-reflectivity of traffic signs?*

The responses are listed in the following table.

Table 3-14 Methods used by DOTs for measuring retro-reflectivity of traffic signs

Methods of measuring retro-reflectivity of traffic signs reported by DOTs
Ohio DOT does not measure sign retro-reflectivity. The blanket replacement method described in MUTCD Section 2A.08 is used with a 15 year replacement interval to assure signs are replaced before retro-reflectivity falls below minimum required levels in MUTCD Table 2A-3.
Currently none. Considering implementing a sign inventory program to inspect and maintain signs to comply with MUTCD minimum retro-reflectivity requirements.
We have not determined at this time as the compliance date is Jan 2012
Visual inspection.
None
Will be using nighttime inspection in the future.
With the new retro-reflectivity rule, NDDOT is planning on using the calibrated eye method.
Visual inspections
We use expected life cycle
Kansas DOT - We do not measure the retro-reflectivity of the signs. We use the methods noted above to maintain our minimum retro-reflectivity of signs
Florida DOT -N/A
Wisconsin DOT - N/A

Virginia DOT - N/R
Texas DOT - Visual Method
South Carolina DOT - We follow a regular replacement schedule
Oregon DOT - visual inspection
New York DOT – none
Iowa DOT - just rely on day and night visual inspection
Nebraska DOT - nighttime visual

Majority of states use different methods to measure retro-reflectivity of traffic signs which range from

1. Visual inspection
2. Nighttime inspection
3. Replacing the signs before the retro-reflectivity falls below minimum required levels in MUTCD table 2A-3
4. Calibrated eye method

16. *How frequently does your agency perform the measurement of retro-reflectivity?*

The responses obtained are as follows:

Table 3-15 Schedule used by DOTs for measurement of retro-reflectivity

Schedule	Number of DOTs using	Percentage (%)
Monthly	0	0
Quarterly	0	0
Semiannually	1	3.85
Annually	6	23.08
Other	12	46.15
N/R	7	26.92
Total	26	100

Two responses obtained were *'We don't measure'.*

17. *Does your agency use external illumination for overhead guide signs? (Yes or No)*

36% (n= 10) of respondents answered this question as *'Yes',* and 50% (n= 14) of the respondents answered it as *'No'*. 14% (n= 4) of the respondents did not give any response.

18. *If your answer to the above question is 'Yes', what source does your agency use for external illumination of the overhead guide signs?*

The responses obtained are shown in Table 3.16.

Table 3-16 Sources of external illumination for overhead guide signs

Sources of external illumination for overhead guide signs
Mercury Vapor luminaires or induction fixtures
Signlighters mounted at the bottom of the overhead signs.
Lights mounted on the sign structure.
Missouri DOT -Our lighting structures are lit using Metal Halide lamps for color clarity and we have a couple of test LED fixtures that are under evaluation.
Kansas DOT -Electricity, hooked into Westar energy.
Florida DOT - require induction fixtures
Wisconsin DOT still illuminates some overhead signs in the Milwaukee metropolitan area. These are signs with the encapsulated bead high intensity legend and background (ASTM D4956-09 Type II sheeting). As these signs are replaced to our new sheeting standard of Type IX or better, the lights are being turned off. Effectively, WisDOT is phasing out the usage of overhead sign lighting. No new overhead sign lighting is being installed. WisDOT uses 250 Watt Mercury Vapor sign lighting luminaires @ various voltages. The lamp that is used is a deluxe mercury vapor.
Virginia DOT - Generally up lighting using HPS, though some Florescent fixtures remain in operation, we're also looking at white LED.
South Carolina DOT - 400 and 250 W Holophane roadway lighting fixtures.
Nebraska DOT – Luminaries

19. *If your answer to the above question 17 is 'Yes', approximately how much money does your agency spend annually for guide sign external illumination?*

The obtained responses are summarized below

Table 3-17 Annual expenditure for guide sign external illumination

Annual expenditure for guide sign external illumination
$300,000
An annual average would be very low. Because we have had so few overhead signs installed new in the past few years it would have to be $20K or less.
Not sure
$1.5 - $2 million
Missouri DOT -We spend an estimated $300 per year per structure.
Kansas DOT –Unknown
Florida DOT - $60.00 annually per fixture
Wisconsin DOT – unknown
South Carolina DOT - Cost data is not available as the sign lights are often on the same meters as the roadway lighting.
Nebraska DOT – don't know

20. *Does your agency follow the replacement policy for overhead guide signs? (Yes or No)*

46% (n= 13) of the respondents answered this question as *'Yes'*, and 32% (n= 9) of the respondents answered it as *'No'*. 22% (n= 6) of the respondents did not give any response.

21. *If your answer to the above question 20 is 'Yes', please email your replacement policy.*

The responses are listed in the following table. Although 13 respondents answered this question as *'Yes'* only 10 of them mentioned about their replacement policy.

Table 3-18 Replacement policies of DOTs for overhead guide signs

Replacement policies of DOTs for overhead guide signs
The policy is contained in Section 260-5 of the ODOT Traffic Engineering Manual, which is available on-line through the ODOT web site - www.dot.state.oh.us, under the Design Reference Resource Center.
Replacement policy is the same as with all signs. If the retro-reflectivity falls below the standards as set in Chapter 2 of the MUTCD the sign will be replaced.
We replace overhead guide signs on a ten year cycle.
These signs should be included in the "calibrated eye" inspection that is done annually.
A recurring maintenance schedule is used with a maximum 12 year cycle for encapsulated lens sheeting and a 15 year cycle for VIP and DG3 sheeting.
Missouri DOT - Overhead guide signs are replaced in the same manner as any other sign, based on a visual night time inspection that determines when the sign is no longer performing to expectations. I have attached in the email the written guidance that precedes the certification course that is being developed.
Indiana DOT -We established a 20 year replacement cycle on our panel signs, which includes overhead signs.
South Carolina DOT - No written policy at this time.
Oregon DOT http://intranet.odot.state.or.us/erp/documents/desired_conditions.pdf
Kansas DOT – Blanket replacement – periodic corridor and/or intersection sign replacement projects will continue to be programmed by KDOT.

The replacement policies provided by state DOTs can be found in Appendix C.

3.2 Another survey by Joint Technical Committee on Roadway Lighting

Survey of AASHTO Members was conducted by AASHTO Joint Technical Committee in December 2010. This survey was related to roadway lighting. This survey received 25 responses in total. Some of the questions from this survey were found to be related to the survey conducted by KSU team. Those questions and the responses to them are summarized below.

1. *What is your Transportation Agency/Department policy for lighting highway signs?*

The responses obtained were as follows:

Table 3-19 DOTs' policies for lighting highway signs

DOTs' policies for lighting highway signs
We no longer require that our highway signs be illuminated.
We do not directly light our highway guide signs. Roadway lighting is provided on a large percentage of our freeway/expressway segments (which have overhead mounted guide signs).

The roadway lighting and the retro-reflective guide sign sheeting make the signs adequately visible to motorists. On most other roadways, the guide signing is ground mounted and the retro-reflective sheeting material provides adequate visibility
We do not have any signs with lighting at this time
We no longer illuminate signs
We no longer light highway signs but use reflective sheeting.
IESNA RP-19
Currently experimenting with using high performance retro-reflective sheeting and not lighting signs.
No sign lighting is required on the signs with reflective sheeting
Sign will be unlighted
Do not light highway signs
If ASTM Types IX or XI sign sheeting is used for overhead mounted sign, sign illumination is not required.
We do not light highway signs
MDOT does not light signs. All signs are constructed with high intensity retro-reflective sheeting
We do not use lighting for highway signs
We continue to light existing signs and main freeway/populated areas for sign lighting.
We do not.
Our Metro District stopped lighting highway signs several years ago. Some of the outstate districts still use lighting. There is a concern that with the new cutoff style headlights this may become an issue again.
We no longer light our overhead signs. As overhead sign panels are replaced with the higher type sheeting the lighting is deactivated and removed. Very little sign lighting is still in use.
SDDOT does not light highway signs
We have begun to eliminate overhead sign lighting in the last few years when we do a signing project that has overhead sign lighting. The reason we are eliminating the lights is our use of higher intensity sheeting for our overhead signs (Type III background with either Type VIII or Type IX sheeting for legends and borders). We are also installing some monotube structures within the cities of Tulsa and Oklahoma City
Case by case. More likely in urban areas, less likely in rural interstate applications
Previously all overhead signs. Now using highly reflective sheeting without lighting and evaluating effectiveness.
All overhead signs on the Baltimore and Washington Beltways are lighted. All overhead exit direction and left exit sign are lighted. All non-illuminated overhead signs must have type 9 or better sheeting
http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1020.pdf See page 1020-5 of this linked document
MassDOT does not illuminate highway Signs.

Out of 25 respondents 22 (88%) said they do not illuminate the signs.

2. *In the design of new projects does the Transportation Agency/Department typically use additional lighting on specific signs? (Yes or No)*

   20 respondents answered this question as *'Yes'* and 4 of them answered it as *'No'*.

3. *If the Transportation Agency/Department typically uses additional lighting on specific signs, please identify types of sign that additional lighting is provided?*

The responses obtained were as follows:

Table 3-20 Types of sign with additional lighting

Type of sign with additional lighting
None
Rarely on severely curved roadway sections
None
N/A
Main freeway/more populated areas
NA
Guide signs in urban areas on overhead structures
Currently no lighting unless compelling reason to add it to overhead signs.
http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1020.pdf See page 1020-5 of this linked document
Not Applicable

4. *Has your Transportation Agency/Department deactivated sign lighting of existing signs? (Yes or No)*

16 respondents answered this question as *'Yes'* and 7 of them answered it as *'No'*.

5. *If the Transportation Agency/Department has deactivated sign lighting of existing signs, what was the reasoning and was there any formal documentation of this reasoning?*

The responses are shown on the next page.

Table 3-21 Reasons for deactivation of sign lighting

Reasons for deactivation of sign lighting reported by DOTs
To conserve energy as well as the improvements in retro-reflective paint made the need for sign lighting not warranted
Sign lights were deactivated in favor of reflective sheeting.
Operational and maintenance costs. Sign lighting is on an individual basis and there is no formal documentation.
Deactivated sign lighting on a portion of the freeway. Followed lead of various other DOTs that have done this successfully. Consulted with local FHWA office prior to initiating experiment.
Remove sign lighting when new reflective signs are installed
Replacement of sign face of improved reflectivity. Contact James Roth for particulars of documentation 614-752-0438
Have no idea why
Adopted higher retro-reflective sign sheeting (ASTM Types IX or XI).
Brighter sheeting negated the need for the lights and they were a maintenance problem.
We have retro-reflective sheeting that addresses our needs
N/A
Our Metro district decided that it was not needed many years ago. I am not certain if there was any documentation.
This was based on the use of Type IX sheeting. There was no study or formal documentation.

We have heard no complaints and know of no crash issues.
NA
The Oklahoma DOT is gradually eliminating the use of sign lighting as we replace the signs on our overhead sign structures. We have gone to the use of Type III sheeting for the background and Type VIII or Type IX sheeting for legends and borders.
Signing material upgrades to higher reflectivity as well as maintenance considerations.
Lighting was deemed unnecessary due to use of highly reflective sheeting. No formal documentation for reasoning.
A few signs that do not meet the above policy, have type 9 or 11 sheeting, and that were difficult for maintenance have been disconnected.
Reasoning would be to align with policy. http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1020.pdf See page 1020-5 of this linked document
MassDOT does not light signs due to the maintenance involved and the power cost associated with illuminating highway signs. MassDOT does not have any formal documentation available.

6. *Is Light Emitting Diode (LED) lighting used by your Transportation Agency/Department*?

   15 respondents answered this question as *'No'* and 10 of them answered it as *'Yes'*.

In the AASHTO survey, out of 25 respondents, 22 (88%) said that they no longer illuminate highway signs. The same question was asked by KSU team in their survey for which out of 28 respondents 50% (n=14) of the respondents said they no longer illuminate the signs and 36% (n=10) of them said they still illuminate the signs.

For another question in AASHTO which asked, "Has your transportation agency deactivated sign lighting of existing signs", 16 respondents answered *'Yes'* and 7 of them answered *'No'*.

Question 5 in AASHTO survey asked what the reason for deactivation of sign lighting was. From the table above it can be seen that the answer varies from "to conserve energy to sign lighting was deactivated in favor of retro-reflective sheeting."

The majority of states stated that they are using higher retro-reflectivity sheeting material and therefore lighting is unnecessary. None of the states had conducted research to prove that.

3.3 Summary

Based on the survey analysis it was observed that High Intensity Prismatic and DG3 materials were most often used materials by state DOTs for background and the legend. Series E (Modified) font received 48.54% response making it popular choice for the fonts used on overhead guide signs. Out of 28 respondents 19 said that they have usage policy for the type of sheeting material used for overhead guide signs and 18 of them provided details about their policies. Ten respondents said that they use external illumination for overhead guide signs. The sources of external illumination were Mercury Vapor lamps, Metal Halide lamps and inductions fixtures. Some states are also evaluating LEDs as a potential source of external illumination for overhead guide signs.

Chapter 4 - Instrument and Laboratory Tests

An illumination controlling device was built in the laboratory. This instrument was used to carry out the pilot tests on the vehicle headlamps to read the illumination levels. The Pulse-Width-Modulation (PWM) headlight dimmer modules used pulse-width modulation to allow the user to dim the car's headlights to one of the 16 different brightness levels. The dimmer is composed of an Atmel AT91SAM7s-EK microprocessor development board and a custom analog breadboard with four headlight driver circuits.

On startup, the microprocessor's PWM peripheral is configured to produce a 12.5 kHz square wave with a variable duty cycle and the microprocessor's periodic interrupt timer (PIT) generates a software interrupt every millisecond. When the PIT interrupts, the microprocessor reads the value of the duty cycle selector knob, a 16-position binary encoder. If the value of the duty cycle encoder has changed since the last time it was read, the microprocessor retrieves a new configuration value for the PWM peripheral from the duty cycle lookup table. It then re-configures and enables the PWM module to produce a waveform with the desired duty cycle.

The custom analog breadboard contains four headlight driver circuits, which are controlled by the PWM signal from the microprocessor. Large (model number IRF9540) p-channel power MOSFETs (Metal Oxide Semiconductor Field Effect Transistor) act as voltage-controlled current switches connected in series with the car's headlights. Changing the duty cycle of the PWM waveform generated changes how long current is allowed to flow through the headlights, increasing or decreasing their apparent brightness. The power transistors are mounted on external heat sinks to allow them to dissipate the heat generated by large headlight currents, and because the microprocessor is unable to directly drive the gates of the large power FETs (Field Effect Transistor), the PWM signal to each headlight driver circuit is buffered by a 74HC04 hex inverter and a smaller 2N7000 n-channel MOSFET.

The headlight dimmer module is connected to the car's electrical system by means of custom fuse-connector cables. To connect the dimmer to the car, the user simply removes the car's headlight fuses and plugs the dimmer's cables into the empty sockets. When the dimmer is turned on, current that would normally flow to the headlights is routed through the dimmer's power MOSFETs, effectively replacing the car's headlight fuses with voltage-controlled switches. To ensure that the headlights are still protected, the headlight fuses are then inserted in special inline fuse holders built into the dimmer’s cables. The PWM headlight dimmer is compatible with all makes and models of car that use ATO (Auto) or Mini-style blade fuses. The dimmer can be powered two ways: if the car’s fuse box is located in the driver’s cabin, the dimmer module plugs into the car’s cigarette lighter; if the fuse box is under the hood, the dimmer’s power cable clamps directly to the car’s battery terminals.

The PWM headlight dimmer is easy to use. After connecting the dimmer to the car’s fuse box, the user starts the car and turns on the headlights with the switch. The user then turns on the dimmer’s power switch, and dims the headlights by turning the duty cycle select knob on the front of the dimmer. The instrument’s outside view with the encoder knob, the power FETs and some brief user instructions as well as the printed-circuit boards of the microcontroller and the custom analog breadboard are shown in Figure 4.1.

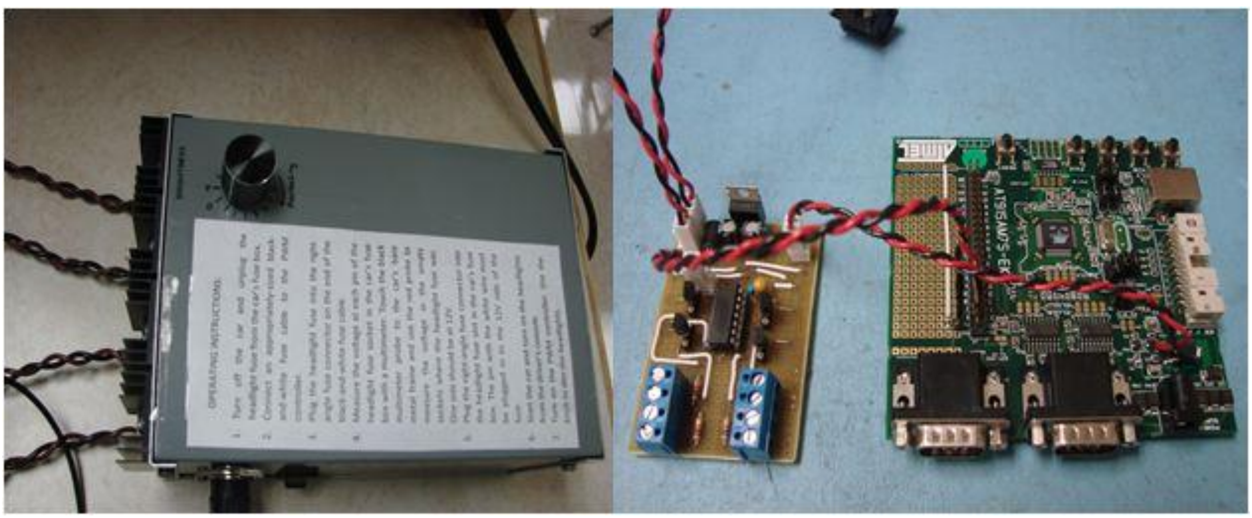


Figure 4-1 Outside view of encoder knob and printed circuit boards of microcontroller

Preliminary measurements were carried out in the laboratory with the use of a Minolta illuminance meter, 60W sealed-beam headlights and the PWM instrument. The bench-top laboratory set up used in testing can be seen in Figure 4.2. Sixteen (including level 0) different levels of illumination were generated and the average voltage across the headlights and the illumination in units of lux at a distance of 1 meter were recorded. This distance of 1 meter was assumed just for testing purpose.

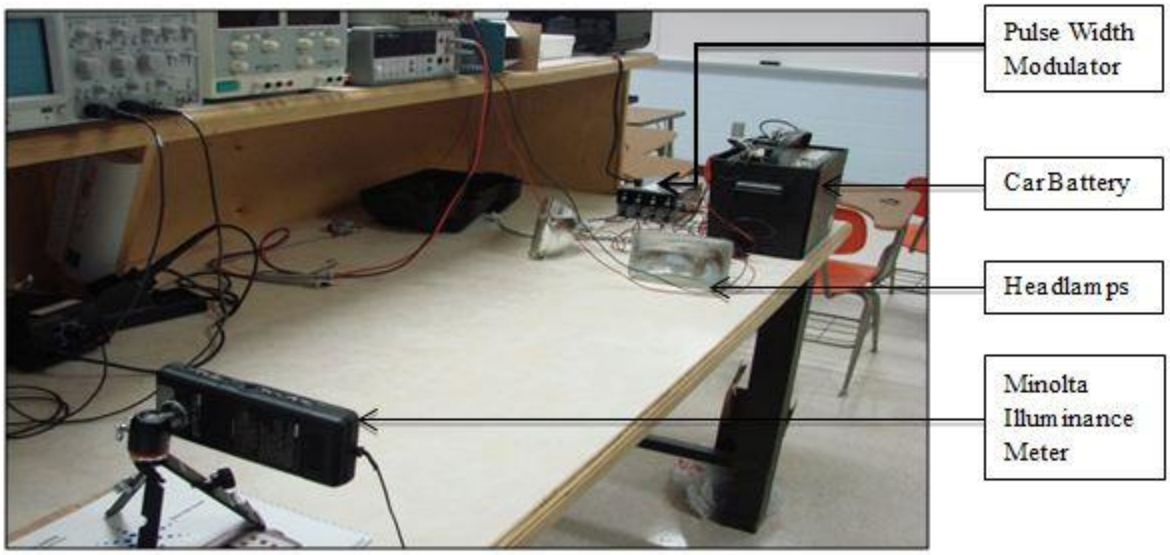


Figure 4-2 Laboratory set up used for pilot tests

The obtained illumination levels and voltages for both the headlamps can be seen in Table 4.1 and Table 4.2 respectively and graphs of illumination levels and average voltages versus position on the knob can be seen in Figure 4.3

Table 4-1 Obtained illumination levels and voltages for the first headlamp

Position on the knob	Illumination (lux)	Delta	Percentage Increase	Voltage
0	2.66			0.6
1	87.4	84.74	96.96	1.42
2	317	229.6	72.43	2.25
3	658	341	51.82	3.06
4	1080	422	39.07	3.85
5	1560	480	30.77	4.64
6	2090	530	25.36	5.41
7	2660	570	21.43	6.18
8	3250	590	18.15	6.95
9	3890	640	16.45	7.7
10	4540	650	14.32	8.45
11	5210	670	12.86	9.19
12	5930	720	12.14	9.92
13	6660	730	10.96	10.67
14	7470	810	10.84	11.44
15	8330	860	10.32	12

Table 4-2 Obtained illumination levels and voltages for the second headlamp

Position on the knob	Illumination (lux)	Delta	Percentage Increase	Voltage
0	5.08			0.6
1	114	108.92	95.54	1.49
2	365	251	68.77	2.31
3	720	355	49.31	3.11
4	1150	430	37.39	3.9
5	1640	490	29.88	4.68
6	2180	540	24.77	5.45
7	2750	570	20.73	6.22
8	3360	610	18.15	6.98
9	4000	640	16.00	7.74
10	4650	650	13.98	8.48
11	5320	670	12.59	9.22
12	6000	680	11.33	9.95
13	6710	710	10.58	10.69
14	7450	740	9.93	11.41
15	8230	780	9.48	11.97

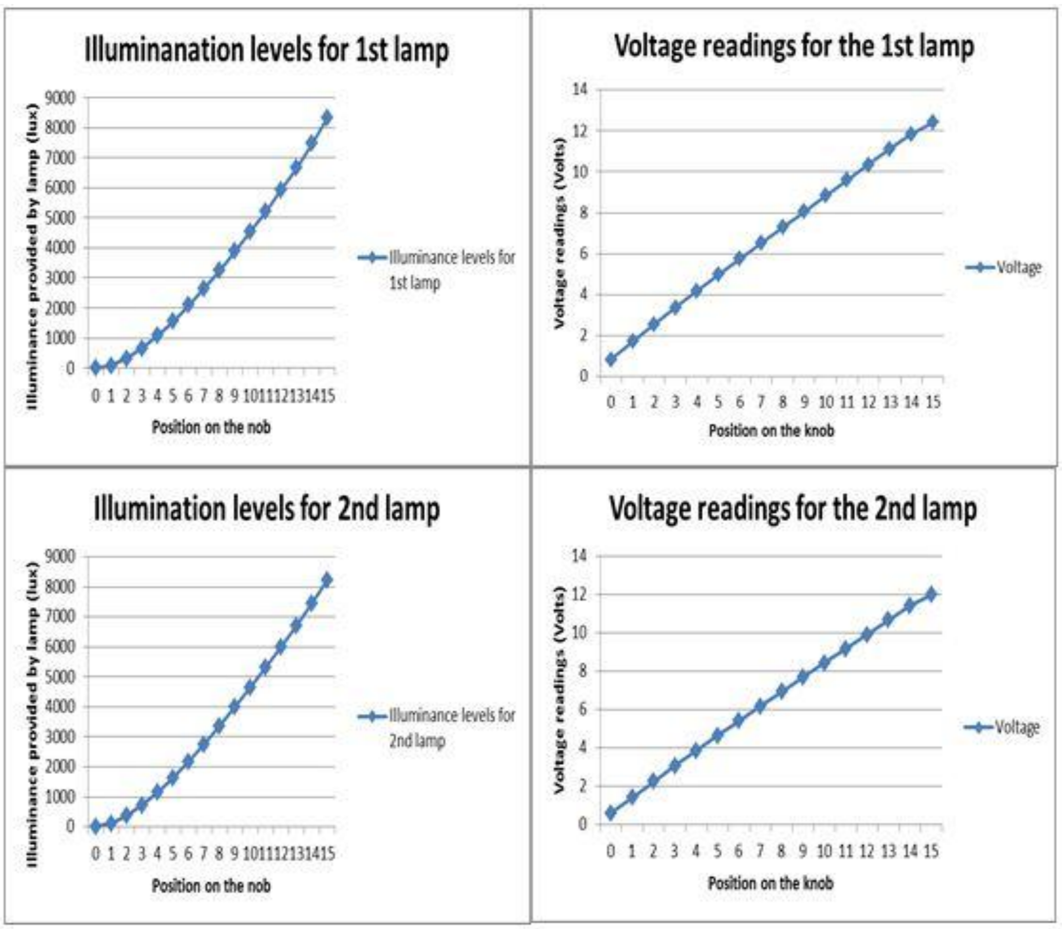


Figure 4-3 Graphs showing illumination levels obtained and voltages obtained versus position on the knob

It can be seen from the graphs that the average voltage readings across the headlight filament are very linear with the position of the digital encoder. The linearity of the corresponding illumination levels is also good except at the first three steps, which was probably due to the highly non-linear behavior of the resistance change of the filament with temperature. Further studies should be conducted to investigate this non-linear behavior.

4.1 Testing of illumination controlling device in the field

The illumination controlling device was taken to the field to obtain illumination levels which are equivalent to each position on the knob. The tests were conducted twice. Once when the distance between the sign and the headlamps was 73.15 meters (240 ft) and when the distance between the sign and the headlamps was 54.86 meters (180 ft). The results from these tests helped the experimenters to conduct field studies in which human subjects read the words on the signs.

4.1.1 Procedure

1. The illumination controlling device was connected to the fuse box of the car (Chevy Impala, 2008).
2. The sign was mounted on the fixture in such a way that height from the road surface to the bottom of the sign was 2.43 meters (8 ft) and the lateral distance from the edge of the driving lane was 1.82 meters (6 ft).
3. The headlamps were turned on to the first level of illumination.
4. One of experimenter was standing on the ladder and changed the position of sensor of the Minolta Illuminance meter. The sensor was isolated from the display screen by using a cable. The experimenter standing behind the sign read the illumination readings.
5. Three illumination readings were taken for each knob position. These points were fixed by sticking Velcro on the sign so that each time the reading was taken at the same position. See Figure 4.4.
6. The average of these readings was taken to find out the illumination level related to each position on the knob.

The obtained illumination readings for each knob position at 73.15 meters (240 ft) and 54.86 meters (180 ft) can be seen in Table 4.3 and Table 4.4.

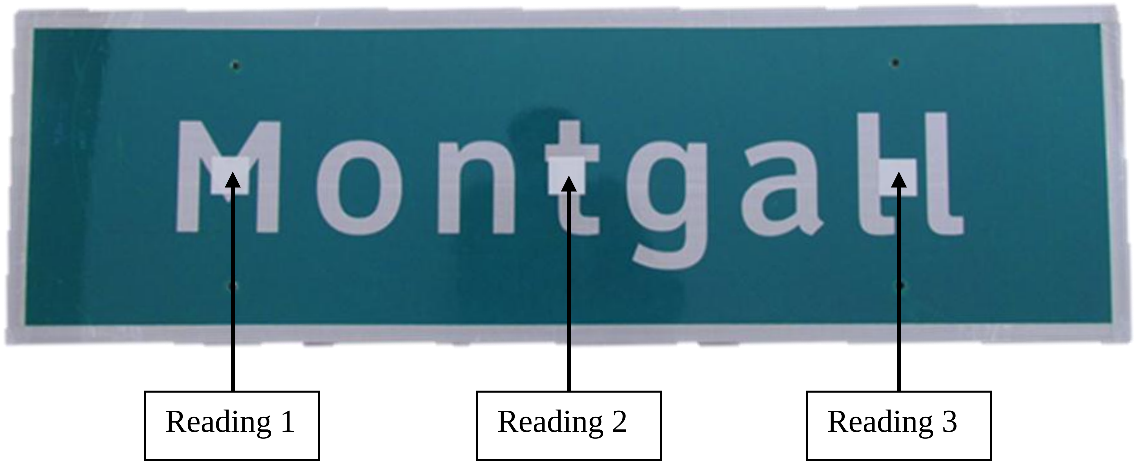


Figure4-4 Sign used for taking illumination readings with Velcro

Table 4-3 Illumination readings for 73.15 meters (240 ft) distance between the sign and the headlamps

Knob position	Reading 1(lux)	Reading 2(lux)	Reading 3(lux)	Average(lux)
0	0.04	0.04	0.04	0.04
1	0.04	0.04	0.04	0.04
2	0.05	0.04	0.04	0.04
3	0.05	0.05	0.04	0.05
4	0.06	0.05	0.05	0.05
5	0.06	0.06	0.05	0.06
6	0.07	0.06	0.06	0.06
7	0.08	0.07	0.07	0.07
8	0.09	0.08	0.08	0.08
9	0.1	0.09	0.09	0.09
10	0.11	0.1	0.1	0.10
11	0.12	0.11	0.11	0.11
12	0.13	0.12	0.12	0.12
13	0.15	0.14	0.13	0.14
14	0.16	0.15	0.14	0.15
15	0.17	0.17	0.16	0.17

Table 4-4 Illumination readings for 54.86 meters (180 ft) distance between the sign and the headlamps

Knob position	Reading 1(lux)	Reading 2(lux)	Reading 3(lux)	Average(lux)
0	0.05	0.04	0.04	0.04
1	0.05	0.04	0.04	0.04
2	0.05	0.05	0.05	0.05
3	0.06	0.05	0.05	0.05
4	0.06	0.06	0.06	0.06
5	0.07	0.07	0.07	0.07

6	0.08	0.08	0.08	0.08
7	0.09	0.09	0.09	0.09
8	0.11	0.1	0.1	0.10
9	0.12	0.12	0.12	0.12
10	0.14	0.13	0.13	0.13
11	0.16	0.15	0.15	0.15
12	0.17	0.17	0.16	0.17
13	0.19	0.19	0.18	0.19
14	0.21	0.21	0.2	0.21
15	0.24	0.23	0.22	0.23

Table 4-5 Table showing difference in the illumination levels at 73.15 meters (240 ft) and 54.86 meters (180 ft)

Knob position	Average Illumination at 73.15 meters (lux)	Average illumination at 54.86 meters (lux)	Difference (lux)
0	0.04	0.04	0.00
1	0.04	0.04	0.00
2	0.04	0.05	0.01
3	0.05	0.05	0.00
4	0.05	0.06	0.01
5	0.06	0.07	0.01
6	0.06	0.08	0.02
7	0.07	0.09	0.02
8	0.08	0.10	0.02
9	0.09	0.12	0.03
10	0.10	0.13	0.03
11	0.11	0.15	0.04
12	0.12	0.17	0.05
13	0.14	0.19	0.05
14	0.15	0.21	0.06
15	0.17	0.23	0.06

It can be seen from Table 4.5 that there is no much difference in the illumination levels for the first six knob positions but this difference goes on increasing for following knob positions and become 0.06 lux for the knob positions 14 and 15.

Chapter 5 - Field Evaluation

A field experiment was designed to determine the minimum illumination for street signs. The experiment was approved by the Committee on Research Involving Human Subjects at Kansas State University. The proposal number assigned was 5939. The approval letter can be seen in Appendix D.

5.1Sign types to be used

Three street signs were used during field evaluation. These signs were provided by Kansas Department of Transportation and were used for one other research during March 2010 to April 2010 at Kansas State University. The letters on the signs were composed of a combination of lower-case letters with initial upper-case letter. The height of the initial upper-case letter was 15.24 cm (6 inches) and the height of the lower-case letters was 11.43 cm (4.5 inches). The signs were 1.52 meters (5 ft) wide and 0.45 meters (1.5 ft) in height. The signs can be seen in the following figures.

Figure 5-1 Montgall DG3 retro-reflective material and Series E (Modified) font

Figure 5-2 Montegut Type I retro-reflective material and Series E (Modified) font

Figure 5-3 Mirabeau Type IV retro-reflective material and Series E (Modified) font

Table 5-1 Fonts and sheeting material used for the signs

Sign Number	Font	Sheeting Material	Word on the sign
1.	Series E (Modified)	Type I	Montegut
2.	Series E (Modified)	DG 3	Montgall
3.	Series E (Modified)	Type IV	Mirabeau

The Table 5.2 shows information about the sheeting materials from ASTM D 4956 standard for retro-reflective sheeting.

Table 5-2 Description of sheeting materials according to ASTM D 4956 standard for retro-reflective sheeting

Sheeting Material Type	Description
Type I	A retro-reflective sheeting referred to as "engineering grade" that is typically enclosed lens glass-bead sheeting. Applications for this material include permanent highway signing, construction zone devices, and delineators.
Type IV	A retro-reflective sheeting referred to as "high-intensity" that is typically an unmetallized microprismatic retro-reflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.
DG 3 or Type XI	A retro-reflective sheeting typically manufactured as an unmetallized cube corner microprismatic retro-reflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

5.2 Series E (Modified) font

The standard typefaces used for highway signs in the US are defined in Standard Alphabets for Traffic Control Devices, published by Federal Highway Administration.

These typefaces are as follows.

1. Series A – discontinued
2. Series B
3. Series C
4. Series D
5. Series E
6. Series E (Modified)
7. Series F

The examples of these fonts and the standard spacing for Series E (Modified) font can be seen in Appendix E and Appendix F.

5.3 Design of the experiment

The design chosen for the experiment was Repeated Measures Design. This design is used for the studies in which same measures are collected multiple times for each subject but under different conditions. The strength of this design is that it makes the experiment more efficient and helps to keep the variability low.

5.4 Location for the field trial

The pilot experiment and the field evaluations were conducted in the parking lot of the Saint Thomas More Church in Manhattan, Kansas. The picture of the parking lot can be seen in Figure 5.1 below. The field tests were conducted only during nighttime after 9:00 P.M.

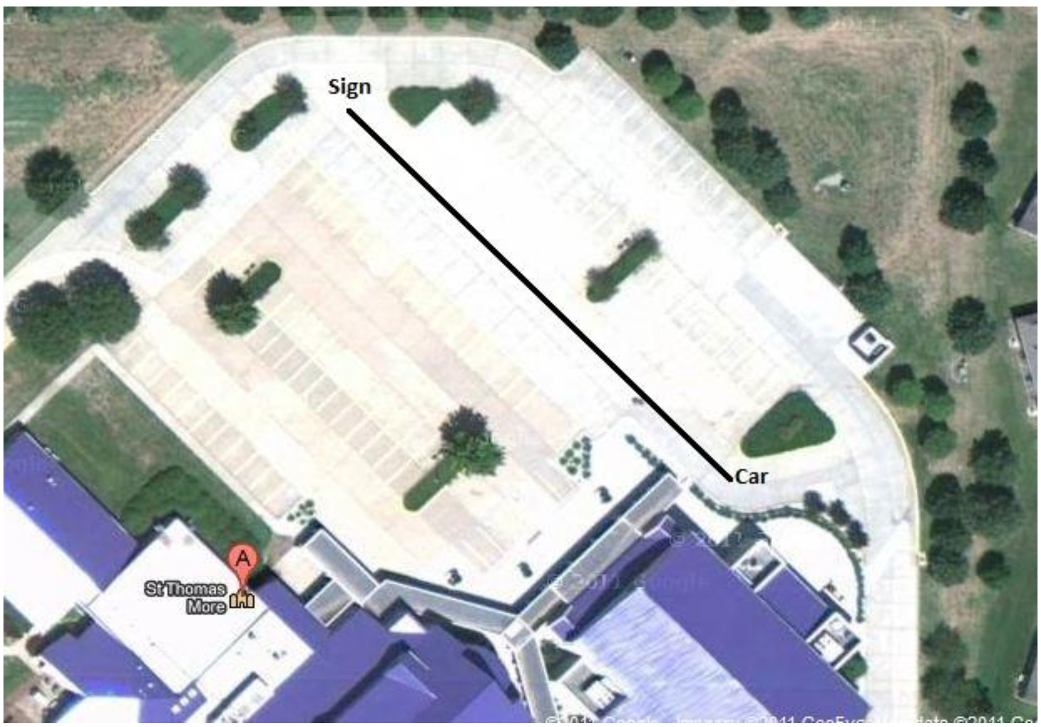


Figure 5-4 Aerial view of Saint Thomas More Church parking lot (maps.google.com)

5.5 Test subjects

10 subjects participated in the field tests. The subjects were students from IMSE department at Kansas State University. The field tests were done for the age group of 18-34 years.

5.6 Design of the fixture for field evaluations

A fixture was designed to hold signs during the field tests. To be on safer side the height of the fixture was kept 2.43 meters (8 ft) (the height from the bottom of the sign to the road surface was 2.43 meters). The lateral offset for the fixture was kept to 1.82 meters (6 ft) from the edge of the driving lane. This lateral offset was in compliance with MUTCD standard. The MUTCD standard for the height of the fixture and the lateral offset can be seen on the next page. The fixture was designed in the IMSE work shop. The picture of the fixture along with the sign mounted on it can be seen in Figure 5.5.

Figure 5-5 Fixture with sign mounted on it

According to MUTCD 2009, Section 2A.18 Mounting Height**,**

"Directional signs on freeways and expressways shall be installed with a minimum height of 7 feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement. All route signs, warning signs, and regulatory signs on freeways and expressways shall be installed with a minimum height of 7 feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement. If a secondary sign is mounted below another sign on a freeway or expressway, the major sign shall be installed with a minimum

height of 8 feet and the secondary sign shall be installed with a minimum height of 5 feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement. Where large signs having an area exceeding 50 square feet are installed on multiple breakaway posts, the clearance from the ground to the bottom of the sign shall be at least 7 feet.

As per the standard the signs on the fixture were mounted at the height 8 ft. and 6 ft. to the right of right edge of driving lane."

According to MUTCD 2009, Section 2A.19 Lateral Offset,

"For overhead sign supports, the minimum lateral offset from the edge of the shoulder (or if no shoulder exists, from the edge of the pavement) to the near edge of overhead sign supports (cantilever or sign bridges) shall be 6 feet. Overhead sign supports shall have a barrier or crash cushion to shield them if they are within the clear zone."

5.7 Procedure

The field tests were carried out during nighttime using the illumination control device which controls the illumination provided by headlamps of the vehicle and the fixture designed to mount the signs. The vehicle used was Chevy Impala (2008). This car was rented from KSU carpool facility.

The field evaluation consisted of 30 minutes session for each subject. In the beginning of this session a consent form was filled out by the subject. The sample consent form can be seen in the Appendix G. Next, the background information about each subject was collected which included, age, gender, wearing corrective lenses or not, last eyesight checkup, frequency of nighttime driving and involvement in any accidents in past 3 years. The data collection sheet can be seen in the Appendix H.

Before the subject started the field test some instructions were given. These instructions are as follows.

1. You will be seated in driver's seat of a stationary experimental vehicle. One of the experimenter will be seated in passenger seat with you.
2. Initially the headlamps of the vehicle will be turned off and they will be turned on to the level 0 of the illumination.

3. You will be asked to read the word on the sign without stressing your eyes. If you cannot read the word on the sign without stressing your eyes, ask the experimenter to go to next level of illumination.
4. When you are able to read the word on the sign, read it aloud so that the experimenter will know that you have read the word and he can record the reading.
5. This procedure will be repeated for two more signs.
6. After this first stage you will be taken to other starting location and the same procedure will be repeated.

According to MUTCD 2009, Section 2A.13 guidance,

"Word messages should be as brief as possible and the lettering should be large enough to provide the necessary legibility distance. A minimum specific ratio of 1 inch of letter height per 30 feet of legibility distance should be used."

Also according to United States Sign Council's Sign Legibility Rules of Thumb book, legibility index of 30 ft/inch is frequently used to address most legibility requirements.

The legibility index is defined as the ratio of distance required to read the sign (ft) to the height of the letters on the sign (inch).

The height of the letters used in this experiment was 15.24 cm (6 inches) for uppercase letters and 11.43 cm (4.5 inches) for lowercase letters. So according to MUTCD and United States Sign Council (USSC) criterion 30 ft/inch, the distance between the signs and the vehicle headlamps was determined to be 54.86 meters (180 ft). Some of the researchers also used the criterion of 40 ft/inch for these signs. To be on the safer side this experiment was conducted for the distances of 54.86 meters (180 ft) and 73.15 meters (240 ft). For the lowercase letters these distances were calculated to be 41.14 meters (135 ft) and 54.86 meters (180 ft) corresponding to legibility indices of 30 ft/inch and 40 ft/inch.

For the first trial the distance between vehicle headlamps and the sign was 73.15 meters (240 ft). The experimenter would adjust the knob on PWM device to the level 0 which was the least illumination level and subject would not be able to read the sign. If the subject was not able to read the sign, the experimenter went on increasing the illumination by adjusting the knob on the controller box and the subject tried to read the word on the sign. As soon as the subject read the word on the sign, the experimenter recorded the position of the knob on the controller box. For the next trial the distance between the vehicle headlamps and the sign was reduced to 54.86 meters (180 ft) and the same procedure was repeated for all 3 signs shown in random order.

5.8 Statistical Analysis

The field tests were conducted on 10 subjects from the age group 18-34 years. The mean age of this population was 21.1 years. Out of the 10 subjects participated 8 were males and 2 were females. Five of them were wearing corrective lenses while participating in experiment. The subjects were also asked a question about their frequency of nighttime driving. Four subjects said that they drive every day during nighttime, 4 of them said they drive once a week during nighttime. One subject said that she drives twice a week during nighttime while one subject said he does not drive at all at night. One subject had a minor accident in the past 3 years.

A statistical analysis was performed on the data collected from the field tests for each subject. The data collected for each subject was arranged in a way that it can be provided as input required by SAS (Statistical Analysis Software). This data can be seen the Appendix I. The SAS program and the SAS output can be seen in the Appendix J and Appendix K respectively.

Table 5-3 SAS output showing tests of fixed effects

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Distance	1	9.29	5.18	0.0479
Sign	2	35	8.94	0.0007
Distance*Sign	2	35	2.30	0.1154

It can be observed from the SAS output above that both the distance and the sign have significant effects on the ability of the subject to read the signs. There was no interaction between the distance and the sign.

Table 5-4 SAS output showing least square means

Least Squares Means

Effect	Distance	Sign	Estimate	Standard Error	DF	t Value	Pr > |t|
Distance	180		0.04500	0.005763	17.4	7.81	<.0001
Distance	240		0.06221	0.005877	18.3	10.58	<.0001
Sign		1	0.06696	0.005471	19.8	12.24	<.0001
Sign		2	0.04750	0.005365	18.7	8.85	<.0001
Sign		3	0.04635	0.005471	19.8	8.47	<.0001

It can be observed from the SAS output above that sign 2 (DG3) and 3 (Type IV) performed better than the sign 1 (Type I). But it was still not clear whether the signs 2 and 3 performed significantly different from each other or not.

Table 5-5 SAS output showing differences of least square means

```
                              Differences of Least Squares Means

                                                                  Standard
Effect          Distance  Sign  _Distance  _Sign  Estimate      Error    DF  t Value  Pr > |t|

Distance        180             240               -0.01721  0.007558  9.29    -2.28    0.0479
Sign                      1                 2      0.01946  0.005450  35.2     3.57    0.0011
Sign                      1                 3      0.02061  0.005491  34.6     3.75    0.0006
Sign                      2                 3     0.001148  0.005450  35.2     0.21    0.8344
```

It can be seen from the SAS output above that the signs 2 and 3 were not significantly different from each other. So it was concluded that materials DG3 and Type IV perform better than Type I material for nighttime visibility but they are not significantly different from each other. The Kansas Department of Transportation already is using Type IV material for their signs. Based on the results of statistical analysis they can continue using Type IV material. It can be seen from Table 5.6 that Type I material requires the most illumination at both the distances of 73.15 meters (240 ft) and 54.86 meters (180 ft). The difference in the maximum and minimum illumination levels at 73.15 meters (240 ft) distance was larger whereas it was smaller for the distance of 54.86 meters (180 ft).

Table 5-6 Table showing mean illumination level required for subjects to read the words on the sign and corresponding knob position

Sheeting Material	Distance (ft)	Max illumination (lux)	Min illumination (lux)	Mean illumination (lux)	Corresponding knob position
Type I	240	0.17	0.05	0.08	8
DG3		0.17	0.04	0.06	5
Type IV		0.07	0.04	0.05	4
Type I	180	0.07	0.04	0.05	2
DG3		0.04	0.04	0.04	0
Type IV		0.05	0.04	0.04	0

5.9 Experiment for testing of LED light

An LED light was provided to KSU team by Mid-American Signal Company for testing purpose. This was 70 W Cool White LED light. It has total 52 LEDs with 13 LEDs each in four banks. The closer view of the bank of LEDs and the full view of the light can be seen in the Figure 5.6 and Figure 5.7 respectively. An experiment was conducted to check the light distribution of this LED light.

Figure 5-6 Closer view of bank of LEDs and full view of the four banks of LEDs

Figure 5-7 Full view of the LED light

5.10 Design of the experiment for testing of LED light

As per the data provided by Kansas Department of Transportation there is no typical size of the overhead guide signs. It depends upon the length of the destination name. But in general the size of the overhead guide sign is 4.57 meters by 2.74 meters (15 ft by 9 ft) for one line of legend and 4.57 meters by 3.65 meters (15 ft by 12 ft) for two lines of legend. This experiment was conducted in room 1027 of Durland Hall at Kansas State University during evening. The maximum height of the wall of the room was 2.74 meters (9 ft) therefore a 4.57 meters by 2.74 meters (15 ft by 9 ft) grid was created on white paper to replicate the highway overhead guide sign. This grid was divided into squares of 0.3 meters by 0.3 meters (1 ft by 1 ft). As per the drawing provided by Kansas Department of Transportation the distance between the sign and the light is between 1.21 meters (4 ft) to 1.52 meters (5 ft). This drawing can be seen in the Appendix L. The light was positioned 1.52 meters (5 ft) away from the grid on the ground and it was pointed upward to the grid. The light was kept on and one person would measure the illumination readings with Minolta illuminance meter in his hand not obstructing the sensor. The obtained illumination readings in lux can be seen the following table.

Table 5-7 Illumination readings for testing of LED light (lux)

Series	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	240	288	359	433	488	526	514	514	496	462	397	338	267	213
B	216	270	327	392	449	497	510	501	463	411	349	288	235	194
C	179	223	280	338	394	433	447	437	394	345	292	238	190	155
D	178	227	263	367	441	500	518	501	439	374	303	240	183	143
E	178	241	324	426	534	614	640	607	515	416	330	247	183	137
F	169	230	320	442	604	689	716	694	578	450	326	234	162	116
G	100	132	183	285	402	511	499	510	423	323	239	191	126	92.3
H	38.7	40.3	47.3	54.4	60.3	68.4	67.9	64.2	61.3	47.6	51.8	45.4	41.6	36

The graph showing light distribution can be seen in Figure 5.8. It can be seen from the graph that as the distance from the light source goes on increasing in the left or right direction, the intensity of light is reduced. The points which were below the light were having very low illumination levels and can be seen at the bottom of the graph.

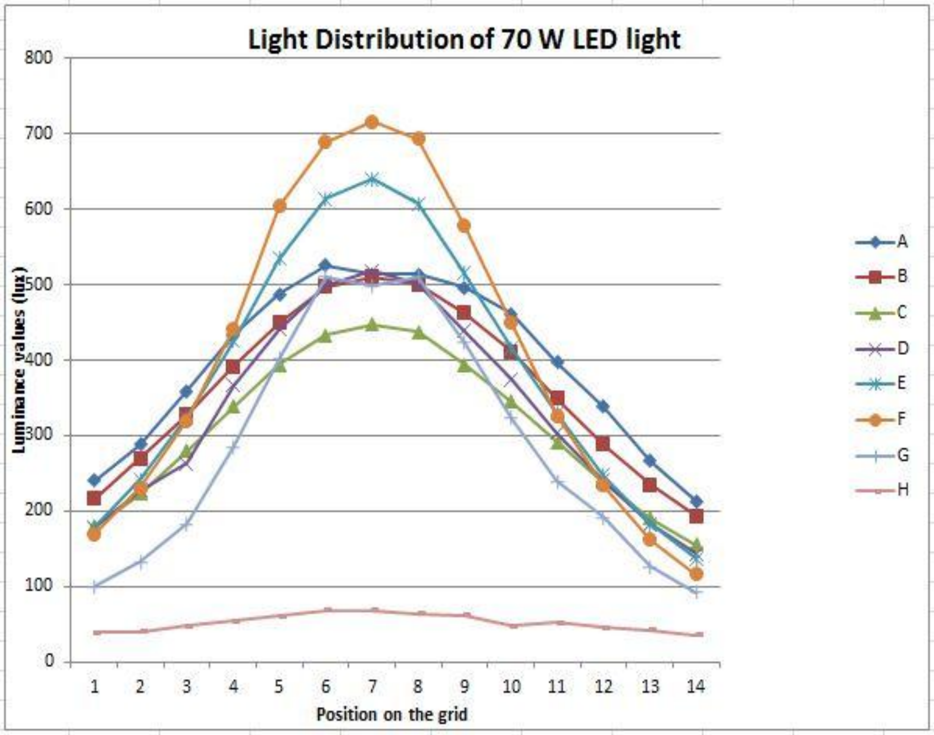


Figure 5-8 Graph showing light distribution for 70W LED light

5.11 Economical comparison of 70W LED lamp versus 250W Metal Halide lamp

Kansas Department of Transportation is currently using 250W Metal Halide lamps at some locations as a source of external illumination for guide signs. One of the objectives of this project was to check if any cheaper and energy efficient source is available to be used as external illumination for guide signs. For this purpose the economical comparison of 70W LED lamp and 250W Metal Halide lamp was done.

The energy consumption for 250W Metal Halide lamp considering the lamp is used 10 hours per day is 2.5 KWH. The electricity charges are $0.08 per KWH. Thus the 250W Metal Halide lamp costs

2.5 x 0.08 = $0.2 per day

The annual cost = $0.2 x 365 = $73

The energy consumption for 70W LED lamp considering the lamp is used 10 hours per day 0.7 KWH. The electricity charges are $0.08 per KWH. The 70W LED lamp costs

0.7 x 0.08 = $0.056 per day

The annual cost = $0.056 x 365 = $20.44

Table 5-8 Economical comparison of 70W LED lamp versus 250W Metal Halide lamp

	70 W LED Light	**250W Metal Halide Lamp**
Initial cost of fixture	$649.35	$200
Operating cost for 10,000 hours	$20.44 per year x 2.73 years = $55.80	$73 per year x 2.73 year = $199.29
Operating cost for 60,000 hours	$334.8	$1,195.74 (without considering the cost of replacement of lamp)

Chapter 6 - Conclusions

Based on the survey analysis it was observed that High Intensity Prismatic and DG3 materials were most often used materials by state DOTs for background and the legend. Series E (Modified) font received 48.54% response making it popular choice for the fonts used on overhead guide signs. Out of 28 respondents 19 said that they have usage policy for the type of sheeting material used for overhead guide signs and 18 of them provided details about their policies. Ten respondents said that they use external illumination for overhead guide signs. The sources of external illumination were Mercury Vapor lamps, Metal Halide lamps and inductions fixtures. Some states are also evaluating LEDs as a potential source of external illumination for overhead guide signs.

It can be seen from the SAS output in the previous chapter that both the distance and the sign were having significant effects on the ability of the subject to read the signs but there was no interaction between the distance and the sign. The signs 2 and 3 performed better than the sign 1 but they were not significantly different from each other. So it can be concluded that the materials DG3 and Type IV perform better than Type I material for nighttime visibility but they are not significantly different from each other.

The economical comparison of 70W LED lamp versus 250W Metal Halide showed that the operating cost of 70W LED light is $55.80 for 10000 hours and that of 250W Metal Halide lamp is $199.29. This proves that the LED lights can be one of the options for replacing the current use of Metal Halide lamps.

6.1 Future work

1. This research included subjects from the age group of 18 to 34 years. The same research can be conducted for different age groups like 35 to 54 and 54 and older population.
2. The vehicle used in this experiment was Chevy Impala (2008). The similar research can be conducted in future using different vehicles.
3. The testing of LED light was conducted at KSU campus. It showed that as the distance from the light source increased to the left or to the right direction, the intensity of light reduced. The Kansas Department of Transportation currently uses 250 W Metal Halide

lamps for guide signs. Similar testing should be performed for these lights and compared to the results obtained from the testing of the LED light.

References

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Appendix A - Minimum Retro-reflectivity Values

Black on Yellow and Black on Orange Warning Signs

Legend Color- Black

Background Color- Yellow or Orange

Table A-1 Minimum retro-reflectivity guidelines for black on yellow and black on orange warning signs

Sign Size		≥48 in*	36 in*	≤30 in*
Legend	Material Type			
Bold Symbol	All	15	20	25
Fine Symbol & Word	I	20	30	45
	II	25	40	60
	III	30	50	80
	IV & VII	40	70	120

*cd/lx/m^2

White on Red Regulatory Signs

Legend Color- White

Background Color- Red

Table A-2 Minimum retro-reflectivity guidelines for white on red regulatory signs

Traffic Speed	45 miles/hr. or greater						40 miles/hr. or less					
Sign Size	≥48 in*		36 in*		≤30 in*		≥48 in*		36 in*		≤30 in*	
	W*	R*	W*	R*	W*	R*	W*	R*	W*	R*	W*	R*
All Signs	50	10	60	12	70	14	30	6	35	7	40	8

*cd/lx/m^2

Black on White Regulatory and Guide Signs

Legend Color- Black and/or Black and Red

Background Color- White

Table A-3 Minimum retro-reflectivity guidelines for black on white regulatory and guide signs

Traffic Speed		45 miles/hr. or greater			40 miles/hr. or less		
Sign Size		≥48 in*	36 in*	≤30 in*	≥48 in*	36 in*	≤30 in*
Material							
Ground Mounted	I	20	35	50	15	20	35
	II	25	45	70	20	30	55
	III	30	60	90	25	45	75
	IV & VII	40	80	120	35	60	100
Overhead Mounted	I				40	50	100
	II				50	75	135
	III				65	115	185
	IV & VII				90	150	250

*cd/lx/m^2

White on Green Guide Signs

Legend Color- White

Background Color- Green

Table A-4 Minimum retro-reflectivity guidelines for white on green guide signs

Traffic Speed	45 miles/hr. or greater		40 miles/hr. or less	
	White*	Green*	White*	Green*
Ground Mounted	35	7	25	5
Overhead Mounted	110	22	80	16

*cd/lx/m^2

Appendix B - State DOT Signing Policies

Idaho DOT signing policy

SECTION 712 - SIGNING MATERIALS

712.02- Reflective Sheeting

1. Materials – Retro-reflectivity sheeting material shall conform to ASTM D 4956, except the minimum coefficients of retro-reflection for brown type I sheeting shown in ASTM D 4956, Table 1 are amended as follows: 2.0 cd/fc/ft2 (2.0 cd/lx/m2) at 0.2° observation angle and -4° entrance angle, 1.0 cd/fc/ft2 (1.0 cd/lx/m2) at 0.2° observation angle and +30° entrance angle and at 0.5°observation angle and -4° entrance angle, and 0.5 cd/fc/ft2 (0.5 cd/lx/m2) at 0.5° observation angle and +30° entrance angle.

   Retro-reflective sheeting material shall conform to ASTM D 4956 supplemental requirement S1 if specified. Reboundable retro-reflective sheeting shall conform to ASTM D 4956 including supplemental requirement S2.
2. Reflectivity Requirements –
   a. Class A. All reflective sheeting used for direct applied legends, borders and sign backgrounds shall meet the retro-reflective requirements of ASTM D 4956, Type I sheeting.
   b. Class B. All reflective sheeting used for reflector units, removable cutout legends, borders, orange colored signs, barricades, drums, vertical panels, and all STOP, YIELD, DO NOT ENTER, and WRONG WAY signs shall meet the retro-reflectivity requirements of ASTM D 4956, Type III sheeting.
3. Fabrication – The reflective sheeting shall be applied on aluminum or plywood sections as required in accordance with the manufacturer's recommendations and in such a manner that no background material will be visible when the sign is assembled.

   Splicing of reflectorized sheeting will not be permitted on panels 24 in. (600 mm) or less in width. On larger panels only one splice will be accepted per sign. Splices shall be horizontal or at 45 degrees from horizontal with the top sheet overlapping the bottom sheet not less than 3/16 in. (5 mm) except for signs screen processed with transparent color which shall have butt splices. Butt splices shall not have a gap of more than 1/32 in.

(1 mm) between the sheets or reflective material. Manufactured splices in the reflective sheeting will be accepted in addition to the above limitations.

Cracks, discoloration, appearance of air pockets, or any other indication of non-adherence in the sheeting will not be accepted.

Finish-Sign edges and all splices of the reflective sheeting shall be sealed in conformance with the methods specified by the reflective sheeting manufacturer.

Direct applied cutout reflective sheeting legends, borders and symbols shall be cut with a smooth regular outline, free from ragged or torn edges. Letters, numerals and symbols having interior or exterior rounded corners shall be cut with a smooth 3/16 in. ± 1/16 in. (5 mm ± 2 mm) radius.

Ohio DOT signing policy

SECTION 630.04

Sign Fabrication

For flat sheet, double faced mile marker, double faced street name and ground mounted extrusheet signs, use Type G, H or J reflective sheeting for background and reflective legends. For overhead extrusheet signs, use Type G, H or J reflective sheeting for the background, and use Type H or J reflective sheeting for reflective legends, shields and symbols (including hazardous cargo plate, airport symbol, arrows and borders). Apply reflective sheeting to the surface according to the manufacturer's recommendations, with no blisters, wrinkles, tears, or blemishes. Do not use reboundable or damage control sheeting for permanent signs.

SECTION 730.19

Reflective Sheeting Type G

Furnish Type G reflective sheeting according to Supplement 1049, and according to ASTM D 4956, Type III or IV, including supplemental requirement S1. Furnish materials according to the Department's Qualified Products List (QPL).

SECTION 730.192

Reflective Sheeting Type H

Furnish Type H reflective sheeting according to Supplement 1049, and according to ASTM D 4956, Type VIII including supplemental requirement S1. Furnish materials according to the Department's Qualified Products List (QPL).

SECTION 730.193

Reflective Sheeting Type J

Furnish Type J reflective sheeting according to Supplement 1049, and according to ASTM D 4956, Type IX, including supplemental requirements S1. Furnish materials according to the Department's Qualified Products List (QPL).

Virginia DOT signing policy

The Clearview Highway font was developed to provide increased visibility and reduced halation (over glow) on highway signs. The Federal Highway Administration (FHWA) has issued an Interim Approval for the optional use of this font, if a jurisdiction submits a written request. VDOT has requested and received a conditional usage statement that will allow us to transition to using Clearview font for positive contrast (white type) legends on guide signs.

Designs for positive contrast guide signs shall now be accomplished using Clearview font, if it is practical to achieve. The legend shall be spaced according to Clearview spacing tables and not E-Modified. Action word messages and cardinal directions shall remain in all upper case letters as specified in the MUTCD. A guide for converting the Standard Highway Signs (SHS) Alphabet to the Clearview font is shown below:

Table B-1 Guide for converting SHS alphabet to Clearview font

SHS Standard Alphabet	Clearview "W" Series
Series B	Clearview 1W
Series C	Clearview 2W
Series D	Clearview 3W
Series E	Clearview 4W
Series E-Modified	Clearview 5W and 5WR*
Series F	Clearview 1W

*Clearview 5-W-R has tighter letter space than 5-W and is designed for replacement of overhead guide signs in which the 5-W is too wide for the specific application

Clearview font shall be fabricated using prismatic sheeting for the legend and permanent Type III (high intensity) or prismatic sheeting for the background. This applies to overhead and ground mounted guide signs. Clearview font may also be used on guide sign overlayments, in accordance with the same specifications and if there is adequate space on the panel.

This does not apply to signs with unique designs using non-highway fonts.

Oregon DOT signing policy

2.0 DESIGNING SIGNS

2.1 Choosing substrate and sheeting types

ASTM TYPE IX –

This sheeting is similar to type VII but has a much wider angularity and is not quite as bright as the type VII. It can be used for ground mounted signs but should be reserved for places where high-impact is needed. It can also be used for background and legend on overhead mounted signs, even extruded panel signs. Viewing distance on this sheeting is up to 800 feet away. Normal usage is for signs mounted on signal poles and other locations where the wide angularity is needed. The warranty on this sheeting is 12 years and is only warranted on aluminum substrate. The sheeting can be used on HDO plywood but there is no warranty when applied to this substrate. This sheeting also comes in fluorescent colors; yellow, yellow-green, and orange. In the fluorescent colors, a ten year warranty applies.

2.3 Designing guide signs

Freeway and expressway design

Legends on all overhead guide signs shall be either ASTM Type VII or ASTM Type IX retro-reflective sheeting. All "Exit Only" panels on overhead guide signs shall be ASTM Type IX and utilize Fluorescent Yellow retro-reflective sheeting.

Appendix C - State DOT sign replacement policy

Ohio DOT sign replacement policy

260-5 Systematic Sign Replacement Program

Highway signs utilize white or colored reflective sheeting materials containing optical elements designed to return a large portion of incident light back towards the source. At night, this property, known as retro-reflectivity, redirects incident light from a vehicle's headlights back toward the vehicle's occupants. Retro-reflectivity allows highway signs to remain visible after dark.

The color and retro-reflective properties of highway signs degrade over time, due primarily to exposure to ultraviolet light and environmental contaminants. Sign color will fade, and retro-reflectivity will be reduced, over time. The purpose of this standard is to assure adequate sign appearance and visibility by establishing a statewide uniform practice for the systematic replacement of permanent traffic control signs on ODOT-maintained highways.

All new permanent traffic control signs are required to be reflectorized with Type G, H or J reflective sheeting *(see Section 220-6)*. It is expected that signs fabricated with Type G, H or J reflective sheeting will have a sign service life of fifteen years. Sign service life is the period of time that a sign has an adequate appearance, proper color retention and contrast, and sufficient retro-reflectivity to effectively convey its message both day and night.

FHWA issued color specifications for retro-reflective sheeting materials in 2002. In addition, FHWA published minimum sign retro-reflectivity requirements in December 21, 2007, with an effective date of January 22, 2008. We expect to have this information incorporated into the OMUTCD within two years. FHWA established the following target compliance dates for the minimum retro-reflectivity requirements:

1. Four years for implementation and continued use of an assessment or management method that is designed to maintain traffic sign retro-reflectivity at or above the established minimum levels;
2. Seven years for replacement of regulatory, warning and ground-mounted guide (except street name) signs that are identified using the assessment or management method as failing to meet the established minimum levels; and

3. Ten years for replacement of street name signs and overhead guide signs that are identified using the assessment or management method as failing to meet the established minimum levels.

To avoid requiring the Districts to periodically measure sign color and retro-reflectivity to determine replacement needs, this Section establishes a procedure for the systematic replacement of traffic control signs based on expected sign service life.

Each District shall develop and implement a program to provide for the systematic replacement of permanent traffic control signs on a fifteen year cycle. This should be done on a route by route basis, with signs on the entire length of a route within a District or County, or on a segment of a route within a District or County, scheduled for replacement on a fifteen year cycle.

The District should make preparations well in advance to provide sufficient time to assure signs are replaced within the recommended time interval. Sign replacements may be by contract or force account, or a combination of the two.

All signs on a route or route segment should be replaced at the same time. Signs that have been installed within two years of the scheduled replacement may remain in place. Type G, H or J signs that are removed that have sufficient remaining service life may be returned to District stocks to be used in maintenance activities (e.g., knockdown replacements).

The District may elect to delay sign replacements on a route segment for up to two years to allow the sign replacement to be combined with other scheduled work for that section of highway, provided the District verifies that the signs have sufficient retro-reflectivity to effectively convey their messages both day and night, and are at or above minimum reflectivity levels established by FHWA.

The District should develop a program to upgrade all existing Type F signs with Type G, H or J signs over an eight year period. Type F signs may remain in the field until they have reached the end of their sign service life.

Appendix D - IRB Approval Letter

KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: Margaret Rys
IMSE
2015 Durland Hall

Proposal Number: 5939

FROM: Rick Scheidt, Chair
Committee on Research Involving Human Subjects

DATE: August 2, 2011

RE: Proposal Entitled, "Determine the Minimum Luminance for Traffic Signs"

The Committee on Research Involving Human Subjects / Institutional Review Board (IRB) for Kansas State University has reviewed the proposal identified above and has determined that it is EXEMPT from further IRB review. This exemption applies only to the proposal - as written – and currently on file with the IRB. Any change potentially affecting human subjects must be approved by the IRB prior to implementation and may disqualify the proposal from exemption.

Based upon information provided to the IRB, this activity is exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, **45 CFR §46.101, paragraph b, category: 2, subsection: ii.**

Certain research is exempt from the requirements of HHS/OHRP regulations. A determination that research is exempt does not imply that investigators have no ethical responsibilities to subjects in such research; it means only that the regulatory requirements related to IRB review, informed consent, and assurance of compliance do not apply to the research.

Any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Committee on Research Involving Human Subjects, the University Research Compliance Office, and if the subjects are KSU students, to the Director of the Student Health Center.

Appendix E - Standard Typefaces for Highway Signs

Series B

Series C

Series D

Series E

Series E Modified

Series F

Appendix F - Standard Spacing for Series E (Modified) Font

Standard Alphabets Spacing Chart

Measurements based on four inch (4") upper case letter height

Series E Modified 2000

Character	Left (inch)	Width (inch)	Right (inch)
A	.160	4.043	.160
B	.560	3.242	.320
C	.400	3.242	.320
D	.560	3.242	.400
E	.560	2.962	.280
F	.560	2.962	.280
G	.400	3.242	.400
H	.560	3.242	.560
I	.560	.800	.560
J	.160	3.042	.560
K	.560	3.282	.080
L	.560	2.962	.080
M	.560	3.722	.560
N	.560	3.242	.560
O	.400	3.362	.400
P	.560	3.242	.160
Q	.400	3.362	.400
R	.560	3.242	.280
S	.440	3.242	.440
T	.160	2.962	.160
U	.560	3.242	.560
V	.160	3.682	.160
W	.160	4.243	.160
X	.280	3.482	.280
Y	.160	4.043	.160
Z	.280	3.242	.280
a	.440	2.642	.800
b	.800	2.642	.440
c	.440	2.642	.440
d	.440	2.642	.800
e	.440	2.642	.440
f	.400	1.681	.440
g	.440	2.642	.800
h	.800	2.642	.800
i	.800	.800	.800
j	.080	1.481	.800
k	.800	2.642	.440
l	.800	.800	.800
m	.800	4.403	.800
n	.800	2.642	.800

Character	Left (inch)	Width (inch)	Right (inch)
o	.440	2.722	.440
p	.800	2.642	.440
q	.440	2.642	.800
r	.800	2.000	.160
s	.360	2.642	.440
t	.360	2.081	.480
u	.800	2.642	.800
v	.360	3.082	.360
w	.360	4.083	.360
x	.440	3.202	.440
y	.360	3.402	.360
z	.480	2.722	.480
1	.480	1.200	.560
2	.440	3.242	.440
3	.120	3.242	.400
4	.120	3.722	.560
5	.440	3.242	.440
6	.400	3.242	.400
7	.240	3.242	.400
8	.400	3.242	.400
9	.400	3.242	.400
0	.400	3.362	.400
&	.400	3.602	.400
!	.560	.800	.560
"	.560	2.281	.560
#	.400	3.522	.400
$	.440	3.242	.440
¢	.400	2.682	.280
/	0	4.283	0
aster	.320	2.241	.320
period	.160	.800	.160
comma / apos	.160	.800	.160
colon	.160	.800	.160
(	.400	1.521	.160
)	.160	1.521	.400
hyphen	.120	1.401	.120
@	.400	4.043	.400
=	.120	2.601	.120
+	.120	2.601	.120
?	.280	2.762	.280

REFER TO FORWARD IN STANDARD ALPHABETS METRIC VERSION FOR NOTES ON APPLICATION OF SPACE VALUES

Appendix G - Sample Consent Form

KANSAS STATE UNIVERSITY
INFORMED CONSENT FORM

PROJECT TITLE: **Determine the Minimum Luminance for Traffic Signs**

APPROVAL DATE OF PROJECT: 08/05/2011 **EXPIRATION DATE OF PROJECT: 09/01/2011**

PRINCIPAL INVESTIGATOR: CO-INVESTIGATOR(S): **Dr. Margaret Rys, Aditya Gund**

CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS: **malrys@ksu.edu, adityag@k-state.edu**

IRB CHAIR CONTACT/PHONE INFORMATION:

- **Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.**
- **Jerry Jaax, Associate Vice President for Research Compliance and University Veterinarian, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.**

SPONSOR OF PROJECT:

PURPOSE OF THE RESEARCH: **The project will consist of finding the minimum illumination requirement for traffic signs for different age groups. It will also consist of determining if the external illumination is required for signs or not.**

PROCEDURES OR METHODS TO BE USED: **The subject will be sitting in a stationary experimental vehicle during nighttime. The subjects will be required to read the word on the sign from different starting points defined by the experimenters.**

LENGTH OF STUDY: **2-3 weeks**

RISKS ANTICIPATED: **None**

BENEFITS ANTICIPATED: **Better traffic signs (made with newer retro-reflective sheeting) can be required on our streets and highways.**

EXTENT OF CONFIDENTIALITY: **Each subject will be given an identification number. Only researchers will know this number. The data will not be link to individual subject.**

IS COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS: **N/A**

PARENTAL APPROVAL FOR MINORS: **N/A**

TERMS OF PARTICIPATION: I understand this project is research, and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

(Remember that it is a requirement for the P.I. to maintain a signed and dated copy of the same consent form signed and kept by the participant)

Participant Name: ______________________________________

Participant Signature: ______________________________________ **Date:** ______________________

Witness to Signature: (project staff) ______________________________ **Date:** ______________________

Appendix H - Data Collection Sheet

Age – 18-22 23-26 27-30 31-34

Gender – M F

Do you wear corrective lenses? Y N

When did you last have your eye checkup?

Month__________ Year_________

How frequently do you drive during nighttime?

Everyday Once in a week once in a month

Did you have any accidents in the past three years while driving at nighttime? If yes please explain.

____

____

Subject	Distance	Sign	Position on the knob	Luminance level
1	240 ft.	1		
		2		
		3		
1	180 ft.	2		
		1		
		3		

Appendix I - Data for statistical analysis

Subject	Distance	Sign	Knob Position	lux
1	240	1	9	0.09
1	240	2	4	0.05
1	240	3	5	0.06
1	180	2	1	0.04
1	180	1	4	0.06
1	180	3	3	0.05
2	240	1	8	0.08
2	240	2	1	0.04
2	240	3	0	0.04
2	180	2	0	0.04
2	180	1	2	0.05
2	180	3	0	0.04
3	240	1	8	0.08
3	240	2	2	0.04
3	240	3	7	0.07
3	180	2	0	0.04
3	180	1	3	0.05
3	180	3	3	0.05
4	240	1	9	0.09
4	240	2	0	0.04
4	240	3	5	0.06
4	180	2	0	0.04
4	180	1	2	0.05
4	180	3	0	0.04
5	240	1	.	.
5	240	2	4	0.05
5	240	3	.	.
5	180	2	0	0.04
5	180	1	1	0.04
5	180	3	0	0.04
6	240	1	15	0.17
6	240	2	15	0.17
6	240	3	4	0.05
6	180	2	1	0.04
6	180	1	4	0.06
6	180	3	3	0.05
7	240	1	4	0.05

Subject	Distance	Sign	Knob Position	lux
7	240	2	0	0.04
7	240	3	0	0.04
7	180	2	0	0.04
7	180	1	0	0.04
7	180	3	0	0.04
8	240	1	7	0.07
8	240	2	0	0.04
8	240	3	0	0.04
8	180	2	0	0.04
8	180	1	2	0.05
8	180	3	0	0.04
9	240	1	6	0.06
9	240	2	1	0.04
9	240	3	4	0.05
9	180	2	0	0.04
9	180	1	5	0.07
9	180	3	0	0.04
10	240	1	4	0.05
10	240	2	0	0.04
10	240	3	1	0.04
10	180	2	0	0.04
10	180	1	3	0.05
10	180	3	0	0.04

Appendix J - SAS program

```
options nocenter;
data;
input Subject     Distance    Sign  Knob  lux;
datalines;
1      240    1      9      0.09
1      240    2      4      0.05
1      240    3      5      0.06
1      180    2      1      0.04
1      180    1      4      0.06
1      180    3      3      0.05
2      240    1      8      0.08
2      240    2      1      0.04
2      240    3      0      0.04
2      180    2      0      0.04
2      180    1      2      0.05
2      180    3      0      0.04
3      240    1      8      0.08
3      240    2      2      0.04
3      240    3      7      0.07
3      180    2      0      0.04
3      180    1      3      0.05
3      180    3      3      0.05
4      240    1      9      0.09
4      240    2      0      0.04
4      240    3      5      0.06
4      180    2      0      0.04
4      180    1      2      0.05
4      180    3      0      0.04
5      240    1      .      .
5      240    2      4      0.05
5      240    3      .      .
5      180    2      0      0.04
5      180    1      1      0.04
5      180    3      0      0.04
6      240    1      15     0.17
6      240    2      15     0.17
6      240    3      4      0.05
6      180    2      1      0.04
6      180    1      4      0.06
6      180    3      3      0.05
7      240    1      4      0.05
7      240    2      0      0.04
7      240    3      0      0.04
7      180    2      0      0.04
7      180    1      0      0.04
7      180    3      0      0.04
8      240    1      7      0.07
8      240    2      0      0.04
8      240    3      0      0.04
8      180    2      0      0.04
8      180    1      2      0.05
8      180    3      0      0.04
9      240    1      6      0.06
```

```
9      240    2      1      0.04
9      240    3      4      0.05
9      180    2      0      0.04
9      180    1      5      0.07
9      180    3      0      0.04
10     240    1      4      0.05
10     240    2      0      0.04
10     240    3      1      0.04
10     180    2      0      0.04
10     180    1      3      0.05
10     180    3      0      0.04
;
*input Subject    Distance    Sign  Knob  lux;
proc print;
run;
proc mixed;
class subject distance sign;
model lux = distance sign distance*sign/ddfm = satterth;
random subject subject*distance;
lsmeans distance sign distance*sign/pdiff adjust = tukey;
run;
quit;
```

Appendix K - SAS Output

Obs	Subject	Distance	Sign	Knob	lux
1	1	240	1	9	0.09
2	1	240	2	4	0.05
3	1	240	3	5	0.06
4	1	180	2	1	0.04
5	1	180	1	4	0.06
6	1	180	3	3	0.05
7	2	240	1	8	0.08
8	2	240	2	1	0.04
9	2	240	3	0	0.04
10	2	180	2	0	0.04
11	2	180	1	2	0.05
12	2	180	3	0	0.04
13	3	240	1	8	0.08
14	3	240	2	2	0.04
15	3	240	3	7	0.07
16	3	180	2	0	0.04
17	3	180	1	3	0.05
18	3	180	3	3	0.05
19	4	240	1	9	0.09
20	4	240	2	0	0.04
21	4	240	3	5	0.06
22	4	180	2	0	0.04
23	4	180	1	2	0.05
24	4	180	3	0	0.04
25	5	240	1	.	.
26	5	240	2	4	0.05
27	5	240	3	.	.
28	5	180	2	0	0.04
29	5	180	1	1	0.04
30	5	180	3	0	0.04
31	6	240	1	15	0.17
32	6	240	2	15	0.17
33	6	240	3	4	0.05
34	6	180	2	1	0.04
35	6	180	1	4	0.06
36	6	180	3	3	0.05
37	7	240	1	4	0.05
38	7	240	2	0	0.04
39	7	240	3	0	0.04
40	7	180	2	0	0.04
41	7	180	1	0	0.04
42	7	180	3	0	0.04
43	8	240	1	7	0.07
44	8	240	2	0	0.04
45	8	240	3	0	0.04
46	8	180	2	0	0.04
47	8	180	1	2	0.05
48	8	180	3	0	0.04
49	9	240	1	6	0.06
50	9	240	2	1	0.04
51	9	240	3	4	0.05
52	9	180	2	0	0.04
53	9	180	1	5	0.07
54	9	180	3	0	0.04
55	10	240	1	4	0.05
56	10	240	2	0	0.04
57	10	240	3	1	0.04
58	10	180	2	0	0.04
59	10	180	1	3	0.05
60	10	180	3	0	0.04

The Mixed Procedure

Model Information

Data Set	WORK.DATA1
Dependent Variable	lux
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Class Level Information

Class	Levels	Values
Subject	10	1 2 3 4 5 6 7 8 9 10
Distance	2	180 240
Sign	3	1 2 3

Dimensions

Covariance Parameters	3
Columns in X	12
Columns in Z	30
Subjects	1
Max Obs Per Subject	60

Number of Observations

Number of Observations Read	60
Number of Observations Used	58
Number of Observations Not Used	2

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-231.39172582	
1	2	-241.57000989	0.00000070
2	1	-241.57012908	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Estimate
Subject	0.000053
Subject*Distance	0.000184
Residual	0.000286

Fit Statistics

-2 Res Log Likelihood	-241.6
AIC (smaller is better)	-235.6
AICC (smaller is better)	-235.1
BIC (smaller is better)	-234.7

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Distance	1	9.29	5.18	0.0479
Sign	2	35	8.94	0.0007
Distance*Sign	2	35	2.30	0.1154

Least Squares Means

Effect	Distance	Sign	Estimate	Standard Error	DF	t Value	Pr > |t|
Distance	180		0.04500	0.005763	17.4	7.81	<.0001
Distance	240		0.06221	0.005877	18.3	10.58	<.0001
Sign		1	0.06696	0.005471	19.8	12.24	<.0001
Sign		2	0.04750	0.005365	18.7	8.85	<.0001
Sign		3	0.04635	0.005471	19.8	8.47	<.0001
Distance*Sign	180	1	0.05200	0.007229	36.7	7.19	<.0001
Distance*Sign	180	2	0.04000	0.007229	36.7	5.53	<.0001
Distance*Sign	180	3	0.04300	0.007229	36.7	5.95	<.0001
Distance*Sign	240	1	0.08193	0.007539	39.1	10.87	<.0001
Distance*Sign	240	2	0.05500	0.007229	36.7	7.61	<.0001
Distance*Sign	240	3	0.04970	0.007539	39.1	6.59	<.0001

Differences of Least Squares Means

Effect	Distance	Sign	_Distance	_Sign	Estimate	Standard Error	DF	t Value	Pr > |t|
Distance	180		240		-0.01721	0.007558	9.29	-2.28	0.0479
Sign		1		2	0.01946	0.005450	35.2	3.57	0.0011
Sign		1		3	0.02061	0.005491	34.6	3.75	0.0006
Sign		2		3	0.001148	0.005450	35.2	0.21	0.8344
Distance*Sign	180	1	180	2	0.01200	0.007558	34.6	1.59	0.1215
Distance*Sign	180	1	180	3	0.009000	0.007558	34.6	1.19	0.2418
Distance*Sign	180	1	240	1	-0.02993	0.009923	23.8	-3.02	0.0060
Distance*Sign	180	1	240	2	-0.00300	0.009689	22.5	-0.31	0.7597
Distance*Sign	180	1	240	3	0.002296	0.009923	23.8	0.23	0.8190
Distance*Sign	180	2	180	3	-0.00300	0.007558	34.6	-0.40	0.6939
Distance*Sign	180	2	240	1	-0.04193	0.009923	23.8	-4.23	0.0003
Distance*Sign	180	2	240	2	-0.01500	0.009689	22.5	-1.55	0.1355
Distance*Sign	180	2	240	3	-0.00970	0.009923	23.8	-0.98	0.3380
Distance*Sign	180	3	240	1	-0.03893	0.009923	23.8	-3.92	0.0006
Distance*Sign	180	3	240	2	-0.01200	0.009689	22.5	-1.24	0.2283
Distance*Sign	180	3	240	3	-0.00670	0.009923	23.8	-0.68	0.5058
Distance*Sign	240	1	240	2	0.02693	0.007855	35.8	3.43	0.0015
Distance*Sign	240	1	240	3	0.03222	0.007967	34.6	4.04	0.0003
Distance*Sign	240	2	240	3	0.005296	0.007855	35.8	0.67	0.5045

Differences of Least Squares Means

Effect	Distance	Sign	_Distance	_Sign	Adjustment	Adj P
Distance	180		240		Tukey-Kramer	0.0479
Sign		1		2	Tukey-Kramer	0.0030
Sign		1		3	Tukey-Kramer	0.0018
Sign		2		3	Tukey-Kramer	0.9759
Distance*Sign	180	1	180	2	Tukey-Kramer	0.6117
Distance*Sign	180	1	180	3	Tukey-Kramer	0.8382
Distance*Sign	180	1	240	1	Tukey-Kramer	0.0497
Distance*Sign	180	1	240	2	Tukey-Kramer	0.9996
Distance*Sign	180	1	240	3	Tukey-Kramer	0.9999
Distance*Sign	180	2	180	3	Tukey-Kramer	0.9986
Distance*Sign	180	2	240	1	Tukey-Kramer	0.0021
Distance*Sign	180	2	240	2	Tukey-Kramer	0.6366
Distance*Sign	180	2	240	3	Tukey-Kramer	0.9219

Distance*Sign	180	3	240	1	Tukey-Kramer	0.0048
Distance*Sign	180	3	240	2	Tukey-Kramer	0.8150
Distance*Sign	180	3	240	3	Tukey-Kramer	0.9835
Distance*Sign	240	1	240	2	Tukey-Kramer	0.0181
Distance*Sign	240	1	240	3	Tukey-Kramer	0.0035
Distance*Sign	240	2	240	3	Tukey-Kramer	0.9837

Appendix L - Standard for distance of light from the sign