Determining Cost-Effective Policy for Visibility of Overhead Guide Signs on Highways

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Overhead guide sign visibility on highway, can be achieved either by illumination or by using retroreflective sheeting. Two surveys were sent to all U.S. departments of transportation, to determine the states' policies for increasing overhead guide sign visibility. Results showed that 57% of states currently illuminate guide signs, and the most used retroreflective sheeting by states that do not illuminate signs is Diamond Grade for legend and High Intensity for background. Based on cost analysis, the LED light source and the High Intensity (types III and IV) retroreflective sheeting are the most cost-effective methods for increasing guide signs visibility.

INTRODUCTION

Drivers of all ages often experience more difficulty driving at night as compared with daytime driving. Different issues related to driver visibility of the road include a driver's visual acuity, contrast sensitivity, distance judgment, and color discrimination (Lagergren 1987). Guide signs are typically green signs located along a roadway to notify drivers of destinations and exit information. Overhead guide signs are important for improving driver guidance. The objective of these signs is to provide drivers with information regarding destinations and necessary instructions for reaching specific destinations. As stated by Bullough et al. (2008) "overhead highway signs must be highly visible and legible so that drivers can detect, read and interpret the information contained on the signs in time to respond appropriately" (Bullough, Skinner, and O'Rourke 2008).

As required in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), overhead guide signs must either be illuminated or retroreflective (FHWA 2009). Many departments of transportation (DOTs) in the United States are considering whether to illuminate the current overhead guide signs or replace these signs by brighter retroreflective sheeting to improve their visibility to drivers, especially elderly drivers, during nighttime. The 2009 MUTCD specifies minimum levels of retroreflectivity for signs. Retroreflectivity is an optical phenomenon in which the reflected light rays returned in an opposite direction that is close to the direction from which the rays came (Austin and Schultz 2009). The objective of the minimum retroreflectivity requirement is to improve safety on U.S. roadways by ensuring that roadway users, especially the elderly, are able to detect and react completely to traffic signs in order to facilitate safe, uniform, and efficient travel (Jonathan and Carlson 2012). Roadway lighting also contributes to highway safety by increasing drivers' visual comfort and reducing driver fatigue (IDOT 2002).

Energy conservation is essential in the midst of a worldwide energy crisis. As of 2007, in the United States, the estimated street and area light sources number was 131.356 million with a total annual consumption of 178.3 billion kWh (Navigant Consulting Inc. 2008). In addition, U.S. road lighting is estimated to be 14 billion kWh of the annual energy, which represents approximately 3% of total electricity consumption in the United States (Li et al. 2009).

Problems directly related to the energy crisis force DOTs to study the use of energy-efficient lighting technology used for street lighting, including overhead guide sign lighting. This paper presents the results of two surveys, a lighting survey and a retroreflectivity survey, related to overhead guide sign visibility. In addition, a detailed cost analysis is conducted among six types of light sources used by state DOTs, in order to find the most cost effective source. Similarly, a cost analysis of three retroreflective sheeting used by states DOTs is provided to find the most cost-effective retroreflective sign sheeting.

LITERATURE REVIEW

Traveling on U.S. roadways can be confusing and challenging for all drivers if driving routes are not easily understood or clearly marked, especially when the driver is unfamiliar with the driving location (Amparano and Morena 2006). This issue can be enormous for older drivers, especially those who have cognitive or physical disabilities (Amparano and Morena 2006). However, various engineering opportunities such as sign placement, legibility of sign lettering, retroreflectivity, and sign size can enhance a driver's ability to detect signs and comprehend sign messages.

The American Society for Testing and Materials (ASTM) details sheeting material components that can be used in constructing retroreflective guide signs. ASTM D4956 –11a is a standard that describes the different types of retroreflective sheeting material that can be used on traffic signs (ASTM 2011). According to ASTM D4956 - 11a standard, there are 11 types of retroreflective sheeting with a variety of applications (ASTM 2011).

The 2009 MUTCD minimum retroreflectivity requirements refer to sheeting types as defined in ASTM D4956. A common problem associated with retroreflective sheeting, however, is that even though a particular type of sheeting may initially meet minimum retroreflectivity levels, it may quickly degrade below minimum retroreflectivity levels because of weather or other environmental causes. The MUTCD has no instructions about the longevity of sheeting materials used for overhead guide signs. Agencies may overcome this problem by using higher performance sheeting, which may have a higher initial cost but remain above the minimum retroreflective requirement longer and provide a more efficient life-cycle cost.

Guide signs must be visible and clear for intended drivers in order to allow for proper driving response time. Desirable attributes for guide signs include high visibility and legibility during daytime and nighttime. Legibility is defined as adequately sized letters, symbols, or arrows, and a short legend for quick comprehension by a road user approaching a sign (Gowda 2010).

The use of retroreflective sheeting materials for signs is beneficial in making them more conspicuous, especially in high visual "noise" locations (Amparano and Morena 2006). Research performed at the University of South Dakota shows that the time required by senior drivers to detect signs in complex backgrounds can be reduced significantly by using super-high-intensity sheeting materials (Amparano and Morena 2006). Also, detection distance for fluorescent signs is significantly greater than non-fluorescent signs for both younger and older drivers, though older drivers benefited the most.

McGee and Paniati (1998) performed a study, in which they created an implementation guide for determining minimum retroreflectivity requirements for traffic signs, to assist governmental and private agencies in the establishment of a cost-effective program for the replacement of ineffective traffic signs (McGee and Paniati 1998). The researchers provided a description of different types of retroreflective sheeting materials and the difference among them according to the coefficient of retroreflection at different entrance and observation angles. The observation angle can be defined as the angle between a retroreflected beam toward an observer's eye and the line formed by the light beam striking a surface, and the entrance angle is the angle between a headlamp ray to the sign and a line perpendicular to the sign face. The researchers also quoted minimum retroreflectivity values for four groups of signs based on earlier research. In addition, the report presented the concept of Sign Management System that was defined by a coordinated program of policies and procedures, ensuring that highway agencies provide a sign system that meets drivers' needs according to budget constraints (McGee and Paniati 1998). In their research, McGee and Paniati (1998) suggest planning and developing an effective sign inventory process, including the involvement of key personnel, selecting a location as a reference system, selecting data elements, selecting inventory software, preparing for data collection, starting initial data collection, and maintaining inventory.

In a study performed by Bullough et al. (2008), researchers concluded that the measured luminance values, the resulting calculated luminance contrasts, and the visual response values indicated that in terms of visual performance, unlighted highway signs and new signs constructed from four types of retroreflective materials are similar to externally illuminated signs meeting the American Association of State Highway and Transportation Officials (AASHTO 2005) recommendations for guide sign illumination from a 328.083 ft (or 100 meters) viewing distance (Bullough, Skinner, and O'Rourke 2008). The important factors in their study include location of the signs relative to vehicles, headlight condition, ambient illumination, and other factors affecting actual luminance of sign background and characters.

Jonathan and Carlson (2012) performed a study in which four states (New York, Minnesota, Arizona, and Missouri) were selected to provide examples of effective and beneficial practices demonstrating how various agencies meet the MUTCD roadway sign retroreflectivity requirements. Researchers used three sources to gather information: (1) existing published research, (2) existing guidance and policies, and (3) a telephone survey. The survey included 14 questions, and 48 public agencies participated. Survey findings identified several strategies and techniques that were considered effective practices among the states. Among participating states and local agencies, the decision to replace a sign was based on four methods: (1) The expected sign life method was the most selected method for replacing signs (approximately 37.5%), (2) the most popular practice among participating states was nighttime visual inspection, involving training programs to ensure inspector proficiency (32.5%); (3) about 20% of agencies performed the blanket replacement method; and (4) 5% of agencies used the process of measuring retroreflectivity. However, the process of measuring retroreflectivity and control sign methods is associated with high cost due to the expensive retroreflectometer used and time spent taking measurements. Cost and time are crucial deciding factors in whether to use these methods or not. Purchasing a retroreflectometer can be expensive; however, resulting measurements could be valuable enough to justify the extension of sign replacement periods. Replacing signs based on retroreflectivity measurements can be time-consuming, though. If an agency has a retroreflectometer, maximum benefit is derived when used in conjunction with daily routine maintenance.

BASICS OF ILLUMINATION AND RETROREFLECTIVITY

Roadway lighting is a basic public amenity that contributes to a safer environment for drivers and pedestrians. Personal security, traffic flow operations, and safety can be improved by efficient roadway lighting (Medina, Avrenli, and Benekohal 2013). Drivers can easily recognize street conditions and geometry of the roadway with proper roadway lighting.

Overhead guide signs can be illuminated from the back, or back-illuminated, by using external light sources that illuminate the sign face (Bullough, Skinner, and O'Rourke 2008). External light sources are light fixtures designed to illuminate overhead guide signs by transforming electrical power into a visible light. Retroreflective sheeting materials can also be used to enhance overhead guide sign visibility for drivers.

Signs manufactured with retroreflective sheeting materials are commonly used on U.S. highways (Bullough, Skinner, and O'Rourke 2008). One important advantage of using retroreflective sheeting materials is that they do not require electrical power because they rely on efficient retroreflection of illuminance from oncoming vehicle headlamps which is reflected back toward the vehicle.

It is important to distinguish between two important terms: "efficiency" and "efficacy." Efficiency is used when both input and output units are equal. The term efficacy is used when input and output have two different units, i.e., for measuring luminous efficacy, the input unit is "watt" and the output is "lumen" (USDOE 2009).

A light source is a device that actually converts electrical energy to visible light in a specific manner based on the source type. Because of human eyes' shift response to light levels at nighttime, light sources that produce greater short-wavelength (blue) light are relatively more effective for vision than those associated with little short-wavelength light, even if the level of measured light is the same (Bullough 2012a). One wavelength is the distance between two consecutive corresponding points of the same wave. Light sources used for roadway illuminating devices can be categorized into conventional lighting including incandescent lamps and electric discharge lamps, and into new light source generation, including Light Emitting Diode (LED) and induction lighting.

In incandescent lamps, an electrical current passes through a wire causing it to heat up to a certain level, which allows the wire to glow and emits light (Lopez 2003). According to Lopez (2003), two important types of incandescent lamps exist: common incandescent and tungsten halogen. Both types are low in cost, but they have low efficacy (lumen per watt). Electric discharge light sources produce light through the passage of an electric current through a vapor or gas instead of through a tungsten wire as in incandescent lamps (Lopez 2003). According to Lopez (2003), five common types of electric discharge light sources exist: fluorescent, induction fluorescent, mercury vapor (MV), high pressure sodium (HPS), low pressure sodium (LPS), and metal halide (MH). Two types of MV light sources are available in the market: clear light and phosphor-coated light. MV light sources include a phosphor-coated light source primarily used for sign lighting (Lopez 2003). In the HPS, light is produced by an arc in a ceramic tube containing sodium and other elements (Lopez 2003). In the LPS, light is produced by an arc in a long tubular glass envelope (bulb) containing sodium only (Lopez 2003). The MH light source is similar to the mercury light source, but in addition to mercury it contains various metal halides, which provide excellent color rendering and result in a white light (Lopez 2003). Metal halides are compounds between metals and halogens. Induction lighting is a modern fluorescent lamp that uses radio frequencies to stimulate lamp material to produce light, unlike conventional fluorescent lamps that use electrodes at either end of the lamp tube (Bullough 2012b). Induction lighting is a new lighting technology with some advantages over conventional lighting in the areas of efficacy and lifespan (Deco Lighting 2012). LEDs are "semiconductors that emit light when electrical current runs through them" (Avrenli, Benekohal, and Medina 2012).

SURVEY AND SURVEY ANALYSIS

Two surveys were sent to each of the 50 DOTs in the United States via e-mail. The first survey will be referred to as the "retroreflectivity survey." This survey was collected between February and March 2011. The motivation behind this survey was to obtain information from DOTs related to overhead guide signs, including type of sheeting material used, sign maintenance and inventory, and retroreflectivity measurement. The other survey will be referred to as the "lighting survey." This survey was collected between August 9 and September 15, 2012. The motivation behind the lighting survey was to obtain information from DOTs related to overhead guide signs, including current usage of overhead guide sign lighting, light source types and optical packages used in overhead guide signs illumination, policy and/or procedures used in designing and installing overhead guide signs, and any new types of guide sign illumination used or planned to be used in the future.

Analysis of the Retroreflectivity Survey

Responses to the retroreflectivity survey were received from 28 DOTs (56%). A discussion of each question in the retroreflectivity survey follows.

1. *Does your agency have a usage policy or policies for the type of sheeting material used for overhead guide signs?* (*Yes or No*)

A total of 19 states (68%) responded "Yes," seven states (25%) responded "No," and two states (7%) did not give any response.

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 legend of a sign represents the information part on the sign. For a sign's legend and background, some states use two or more types of sheeting material. For sign legend, the majority of states are using Diamond Grade (types IX and XI), followed by High Intensity (types III and IV). For sign background, the majority of states are using High Intensity (types III and IV), followed by Diamond Grade (types IX, and XI).

3. *What type of font does your agency use for overhead guide signs?*
Some states use more than one font on signs. The majority of states are using Series E (Modified) font, Clearview 5W font, and Clearview 5WR font.

4. *What minimum value of retroreflectivity does your agency use for overhead guide signs? Please mention the values used for legend and background separately.*
A total of 11 states use the MUTCD minimum values for retroreflectivity values of overhead guide signs. Other states have minimum retroreflectivity values, as shown in Table 1.

Table 1: Specific Values of Retroreflectivity Used by DOTs for Overhead Guide Signs

Retroreflectivity Value for Background ($cd/lux/m^2$)*	**Retroreflectivity Value for Legend ($cd/lux/m^2$)***
Lighted - 30, Unlighted - 35	Lighted - 250, Unlighted - 380
25	250
38	380
45	250

* The unit of retroreflectivity is ($cd/lux/m^2$), where cd is candela, which is the SI unit of luminous intensity, lux is the SI unit of illuminance, and m is meter.

5. *Does your agency keep inventory of in-service traffic signs?* (*Yes or No*)
A total of 15 states (54%) responded "Yes," 11 states (39%) responded "No," and two states (7%) did not respond.

6. *Does your agency use computerized databases to keep track of inventory?* (*Yes or No*). *If your answer was 'Yes,' how often does your agency update sign inventory?*
A total of 16 states (57%) responded "Yes," nine states (32%) responded "No," and three states (11%) did not respond. Updating the sign inventory schedule by states is performed as follows: Eight states (53.3%) update the schedule daily, three states (20%) update the schedule annually, one state (6.7%) updates the schedule weekly, one state (6.7%) uses other schedules, and two states (13.3%) did not respond.

7. *Does your agency perform any activities for sign maintenance?* (*Yes or No*). *If your answer is 'Yes,' please specify the maintenance activity.*
A total of 20 states (71%) responded "Yes," five states (18%) responded "No," and three states (11%) did not respond. Sign maintenance activities performed by states DOTs include replacing signs based on states' replacement policies (10 to 12-year cycle), repairing damaged signs, sign cleaning, and annual daytime and nighttime sign inspection.

8. *How often does your agency perform the inspection of traffic signs? Please specify.*
   A total of 13 states (46.4%) perform annual inspection, 10 states (35.7%) perform inspection without specific schedule, one state (3.6%) performs monthly inspection, one state (3.6%) did not respond, and three states (10.7%) perform inspection biannually.

9. *What type of inspection activity does your agency perform? Please specify.*
   Some states perform more than one activity (because the states are using more than one procedure, percentage addition will not match 100%): 10 states (30.3%) perform daytime and nighttime visual inspection, eight states (24.2%) perform nighttime visual inspection, five states (15.2%) perform visual inspection, two states (6.1%) did not respond, and eight states (24.2%) responded with additional inspection types such as taking retroreflectivity readings of suspect signs, replacing signs on a 12-year cycle, having no inspection program, performing random nighttime and daytime inspection, or using a combination of expected sign life and blanket replacement methods to maintain retroreflectivity.

10. *Does your agency use any instrument for measuring retroreflectivity?* (*Yes or No*).
    A total of 15 states (53.5%) responded "No," eight states (28.5%) responded "Yes," and five states (18%) did not respond.

11. *If your agency does not use any instrument for measuring retroreflectivity, what method do you follow to measure retroreflectivity of traffic signs?*
    A majority of state DOTs that do not use any instrument for measuring retroreflectivity use alternative methods to measure traffic sign retroreflectivity, including nighttime visual inspection. Some states perform sign replacement before retroreflectivity falls below the minimum required levels by the MUTCD.

12. *How frequently does your agency perform the measurement of retroreflectivity?*
    A total of six states (21.4%) measure retroreflectivity annually, one state (3.55%) measures biannually, two states (7.15%) do not measure retroreflectivity, seven states (25%) did not respond, and 12 states (42.9%) responded that they measure in other ways, meaning no specific schedule is available.

13. *Does your agency use external illumination for overhead guide signs?* (*Yes or No*). *If your answer to the above question is 'Yes,' what light source does your agency use for external illumination of the overhead guide signs?*
    A total of 10 states (36%) responded "Yes," 14 states (50%) responded "No," and four states (14%) did not respond. Major sources used for overhead guide sign illumination include MV, MH, HPS, induction lighting, and LED.

14. *Does your agency follow the replacement policy for overhead guide signs?* (*Yes or No*)
    A total of 13 states (46%) responded "Yes," nine states (32%) responded "No," and six states (22%) did not respond.

Analysis of the Lighting Survey

Responses to the lighting survey were received from 31 DOTs (62%). A discussion of each question in the lighting survey follows.

1. *Does your state currently use lighting for some overhead guide signs?*
   Among the 31 states that responded, responses were divided into two scenarios for analysis. Scenario 1: 12 states (38.7%) responded "Yes," 14 states (45.2%) responded "No," and five states (16.1%) responded that they had used sign lighting in the past but were currently phasing

it out. Scenario 2: States that currently illuminate guide signs but are phasing out illumination are counted as illuminating overhead guide signs. As a result, 17 states (54.8%) responded "Yes," and 14 states (45.2%) responded "No."

In the retroreflectivity survey shown previously, question 13 related to question one in the lighting survey. Answers to this question resulted in the inclusion of three additional states to the lighting survey. In another survey conducted by AASHTO Joint Technical Committee in December 2010, (AASHTO Survey), data were found for one additional state, and this state does not illuminate highway signs (AASHTO 2011).

The following are the updated scenarios after combining the results of the three surveys (involving 35 states). Scenario 1: In regard to whether states are using overhead guide sign lighting, 14 states (40%) responded "Yes," 15 states (42.9%) responded "No," and six states (17.1%) responded that they used overhead guide sign lighting in the past but are currently phasing it out. Scenario 2: States that currently illuminate guide signs but are phasing out illumination are counted as illuminating overhead guide signs. As a result, 20 states (57.15%) responded "Yes," and 15 states (42.85%) responded "No."

2. *What lamp type is currently used in the illumination of overhead guide signs in your state? (e.g., Metal Halide, High Pressure Sodium, Induction Lighting, LED, or others)*
   For the 17 states (54.8%) that responded to the lighting survey and answered that they light overhead guide signs, the lamp types used for illumination are MH, HPS, MV, Induction lighting, and LED. Results for question 13 in the retroreflectivity survey for the three additional states that are illuminating their overhead guide signs were also included. Among the 20 states that use lighting for overhead guide signs, including states in the retroreflectivity survey, five states (25%) (Alabama, Missouri, Oregon, West Virginia, and Wyoming) use MH lighting only. Six states (30%) (Alaska, Idaho, Illinois, Iowa, Nebraska, and Virginia) use HPS. Two states (10%) (Wisconsin and Texas) use MV. One state (5%), Florida, uses Induction lighting, and South Dakota (5%) uses LED lighting. Combining the remaining states (25%), they use two types of lighting. Kansas and North Carolina use MV and HPS, South Carolina uses MV for greater light clarity, and Utah uses HPS and some Induction lighting. One state, New Mexico, did not disclose what type of lighting they use.

3. *Which optical package is typically used for the lighting in your state? (e.g., reflector/clear flat glass, refractor, stippled flat glass, or others)*
   Two types of glass related to overhead guide sign lighting are used by DOTs: clear glass and prismatic glass. Prismatic glass has one smooth side and the other formed into sharp-edged ridges to reflect the light that passes through.

4. *Are AASHTO or Illuminating Engineering Society (IES) sign lighting levels used in the design of your overhead guide sign lighting or are installations based on historical practice and/or experience?*

   Among the 17 states that responded that they are lighting their overhead guide signs, three states (17.65%) (Idaho, South Carolina, and South Dakota) use AASHTO standards, four states (23.53%) (Alabama, Illinois, West Virginia, and Wyoming) use IES standards, three states (17.65%) (Florida, North Carolina, and Utah) use both AASHTO and IES standards, three states (17.65%) (Alaska, Oregon, and Texas) use historical practice and experience, one state (5.87%), Virginia, has its own standards and policies, and three states (17.65%) (Iowa, Nebraska, and New Mexico) have or use no standards or specifications.

5. *Are you looking at other emerging sources for your overhead guide signs lighting? (e.g., Ceramic Metal Halide, Induction lighting, LED, Plasma, or other)*
   Among the 17 states that answered "Yes" to question one in the lighting survey, 11 states (64.7%) answered "Yes," and six states (35.3%) answered "No." The states that answered "Yes" are divided into four groups according to their reported future plans. The first group of six states (54.55%) (Florida, Idaho, South Dakota, South Carolina, Virginia, and West Virginia) includes those looking to switch to LED lighting. The second group includes two states (18.18%) (Oregon and Wyoming) that are transitioning to induction lighting. The third group, comprising two states (18.18%) (North Carolina and Utah), includes those hoping to use or upgrade retroreflective sheeting on overhead guide signs. The last group comprises one state (9.09%), Illinois, which is trying to eliminate overhead guide sign lighting. States that answered "No," including Alabama, Alaska, Iowa, Nebraska, Texas, and North Carolina, are attempting to eliminate guide sign lighting with retroreflective sheeting on guide signs.

SURVEYS SUMMARY

In summary, some states are moving toward discontinuation of overhead guide sign illumination and transitioning to brighter retroreflective sheeting material. Other states are modifying lighting and moving toward new energy efficient light source types such as LEDs and induction lighting.

From the retroreflectivity survey, 68% of the states responded that they have policies for the types of sheeting material used for overhead guide signs. For legend, the most used sheeting material by state DOTs is Diamond Grade (types IX and XI) followed by High Intensity (types III and IV). For background, the most used sheeting material by state DOTs is High Intensity (types III and IV) followed by Diamond Grade (types IX and XI). The popular font size selected by state DOTs is Series E (Modified), followed by Clearview 5W and Clearview 5WR.

Regarding minimum retroreflectivity values of the guide signs, most states follow MUTCD minimum values, while other states have their own minimum values, as shown in Table 1. Approximately 71% of state DOTs perform activities related to sign maintenance, while 18% do not. Approximately 46% of the states perform annual inspection of traffic signs, and 35% perform unscheduled inspection. 46% of state DOTs have policies to replace overhead guide signs, while 32% do not.

From the lighting survey analysis, including analysis of the two other surveys (retroreflectivity and AASHTO), states have two procedures or future plans for improving overhead guide sign visibility during nighttime: (1) illuminating signs, usually with newer, more efficient light sources, or (2) using newer, brighter retroreflective sheeting material. The main objective is to provide adequate sign visibility while saving energy and reducing cost. Among states surveyed, 57% illuminate overhead guide signs and 43% do not. According to states that responded to the lighting survey and illuminate their signs, the most common light sources currently used in illuminating overhead guide signs are MH, MV, HPS, induction lighting, and LED.

In designing overhead guide sign lighting, states may refer to AASHTO standards, IES standards, both AASHTO and IES standards, historical practices and experiences, or to a state's own standards. States' future plans for overhead guide signs are distributed between modifying existing overhead guide sign lighting into new, more efficient methods of illumination, which save energy and cost, or using guide signs with using new, brighter retroreflective sheeting.

LIGHT SOURCES COST ANALYSIS

Various companies were contacted regarding the cost of six light sources. Four companies sent us valuable information about the cost and the lifespan of the light sources. The information obtained regarded light sources that have a 250W high intensity discharge equivalent: the 70W Cool White

LED, the 81W LED, the 62W LED, the 75.4W LED, the 85W induction lighting, and the 250W MH.

Cost calculations were based on using the light source for an average of 11-hour per night (average daily operating hours), and the price of electricity is assumed to be $0.08 per kW. Labor and equipment costs were not included.

In this section, a detailed comparison between the six light sources is presented. As shown in Table 2, the least common value for the lifespan of the six light source types is 75 years. Actually, none of the six light sources will be utilized for this entire period of time, thus 50 years was selected for the sake of comparison. The reason for selecting this period is to include the maintenance effect of the different light sources over time.

The actual information we obtained about the lifespan of the 81W LED and the 85W induction is different than that shown in Table 2. The manufacturers of these two types of light sources claim that the lifespan for each light source is 100,000 hours. Other manufacturers doubt that these light sources will have a lifespan of 100,000 hours. Generally, in the case of the LED, the threshold of lumen output will not be 70% of initial lumens based on information from a study by Neary and Quijano (2009). Because of this concern, the 81W LED and the 85W induction lighting lifespan will be considered to be 50,000 hours instead of 100,000 hours in the comparison, which will increase the lifespan safety margin.

The cost analysis shown in Table 2 includes the following cost components of each light source: initial, operating, and maintenance. Based on the average annual cost of each light source as shown in Table 2, the 85W induction light source is the most cost-effective, followed by the 62W LED, the 81W LED, the 75.4W LED, the 70W LED, and the 250W MH. Considering the annual power consumption, the 62W LED is the most effective in power consumption.

Considering Table 2, the data of initial light source cost and lifespan in hours for each source were obtained from the manufacturers. Life in years is calculated by dividing the life in hours by the average daily operating hours (11-hours) and dividing the result by 365 (days per year). i.e., the 70W LED life is approximately 15 years (60,000 hours/ [11-hour per day × 365 days per year]). The daily power consumption is calculated by multiplying the wattage consumed per hour for each light source by the average daily operating hours, i.e., the daily operating hours of the 70W LED is 0.77 kW (0.07 kW × 11-hour). The annual power consumption is calculated by multiplying the daily power consumption by 365 (days per year), i.e., for the 70W LED, the yearly power consumption is 281kW (0.77 kW per night × 365 days per year). The power consumption per life is calculated by multiplying the yearly power consumption for each light source by the hours per life and then dividing by the average operating hours per day and then dividing by 365 days per year, i.e., for the 70W LED, the power consumption during life is 4,199 kW (281 kW × 60,000 hours / [11-hour × 365-day]). Number of required maintenance during a 50-year period is calculated by dividing the 50-year period by the lifespan in years for each light source and subtracting one. One is subtracted because it is assumed that at the first-time installation no maintenance is required, and the light source is ready to be used, i.e., in the case of the 70W LED, the number of maintenance during the 50-year period is 2.33 times ([50-year/15-year]-1). Total power consumption in the 50-year period is calculated by multiplying the power consumption per year times 50, i.e., in the case of the 70W LED, the power consumption during the 50-year period is 14,050 kW (281kW × 50-year). The daily operating cost of each source is calculated by multiplying the daily power consumption by the electricity price ($0.08 per kW). i.e., for the 70W LED, the daily operating cost is $0.0616 (0.77 kW × $0.08). The annual operating cost is calculated by multiplying the daily operating cost by 365 days per year, i.e., for the 70W LED, the annual operating cost is $22.48 ($0.0616 × 365-day). The life operating cost is calculated by multiplying the annual operating cost by the light source lifespan in hours, then dividing by the daily operating hours and then dividing by 365 days per year, i.e., for the 70W LED, the life operating cost is $336 ($22.48 × 60,000 hours/ [11-hour × 365-day]).

Table 2: Lighting Sources Cost Comparison

			81W LED					
	Details	**70W LED**	**No Defrost**	**With Defrost**	**62W LED**	**75.4W LED**	**85W Induction**	**250W MH**
1	Initial cost ($)	1195.74	550.8	730.8	600	675.75	678.3	678.3
2	Life (hours)	60,000	50,000	50,000	50,000	50,000	50,000	30,000
3	Life (years)	≅ 15	≅ 12.5	≅ 12.5	≅ 12.5	≅ 12.5	≅ 12.5	≅ 7.5
4	Daily power consumption (kW)	0.77	0.891	1.463	0.682	0.8294	0.935	2.75
5	Annual power consumption (kW/year)	281	325.2	393.86[1]	248.93	302.73	341.3	1,003.75
6	Life power consumption (kW)	4,199	4,049.8	4,904.8	3,100	3,770	4,250.31	7,500
7	Number of maintenance in 50-year	2.33	3	3	3	3	3	5.66
8	Total power consumption (kW/50-year)	14,050	16,260	19,693	12,446.5	15,136.5	17,065	50,187.5
9	Daily operating cost ($)	0.0616	0.07128	0.11704[2]	0.05456	0.06635	0.0748	0.22
10	Annual operating cost ($)	22.48	26.02	31.51	19.91	24.22	27.30	80.30
11	Life operating cost ($)	336	324	392.4	248	301.6	340	600
12	Maintenance required	Replace fixture	Replace fixture	Replace fixture	Replace fixture	Replace fixture	Replace lamp	Replace lamp
13	Maintenance cost($/each time required)	1,195.74	550.80	730.8	600	675.75	75.00	30.00
14	Total maintenance cost ($/50-year)	2,786.07	1652.4	2192.4	1,800	2,027.25	225.00	169.8
15	Total operating cost ($/50-year)	1,124	1,301	1,575.5	995.72	1,211	1,365	4,015
16	Total Cost ($/50-year)	5,105.8	3,504.2	4,498.7	3,395.72	3,914	2,268.3	4,863.1
17	Average annual cost ($)	102.12	70.08	89.97	67.91	78.28	45.37	97.26

[1]Considering the operating time for the defrost option is only four months.

[2]This number is calculated considering the defrost option is being used.

The required maintenance is related to the light source type. For all LED types, the required maintenance is replacing the entire light source fixture. For the other light source types, replacing the lamp is the main required maintenance. The LED maintenance cost will be equal to the initial installation cost at each time required; and here an assumption is used in that the cost will be the same over time, i.e., in the case of the 70W LED, 2.33 maintenance times required during 50 years for a total maintenance cost of $2,786.07 (2.33 times × $1,195.74).

The total cost for each light source during the 50-year period is calculated by adding the initial cost of the light source, the operating cost during 50 years, and the maintenance cost during 50 years, i.e., for the 70W LED, the total cost is $5,105.8 ($1195.74 + $1124 + $2,786.07). The average annual cost is calculated by dividing the total cost by 50, i.e., for the 70W LED, the average annual cost is $102.12 ($5,105.8/50-year).

For the LED light source, a defrost option may be required for the 81W LED if it is used in areas that experience a lot of snow and frost during the winter. The initial cost of the defrost option is approximately $180. If the 81W LED light source is equipped with the defrost option and the unit is energized, it consumes an additional 52W per hour if the ambient temperature falls below 0^{o} C. The defrost option automatically turns off when the ambient temperature rises above freezing. The period of defrost option usage is assumed to be four months during winter (about 120 days) and it is energized similarly to LED for 11 hours per day, an additional 0.572 kW will be used per day, for a daily cost of $0.04576. During the four months of winter, the operating cost of the defrost option is $5.49 per year (0.572 kW × $0.08 × 120 days). The defrost option associated with the 81W LED consumes 68.64 kW during the winter period each year, and 1,709.6 kW during its lifespan, with a total operating cost of $136.8 (1,709.6 kW × $0.08). Based on the manufacturer, the lifespan of the defrost option of LED is the same as the life of LED.

RETROREFLECTIVE SHEETING MATERIALS COST ANALYSIS

Various companies were contacted regarding the cost of three types of retroreflective sheeting materials used on overhead guide signs. Three companies returned valuable information about the cost and the lifespan of the three retroreflective sheeting materials: Engineering Grade, High Intensity, and Diamond Grade. Only the cost of the retroreflective sheeting material is considered in the following sections; other costs related to overhead guide signs are ignored, i.e., the sign sheet metal and the other sign fixture component costs.

In this section, a detailed comparison between the three retroreflective sheeting materials is presented. Labor costs and equipment are identical for the three types of retroreflective sheeting material during first-time installation and replacement. Labor and equipment costs are assumed to be $200 each time of replacement per each sign sheeting type. This assumption is based on using two workers and one bucket truck to replace or install the sign sheeting. A 50-year life cycle is considered to obtain the replacement effect for the three retroreflective sheeting based on lifespan. Table 3 compares the retroreflective sheeting costs in details. The cost analysis include initial and maintenance or replacement cost components of each retroreflective sheeting for a 15 ft × by 9 ft sign size per lifespan of each sheeting type. A sign of 15 ft × by 9 ft is used for comparison purposes.

Table 3: Retroreflective Sheeting Material Cost Comparison of a 15 ft × 9 ft Sign

	Details	**Engineering Grade**	**Diamond Grade**	**High Intensity**
1	Initial cost ($/ft^2)	0.8	3.93	1.45
2	Life (years)	7	12	10
3	Cost of (15 ft × 9 ft) sign sheeting ($)	108	530.55	195.75
4	Labor cost per each installation/replacement ($)	200	200	200
5	Number of sign installation/replacement in 50-year	7.14	4.17	5
6	Required sign sheeting cost ($/50 years)	771.12	2,212.40	957.5
7	Required labor cost ($/50 years)	1,428	834	1000
8	Total cost ($/50 years)	2,199.12	3,046.40	1,957.50
10	Average cost per year ($)	43.98	60.93	39.15

In explaining the calculations in Table 3, the initial cost and lifespan information were obtained from the manufacturers. The sheeting material cost for the 15 ft × 9 ft sign size is calculated. The number of sign sheeting replacement/installation in a 50-year cycle is calculated by dividing 50 by the sheeting material lifespan for each sheeting type. The material cost during a 50-year cycle is calculated by multiplying the number of sign sheeting replacement/installation by the cost of the 15ft × 9ft sign. The required labor cost in a 50-year cycle is calculated by multiplying labor cost by the number of sign sheeting replacement/installation. The total cost for each sheeting during a 50-year cycle is calculated by adding the material cost in a 50-year cycle to the labor cost in a 50-year cycle. The average annual cost is calculated by dividing the total cost during the 50-year cycle by 50. Based on cost analysis results shown in Table 3, The High Intensity is the most cost-effective sign sheeting, followed by Engineering Grade, and then by the Diamond Grade.

CONCLUSIONS

The most commonly used sheeting material by states for overhead guide sign legend is the Diamond Grade (type IX followed by type XI). For sign background, High Intensity (types III and IV) are the most commonly used. Most states use Series E (Modified) font, followed by Clearview 5W and 5WR for guide signs.

States have two options or future plans for increasing overhead guide sign visibility during nighttime: either by illuminating signs, usually with newer, more efficient light sources, or using newer, brighter retroreflective sheeting materials. Approximately 57% of state DOTs illuminate their overhead guide signs, while 43% do not. The most common light sources used currently to illuminate overhead guide signs are MH, MV, HPS, induction lighting, and LEDs.

Based on the cost comparison of the six light sources, the 85W induction lighting is the most cost-effective, followed by the 62W LED, the 81W LED, the 75.4W LED, the 250W MH, and the 70W Cool White LED. New light source generations (LED and induction lighting), are much better based on the life cycle cost than the conventional light sources (MH, MV, and HPS). In general, induction lighting is the most cost-effective light source followed by LEDs. Considering environmental issues and power consumption, LEDs are more environmental friendly than induction light sources because LEDs are free from mercury and lead materials and have lower energy consumption. This will result in making LEDs much better than induction, and in our case, the 62W LED will be the best choice among the six light sources. Based on the cost analysis of the three retroreflective sheeting materials, the High Intensity is the most cost-effective retroreflective sheeting.

Overall, comparing the best options used to increase sign visibility, sign illumination and sign retroreflectivity, it is found that using retroreflective sheeting is more cost-effective than sign illuminating. This means the High Intensity retroreflective sheeting is the best option, based on the cost analysis, to increase overhead guide sign visibility to drivers during nighttime.

One of the limitations of this paper is the unavailability of labor and equipment costs when installing or performing maintenance to the different light sources.

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