

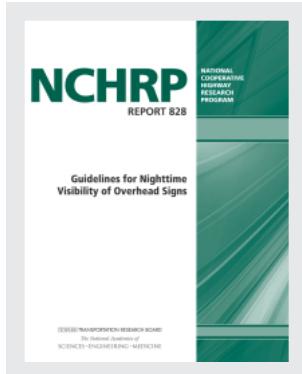
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 828

**Guidelines for Nighttime
Visibility of Overhead Signs**

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WASHINGTON, D.C.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 828

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FOR E W O R D

By Edward T. Harrigan

Staff Officer

Transportation Research Board

This report presents proposed guidelines for nighttime overhead sign visibility, formatted as a potential replacement for the current Chapter 10, Roadway Sign Lighting, in the 2005 *AASHTO Roadway Lighting Design Guide*. The proposed Chapter 10 is called “Overhead Sign Lighting.” Thus, the report will be of immediate interest to engineers in state highway agencies and other transportation agencies with responsibility for the management of overhead guide signs and street signs.

A frequent dilemma facing highway agencies is deciding how to provide effective nighttime performance for overhead signs. While the *Manual on Uniform Traffic Control Devices* (MUTCD) provides minimum retroreflectivity standards for overhead signs, there are few guidelines that agencies can reference to decide how to provide sufficient nighttime performance of overhead signs in site-specific situations. The common wisdom is that overhead guide sign lighting may be turned off in rural areas if highly reflective sheeting materials are used. However, there is little consensus about the use of lighting in suburban and urban areas where visual backgrounds and roadway geometries are more complex. Moreover, the presence and amount of roadway lighting, roadway geometry, traffic volume, traffic speed, and sign position and orientation with respect to oncoming traffic can also create challenges to the effective nighttime performance of overhead signs.

The objective of this research was to develop guidelines for providing effective nighttime performance of overhead guide signs in site-specific situations. The research was conducted by the Texas A&M Transportation Institute, College Station, Texas, supported by the Virginia Tech Transportation Institute, Blacksburg, Virginia.

The research was conducted in two phases. In the first phase, a closed-course study was conducted at the Virginia Smart Road at the Virginia Tech Transportation Institute. The goal of this study was to determine legibility distances for drivers in controlled conditions for three different sign legend and background configurations lit by either high pressure sodium or light emitting diode systems or they were unlit. In the second phase, an open-road study was conducted by the Texas A&M Transportation Institute in three urban areas—Bryan/College Station, Texas; San Antonio, Texas; and Orlando, Florida. The goal of the open-road study was to determine the effects of sign luminance and visual complexity on the distance at which a driver can read overhead signs and street signs. Both studies employed cohorts of recruited drivers evenly split in terms of gender and age.

The key outcome of the research is the proposed “Guidelines for Nighttime Overhead Sign Visibility” presented as a proposed replacement for the current Chapter 10, Roadway Sign Lighting, in the *AASHTO Roadway Lighting Design Guide*. The proposed Chapter 10 is called Overhead Sign Lighting and is included in this report in Appendix D. The closed-course study

found that sign lighting does not significantly impact legibility distance of signs in rural and dark areas, suggesting that sufficient illumination for visibility was provided by headlamps. Using software developed for the open-road study, digital images were analyzed to quantitatively measure visual complexity in urban and suburban areas. Visual complexity of sign surroundings was found to reduce the distance at which a driver can correctly recognize information from signs, however, this effect can be countered by increases in the legend luminance.

This report fully documents the research and includes four appendixes:

- Appendix A Incremental Effects of Light Sources and Sign Sheeting on Legend Luminance for Overhead Guide Signs
- Appendix B Assessment of Background Complexity Using Digital Images of Roadway Scenes by Image Processing
- Appendix C Open-Road Study Details
- Appendix D Guidelines for Nighttime Overhead Sign Visibility

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SUMMARY

Guidelines for Nighttime Visibility of Overhead Signs

Effective highway signing is an important component to driver decision making, comfort, and safety. The objective of this research was to develop guidelines for providing effective nighttime performance of overhead signs. The need for this work has stemmed from a transition covering a period from a time when, by policy and need, all overhead guide signs were lighted, to the current time when only certain overhead signs are lighted. At the same time, overhead street name signs have seen a reverse trend and are now more commonly lit (usually with internal illumination), especially at signalized intersections.

Research has repeatedly shown that when overhead guide signs are constructed with the newest retroreflective sign sheeting materials and highway font, and installed in rural areas with little to no visual clutter, sign lighting is not needed. However, there has been little research to address or identify the conditions in which sign lighting is needed or what type of retroreflective material for overhead signs will meet the needs of nighttime motorists.

Going into this research, it was generally thought that sign lighting may be needed in areas with high levels of visual clutter or areas where the geometrics of the highway are such that inadequate headlamp illumination is directed to overhead signs. The existing relevant policies and guidelines regarding sign lighting provided little useful information to determine when sign lighting is needed, and the reference material available was out of date. The research conducted and described in this report was designed to provide new discoveries related to the needs of nighttime motorists with a focus on overhead sign visibility. Two complementary nighttime visibility studies were conducted—both of which were specifically designed to produce results that can be used to develop guidelines for overhead sign visibility.

The first study was conducted on a closed course and investigated the legibility distances of three different sign legend and background configurations under different sign lighting treatments. The signs were lit by either high-pressure sodium (HPS) or light-emitting diode (LED) systems or they were not lit at all. Additionally, roadway lighting was added for some trials to evaluate its effect. The sheeting materials that made up the sign configurations are commonly used and are specified in the *Manual on Uniform Traffic Control Devices* (MUTCD). The sheeting types (American Society for Testing and Materials [ASTM] Types III, IV, and XI) represent a variety of retroreflective properties. Findings from the closed-course study indicate that sign lighting does not significantly impact legibility distance of signs in rural and dark areas, suggesting that headlamps alone provide sufficient illumination for visibility. Photometric analyses determined the extent of the lighting impact in terms of luminance and contrast on the sign's legend and background. Measurements of luminance and contrast were found to have no impact on legibility distance under the controlled conditions of the closed-course study.

The second study was conducted on the open road. The study investigated the effects of both sign luminance and visual complexity on the distance at which a driver can read

overhead signs during a recognition task. Visual complexity was measured with a software tool developed specifically for this research. The tool identifies elements of the visual scene from a photometrically calibrated digital image and quantifies their effects into a measure of visual complexity. The tool was developed using nighttime images and ratings from a different set of study participants. Findings from the open-road study indicate that the visual complexity of sign surroundings reduces the distance at which drivers correctly recognize information from signs, but this is countered by increases in legend luminance.

The combined findings from the closed-course and open-road studies provided a number of results that were used to develop revised guidelines designed to provide adequate nighttime visibility of overhead signs. One of the most useful findings was the development of an empirically derived relationship that describes the connection between the needs of nighttime motorists and the visual complexity surrounding an overhead sign. With a visual complexity scale of 1 through 5, the research findings show that the negative effects of increasing visual complexity can be countered with an increase in legend luminance of 5.6 cd/m^2 (using the FHWA's base level of 2.3 cd/m^2 as the absolute minimum needed for nighttime drivers in rural conditions as the baseline visual complexity level of 1).

The proposed guidelines resulting from this study are based on needs of nighttime motorists and have been formatted specifically for the AASHTO *Roadway Lighting Design Guide*, which is currently being updated. The proposed guidelines are flexible and should provide performance targets for innovations in sign lighting and sign sheeting technologies for years to come. The revised chapter on roadway sign lighting (shown in Appendix D of this report) was provided to the AASHTO Task Force responsible for revisions. This approach allows for a quick review by state agencies, with eventual adoption in the most appropriate professional reference document for sign lighting. The guidelines also include recommended retroreflective sheeting materials that can be used to meet nighttime driver needs for specific complexity levels. This information was added to assist state agencies when they are updating their policies and specifications specific to overhead signing.

CHAPTER 1

Introduction

Effective highway signing is an important component to driver decision making, comfort, and safety. Signs must be visible and at the right location for drivers to have adequate time to properly respond to them. Sign visibility is made possible when at least one light source provides illumination. While daytime sign visibility is generally provided by natural light from the sun, the principal source of light for nighttime sign visibility is the vehicle's headlamps. Retroreflective sign sheeting materials are used on practically all traffic signs to redirect the vehicle headlamp illumination back toward the driver, which enhances the nighttime visibility of the signs.

There are also other sources of light that can help illuminate signs at night. Sign lighting, which can be external or internal to the sign, can be used to supplement vehicle headlamp illumination. Sign lighting has been used throughout the United States to enhance the nighttime visibility of signs. However, as retroreflective sheeting materials have become more efficient at returning vehicle headlamp illumination back toward the driver, the use of sign lighting has decreased.

Other light sources may also contribute to sign lighting, such as overhead roadway lighting and lights from nearby businesses. On the other hand, when these additional light sources grow to a certain point or are poorly designed or controlled, they can create a complex nighttime viewing environment that can negatively impact sign visibility to the point that sign lighting may be needed.

The available nighttime sign visibility guidelines have generally been developed from data collected in conditions representing rural environments that are not visually demanding (1). Organizations such as the Illuminating Engineering Society of North America (IESNA) and AASHTO indicate that signs should be brighter in areas of increased ambient light (2, 3). There are multiple shortcomings of those guidelines, and they are in need of an update. The purpose of this research was to develop new information about the signing needs of nighttime drivers to help revise nighttime sign visibility guidelines for highway agencies across the United States.

Research Objectives

The objective of this research was to develop data-supported guidelines adapted to site-specific situations for providing effective nighttime visibility of guide and street name signs. The need for this work is a result of a transition from a time when, by policy and need, most overhead guide signs were lit, to the present time when only certain signs are lit. Research has repeatedly shown that when signs are constructed with the newest retroreflective sheeting materials and highway font, and installed in rural areas with little to no ambient background visual clutter, sign lighting is not needed, except for conditions of unusual highway geometries or disadvantaged sign locations. On the other hand, in highly developed areas, there can be so much visual background clutter that sign lighting may be needed to meet the needs of nighttime drivers.

While the overhead guide sign evolution has been trending toward fewer lit signs, the trend for overhead street name signs has been somewhat the opposite, especially at signal-controlled intersections, which happen to generally coincide with relatively higher visually complex background scenes compared with stop-controlled intersections. The newest internally illuminated overhead street name signs are generally made with LEDs, which require less maintenance and use less power than previous generations of internally illuminated light sources.

Research Approach

The research was divided into 11 tasks across 3 phases. The first phase (Tasks 1–4) involved a literature review, agency interviews, a pilot study to test a study concept, and an interim report in preparation for a meeting with the NCHRP Project 05-20 panel. The second phase (Tasks 5–8) comprised the principal research tasks, including the closed- and open-road testing with study participants and an analysis of the study data. The third phase (Tasks 9–11) involved the development

of the final project deliverables. The research tasks were as follows:

- **Task 1—Review Relevant Literature.** This task involved searching for and reporting on literature relevant to the visibility of signs at night, with an emphasis on overhead guide signs. This literature included research on not only the factors that impact visibility but also the national and international standards and guidelines that address it. Chapter 2 contains the findings from the literature review.
- **Task 2—Conduct Focused Interviews.** The second task involved phone interviews with state agencies to determine the state of knowledge and practice, emerging technologies, and policies and practices of lighting overhead guide signs and street name signs. The survey also inquired about the sheeting used on the signs because most agencies tend to use retroreflective sheeting in place of sign lighting. Chapter 2 also contains the findings from the interviews with state agencies.
- **Task 3—Conduct Proof-of-Concept Research on Measuring Background Complexity.** The objective of this task was to create a method to measure the roadway environment complexity. Study participants not used in the other tasks rated the roadway complexity from several images of guide signs at night. Statistical modeling matched the ratings given by the study participants with measures obtained by image processing software. The resulting model was used to identify how the components of an image (representing the driver's view) as evaluated by the software influence the driver's perception of complexity. The research included an assessment of environmental (background) complexity because it was hypothesized that complex environments inhibit a driver's ability to see and read overhead guide signs. The specific results of the proof-of-concept work are not detailed in this report because they led to the work completed in Task 5.
- **Task 4—Prepare Interim Report and Meet with NCHRP Project 05-20 Panel.** An interim report summarizing the work and findings of the first three tasks was produced before meeting with the NCHRP Project 05-20 panel. Input from the study panel at the meeting was used to direct the work in the second phase of the research.
- **Task 5—Develop a Technique to Assess Ambient Luminance and Background Complexity.** This task was an extension of the proof-of-concept work in Task 3 that produced a systematic method for processing images based on the model developed in Task 3. The technique used to assess the ambient luminance and background complexity is presented in Appendix B.
- **Task 6—Conduct Closed-Course Study.** The closed-course study was designed as a factorial experiment that tested the effects of sign lighting, retroreflective sheeting, and street lighting on the legibility of overhead guide signs. The measure of interest was the distance from the sign at which study participants read the sign legend. The study design and findings from the closed-course study are presented in Chapter 3. Additional information about how the light sources and sheeting affect measured luminance and contrast is provided in Appendix A. The findings suggest that luminance (within levels of the study) has little impact on guide sign legibility in rural environments (i.e., low visual complexity and no sources of glare). The type of sign lighting and the use of street lighting had minor impacts on the guide sign legibility distance. As expected, younger-aged drivers correctly read signs earlier than older-aged drivers.
- **Task 7—Conduct Open-Road Study.** The open-road study was designed to evaluate the factors that influence the recognition of overhead and shoulder-mounted guide and street name signs in real driving environments. At each of three locations across the United States, the research team identified a study corridor and recruited participants to drive through it in an instrumented vehicle. Images of the roadway scene approaching each study sign were evaluated with the image processing tool developed in Tasks 3 and 5 to determine the level of visual background complexity. Research participants drove the study corridor at night and identified signs of interest as soon as they could. The study design and findings from the open-road study are presented in Chapter 4. The findings indicate that visual complexity negatively affects the distance at which a driver recognizes a sign's message. Increased sign luminance was found to result in increased recognition distance. Details of this task are included in Appendix C.
- **Task 8—Analyze Study Data.** This task involved the analysis and synthesis of the findings from the closed-course research and the open-road research. The key findings that were identified were used to develop data-supported guidelines for nighttime sign visibility.
- **Task 9—Prepare Phase II Deliverables.** This task involved reporting on the findings from Tasks 5–8 and producing data-supported guidelines for nighttime sign visibility. Chapter 5 contains a description of the key findings and assumptions used to develop the guidelines. The guidelines are included in Appendix D as a revised Chapter 10 of the 2005 AASHTO *Roadway Lighting Design Guide* (Chapter 10 is Roadway Sign Lighting).
- **Task 10—Prepare Draft Final Report.** In November 2015, a draft final report was submitted to the NCHRP Project 05-20 panel.
- **Task 11—Review and Revise Final Report.** This document represents the final product of the research, having been revised based on input from the NCHRP Project 05-20 panel.

CHAPTER 2

Background

Traffic control devices (TCDs) must be visible at an appropriate distance for drivers to respond to them properly. With a lack of natural light at night, other light sources must be used to provide the luminance necessary for drivers to see TCDs. Guide and street name signs placed overhead or mounted on the shoulder tend to be manufactured with retroreflective sheeting, which, upon illumination from a vehicle's headlamps, return some of the light back to the driver. When retroreflective sheeting is not used, the signs must be internally or externally illuminated, as directed in the MUTCD (4). There are several factors that influence the visibility of guide signs. This chapter summarizes previous research and other sources of information regarding issues and complexities of guide sign visibility at night. Included are results of a survey of state departments of transportation (DOTs) that specifically investigated sign lighting policies and practices.

Luminance Requirements for Sign Visibility

Light within the visible spectrum is necessary for the human eye to perceive objects. Objects that do not independently emit light must be illuminated in order to be seen, and *illuminance* describes the intensity of the light incident on the surface. *Luminance* describes the intensity of light reflected at the surface in the direction of a viewer. As luminance is the light from the perspective of a driver, several studies have investigated the ability of drivers to see objects or road features based on luminance.

Early laboratory research employed practices similar to a common eye exam. In 1977, Richards used a static vision testing method by seating subjects in front of an eye chart (5). By applying four lighting levels from a projector calibrated to simulate a vehicle's headlamp, Richards provided luminance at levels from 0.03 to 34 cd/m². Not only did acuity decrease with age and luminance, but the acuities at each luminance value decreased with letter contrast.

Schnell et al. presented subjects with an image of a 2-in. symbolic sign, instructing them to walk toward the screen until the symbol was identifiable (6). Luminance was measured from the front of the screen, and the researchers concluded that 82 cd/m² was the maximum background luminance beyond which there was no improvement in detecting the symbol.

Interactions between color and luminance and their influence on sign recognition have also been studied (7, 8). Forbes determined that signs with greater luminance require shorter subject glances (7). Padmos found that color recognition occurs at lower luminance levels than legibility (8). Early color recognition helps drivers detect and comprehend the message of a traffic sign earlier because the color is associated with the sign's meaning.

Carlson and Hawkins studied the effects of luminance on the legibility distance of overhead guide signs (1). They varied the luminous intensity of a test vehicle's headlamps at 32 different levels while study participants read the signs at distances corresponding to specific legibility indices. Figure 1 shows the cumulative distributions of correct readings by legibility index and luminance. The findings were used to develop sign retroreflectivity requirements for overhead signs based on providing a minimum amount of luminance so that 50 percent of elderly drivers have a 40-ft/in. legibility index. The corresponding luminance is 2.3 cd/m².

Figure 1 illustrates a great amount of diversity in the visual abilities of drivers. In Carlson and Hawkins's study, the 10 percent of elderly drivers with the best vision needed less than 1 cd/m² to correctly read the overhead sign at a 40-ft/in. legibility index (1). The 10 percent of elderly drivers with the poorest vision needed more than 10 cd/m² of luminance to correctly read the sign at the same location. Luminance of approximately 30 cd/m² was needed to reach 100 percent correct responses at a distance corresponding to a 40-ft/in. legibility index. The amount of luminance necessary to correctly read the overhead sign decreased at closer distances (i.e., a legibility index of 20 or 30 ft/in. instead of 40 ft/in.).

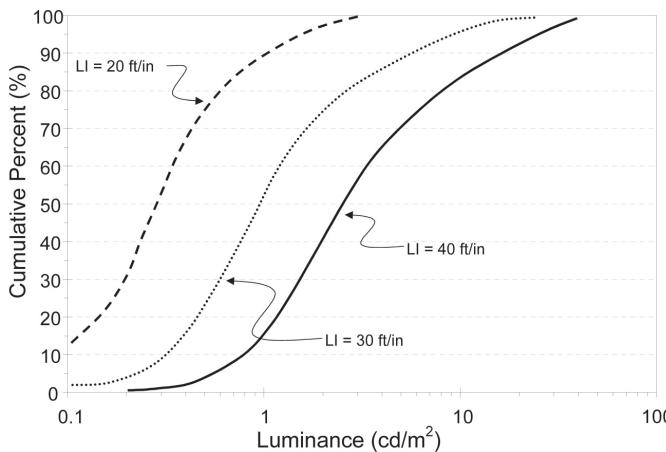


Figure 1. Cumulative percent of correct responses for three legibility indices (LIs) when varying sign luminance (1).

The 2.3 cd/m² luminance value that met the needs of 50 percent of older drivers at a 40-ft/in. index was adequate for approximately 80 percent of the drivers at a 30-ft/in. index and 100 percent of the drivers at a 20-ft/in. index.

The luminance and legibility data presented in Figure 1 were collected in a rural environment with no distracting objects or glare sources. Follow-up research revisited the issue of luminance required to correctly read overhead guide signs but increased the complexity of the visual background by including roadway lighting and glare sources (9). The study used signs of the following color combinations: white on green, white on blue, and white on brown. By including additional light sources, the research identified the luminance needed for nighttime legibility under four different environments: rural/dark, rural/dark with roadway lighting, rural/dark with glare, and rural/dark with roadway lighting and glare. When glare was added to the rural/dark conditions, the amount of luminance needed to correctly read the signs nearly doubled. Roadway lighting added to the glare condition countered the impact of the glare, and only 15 percent more luminance was needed to achieve the same legibility. Findings were mixed when roadway lighting was added without the glare sources.

The previous findings indicate that increased luminance results in increased distance at which drivers can read signs. The results are limited, however, because they primarily represent the experience of drivers in dark and rural conditions and under low workload. The research by Holick and Carlson suggested that drivers require more luminance to view signs as more light sources are added to a scene, but there is a lack of information about how light and driving scenarios that are more complex than rural conditions interact to affect the detectability and legibility of signs (9).

Lighting Sources

The luminance to read traffic signs at night can come from lights added to the signs or from vehicle headlamps. As mentioned, the MUTCD requires that signs without retroreflective sheeting be illuminated by additional sign lighting, and some agencies light their signs even if the signs are retroreflective. This section discusses policies, guidelines, and practices related to sign lighting and vehicle headlamps.

Sign Lighting

The consistent illumination provided by permanent sign lighting (whether external or internal) facilitates the rapid and accurate recognition and understanding of a sign's message at night. This is especially helpful in situations with high traffic volume, complex design, adverse weather, and increased ambient luminance. The additional lighting may even be necessary if the retroreflective sheeting is not efficient enough for sign legibility or when recognition and legibility distances need to be increased. This section presents some guidelines associated with providing sign lighting and trends in sign lighting found among transportation agencies.

Guidelines for Sign Lighting

The MUTCD contains several statements concerning the illumination and visibility of signs, especially for nighttime conditions. Section 2A.07 states the following:

Regulatory, warning, and guide signs and object markers shall be retroreflective or illuminated to show the same shape and similar color by both day and night ...

and

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

While the MUTCD includes minimum maintained sign retroreflectivity levels (Section 2A.08), it contains no specifications for the amount of lighting needed when signs are not retroreflective. Additionally, the retroreflectivity levels in the MUTCD are considered **minimums**, which were established based on driver visibility needs in dark/rural conditions. There is no information about when retroreflective sheeting alone and illuminated by headlamps does not provide a high level of visibility and legibility for other conditions. It is possible that areas of high complexity or greater ambient luminance would reduce sign visibility and legibility.

MUTCD Section 2E, which discusses guide signs on freeways and expressways, states that the legends should be retro-

Table 1. Ambient luminance descriptions (3).

Level of Ambient Luminance	Description
Low	Low levels of ambient luminance exist in rural areas without roadway and/or intersection lighting. Objects at night are visible only in bright moonlight. There is very little or no other lighting in the area.
Medium	Medium levels of ambient luminance exist in intermediate areas with some roadway and/or intersection lighting. May contain small areas of commercial lighting.
High	High levels of ambient luminance exist in urban areas with high levels of roadway lighting. May contain brightly lighted commercial advertising signs, building facades, and/or highly illuminated parking facilities.

reflective and the backgrounds that are not independently illuminated should be retroreflective. Additionally, it states that the illumination provided by low-beam headlamps is relatively small. Such information supports the following guidance in Section 2E.06:

Overhead sign installations should be illuminated unless an engineering study shows that retroreflectorization alone will perform effectively. The type of illumination chosen should provide effective and reasonably uniform illumination of the sign face and message.

Though not directly related to sign illumination, the MUTCD covers situations of inadequate sight distance and unique roadway geometries by including guidance for advance street name signs for conventional roadways (placed at a distance appropriate for a driver to properly decelerate and turn) and pull-through signs for freeways and expressways. On freeways, there are requirements for guide signs to be repeated on approaches to interchanges (they must be placed 1 mi in advance of and at the theoretical gore and are recommended at 2-mi and 0.5-mi locations). The redundancy of these types of signs is one way to address the limitations of complex situations and undesirable geometrics or line of sight obstructions.

Despite the amount of detail in the MUTCD indicating where signs are to be placed, what information they must contain, and how that information is to be relayed to the driver, there are few specifics that describe how to achieve *high visibility* and *high legibility* for guide signs other than stating that the legends must be retroreflective and the whole sign should be illuminated unless an engineering study indicates that illu-

mination is unnecessary. There is no information about how to determine whether lighting is needed and the amount of lighting to provide.

Some gaps in the lighting guidelines of the MUTCD are filled by the *AASHTO Roadway Lighting Design Guide* of 2005 (3). Section 10.2 states that retroreflective signing materials by themselves (without sign lighting) may perform adequately if “the sign is in an area that contains a low-to-intermediate ambient light level, and there is at least 1,200 ft (366 m) or more of tangent sight distance in advance of the overhead sign.” Additionally, the design guide states that “high levels of ambient luminance may make sign lighting warranted regardless of the retroreflective properties of the sign face material.” Background ambient luminance is divided into three classifications and described qualitatively, as shown in Table 1. The AASHTO guidelines also specify the amount of lighting, in terms of both illuminance and luminance, to provide based on the level of background ambient luminance. These levels are shown in Table 2.

IESNA is another group that provides sign lighting guidelines and recommendations. IESNA guidelines identify five factors that should be considered when evaluating the legibility of guide signs (2):

1. Ambient luminance
2. Sign luminance above ambient luminance
3. Retroreflectivity of sign legend and background materials
4. Contrast between sign legend and background
5. Uniform ratio of sign lighting

Table 2. AASHTO recommended sign lighting levels (3).

Ambient Light Level	Sign Illuminance		Sign Luminance ^a	
	fc	lx	cd/m ²	cd/ft ²
Low	10–20	100–200	22–44	2.2–4.4
Medium	20–40	200–400	44–89	4.4–8.9
High	40–80	400–800	89–178	8.9–17.8

Note: Adapted from Table 10-1 in *Roadway Lighting Design Guide*, 2005, by the American Association of State Highway and Transportation Officials.

^a Based on a maintained reflectance of 70 percent for white sign letters.

Table 3. IESNA recommended sign lighting levels (2).

Ambient Light Level	Sign Illuminance		Sign Luminance ^a	
	fc	Ix	cd/m ²	cd/ft ²
Low	13	140	20	1.9
Medium	26	280	40	3.7
High	52	560	80	7.4

^a Sign luminance is based on maintained reflectance of 45 percent for white sign letters, assumed to be diffuse.
Source: Recommended Sign Lighting Levels (IES RP-19-01 Deprecated—please check www.ies.org/bookstore for updates), published with permission by the Illuminating Engineering Society of North America.

Table 3 shows the recommended IESNA lighting levels, based on the same three ambient lighting classifications.

Based on the MUTCD guidelines and those in Tables 2 and 3, there appears to be a general consensus that sign lighting is not needed in rural areas as long as the retroreflective sheeting meets the MUTCD minimum standards. There is ambiguity, however, regarding the use of sign lighting in urban areas with medium or high levels of ambient luminance or for unique conditions, such as unusual geometrics or areas of frequent dew, fog, or frost. The MUTCD suggests that lighting may be appropriate for some conditions, but practitioners may have difficulty determining whether or not lighting should be used because of the subjectivity in specifying the level of ambient luminance or other appropriate conditions. An example of research that has provided specific recommendations was produced for the Florida Department of Transportation and suggests that sign lighting be used for overhead signs on curves in urban areas when the curve radius is shorter than 2,500 ft (10).

Beyond the question of whether or not sign lighting is needed, there is also an interesting conflict between the guidelines of the MUTCD and those adopted by AASHTO and IESNA. For areas with low ambient luminance, AASHTO and IESNA recommend sign luminance levels in the range of 20 to 44 cd/m², as shown in Tables 2 and 3. The minimum maintained retroreflectivity levels in the MUTCD were derived from human factor studies performed in a dark, rural setting (low ambient luminance) (1). It was found that luminance of 2.3 cd/m² was sufficient for half of older drivers to correctly read overhead guide signs at an index of 40 ft for each inch of legend letter height. Beyond 20 cd/m² would have met the needs for nearly all of the older drivers, suggesting that a guideline of 20–44 cd/m² is too conservative for a rural setting. Additional lighting and glare sources were added in a follow-up study to represent conditions closer to those of the medium level of ambient light shown in Tables 2 and 3 (9). Under these conditions, the required luminance was near 10 cd/m²—still much lower than the AASHTO and IESNA recommended range of 40 to 89 cd/m².

Another ambiguity comes from the use of both illuminance (the measure of light reaching the sign) and luminance (the measure of light reflected back to the driver) in Tables 2 and 3. Each table has luminance calculated from a constant proportion of illuminance. The reflective efficiencies used are 70 and 45 percent. It is not clear whether these values are representative of modern sign sheeting products, where retroreflectivity varies by the angles of light incident on and reflecting from the surface. Additionally, there are several factors that affect the luminance of a sign. As luminance is also the measure that best represents the perspective of a driver viewing a sign, the guidelines may be most applicable by providing luminance levels alone and not values of illuminance. As sign sheeting becomes more efficient (which has regularly happened since the publication of the AASHTO and IESNA guidelines), less illuminance is needed to provide drivers with a comparable amount of luminance.

A final difficulty in applying the AASHTO and IESNA guidelines is the distance from the sign at which the luminance should be measured. While illuminance does not change at the sign face, the luminance will change with both distance and the angle made from the light source and the location where the light is measured. The research conducted for developing the MUTCD minimum retroreflectivity levels used luminance measured at a distance corresponding to an index of 40 ft for each inch of legend letter height. Sign luminance should be measured at the distance at which a driver is expected to read a sign. For overhead guide signs, that distance may be several hundred feet because the legends are often 16 in. (uppercase letters) or taller.

The MUTCD, AASHTO, and IESNA guidelines attempt to provide practitioners information to help determine when sign lighting is appropriate, and, to some extent, the amount of lighting that should be used. There are some apparent inadequacies and inconsistencies in the guidelines, however. This research was intended to produce information that would resolve these limitations.

Lighting Trends

The cost of lighting overhead guide signs and the evolution of retroreflective sign sheeting products has led to a growing

interest among transportation agencies to determine when sign lighting is appropriate. As retroreflective sign sheeting materials have become more efficient in terms of returning headlamp illumination back to the driver, there has been a trend to turn off or remove most overhead guide sign lighting. Additionally, new fonts have been designed to perform best with newer sheeting materials, thus adding more legibility to overhead guide signs and further pushing the issue of whether lighting is needed.

Surveys indicate that many transportation agencies have systematically adopted policies of using highly efficient sign sheeting for overhead guide signs to replace the use of sign lighting. In a 2008 survey by the Wisconsin DOT, only six of the responding 30 states still used sign lighting for overhead guide signs (11). The general consensus of the six states still lighting signs was that lighting was used on a case-by-case basis. The primary concern of the agencies using lighting was maintaining adequate visibility during dew, frost, fog, snow, or when unusual roadway geometrics limit the amount of headlamp illumination reaching the sign. A similar survey conducted by AASHTO indicated that 21 out of 36 state DOTs (62 percent) have deactivated sign lighting due to the cost savings from improved retroreflective sheeting (12). The 15 states still lighting overhead signs use lighting for urban areas, freeways, and exit signs. Only five of the responding states indicated that sign lighting is used in the design of new projects. Findings in a survey for the Kansas DOT concur with the conclusions of the other surveys, indicating that most states are moving away from overhead sign lighting, especially outside city limits (13). Half of the respondents indicated that sign lighting is being eliminated in all places.

An interesting finding by the Wisconsin DOT is that the states that no longer use sign lighting have received little or no complaints regarding the change (11). While it is clear that headlamp luminance reflected from modern sign sheeting is sufficient for legibility in rural and dark areas, it seems there has been no study (by a transportation agency or otherwise) confirming that the headlamp luminance is unconditionally sufficient in all areas. The hesitation of some transportation agencies to remove sign lighting in urban areas (based on the survey results) suggests that there may be conditions for which highly efficient retroreflective sheeting alone is inadequate.

Survey of State Transportation Departments

One of the tasks of this research project involved a survey of 11 state transportation departments about lighting overhead guide signs and street name signs in their jurisdiction. The 11 agencies were selected based on responses to previous (Washington State DOT and AASHTO) studies suggesting that they have policies for lighting signs. The survey was conducted to gather information about the agencies' decisions to light signs. While the agencies were known to light signs at one point based on the previous surveys, Table 4 indicates the basic response for each agency's current policy.

Six of the 11 surveyed states no longer light overhead guide signs. The primary reason for discontinuing the policy to provide overhead guide sign lighting was cost. Three of the six states that no longer provide lighting stated that newer and brighter retroreflective materials had improved nighttime visibility such that lighting overhead signs was no longer necessary, even though they had not formally researched the issue. In multiple cases, the procedure for phasing out sign lighting involved replacing the sheeting and turning off and removing the lighting equipment.

The four states that light overhead signs on a case-by-case basis provided a variety of scenarios for which sign lighting is used in their jurisdiction. Limited sight distance or unusual geometry, frequent fog, and continuous roadway lighting use are some of the criteria used to determine whether signs should be lit. These reasons are consistent with the 2008 Wisconsin DOT survey (11). Florida was the only state to still have a policy for lighting all overhead guide signs. The only regular exception is if there is no access to nearby electricity.

The states that use lighting were asked how the agency determines the amount of illumination provided for overhead guide signs. The most common answer was that the level of illumination is determined based on AASHTO or IESNA guidelines, such as those in Tables 2 and 3. Two of the states indicated that they have reduced the level of illumination as the retroreflective sign sheeting has improved.

The same 11 states were asked about their policies for and experiences using internally illuminated street name signs at signalized intersections. Texas and Florida were the only states whose transportation departments illuminate street name signs: Texas on a case-by-case basis that is being phased out,

Table 4. Summarized policies for lighting overhead guide signs.

Survey Response	State Agency
No longer light overhead guide signs	Delaware, Illinois, Mississippi, Ohio, Oregon, Texas
Light overhead guide signs on case-by-case basis	Maryland, New Jersey, Pennsylvania, Virginia
Light all overhead guide signs	Florida

and Florida with a policy for lit street name signs when possible. The other agencies do not have internally illuminated street name signs within their jurisdiction, though there is no prohibition against local municipalities lighting street name signs as long as they are responsible for the costs and maintenance.

The surveys of state agencies indicate a consistent reduction in the use of sign lighting as agencies either eliminate it entirely or require it less frequently.

Retroreflective Sign Sheeting

Retroreflectivity is an optical property of a material that enables incoming light to be reflected back to its source. It is measured as the ratio of light reflected back to the receptor compared with the amount that is emitted by the source. The ratio fluctuates based on the reflective elements in the sign sheeting and the viewing angle formed between the light source (headlight), the viewing surface (sign face), and the receptor (driver's eyes).

Both ASTM and AASHTO have created specifications for retroreflective sheeting. Most of the previous research on retroreflectivity has been based on the ASTM standard; therefore, the ASTM standard is referenced in this report rather than the AASHTO standard. The latest ASTM D4956 specification contains seven classifications for rigid sign sheeting (Types I, II, III, IV, VIII, IX, and XI). Initially, the classifications increased sequentially based on retroreflective performance, but new materials have been added in chronological order of development since 1989. As a result, the current classification system does not necessarily indicate relative performance. Rather, each type of sheeting material has unique specifications for performance at various angles of retroreflection. Retroreflectivity tends to decrease as the angles of retroreflection widen. The result is that each type of material has a different level of performance depending on the entrance and observation angles determined by the heights of the headlamps and driver and the position of the vehicle with respect to a sign. Type IX sheeting, for example, tends to be less bright at long distances than Type VIII sheeting, but brighter at short distances.

Sheeting Types I through III are beaded, and Types IV through XI are microprismatic. Premium types of microprismatic sheeting such as Type XI can be more expensive than other microprismatic materials, so some states, such as Missouri and Texas, now specify that sign legends be microprismatic (Type VIII for Missouri and Type XI for Texas) and the background be composed of either a Type III or Type IV sheeting (14). Such combinations can achieve high legend luminance and high contrast at less expense than purchasing a sign made entirely with Type XI sheeting. Standards for minimum levels of retroreflectivity are detailed in the MUTCD.

Visual Performance of Retroreflective Signs

Research from the 1960s investigated the legibility of different combinations of materials used on overhead guide signs. It was concluded that many material types might provide satisfactory legibility without the use of sign lighting, though the conclusion was drawn based on the results from young drivers (15). Research from the 1970s suggested that sign lighting on overhead guide signs could be eliminated when using Type III sheeting if there is a straight approach to the sign (16, 17). It was also suggested that sign lighting be used on curves or where only the low beams of vehicle headlamps were allowed. In 1984, Gordon evaluated the request by the California Department of Transportation (Caltrans) to use non-illuminated overhead signs (18). The Caltrans review team concluded that button copy signs with opaque backgrounds functioned satisfactorily without external sign lighting. There were, however, recommendations to maintain sign lighting for freeway off-ramp and lane-assignment signs that call for immediate lane changes. Additionally, sign lighting is to be used where fog and dew occur frequently.

Zwahlen et al. investigated the feasibility of removing lighting from overhead guide signs when retroreflective sheeting is used (19). They evaluated four different sheeting combinations with and without exterior sign lighting. Based on the field and photometric evaluations, they concluded that either white Type VII or Type IX legends on green beaded Type III backgrounds could provide adequate appearance, conspicuity, and legibility without the use of additional sign lighting. The same researchers later performed a more thorough investigation with only older drivers using six material and lighting combinations (20). The researchers found that unlit signs (illuminated only by headlamps) composed of Type IX on Type IX sheeting or Type VII on beaded Type III sheeting performed better than the lighted signs composed of Type III on Type III sheeting. Although it seems the study was executed only on rural roads, the researchers recommended that the Ohio DOT discontinue its practice of lighting signs.

Multiple studies indicate that signs made with microprismatic sheeting tend to perform better than signs of older sheeting types, even when the older signs are lit (21–24). Bullough et al. compared the performance of unlit signs made from new sheeting (Types VII, VIII, and IX) with lit signs of older sheeting (Types I and III) installed along an expressway in an urban area (23). Based on the photometric measurements of the signs (values of luminance and contrast) and the resulting relative visual performance and response times, the researchers calculated that visibility of the unlit signs with high-performance sheeting was similar to that of the older signs equipped with external sign lighting. The Indiana DOT evaluated the feasibility of discontinuing lighting overhead guide signs on freeways based on comparisons of the conspicuity, legibility,

and appearance of various combinations of sign sheeting types used on legends and backgrounds (24). The DOT determined that it should start using microprismatic sign sheeting (Types IV through XI) on its overhead guide sign legends and backgrounds, and discontinue lighting such signs.

Factors Limiting Retroreflection

There are several factors that limit the amount of luminance a retroreflective sign can direct back to drivers. One is the physical degradation of the sign sheeting, which slowly occurs over time. Research simulating the long-term degradation of sign sheeting indicates that white prismatic sheeting will satisfy MUTCD minimum requirements for at least 20 years (25). In the same study, the green sheeting samples used for sign backgrounds also did not degrade to an unacceptable level. Even though the products are likely to meet the MUTCD minimum criteria for a long time, it is important to recognize that those guidelines represent minimums and that the retroreflective performance regularly declines throughout the time the sign is in service. Another physical factor that affects retroreflectivity is the presence of dew, frost, and dirt that can accumulate on signs. While dew and frost are present only during certain times of the day, the effects of dirt are not restricted to these periods. It is not uncommon for some agencies to have sign cleaning programs, at least for signs that are reasonably accessible.

The second factor limiting the luminance reflected back to drivers, which has already been mentioned, is the angle of retroreflection formed between the headlamps, the surface of the sign, and the driver's eyes. This angle is different for each combination of driver, vehicle, and sign location, and continually changes as a driver approaches a sign. Each classification of sign sheeting has different performance specifications for certain angles of retroreflection, so some products perform better than others depending on the geometric conditions and location of the vehicles with respect to a target sign. Research conducted for Florida DOT (that was later adopted into policy) recommended that Type XI sheeting be used for overhead guide signs as long as the sign is not on a curve with a radius shorter than 2,500 ft in urban areas or 800 ft in rural areas (10). Sign lighting should be used in those particular instances because the geometric conditions result in wide angles of retroreflection.

Implementing Newer Retroreflective Sign Technology

As agencies replace lighting with efficient sheeting, there appears to be a consistent thought that as retroreflective sign sheeting becomes more efficient, the need for sign lighting decreases. Since the recommended values of illuminance and

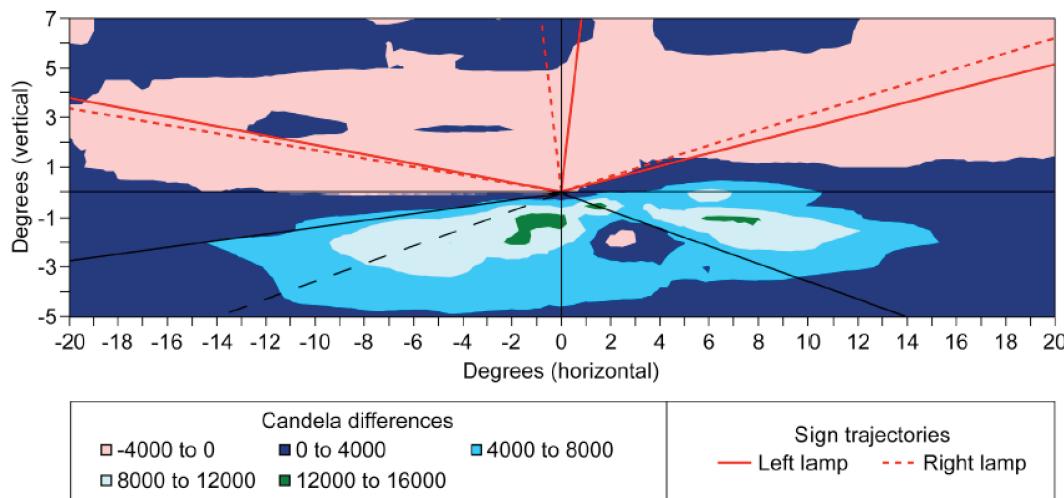
luminance in the IESNA and AASHTO guidelines change based on ambient luminance, it would seem sensible that signs in rural areas with little visual clutter do not need to be lit. However, there is still the question of whether headlamps are sufficient as the only source of nighttime illumination (which occurs when signs are not lit). The following section discusses characteristics of vehicle headlamps that affect the amount of illuminance on a sign.

Vehicle Headlamps

Headlamps have regularly evolved since their first use in the 1880s. While this evolution has led to overall improvements in performance, there have been significant changes to the light distribution, impacting the light available for retroreflection from traffic signs. Only after headlamp specifications were introduced in the 1990s were standards for retroreflective signs addressed (26). Before 1997, the Federal Motor Vehicle Safety Standard (FMVSS) 108 included headlamp intensity and distribution requirements for all vehicles sold in the United States (27). It allowed more light to be emitted by headlamps above the horizontal plane than used in European and Japanese vehicles. Light above the horizontal plane is helpful for illuminating overhead guide signs. In 1997, the FMVSS Standard was revised to form a global compromise of the specifications for the United States, European, and Japanese headlamps (27). The most significant change was that the headlamps projected less light above the horizontal plane, reducing the amount of light available for overhead signs. Chrysler et al. showed that the evolution of headlamps has resulted in less and less light illuminating traffic signs (28).

Sivak et al. showed how recent changes in headlamp design affect the illumination of traffic signs, including overhead signs (29). They compared the differences between 1997 tungsten-halogen headlamps and 2004 high-intensity discharge (HID) low-beam headlamps for U.S. vehicles. Figure 2 shows the difference between the median 2004 HID luminous intensities and the median 1997 tungsten-halogen luminous intensities for the central part of the beam pattern (2004 HID minus 1997 tungsten-halogen). Figure 2 shows that the newer headlamps provide more illumination on the pavement in front of the vehicle, but less illumination above the horizontal plane. Sivak et al. indicated that traffic signs, including overhead signs, are less visible using the newer low-beam headlamps. The reduction of light on traffic signs reached up to 69 percent for overhead signs, 64 percent for right-shoulder-mounted signs, and 67 percent for left-shoulder-mounted signs.

Headlamp degradation, which became more common as replaceable bulbs became the standard over sealed beam lamps, also negatively affects the illumination. Modern headlamps with replaceable bulbs suffer from yellowing and fogging caused by factors like acid rain, condensation, dirt, and



Note: The solid lines below the horizontal represent the edges of a straight and level roadway with two 3.7-m wide lanes. The dashed line below the horizontal represents the road midline. The red lines above the horizontal represent the positions of three types of signs (right, left, and overhead) from the perspective of the left and right headlamps.

Figure 2. Difference between the 2004 high-intensity discharge and 1997 tungsten-halogen headlamps (29).

heat that did not have as great of an effect on sealed beam headlamps (30). The evolution of headlamps has resulted in less illumination reaching traffic signs, whether a result of changes in the distribution of light or the construction that allows for degradation from the natural elements. Because overhead signs without sign lighting must be retroreflective and rely on headlamp illumination, these changes affect the sign's visibility.

Roadway Lighting

Although not directed at signs, roadway lighting provides illumination that may affect the visibility of the sign. Roadway lighting is intended to enhance the ability of road users to identify and respond to unexpected hazards. There have been numerous studies on roadway lighting, but none appear to identify the effects of roadway lighting on the luminance and visibility of traffic signs, especially overhead guide signs. Roadway lighting is not intended to light overhead retroreflective signs, though it does provide some useful illumination if sign lighting is out of service (2).

There have been several studies of the operational effects of roadway lighting, with findings of increased speeds and capacity (31–33) and reduced crash frequencies (34–45). Elvik and Vaa (46) and Monsere and Fischer (47) found that reductions in roadway lighting resulted in increases in crashes. These positive effects of roadway lighting often overshadow the notable costs and negative effects. The initial installation, regular maintenance, and energy consumption are clear capital costs of lighting. In addition, roadway lighting causes light pollution, disability glare, and discomfort glare. Each of these negatively affects sign visibility.

It has been estimated that about 35 to 50 percent of light pollution is caused by roadway lighting, which can come in the form of sky glow, light trespass, and glare (48). While sky glow and light trespass (light entering a property or building from an outside source) negatively affect the well-being of residents, bright lighting and glare can reduce contrast sensitivity and color perception and negatively affect older drivers whose eyes cannot quickly adjust to different levels of lighting. Several state and local governments have addressed the negative environmental effects of roadway lighting through ordinances to evaluate (and mitigate when appropriate) light trespass or sky glow (12). Though there is inconsistency in lighting ordinances from one agency to another, some of the mitigation measures include shielding luminaires and dimming or turning off the lights during curfew times. These inconsistencies have resulted in the development of the Model Lighting Ordinance (MLO) by IESNA and the International Dark-Sky Association to standardize ordinances and eliminate confusion that may arise as engineers and developers work in different regions. The MLO recommends methods for controlling light pollution while maintaining necessary light for areas that need it through listing specific levels of lighting, types of luminaires to use, and methods for shielding light from unintended targets.

Disability glare has a direct link to the physiology of the eye and is caused by light scatter from the ocular media in the eye (49). Light entering the eye collides with components of the ocular media such as the cornea, lens, and vitreous humor. At each collision, photons scatter and cast a veil of light across the retina. Up to 30 percent of the stray light is from the cornea, approximately the same amount is from the lens, and the rest is scattered in the retina itself (50, 51).

Measurements presented by Adrian and Bhanji showed that much of the scattering also occurs in the vitreous humor (52). The veil of light has the effect of reducing the contrast of an object, which would have the same effect as increasing the background luminance of the object.

Discomfort glare is from a light source that causes the observer to feel uncomfortable. Van Bommel and deBoer stated that discomfort glare is based primarily on the observer's light adaptation level, and the size, number, luminance, and location of the light sources in the scene (53). The definition of discomfort, however, is not precise, and some research has shown that a person's response to a glare source is based more on his or her emotional state than on the light source itself. Disability and discomfort glare are difficult to identify and quantify in order to comprehensively evaluate their effects on traffic sign visibility, but both types of glare represent conditions that drivers can encounter in urban areas with multiple, bright light sources.

Effects of Complex Environments on Sign Visibility

The previous sections introduced several topics associated with lighting that affect sign visibility, specifically the needs of drivers, guidelines and trends for sign lighting, retroreflective sheeting, changes in headlamp illumination, and roadway lighting. This section discusses how the complexity of the visual field may influence the visibility of traffic signs.

Visually Complex Backgrounds

Lerner et al. indicated that irrelevant visual information leads to information overload in drivers, disrupting the detection and processing of information relevant to the driving task (54). It should not be surprising that increases in the complexity of a roadway and its background environment have adverse operational effects, such as increased crash rates and reduced traffic flow (55–57). Since visual clutter competes for a driver's attention, potentially affecting the conspicuity, visibility, and legibility of a sign, the complexity of the visual field should be accounted for in an assessment of a sign's visual performance.

Sign conspicuity is a measure of how noticeable a sign is in its surrounding environment and how well it attracts a driver's attention. Signs in rural areas at night tend to have a high level of conspicuity because there are few objects competing for a driver's attention. In urban areas, where ambient luminance increases the visibility of other objects, the visual field is much more complex and a sign's conspicuity is reduced. It has been shown that visual complexity negatively affects an object's conspicuity (58–63).

Complexity also has been shown to affect sign visibility from a perspective of conspicuity and legibility (64–66). Schieber

and Goodspeed found that a sign's visibility improves most when increasing a sign's brightness if the sign is in a visually complex environment, such as an urban setting (67). Little, if any, improvement to a sign's visibility can be expected when increasing sign brightness in rural areas with low complexity. Other research indicates that increasing sign brightness can mitigate the adverse effects of visual complexity (61, 68).

A final element of the visual performance of signs is legibility. It is accepted that a sign has already been detected when it is read. While there has been a substantial amount of research on sign legibility, few studies (if any) have included the effects of background complexity. Mace et al. found that visual complexity had no effects on the legibility of warning signs (69), but Holick and Carlson found that background complexity influenced how much luminance was necessary to read overhead guide signs (9). With increased background complexity, there was an increase in the minimum luminance at which a sign was legible.

Measuring Background Complexity

Despite the amount of research investigating how complex environments affect the visual performance of signs, there has been no systematic or quantitative method to classify the level of background complexity. One proposed method is the use of image processing technology, which has been utilized in target recognition, traffic surveillance, pavement crack estimation, remote sensing, and some medical applications. Methods have included evaluating color distribution and variance (70), analyzing edge level percentages (71), and determining entropy of an image (72, 73). Although one of the benefits of image processing is the ability to control the amount of subjectivity in the analysis, it is not uncommon for subjectivity to be introduced in the form of ratings or rankings. This is done so elements derived from the image processing can be identified as contributing to a human's perspective of the desired measure (such as complexity). Okawa (70) and Cardaci et al. (72) are two examples where test participants were used to rate images that were also processed with a specific algorithm. The research described in this report developed a technique to measure the visual complexity of an environment as one part of evaluating a sign's visual performance. The technique was used in the analysis presented in Chapter 4.

Measuring Sign Visual Performance: Recognition and Legibility

Reading traffic sign messages during the driving task involves components of both recognition and legibility. Legibility is the ability to read the sign message without first having an expectation for what the sign says. Since drivers have specific destinations, they tend to use search tactics that reflect top-down processing for recognition on guide and street name signs based

on the expected message of the sign. In some circumstances, however, unfamiliar drivers may read a sign without having initial clues regarding its message. These instances involve bottom-up processing, indicating a reliance on legibility over recognition since the driver has no prior expectation for the sign's message. The expectation for a sign's message increases the distance at which a driver would otherwise be able to read a sign. Recognition and legibility distances are indicative of a sign's visual performance.

Studies measuring a sign's recognition or legibility tend to evaluate the distance from a sign at which a driver can read or

identify the legend. Recognition distance tends to be longer than legibility distance because of the clues provided by the expectation for a particular message. Several researchers have measured legibility or recognition distances, or both, for signs under different study conditions. A short review of some of the study findings associated with guide signs is presented in Table 5. Average legibility index or recognition index for each study is provided. The average legibility index ranges from 30–44 ft/in.; recognition index ranges from 48–75 ft/in.

Although only general findings are reported in Table 5, the studies primarily analyzed the factors (such as driver age and

Table 5. Recognition and legibility indices from guide sign studies.

Road Conditions	Recognition Index	Legibility Index	General Description
Closed Course	75 ft/in.	40 ft/in.	Garvey et al. (74)—Older study participants read shoulder-mounted signs from the passenger seat to evaluate different fonts on ASTM Type III and Type IX sheeting. Test words were unfamiliar location names. The indices combined both daytime and nighttime viewing.
	48.5 ft/in.	40.5 ft/in.	Hawkins et al. (75)—Older and younger study participants (more older than younger) read shoulder-mounted and overhead signs at night from the passenger seat of a sedan. The signs used three different fonts and Type III sheeting. Test words were not driving related, and the recognition and legibility tasks may have been affected by complicated tasks assigned to the participants. There were small differences between the indices for overhead- and shoulder-mounted signs.
	n/a	38.4 ft/in.	Carlson (76)—Younger, middle-aged, and older study participants read shoulder-mounted and overhead guide signs at night while slowly driving. Two different fonts were tested with Types III, VIII, and IX sheeting. Test words were not driving related.
	n/a	29.8 ft/in.	Chrysler et al. (77)—Older (55–74 years) participants read sign messages at night while slowly driving. Two fonts and three sheeting types were tested. Four sign colors were tested, but only the average legibility index for white on green is shown here. Test words were all four letters in length and driving related.
	n/a	34.4 ft/in.	Carlson et al. (78)—Younger and older study participants read an internally illuminated overhead guide sign while driving on a closed course at night with different levels of illumination. Test words were driving related. The reported value is an average of the legibility indices at different luminance levels.
	n/a	41.2 ft/in.	Miles et al. (79)—Younger and older study participants read overhead and shoulder-mounted guide signs with different fonts while driving at night. The legends were not driving-related words and were constructed of Type XI sheeting.
Open Road	n/a	32.5 ft/in.	Carlson et al. (78)—Younger and older drivers read shoulder-mounted guide signs with legends of different sheeting types representing three illumination levels and two environments (rural and suburban).
	n/a	31.5 ft/in.	Chrysler et al. (80)—Older drivers at night read street name signs on the right side of the road while approaching intersections of different levels of complexity. The average value represents signs with Types III, VII, and IX sheeting.
	n/a	43.8 ft/in.	Funkhouser et al. (81)—Study drivers of mixed ages read overhead guide signs on a toll facility at night. The guide signs were of microprismatic sheeting. Both purple and green backgrounds were tested, but only the average for green signs with 16-in. legends is reported here.

sheeting type) that influence visibility, whether measured as recognition or legibility. Recognition and legibility distances tend to be higher on closed courses and when the tasks given to the participants are not complex.

Conclusion

There are several factors that affect the visibility of traffic signs at night. Multiple organizations have established guidelines to regulate the physical properties that are under an agency's control to ensure visibility from a perspective of light and appearance. However, there are several other considerations related to the driver that limit the ability to truly control the driving experience and, subsequently, a sign's visibility. Minimum luminance levels for sign visibility have

been studied multiple times. Those studies, however, have been conducted almost exclusively in rural and dark conditions. Other research and anecdotal evidence suggest that increased sign luminance is necessary in urban areas or locations where drivers may be affected by lights or other objects that are unrelated to the driving task and reduce the overall visibility of a sign. These may be sources of glare or distractions that increase the workload of the driving task. While lighting guidelines (such as those in Tables 2 and 3) have attempted to address the diverse conditions that can be encountered on the road, there are some apparent deficiencies in the established lighting levels, and perhaps in the subjectivity used to determine the in-situ conditions. This research was conducted in an attempt to amend those deficiencies.

CHAPTER 3

Closed-Course Study

As discussed in Chapter 2, recent trends indicate a movement away from lighting overhead guide signs toward relying on retroreflective sheeting and vehicle headlamps assumed to provide nighttime drivers with sufficient sign luminance for visibility. There are various guidelines suggesting how much illuminance or luminance should be provided, and the MUTCD provides minimum maintenance standards for retroreflectivity when sign lighting is not used.

The literature summarized in Chapter 2 identified the following controllable elements that influence the nighttime visibility of a sign: the use and type of sign lighting, the type of sign sheeting material, the vehicle's headlamps, the background complexity, and the use of street lighting. Most of these factors have been evaluated in separate contexts but not in a full-factorial study identifying the specific influence of single elements. This chapter describes the design and results of a closed-course study that was performed to evaluate how combinations of various lighting sources and types of sheeting contribute to the nighttime visibility of overhead guide signs.

Experimental Design

The purpose of this study was to evaluate the nighttime visibility of guide signs constructed of different materials and illuminated under various lighting conditions. The lighting conditions included the use of different types of sign lighting and intensities, as well as the use of overhead street lighting. The study involved having drivers on a closed course read the legend of an overhead guide sign while approaching the sign. Each participant made multiple runs. A different combination of lighting was used with each run. The legend was also changed each time to ensure the study involved legibility rather than recognition.

Facilities and Equipment

Closed Course

The research was conducted on the Virginia Smart Road at the Virginia Tech Transportation Institute. It was completed in 2013. The Smart Road is a 2.2-mi closed-access test track that simulates a typical stretch of highway with pavement markings and guardrails and includes a frame for mounting a guide sign. Figure 3 is an illustration of the Virginia Smart Road and identifies where the street lighting was located with respect to the overhead guide sign, which was viewed from only one direction. There were more street lights behind the sign than in front of the sign. The luminaires in front of the sign increased the illuminance on the sign (and resulting luminance viewed by the driver), while the luminaires behind the sign acted as glare sources and increased the visual complexity of the scene.

Vehicles

Two Ford Explorers from 1999 and 2000 were the test vehicles. The vehicles had the same body style and internal layout. Each vehicle was similarly instrumented for data collection with digital audio and video recorders, global positioning system (GPS) receivers, and buttons for experimenters to identify critical points in the data stream. The two vehicles' headlamps were identical, and their aim was calibrated prior to each session. The study protocol involved two participants driving at the same time in short succession. The rear view and side mirrors were covered to prevent headlamp glare from the other test vehicle.

Sign Lighting Systems

Two separate lighting systems were used to illuminate the guide signs and compare driver responses with the type of

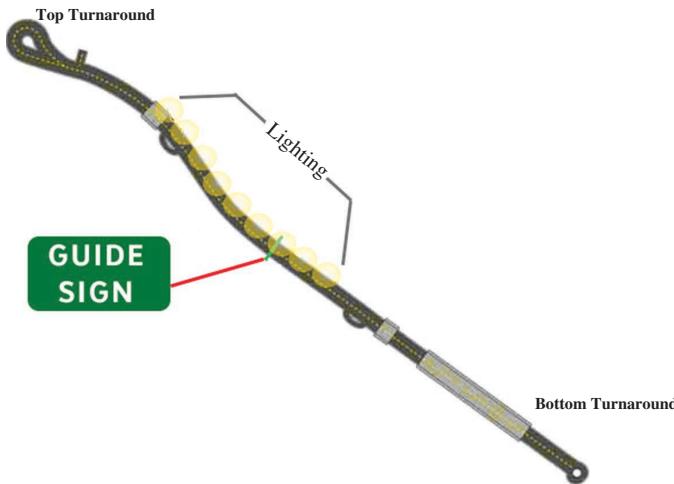


Figure 3. Illustration of the closed-course test road (Virginia Smart Road).

lighting. The two systems consisted of HPS and LED lights. The HPS lighting was a GE Versaflood II luminaire with a correlated color temperature (CCT) of 2,100 K. The LED lighting was two Cree OL Series Flood luminaires with a CCT of 5,700 K. The two lighting systems were closely matched for illuminance, but there were differences in the resulting luminance. Researchers mounted both systems on the sign's frame to eliminate the need to physically change the lighting system during the study. A single HPS luminaire was mounted in the center of the lighting fixture, and two LED luminaires were placed on each side of the HPS luminaire. The lighting fixture was mounted 75 in. from the guide sign. Figure 4 shows

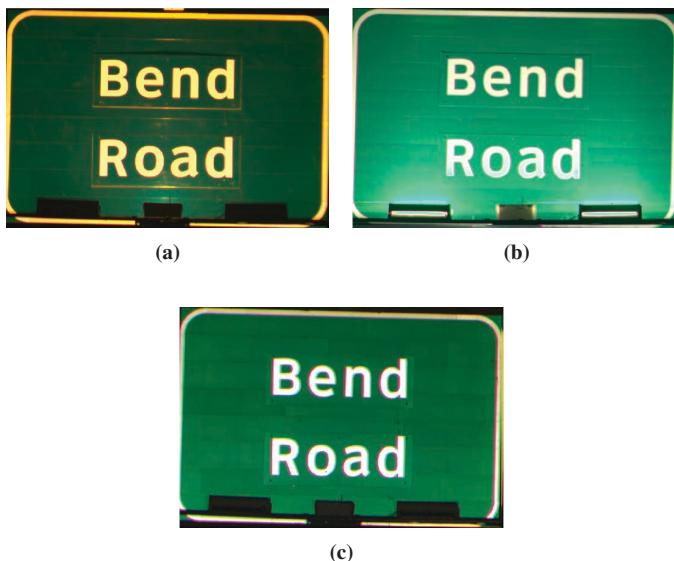


Figure 4. Test sign illuminated under different lighting conditions: (a) HPS, (b) LED, and (c) headlamps only.

one of the study signs illuminated by the two different types of sign lighting and a third condition without sign lighting (headlamps only). The cooler temperature of the HPS lighting compared with the LED lighting can be seen in Figures 4a (HPS) and 4b (LED).

The research team adjusted the orientation, aim, and spacing of the HPS and LED luminaires to make the illumination from the light sources as uniform as possible based on AGI32 light modeling software. Illuminance was measured on the sign surface using a 12-point orthogonal grid.

The intensity of each light was adjustable, which added another factor to the study. Three intensity levels (25, 50, and 100 percent) were selected. There was also a fourth intensity level (off). To select a particular intensity for an experimental run, the researchers designed a method to control the intensity of the sign lighting based on the system's power output. It was observed that different levels of power were needed to produce a comparable illuminance using the two lighting systems. Figure 5 shows how illuminance (measured at the sign face) of the two systems changes with a defined power level and how much luminance (measured at 300 ft from the sign) is provided for a specific amount of illuminance. The luminance (which is affected by the type of retroreflective sheeting) reported in Figure 5 was measured from Type XI green background sheeting with no illumination other than from the specified sign lighting.

Figure 5 shows that the light produced by the LED system is more efficiently reflected as luminance than the light from the HPS system. The amount of illuminance provided by the two lighting systems for a given power level is also inconsistent. Each lighting system was adjusted to a unique power level to achieve a similar illuminance when set at one of the three intensities for the study (25, 50, and 100 percent). With maximum power producing about 600 lx for both systems, the 50 and 25 percent levels produced approximately 300 and 150 lx, respectively. Table 6 indicates the specific values of illuminance for the selected intensity levels. These values closely match the AASHTO and IESNA recommended illuminance levels for low, medium, and high ambient lighting as described in Chapter 2 (Tables 2 and 3).

Retroreflective Sheetling

The sign backgrounds measured 8 ft × 12 ft and were constructed of one of the three sheeting materials: ASTM Type III beaded, Type IV prismatic, or Type XI prismatic. The sign legends were constructed of either ASTM Type IV or Type XI sheeting. The Type IV legend was placed only on the Type III background. The Type XI legend was applied only to the Type IV and Type XI backgrounds. Close-up photos of the sheeting materials are shown in Figures 6–8.

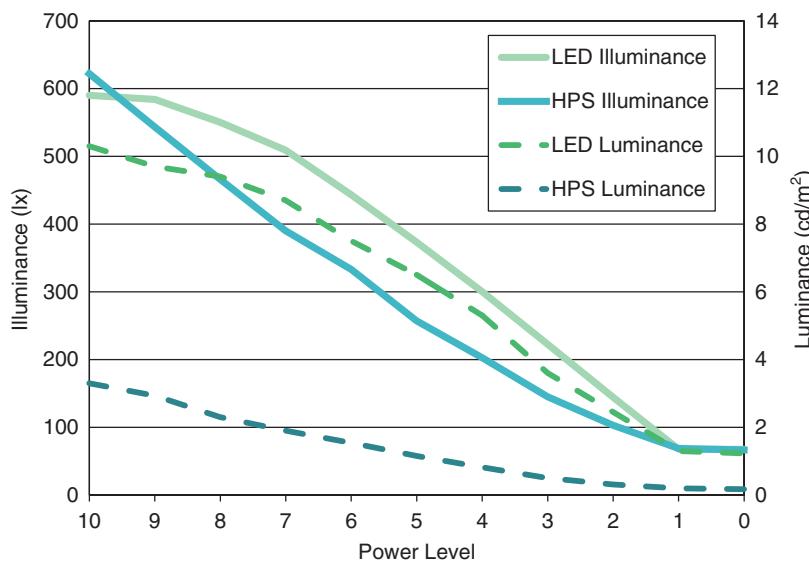


Figure 5. Measures of illuminance and luminance (at 300 ft with Type XI green sheeting) by type of lighting.

Table 6. Measured illuminance for each intensity level and lighting system.

Intensity Level	Illuminance (lx)	
	HPS	LED
100%	622	590
50%	333	300
25%	145	144



Figure 7. Type XI prismatic legend on Type IV prismatic background.



Figure 6. Type IV prismatic legend on Type III beaded background.



Figure 8. Type XI prismatic legend on Type XI prismatic background.

The legends have mixed-case letters with a size corresponding to an uppercase letter height of 16 in. The typeface was Clearview 5WR font. Clearview 5WR ("R" for reduced) is a narrower version of the Clearview font and has a footprint similar to Series E (Modified) (82).

Overhead Street Lighting

The street lighting system consisted of 12 LED luminaires spaced 250 ft (80 m) apart along the road. The three luminaires located in front of the test guide sign were placed starting approximately 650 ft (200 m) before the sign. The remaining luminaires extended 2,500 ft (760 m) beyond the guide sign. The color temperature of the overhead LED lights was 6,000 K. These roadway lights were used for half of the trial runs.

Participants

Twenty-four participants were recruited, with an even split of gender and age (six older males, six younger males, six older females, and six younger females). The data collected for two of the 24 participants were discarded during post-processing when the researchers discovered the vehicle headlamps had not been properly configured before the trials. Each participant passed vision tests that included measurements of acuity, color vision, and contrast sensitivity. No participant was colorblind or had acuity worse than 20/40. Contrast sensitivity was above 25 percent using a Snellen eye chart with an illuminator.

Experimental Procedure

Each participant adjusted basic settings upon sitting in the driver's seat. A researcher sat in the vehicle with the participant to give instructions. The participant drove at a constant speed of 35 mph and with the headlamps on, reading the guide

Table 7. Guide sign legend word groups.

Group 1	Group 2
Lake	Camp
Long	Port
Gray	Cape
Bear	Road
Oven	Park
East	Bend

sign's legend aloud as soon as it was legible. The GPS receiver continuously recorded the location of the vehicle. When the participant correctly read a sign legend, the researcher in the vehicle pressed a button to record in the data stream the moment when the sign was legible. After passing the sign, the participant turned around to repeat the test under different lighting conditions and with a different legend.

The legend was selected from words divided into two different groups, as shown in Table 7. One word from each group was placed on the sign for each lap. The sheeting material was constant throughout a single participant's tests, though the legend changed with each approach to the sign.

Two participants drove at one time, and the timing was arranged so the vehicles never crossed paths. In addition to changing the legend with each lap, the on-site researchers also adjusted the lighting configuration. The two types of sign lighting systems were set to three different intensity levels (100, 50, and 25 percent). These six possible sign lighting settings were matched with whether or not overhead street lighting was used, producing 12 possible combinations when sign lighting was on. Two additional options that involved no sign lighting (and street lighting was either on or off) resulted in 14 total lighting configurations. Each participant in the study completed up to 14 laps. An example protocol for a single participant is shown in Table 8.

Table 8. Example experiment protocol.

Lap	Sign Sheeting	Sign Lights	Sign Lighting Intensity	Overhead Street Lighting	Legend
1	XI on XI	LED	100%	OFF	Camp Lake
2	XI on XI	LED	50%	OFF	Port Long
3	XI on XI	LED	25%	OFF	Cape Gray
4	XI on XI	LED	25%	ON	Road Bear
5	XI on XI	LED	50%	ON	Park Oven
6	XI on XI	LED	100%	ON	Bend East
7	XI on XI	HPS	100%	ON	Long Road
8	XI on XI	HPS	50%	ON	Gray Park
9	XI on XI	HPS	25%	ON	Bear Bend
10	XI on XI	HPS	25%	OFF	Oven Camp
11	XI on XI	HPS	50%	OFF	East Port
12	XI on XI	HPS	100%	OFF	Lake Cape
13	XI on XI	None	0%	OFF	Bear Port
14	XI on XI	None	0%	ON	Park Lake

Table 9. Independent variables and values.

Variable	Number of Levels	Values
Sign Lighting Level	4	100 percent, 50 percent, 25 percent, off
Sign Lighting Type	2	HPS, LED
Legend/Background Sheeting Combination	3	Type IV legend on Type III background, Type XI legend on Type IV background, Type XI legend on Type XI background
Overhead Street Lighting	2	On, off
Age	2	Younger (25–35) and Older (65+)

Participants were assigned a secondary task in which they were asked to read aloud the speeds posted on a speed limit sign. The speeds shown were either 35 or 55 mph. This increased the complexity of the driving task to better simulate a realistic driving scenario and helped the participants maintain their focus on road signs when the only other task would be to read the guide sign. Data for the speed limit sign legibility distance are not reported here.

With legibility distance as the dependent variable, the independent variables were sorted in a $4 \times 3 \times 2 \times 2 \times 2$ mixed factorial design from four combinations of sign lighting levels (off, 25 percent, 50 percent, and 100 percent intensities), three combinations of retroreflective sign sheeting for the legend and background, two types of sign lighting (HPS and LED), two conditions of street lighting (on and off), and two age groups of study participants. Table 9 identifies the different possible settings. Each driver viewed the signs under conditions of the four lighting levels, two types of sign lighting, and two overhead street lighting settings. Each participant, however, only viewed one combination of legend and background sheeting material because the background was too cumbersome to change during the experiment. Legend and background material was a between-subjects variable.

Data

Legibility distance was calculated as the distance between the location of the vehicle at the moment when the researcher pressed the button in the GPS data stream and the stationary location of the guide sign. Audio and video recordings of the participants were used to increase the accuracy of the vehicle's identified location since there was an inherent delay from when the participant read the sign legend and the researcher pressed the button.

In addition to considering the individual factors listed in Table 9, and separate from the data collection with participants in the vehicle, researchers measured the luminance of the target sign at 100-ft intervals from the sign using a Radiant Imaging ProMetric photometer. A 300-mm lens was used to achieve a detailed image from all measurement distances. Each pixel in the image has a corresponding luminance value.

The device was mounted inside the vehicle where the driver sits and aimed in the direction where a driver typically looks. At each 100-ft interval, the photometer captured images for each of the three sign background and legend combinations with each possible scenario of sign lighting type (HPS or LED), intensity (25, 50, or 100 percent), use of street lighting (on and off), and even use of headlamps (on and off, though headlamps were always on in the legibility tests). These combinations resulted in 24 images for each sign sheeting combination when sign lighting was used. There were three additional images captured when sign lighting was turned off: one for when street lighting and headlamps were both on, one for when street lighting was off but headlamps were on, and one for when street lighting was on but headlamps were off. An additional (fourth) image of no sign lighting, no street lighting, and no headlamps was not sensible since there would be no illuminance from any light source. Twenty-seven images for each of the three signs at nine locations resulted in 729 total images.

With a luminance value associated with each pixel in each photometric image, average luminance values for the sign's legend and background were derived from rectangles covering multiple areas of the image, as shown in Figure 9. The



Figure 9. Rectangles selected for calculating sign luminance and Weber contrast.

rectangles covered four regions on the legend and four on the background. A Weber contrast value for each image was calculated from the average luminance of the legend and background, according to Equation 1:

$$C = \frac{L_L - L_B}{L_B} \quad (\text{Eq. 1})$$

where C is the Weber contrast ratio, L_L is the luminance of the sign legend, and L_B is the luminance of the sign background.

Figure 10 illustrates how legend luminance changes with distance from the sign using different types of sign lighting (HPS and LED) and illumination levels (50 and 100 percent). Type XI sheeting is used for those comparisons. Headlamps were always on, and there was no overhead street lighting. A condition with no sign lighting (headlamps only) is also shown using Types IV and XI sheeting. There are minor differences between the luminance measures on the Types IV and XI legends. In all instances, luminance increases as the vehicle approaches the sign, though there are fluctuations along the approach and a notable decrease starting at about 300 or 400 ft from the sign. This unevenness is due to the complex interaction of the retroreflective sheeting and light at the angles formed between the light sources, the sign, and the observer (photometer). It appears that the LED lighting at a 50 percent illuminance level produces nearly the same amount of luminance as the HPS lighting at 100 percent. The contribution of individual light sources on the luminance provided to a driver is described in Appendix A.

Since luminance and, subsequently, Weber contrast are dependent on the distance from the sign, the analyses that

consider the effects of luminance and contrast on legibility distance should use luminance measured from a consistent location from one trial to another. Legend luminance and contrast 640 ft from the sign were used in the analyses because 640 ft represents a legibility index of 40 ft/in. for the 16-in. uppercase letter in the legend. The values were interpolated from measurements at 600 and 700 ft. Figure 11 is a histogram of legend luminance at 640 ft using the 42 factorial combinations of sign sheeting, sign lighting type, sign lighting intensity, and overhead street lighting use. The minimum is 8 cd/m², the median is 21.6 cd/m², and the maximum is 46.7 cd/m². The minimum luminance of 8 cd/m² is about 3.5 times brighter than the minimum luminance level that was used to derive the FHWA minimum retroreflectivity levels for overhead guide signs (2.3 cd/m²). Figure 12 shows the distribution of Weber contrast at 640 ft with the same combinations of lighting, intensity, and sheeting. The minimum is 5.2, the median is 9.0, and the maximum is 20.1. There are also 42 observations.

The study obtained 261 total observations of legibility distance from the 22 participants with usable data. Figure 13 illustrates the distribution of the data. The minimum distance was 197 ft, the maximum was 1,252 ft, and the median and mean were 705 ft and 718 ft, respectively. The median and mean legibility distances were slightly greater than the 640-ft distance representative of a 40-ft/in. legibility index. Most of the observations therefore have a legibility index greater than 40 ft/in. The data are right skewed, an expected feature since the legibility distance cannot be less than 0.

The dependent variable in the analyses described in the next section was the legibility distance from the sign when the drivers correctly read the legend. Variation in the legibility

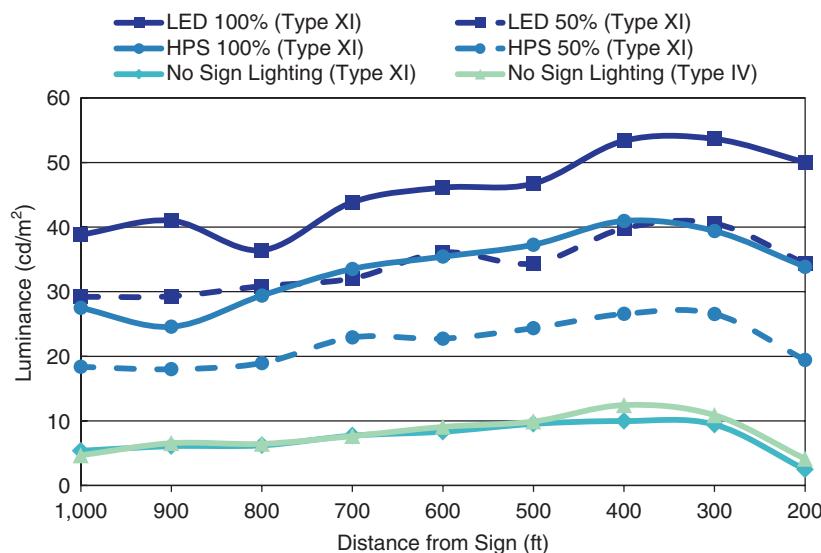


Figure 10. Luminance measurements of sign legend (Type XI) by distance from sign (no street lighting; headlamps on).

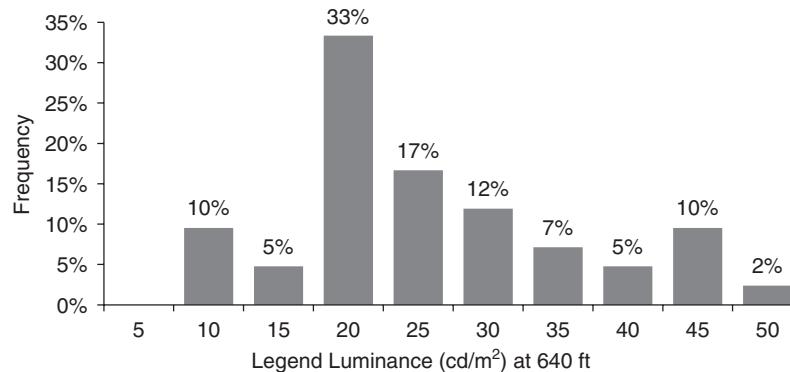


Figure 11. Distribution of legend luminance measured at 640 ft under the closed-course factorial conditions.

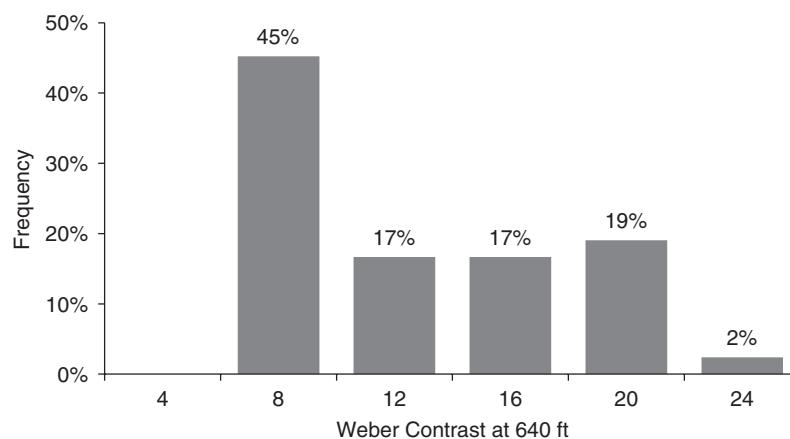


Figure 12. Distribution of Weber contrast values measured at 640 ft under the closed-course factorial conditions.

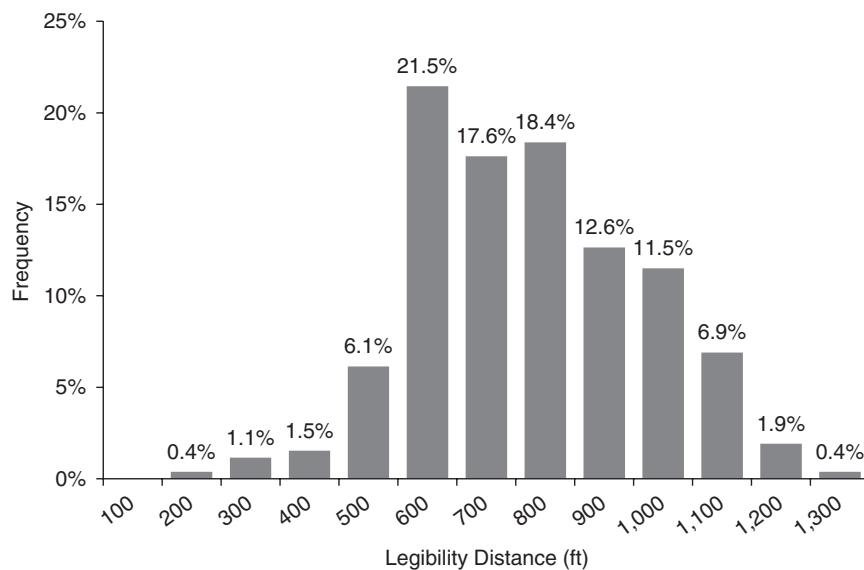


Figure 13. Distribution of legibility distances from the closed-course study.

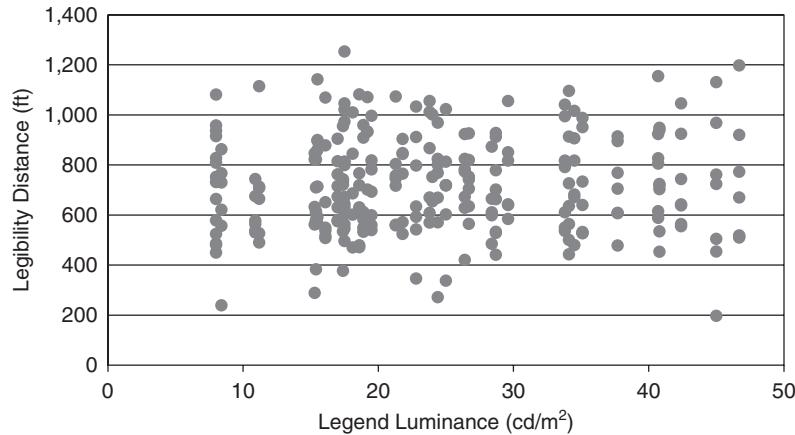


Figure 14. Scatterplot of observations of legibility distance and values of legend luminance measured at a distance of 640 ft. There is no relationship between legibility distance and luminance from these data collected on the closed course.

distance from one observation to another was analyzed with respect to the categorical variables from the factorial experiment (sign lighting type, lighting intensity level, use of overhead street lighting, and sign sheeting material) and the values of luminance and contrast at 640 ft that resulted from the experiment design. The presence of categorical and continuous independent variables meant than an analysis of variance (ANOVA) and an analysis of covariance (ANCOVA) could be performed to identify the factors that influence legibility distance. If lighting or sheeting configurations or luminance or contrast values were found to influence legibility, such findings would support guidelines for signs to be constructed with a certain type of sheeting, illuminated

by a specific type of lighting, or provide a defined level of luminance or contrast.

Analyses

The analyses described in this section focus on the factors that affect legibility distance. One of the hypotheses was that legibility distance is dependent on the luminance of the sign legend and/or the Weber contrast of the sign. The first analysis investigated these relationships. Figures 14 and 15 are scatterplots showing the legibility distance versus legend luminance and Weber contrast, respectively. Based on visual inspection of the plots, legibility distance was not dependent

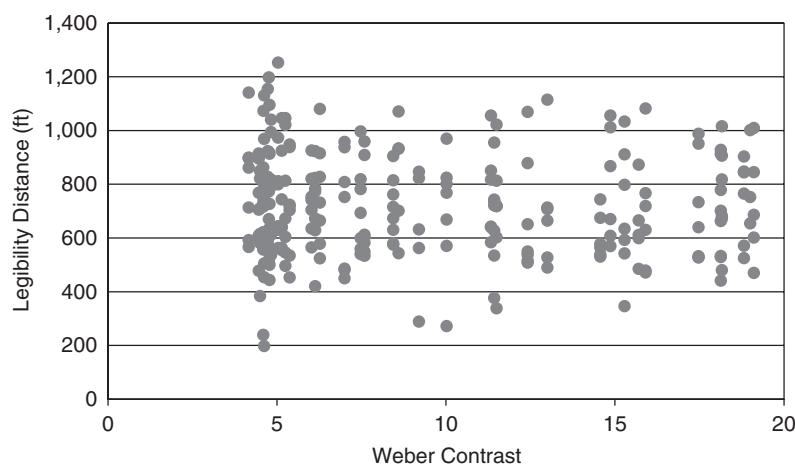


Figure 15. Scatterplot of observations of legibility distance and values of Weber contrast measured at a distance of 640 ft. There is no relationship between legibility distance and contrast from the closed-course data.

on either of the two measurements. Additionally, statistical analysis indicated that there was no relationship, even when considering a potential interaction.

Since there was no relationship between legibility distance and either luminance of the legend or Weber contrast of the sign, an ANOVA test was appropriate for identifying whether or not the categorical factors significantly affect legibility.

Legibility Distance versus Study Factors

An ANOVA test was performed to determine if changes in legibility distance could be attributed to independent variables of age, retroreflective sheeting, sign lighting type, sign lighting intensity, and overhead street lighting use. Each study factor and potential interactions were considered. The study participants were incorporated into the error term to account for the variability between participants and focus on the within-subjects effects. Table 10 contains the results of the test.

The ANOVA test identified only two factors (which are interactions) that significantly affect the legibility distance: Sign Lighting Type \times Sign Lighting Intensity and Sign Lighting Type \times Roadway Lighting \times Age. The legibility distances for the observations under those conditions are shown below.

Table 10. ANOVA results for legibility distance.

Source	F Ratio	Pr > F
Age	2.12	0.164
Sign Sheeting	0.02	0.982
Sign Sheeting \times Age	2.87	0.086
Sign Lighting Type	0.13	0.724
Sign Lighting Type \times Age	3.97	0.065
Sign Sheeting \times Sign Lighting Type	3.52	0.056
Sign Sheeting \times Sign Lighting Type \times Age	2.85	0.090
Sign Lighting Intensity	1.26	0.298
Sign Lighting Intensity \times Age	0.32	0.725
Sign Sheeting \times Sign Lighting Intensity	1.01	0.416
Sign Sheeting \times Sign Lighting Intensity \times Age	0.33	0.858
Sign Lighting Type \times Sign Lighting Intensity	3.77	0.038^a
Sign Lighting Type \times Sign Lighting Intensity \times Age	1.07	0.359
Sign Sheeting \times Sign Lighting Type \times Sign Lighting Intensity	0.95	0.452
Sign Sheeting \times Sign Lighting Type \times Intensity \times Age	0.28	0.890
Roadway Lighting	4.43	0.053
Roadway Lighting \times Age	0.04	0.850
Sign Sheeting \times Roadway Lighting	0.37	0.695
Sign Sheeting \times Roadway Lighting \times Age	0.29	0.754
Sign Lighting Type \times Roadway Lighting	0.2	0.667
Sign Lighting Type \times Roadway Lighting \times Age	6.3	0.027^a
Sign Sheeting \times Sign Lighting Type \times Roadway Lighting	0.84	0.456
Sign Sheeting \times Sign Lighting Type \times Roadway Lighting \times Age	2.89	0.095
Sign Lighting Intensity \times Roadway Lighting	0.08	0.924
Sign Lighting Intensity \times Roadway Lighting \times Age	0.93	0.407
Sign Sheeting \times Sign Lighting Intensity \times Roadway Lighting	1.21	0.329
Sign Sheeting \times Sign Lighting Intensity \times Roadway Lighting \times Age	0.24	0.911
Sign Lighting Type \times Sign Lighting Intensity \times Roadway Lighting	0.89	0.442
Sign Lighting Type \times Sign Lighting Intensity \times Roadway Lighting \times Age	0.36	0.709
Sign Sheeting \times Sign Lighting Type \times Sign Lighting Intensity \times Roadway Lighting	0.06	0.942
Sign Sheeting \times Sign Lighting Type \times Sign Lighting Intensity \times Roadway Lighting \times Age	—	—

Note: A dash (—) means that the effect could not be determined.

^a Variable significant at the 95 percent confidence level.

Sign Lighting Type \times Sign Lighting Intensity

It was shown in Figure 5 that each type of lighting and intensity level results in a unique luminance. Based on that information, it may not be surprising that the interaction of sign lighting type and intensity is a significant factor in the legibility distance. However, the lack of a statistical relationship between luminance and legibility distance (Figure 14) suggests that the effect is not directly related to the additional luminance from the sign lighting. Figure 16 shows mean legibility distances with standard deviations for each sign lighting type and intensity. The difference between the mean legibility distances for LED lighting (which range from 725 to 734 ft) and the mean for no lighting is about 50 ft. The mean legibility distance for no lighting is nearly equal to the mean for HPS lighting at 25 percent intensity. The mean legibility distances for HPS lighting at intensities of 100 and 50 percent differ by about 50 ft.

Sign Lighting Type \times Roadway Lighting \times Age

The second significant factor in the ANOVA test was the interaction of sign lighting type, roadway lighting, and age. There were 12 possible combinations characterizing the interaction of these three main effects. The mean legibility distance

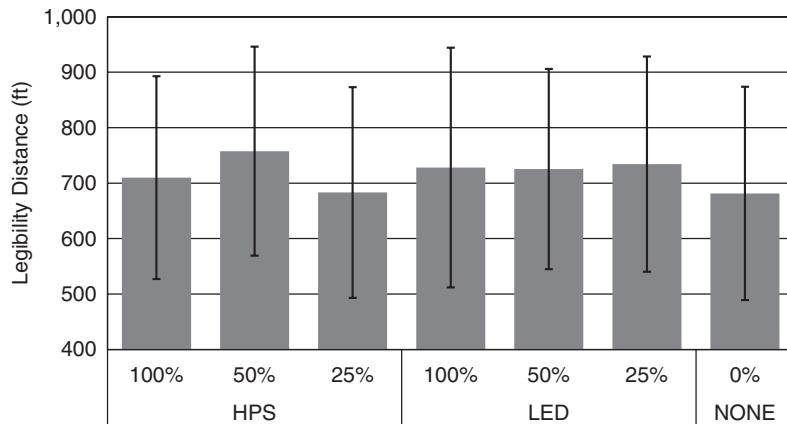


Figure 16. Mean legibility distances with standard deviations for the combination of sign lighting type and intensity.

and standard deviations are shown in Figure 17. Based on visual inspection of each condition group in Figure 17, legibility distances were consistently longer for younger drivers and when roadway lighting was on. The average legibility distance of younger drivers for all conditions was 787 ft; the average for older drivers was 667 ft. The average legibility distance of all drivers without roadway lighting was 694 ft; the average when roadway lighting was on was 743 ft. There appears to be no consistent difference in legibility distance between lighting types when split across the other interacting factors shown in Figure 17. The mean legibility distance without any sign lighting was 681 ft. For the HPS and LED lighting systems, the mean legibility distances were 715 ft and 729 ft, respectively.

Summary of Findings

Statistical analyses could not identify a relationship between legibility distance and values of either sign luminance or Weber contrast. Another iteration of the legibility distances for each

type and intensity of sign lighting (previously shown in Figure 16) is provided in Figure 18 with average values of luminance for the given lighting conditions. It is clear that the differences in legibility distance from one lighting condition to another are not only quite small, they have no noticeable relation to the amount of luminance provided by the lighting. The luminance consistently decreases as the intensity of the lighting decreases from 100 to 0 percent, but there is no consistent change in legibility distance. The luminance values were measured from 640 ft and with the headlamps on to represent the amount of light provided to drivers at a 40-ft/in. index.

The younger study participants had a mean legibility distance 120 ft longer than the older study participants. This is not a surprising finding, as the measured visual acuities of the younger participants were generally better than those of the older participants. Legibility distance also improved by approximately 50 ft when overhead street lighting was on. The material construction of the study sign (whether Type XI legend on Type XI background, Type XI legend on Type IV

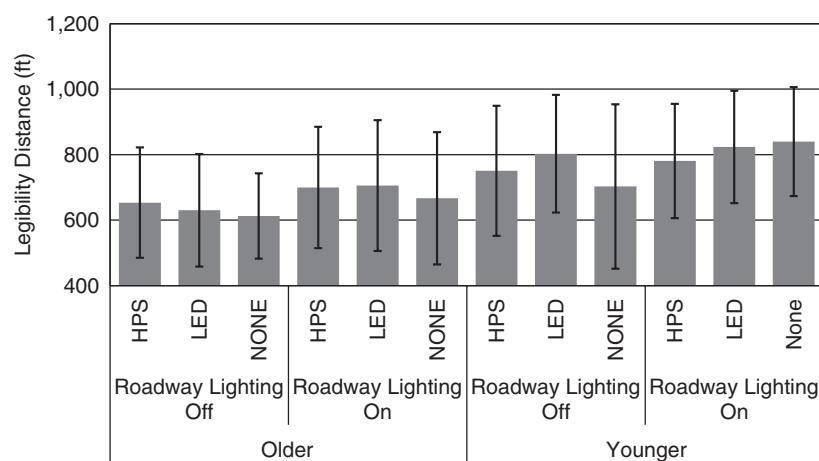


Figure 17. Mean legibility distances with standard deviations for the combination of sign lighting type, roadway lighting, and age.

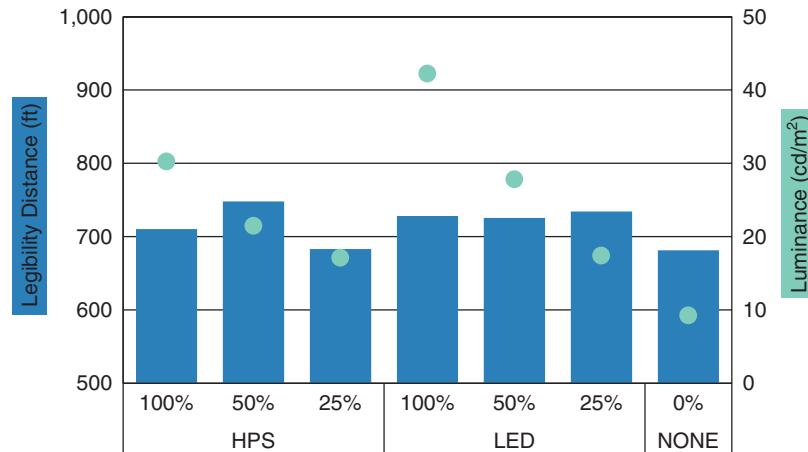


Figure 18. Mean legibility distance for each lighting condition with luminance values measured from 640 ft. Each lighting condition impacts the measured luminance, but there is no consistent relationship with legibility distance.

background, or Type IV legend on Type III background) did not significantly impact legibility distance, whether evaluated alone as a main effect or in an interaction.

Conclusions

While the findings from the closed-course study may appear to contradict the prevailing assumption that sign legibility is dependent on factors such as sign luminance, contrast, and sign sheeting materials, the important element to keep in mind is that the visual complexity of study location can be described as low because the testing facility track generally resembles a stretch of rural highway (with roadway lighting). In addition, the lowest luminance level observed by a driver was 8 cd/m², which is about 3.5 times more than the luminance level used by FHWA to derive minimum maintenance levels for retroreflectivity of overhead guide signs. Additionally, the legends contained only two 4-letter words and the participants drove at a constant speed of 35 mph, there was no interference involving maneuvers of other vehicles, and the drivers were required to read only one guide sign (in addition to two speed limit signs). In short, the workload of the drivers on the closed course was much lower than what is typically experienced when reading overhead guide signs, allowing the drivers to focus more effort than normal on reading the target sign. This is not atypical of closed-course study designs.

With the context described above, it may be said that the legibility distance of a reasonably bright sign will not increase

with sign lighting or a particular type of sign sheeting in an environment where drivers experience low workload and low visual complexity. Although the relationships between legibility and the factors evaluated in the closed-course study did not necessarily result in significant new discoveries, the lack of significance is still useful information, indicating there is no benefit to high levels of sign brightness in areas with low visual complexity. Information in Appendix A provides context on the quantitative effects of the multiple light sources evaluated in the factorial study.

Figure 5 shows measurements of the guide sign illuminance and luminance. As expected, and verified with these measurements, the illuminance reaching a sign is not a good indicator of luminance. This is a particularly useful verification of results that can be used to revise sign lighting guidelines (i.e., removing the illuminance levels). Illuminance level design would be justified if sign sheeting materials were diffuse reflective, which they were a long time ago. However, since essentially all overhead guide signs are made with retro-reflective sheeting materials, luminance is a much more appropriate performance metric for establishing guidelines.

The open-road study described next in Chapter 4 was designed to expose drivers to the variety of conditions encountered when they typically read signs, potentially addressing some of the limitations of the closed-course study. Neighboring businesses, other vehicles (including oncoming vehicles), and complex geometric features are just some of the elements drivers experience on the open road that were not possible in the closed-course study.

CHAPTER 4

Open-Road Study

With the understanding that sign lighting and increased luminance provide no marginal benefit to legibility when drivers are in conditions with low visual complexity, the research team investigated whether or not these factors affected how well nighttime drivers read signs on the open road in more visually complex settings. The closed-course study provided a controlled environment where the tested effects were investigated in a full-factorial type of experiment. The open-road study was able to test drivers in more diverse conditions of visual complexity and workload but at the expense of the tight control and factorial design that was used in the closed-course study. The open-road study was completed in 2013.

Experimental Design

Data for the open-road study were collected in three different locations: Bryan/College Station, Texas; San Antonio, Texas; and Orlando, Florida. With an emphasis on different levels of environmental or background complexity and sign luminance, routes were selected in each location to contain a variety of overhead and shoulder-mounted guide and street name signs situated with various levels of complexity and luminance. The background complexity was affected by roadway alignment, adjacent signs, adjacent commercial and residential buildings, and varying light sources that affect the ambient light and can potentially cause glare. Vehicular traffic impacts background complexity and luminance, but this could not be controlled from one participant to another. To account for this variability as best as possible, the driving tests were only performed Sunday through Thursday after evening rush-hour traffic under uncongested driving conditions. The study protocol was identical between the cities with the exception of the route.

Study Routes

The three study routes in Bryan/College Station (B/CS), San Antonio, and Orlando were selected to take advantage of

the variation in practices for sign lighting and sheeting materials and levels of background complexity and ambient lighting. The routes were selected so that each drive lasted between 30 and 60 min (see Appendix C for additional details). While the closed-course study focused exclusively on overhead guide signs, the open-road study had drivers read overhead and shoulder-mounted guide signs and street name signs. The inclusion of multiple sign types and placement locations resulted in a typical driving experience that encompasses route finding. Examples of the environments encountered on the open road are shown in Figure 19.

The cities where data were collected employ different practices to ensure the signs are visible. Orlando is the only city where the route included overhead guide signs that are lit. Each city has internally illuminated overhead street name signs in addition to unlit overhead street name signs. With different sheeting products used, diversity in lighting practices, and light provided by the surrounding environment in which each sign is located, the open-road study contained a variety of features that influence visibility and how well drivers read a sign. The inability to control for specific factors such as sign lighting or sign sheeting resulted in requiring the use of measured sign luminance as an independent variable, as described in the Analysis section that follows.

Procedure

Seventy-three participants drove in the study, with an even split between male and female participants. There were twice as many older drivers (55+ years) than younger drivers (18–35 years). The number of participants was split nearly even across the three locations. Upon meeting the research team and passing tests of visual acuity, contrast sensitivity, and color blindness, each participant entered the study vehicle, a 2006 Toyota Highlander, and adjusted basic driver settings. The vehicle was instrumented with a GPS receiver for tracking the position of the vehicle and cameras for logging photometric



(a) High Complexity (Overhead Guide Sign)



(b) Low Complexity (Overhead Guide Sign)



(c) High Complexity (Overhead Street Name Sign)



(d) Low Complexity (Overhead Street Name Sign)

Figure 19. Images of guide and street name signs from the study routes in environments of various background complexity.

images. Each study participant drove the vehicle through the designated route. Routing guidance was provided by a researcher in the front passenger seat who also watched for potential traffic conflicts and recorded any relevant comments from the participant. A second researcher sat in the back seat to monitor the data collection equipment and indicate in the data stream when the participant correctly read a sign.

Throughout the drive, the researcher in the passenger seat provided directions and requested that the participant indicate the moment when he or she could read a sign with the corresponding street. The participants were asked to respond when they were confident in their response. For uniformity in the experience from one driver to the next, the researcher instructed the participant to select a specific lane when multi-

ple lanes were available. Appendix C contains the specific instructions provided to the research participants.

Figure 20 shows images of the study vehicle and data collection equipment used for the open-road study.

Data

The procedure for measuring sign luminance varied from that of the closed-course study because the signs were located on the open road and the vehicle containing the photometer could not stop throughout the procedure. During the open-road study, a vehicle-mounted photometer captured images continuously in quick succession while the vehicle approached each sign. The image from a distance to the



(a) Instrumented 2006 Toyota Highlander



(b) Instrumentation Setup



(c) Camera, Internal V-Lambda Filter, and Lens



(d) Camera System with GPS

Figure 20. Open-road data collection equipment.

sign most closely representing 40 ft/in. of letter height was extracted for measuring the luminance of the sign's legend and background.

The visual complexity of the scene approaching the study signs was of interest in the open-road study. The researchers were interested in studying how the complexity of the scenes would impact the distance at which drivers could read the signs. The scene complexity for each sign was determined with the image processing technique discussed in Appendix B. The same images used to measure the sign luminance were evaluated with image processing software that extracted elements of the scene such as the number of light sources, number of objects, and overall image saturation. A level of complexity on a 1–5 scale was assigned to each image based on statistical models validated with data collected from a survey of people who viewed the images and provided subjective complexity ratings. The purpose of the image processing software was to remove the element of subjectivity from the determination of rating visual complexity.

Figure 21 shows values of legend luminance for the different samples. Luminance from both the open-road courses and the closed-course study are shown for comparisons of what the drivers experienced. There is a wide distribution of luminance values across the different locations where data were collected.

Table 11 contains summary statistics that include the levels of complexity encountered. The visual complexity for shoulder-mounted guide signs was comparable to that of overhead guide signs, except in Orlando where the shoulder-mounted guide signs were in locations with greater complexity. The complexity tends to increase from Bryan/College Station, to San Antonio, to Orlando.

Table 12 contains the luminance values of the signs as identified in Figure 21. One important feature in Table 12 is the legend height. Because the legend height was not constant across all signs, the dependent variable in the analyses was the recognition index, measured in feet of recognition distance per inch of letter height. This reduced the need to include the legend

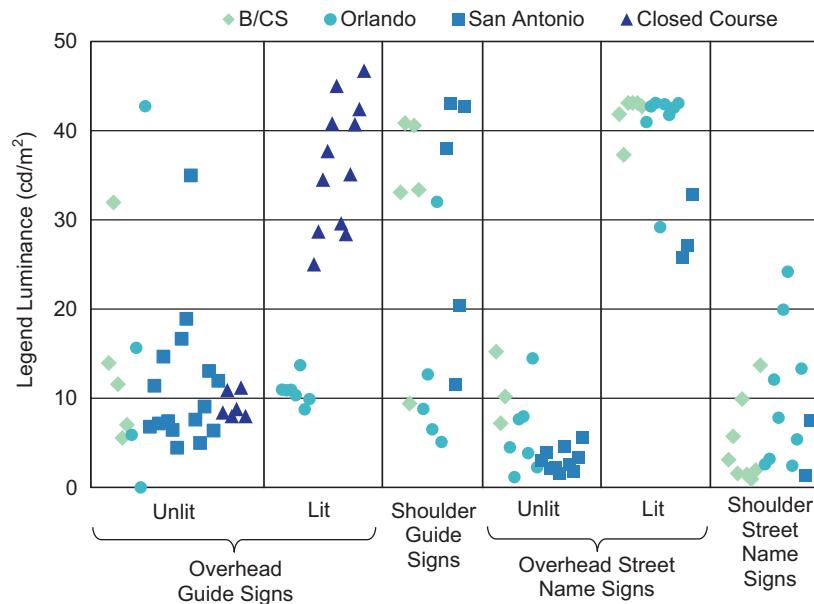


Figure 21. Legend luminance values of signs in the open- and closed-course studies.

Table 11. Signs and complexity ratings by study location.

Location	Total Signs	Sign Type (qty.)	Visual Complexity		
			Min.	Avg.	Max.
Bryan/College Station, Texas	27	Overhead Guide (5)	1	1	1
		Overhead Street Name (9)	1	1.4	2
		Shoulder Guide (5)	1	1	1
		Shoulder Street Name (8)	1	1	1
San Antonio, Texas	36	Overhead Guide (16)	1	1.4	3
		Overhead Street Name (13)	1	1.6	3
		Shoulder Guide (5)	1	1.4	2
		Shoulder Street Name (2)	1	1	1
Orlando, Florida	40	Overhead Guide (11)	1	1.7	3
		Overhead Street Name (15)	1	2.5	4
		Shoulder Guide (5)	2	2.4	4
		Shoulder Street Name (9)	1	1.3	3

Table 12. Summary of open-road sign data.

Sign Type, Lighting	Location	Number of Signs	Legend Luminance			Legend Height (in.)	Avg. Complexity	
			Median	Mean	St. Dev.			
Overhead Guide Signs	Unlit	B/CS	5	11.5	14.0	10.6	16	0.8
		Orlando	4	10.8	16.1	18.9	18	1.2
	Lit	San Antonio	16	8.3	11.4	7.6	16	1.3
		Orlando	7	10.9	10.8	1.5	18	2.0
Shoulder Guide Signs		B/CS	5	33.3	31.4	12.9	16	0.7
		Orlando	5	8.8	13.0	11.0	11–18	2.5
		San Antonio	5	37.9	31.1	14.3	8–16	1.2
Overhead Street Name Signs	Unlit	B/CS	3	10.2	10.9	4.1	9	1.3
		Orlando	7	4.5	6.0	4.5	4–9	2.4
		San Antonio	10	2.8	3.0	1.3	6–8	1.2
	Lit	B/CS	6	42.9	41.8	2.3	9	1.4
		Orlando	8	42.6	40.8	4.7	9	2.8
		San Antonio	3	27.1	28.5	3.7	8	2.0
Shoulder Street Name Signs		B/CS	8	2.5	4.8	4.7	6	0.4
		Orlando	9	7.8	10.1	7.9	4–9	0.9
		San Antonio	2	4.4	4.4	4.3	4–6	0.6

Table 13. Mean recognition index (ft/in.) by sign type and city.

Sign Type	B/CS	San Antonio	Orlando
Overhead Guide Signs	51.7	59.6	41.7
Overhead Street Name Signs	36.2	40.7	25.3
Shoulder Guide Signs	56.4	47.8	39.9
Shoulder Street Name Signs	23.7	26.9	29.8

height when evaluating where drivers were able to correctly read the sign.

Average recognition indices of the observations in the open-road study are provided in Table 13. The values are split by sign type and study location. Recognition indices in Orlando tend to be lower than in the other two cities (except for shoulder-mounted street name signs). The recognition indices for guide signs are consistently greater than those for street name signs.

Figure 22 shows the distribution of all recognition indices from the study. This distribution is similar in shape to the distribution of legibility distances from the closed-course study in Figure 13. The data are right skewed. While the median and mean values of legibility index from the closed-course study were approximately 44 ft/in., the median and mean values of recognition index from the open-road study were approximately 40 and 42 ft/in., respectively. Under normal conditions, recognition distances are expected to be greater than legibility distances. In fact, previous studies that have measured both have observed recognition distances to be between 1.2 and 1.8 times greater than legibility distances (74–81). The legibility and recognition distances (or indices) from the closed-course and open-road studies are not comparable because the open-road study included signs other than just overhead guide signs, involved a driving task that was more difficult because of the increased work load and increased visual complexity, had more complicated sign legends, and included signs that were not constructed of new materials.

The dependent variable analyzed in the open-road study was the recognition index. The values of complexity, luminance, and recognition index in Tables 11 through 13 suggest that some differences in those effects can be attributed to the location (city) and the type of sign viewed. The analysis presented below appropriately includes independent categorical variables for the city and sign type and an interaction term for the combination of city and sign type. The covariates of interest were the rated complexity of the visual scene in which the target sign was placed and the luminance of the legend, each based on a photometric image of the sign taken at a distance representing 40 ft from the sign for each inch of legend uppercase letter height.

Analysis

While the analyses of the closed-course test described in Chapter 3 focused on the individual categorical factors (type of sheeting, type and intensity of sign lighting, and use of street lighting), in addition to the luminance of the sign and Weber contrast as continuous variables, the conditions of the open-road study were not controlled enough to consider individual factors such as street lighting or sheeting type. The recognition index in the open-road study was analyzed with multivariate regression models that used independent variables for luminance, contrast, visual complexity, sign type, and city. The values of luminance and recognition index in Tables 12 and 13 suggest that some of their differences may be attributed to the city and type of sign viewed with possible interactions. The regression models consequently included variables for sign type, city, and their interactions. The dataset contained more than 1,500 total observations of participants reading guide and street name signs.

Even though a categorical factor such as use of sign lighting could have been used, the models included luminance as a covariate instead because the lit overhead guide signs in

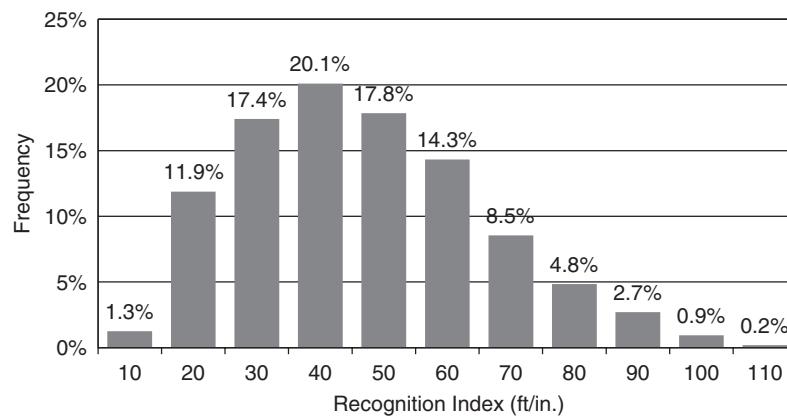


Figure 22. Distribution of recognition index from all observations in the open-road study.

Table 14. Main effects of regression model.

Parameter	F Ratio	Pr > F
Age Group	15.13	0.0002
City	4.20	0.0182
Sign Type	212.03	<0.0001
City × Sign Type	20.56	<0.0001
Complexity	13.50	0.0002
Legend Luminance	57.22	<0.0001

Orlando had relatively low values of luminance as a result of low retroreflective sheeting (which can be seen in Figure 21). A variable for sign lighting would then poorly indicate how well sign lighting could illuminate signs constructed of newer retroreflective products. The use of luminance as a continuous variable is a way to fairly represent the visibility of a sign from the perspective of the driver.

Each participant was included as a random effect in the model. This accounted for differences in their visual acuity, driving behavior, or other characteristics unique to each participant that might affect how well they viewed and read the guide and street name signs. The age group (younger or older) was included to investigate how some differences in recognition index may be attributed to age of the participant, as was done in the closed-course study.

Several regression models were created to investigate how luminance, contrast, and complexity of the visual scene influence driver recognition index. A final model was selected from a stepwise process to ensure all fixed effects were significant based on a 95 percent confidence interval ($\alpha = 0.05$). Weber contrast was not a significant effect. The effects of the final model are identified in Table 14. The resultant model is presented as Equation 2.

$$I_R = 38.9 + \text{AgeGroup} + \text{City} + \text{Sign} + \text{City} \times \text{Sign} \times \beta_1 \\ \times \text{Complexity} + \beta_2 \times \text{Luminance} \quad (\text{Eq. 2})$$

where I_R is the recognition index (ft/in.), AgeGroup represents the age group (younger or older) of the driver, City is the location (Bryan/College Station, San Antonio, or Orlando) where the data were collected, Sign Type is the type of guide or street name sign, Complexity is the rated complexity value of the visual scene where the sign was located, Luminance is the luminance (cd/m^2) of the legend, and β_1 and β_2 are the coefficients of the variables for complexity and legend luminance, respectively. The values for Equation 2 are provided in Table 15.

Figure 23 shows a plot of each actual recognition index from the study with the predicted value from the regression model. Despite the broad distribution of residuals (normally distributed, as shown in Figure 24), the consistent matching

Table 15. Parameters from Equation 2.

Parameter	Value
Intercept	38.9
Age Group	Younger
	Older
City	Bryan/College Station
	Orlando
Sign Type	San Antonio
	Overhead Guide Sign
City × Sign Type	Overhead Street Name Sign
	Shoulder Guide Sign
Orlando	Shoulder Street Name Sign
	Bryan/College Station
Overhead Guide Sign	Overhead Guide Sign
	Overhead Street Name Sign
Shoulder Guide Sign	Shoulder Guide Sign
	Shoulder Street Name Sign
San Antonio	Overhead Guide Sign
	Overhead Street Name Sign
Shoulder Guide Sign	Shoulder Guide Sign
	Shoulder Street Name Sign
β_1 (Coefficient for Complexity)	-1.61
β_2 (Coefficient for Luminance)	0.30

of the data to the line in the actual-by-predicted plot suggests it is a strong model.

Discussion of Model Parameters

The following observations can be made from the values for Equation 2 shown in Table 15:

- The difference in mean recognition index from the group of younger drivers to older drivers is 7.80 ft/in.

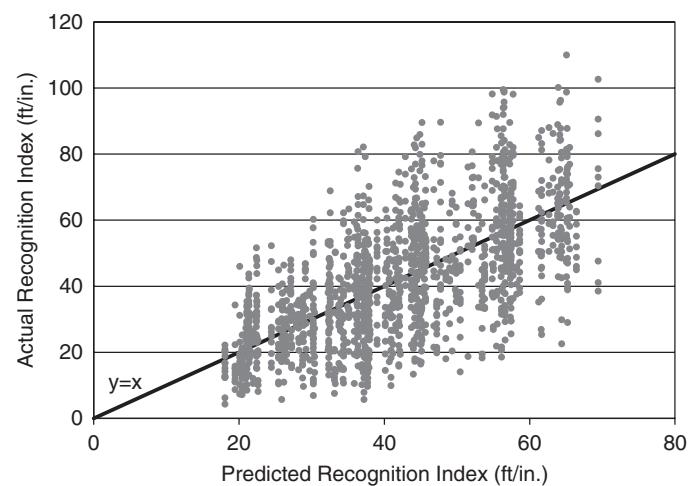


Figure 23. Actual-by-predicted plot for model of recognition index.

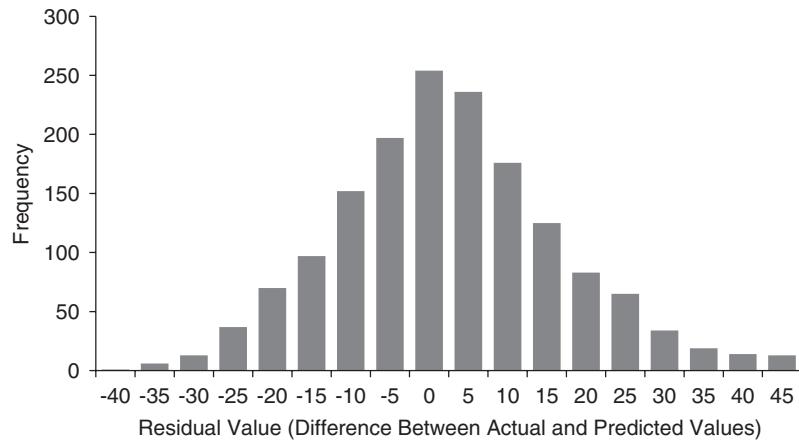


Figure 24. The model residuals have an approximately normal distribution.

- Recognition indices in Orlando were the lowest of the three cities based on the main effect of *City* without any interaction. San Antonio had the greatest recognition indices.
- Based on the main effects disregarding interactions with *City*, overhead guide signs resulted in the greatest recognition indices of the four sign types, approximately 5 ft/in. greater than the recognition indices of comparable shoulder-mounted guide signs. Overhead street name signs had the third highest recognition index. The smallest mean recognition indices were observed with shoulder street name signs. The large differences in mean recognition index from one type of sign to another suggests that there are specific features of the sign types, such as placement location, that influence how well drivers can read the signs despite already accounting for the size of the legend.
- The different values for the interaction of *Sign Type* and *City* suggest that the mean recognition index for each type of sign may vary even by the city where data were collected.
- The expected recognition index decreases as the visual scene becomes more complex. The effect is estimated to be approximately 1.6 ft/in. for every increase in complexity from 1 through 5.
- The expected recognition index increases as the luminance of the legend increases. The effect is approximately 0.3 ft/in. for every 1 cd/m² increase in luminance.

The categorical effects involving the city and type of sign are included in the model to adjust for differences between the types of signs investigated and the location of the study. Although differences in the two age groups of the participants can be accounted for in random effects for each participant, their inclusion in the model provides insight into how recognition index may decrease with age. There was no significant interaction between age group and any other effect.

The key finding of the open-road study is the relationships between recognition index, visual complexity, and legend luminance. The model indicates that recognition index decreases as visual complexity increases. Meanwhile, recognition index increases as legend luminance increases. These opposing effects suggest that increases in legend luminance can counteract the effects of increased visual complexity. Based on the ratio of the coefficients for the effects, a 5.6 cd/m² increase in legend luminance counteracts a unit increase in visual complexity. There is no significant interaction between visual complexity and legend luminance that affects recognition index.

The relationships between recognition index, visual complexity, and legend luminance in Equation 2 are linear. Each unit increase in visual complexity or luminance produces a constant and proportional change in recognition index. It is possible that one or both of the *true* relationships, however, is not linear. Perhaps the influence of luminance on recognition can be more accurately represented by a logarithmic relationship, in common with how other sensory inputs are perceived (such as sound intensity measured in decibels). Models with nonlinear relationships were investigated; however, the nonlinear relationships provided similar confidence but at the cost of added difficulty for interpretation and application.

Conclusions

The open-road study focused on how legend luminance and visual complexity of the nighttime scene affect the ability of drivers to successfully recognize specific information from overhead signs. While the method of conducting this experiment on the open road had similarities with the closed-course study described in Chapter 3, there were some key differences that controlled how the data were analyzed. One was the sizes of the sign legends, which varied because of different sign types and agency policies. Recognition index, which nor-

malizes the recognition distance by the letter height, was used as the dependent variable. Another difference with the open-road study was the diversity in the sign lighting and sheeting materials used. In the field, there were many varieties of sign lighting and sheeting materials experienced, even within a single jurisdiction. The analyses accordingly focused on factors of luminance, contrast, and visual complexity (with categorical variables of sign type and city). The final difference between the two studies was the lack of control for the roadway environment or visual scene in which the study signs were located. One of the principal hypotheses of the open-road study was that the ability of drivers to recognize a destination on an overhead sign is reduced in visually complex and cluttered environments. A complexity level, based on results of computerized image processing and a survey of study participants, was evaluated as a model covariate to identify its effect on recognition index.

The statistical analyses show that recognition index decreases as the visual complexity of the nighttime scene increases.

While the visual complexity measure was designed to characterize the roadway conditions based on the perspective of the driver, visual complexity may also reflect the operating conditions of the roadway and then, indirectly, the resulting workload of the driver. The implication is that the effect of visual complexity that shows a reduction in recognition index is likely a result of driving under greater workload, where the demands of the driving task interfere with the ability to focus on the study task of reading the target sign.

In contrast to the negative effects of visual complexity, increased sign legend luminance was found to result in increased recognition index. The study completed on the closed course (described in Chapter 3) in an environment that was not visually complex or demanding in terms of driver workload produced no relationship between luminance and legibility. However, on the open road, where the visual complexity of the driving task was higher from both a visual and cognitive perspective, increased legend luminance was found to improve the nighttime driver's ability to read a sign legend.

CHAPTER 5

Research Findings

The principal objective of this research was to develop data-supported visibility guidelines for overhead guide and overhead street name signs. The research team reviewed the available literature, surveyed state DOT signing and lighting practices, and conducted a closed-course visibility study and an open-road visibility study involving nighttime drivers reading signs under diverse conditions. In the closed-course study described in Chapter 3, drivers participated in a factorial study that included different types of sign lighting at multiple illumination levels, different types of sign sheeting, and use of overhead street lighting. The open-road study described in Chapter 4 involved having drivers navigate a designated course while searching for specific signs that researchers directed them to find. Because the study involved signs presently in service, there was little control over elements such as sign sheeting type/condition or sign lighting. The results from these research activities were synthesized and combined to revise Chapter 10 of the *AASHTO Roadway Lighting Design Guide* (2005 edition).

This chapter presents a description of the key findings that were implemented in the revisions to Chapter 10 of the *AASHTO Roadway Lighting Design Guide*. The recommended guidelines and revised Chapter 10 are included in Appendix D of this report. Conclusions and future research recommendations are also described in this chapter.

Key Findings

The following points describe specific findings from the research that were used to revise the Chapter 10 materials from AASHTO's *Roadway Lighting Design Guide*, 2005 edition.

- Research has consistently demonstrated that visual complexity has a direct effect on nighttime sign visibility (measured in terms of detection, recognition, and legibility). As the visual complexity increases, signs become harder to see, recognize, and read. While this relationship has been studied

and demonstrated, it had not been quantified in a way that could be used to develop guidelines. In this research, the research team quantified the need for higher levels of sign luminance as visual complexity increases.

- FHWA has researched, developed, and published (in the MUTCD) minimum maintained sign retroreflectivity levels. The minimum retroreflectivity levels are derived from minimum luminance thresholds representing dark rural conditions (i.e., low visual complexity). For overhead guide signs, FHWA used a minimum luminance level of 2.3 cd/m^2 to establish the corresponding minimum retroreflectivity levels.
- Guide sign illuminance measurements provide no indication of the luminance performance from the driver's perspective (see Figure 6). Before the use of guide signs fabricated with retroreflective materials, illuminance thresholds were reasonable design criteria. For decades, guide signs have been fabricated with retroreflective sheeting materials, so there is no longer a need for illuminance thresholds.
- In the closed-course study, which had low visual complexity, guide sign legend luminance ranging from 8 to 47 cd/m^2 (measured at a distance of 640 ft, representing a legibility index of 40 ft/in. of uppercase letter height) performed statistically similarly using legibility as the dependent variable. These levels of legend luminance were higher than the level used by FHWA as an absolute minimum for nighttime performance (2.3 cd/m^2).
- A method was developed to quantify visual complexity on a scale of 1 through 5 (where 1 = *very rural areas* and 5 = *the most visually complex sign surroundings*). The method involves a high degree of expertise, sophisticated equipment, and image processing. While this method was used in the study (and is described in Appendix B), an easier way to estimate visual complexity was needed for the guidelines. Nighttime images representing visual complexity levels of 1 through 5 have been included in the guidelines to help practitioners estimate the appropriate visual complexity level.

- In the open-road study, sign legend recognition decreased with increasing levels of visual complexity. However, the negative impacts of visual complexity were offset with increased levels of legend luminance.
- A statistical relationship that links visual complexity and legend luminance was derived from the open-road study. The linear relationship shows that a 5.6 cd/m^2 increase in legend luminance counteracts a unit increase in visual complexity.

Conclusion

The proposed guidelines have been based on the needs of nighttime motorists and have been formatted specifically for the *AASHTO Roadway Lighting Design Guide*, which is currently being updated. The proposed guidelines are flexible and should provide performance targets for innovations in sign lighting and sign sheeting technologies for years to come. The revised chapter on overhead sign lighting (as shown in Appendix D) was provided to the AASHTO task force responsible for the revisions. This approach allows for a quick review by state agencies, with eventual adoption in the most appropriate professional reference document for sign lighting. The

guidelines also include a link to a list of retroreflective sheeting materials that can be used to meet nighttime driver needs for specific complexity levels. This information was added to assist the state agencies when they are updating their policies and specifications specific to overhead signing.

Future Research Needs

This research produced multiple discoveries that provide for a better understanding of the needs of nighttime motorists. One of the most useful discoveries not fully implemented in the proposed guidelines is the method for quantifying the visual complexity surrounding a sign. The research team developed and used a methodology for the research, but it required specialized equipment and custom-built software. During the research project, unsuccessful attempts were made at simplifying the method so that it could be used by state agencies. A follow-up effort would be to develop a system that could be used to drive a roadway at night, process the surrounding environment around a sign, and provide a visual complexity level. A mobile technology like this would remove the subjectivity associated with the use of the calibrated images used in the proposed guidelines and provide a safer way to implement the guidelines.

Glossary

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CCT	Correlated color temperature
DOT	Department of transportation
FHWA	Federal Highway Administration
GLCM	Gray-level co-occurrence matrix
HPS	High-pressure sodium
IESNA	Illuminating Engineering Society of North America
LED	Light-emitting diode
LOOCV	Leave-one-out cross validation
MLR	Multiple linear regression
MUTCD	<i>Manual on Uniform Traffic Control Devices</i>
TCD	Traffic control device

Terms

Conspicuity	The property of being detected among other objects
Edge ratio	Number of pixels at the edges of objects divided by total pixels in an image
Entropy	A statistical measure of randomness in an image
Illuminance	Intensity of light incident on a surface
Legibility	The ability to read a message without previously knowing the message
Luminaire	A lighting unit
Luminance	Intensity of light directed at a viewer
Photometer	Device for measuring light intensity
Readability	The ability to read a message with either a task of legibility or recognition
Recognition	The ability to read a message with prior knowledge of its message
Retroreflectivity	The reflecting of light back to a source
Visual complexity	Clutter in a scene that inhibits the ability to see a target

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APPENDIX A

Incremental Effects of Light Sources and Sign Sheeting on Legend Luminance for Overhead Guide Signs

This appendix describes an analysis of the photometric data collected during the closed-course study described in Chapter 3. The purpose of the analysis is to identify the effects on legend luminance as a result of the type of sheeting, use of sign lighting, and presence of roadway lighting. The information can help agencies understand how a defined level of luminance can be achieved using available sheeting products and types of lighting.

Findings from the closed-course study (Chapter 3) indicate that increases in sign luminance when a sign is already reasonably bright and in a rural, dark area have no effect on legibility. However, in the open-road study (Chapter 4), where drivers were placed in situations with greater complexity, visibility from a recognition task improved with increased luminance. The analysis presented in this appendix investigated the contributions of light sources and sign sheeting on luminance provided to drivers and provides useful information to those responsible for ensuring signs are visible in urban and suburban environments. When it is unreasonable to take photometric measurements in the field, practitioners can use this information to make better-informed decisions by knowing how much luminance is added from a change in sign sheeting or lighting.

Data

The data used in the analyses were collected on a closed course where the lighting was restricted to the vehicle's headlamps, the roadway lighting (when used), and the sign lighting (when used). Photometric measurements were taken at 100-ft intervals from the guide sign, as described in Chapter 3. The analysis presented in this appendix was concerned with the luminance provided at a single location 640 ft from the sign, where drivers were expected to be able to read a sign with 16-in. letters. The raw luminance data for the 600-ft and 700-ft intervals were interpolated to produce luminance values for 640 ft.

The sign lighting systems used were high-pressure sodium (HPS) and light-emitting diode (LED) lights. The HPS lighting was a GE Versaflood II luminaire with a correlated color temperature (CCT) of 2,100 K. The LED lighting was two Cree OL Series Flood luminaires with a CCT of 5,700 K. The orientation, aim, and spacing of the HPS and LED luminaires were adjusted to make the illumination from the light sources as uniform as possible based on AGI32 light modeling software. Illuminance was measured on the sign surface using a 12-point orthogonal grid. Three intensity levels for sign lighting were used, with values of illuminance identified in Table A-1.

The sign legends were constructed of either American Society for Testing and Materials (ASTM) Type IV or Type XI sheeting. The roadway lighting consisted of LED luminaires spaced 250 ft (80 m) apart along the road. Three luminaires were located in front of the test guide sign starting approximately 650 ft (200 m) before the sign. The color temperature of the LED roadway lights was 6,000 K.

Legend luminance data were collected from combinations of the following factors:

- Sign sheeting:
 - Type IV and Type XI.
- Sign lighting:
 - Two types of sign lighting (HPS and LED) set to provide similar amounts of illumination.
- Sign lighting level:
 - Four possible levels: 100 percent (600 lx), 50 percent (300 lx), 25 percent (150 lx), and off.
- Roadway lighting:
 - Either on or off.

Images captured by a Radiant Imaging ProMetric photometer mounted inside a 2000 Ford Explorer from a driver's view were used to determine luminance values. Measured luminance from the four areas of each photometric image, as shown in Figure A-1, were used to determine an average value

Table A-1. Measured illuminance for each intensity level and lighting system.

Intensity Level	Illuminance (lx)	
	HPS	LED
100%	622	590
50%	333	300
25%	145	144

of legend luminance. An average was used because, at a typical mounting height for overhead signs, luminance from the top row of the legend is generally less than from the bottom row since the headlamp illumination decreases with greater height from the road.

Average luminance values for 28 combinations of sheeting type, sign lighting, lighting level, and roadway lighting were used to evaluate the effects of lighting and sheeting. Table A-2 provides the luminance measurements for the combinations of the study factors at a distance of 640 ft from the sign.

Analysis

The luminance supplied to a driver is a result of the illuminance provided by the various light sources, the efficiency of the reflective material, and the position of the vehicle. The luminance can be defined as a function of these influencing factors:

$$\text{Luminance} = f \left\{ \begin{array}{l} \text{sheeting, headlamps, vehicle location,} \\ \text{sign lighting type, sign lighting intensity} \\ \text{roadway lighting} \end{array} \right\}$$

Luminance can be increased by using a more efficient type of sheeting, adding sign lighting, or changing the intensity

**Figure A-1. Sample areas for calculating averaging luminance.****Table A-2. Legend luminance values at 640 ft from sign.**

Sheeting Type	Sign Lighting	Lighting Level	Roadway Lighting	Luminance (cd/m ²)
IV	HPS	100%	Off	25.0
IV	HPS	100%	On	29.6
IV	HPS	50%	Off	17.0
IV	HPS	50%	On	19.2
IV	HPS	25%	Off	15.3
IV	HPS	25%	On	17.0
IV	LED	100%	Off	37.7
IV	LED	100%	On	40.7
IV	LED	50%	Off	21.3
IV	LED	50%	On	24.4
IV	LED	25%	Off	15.4
IV	LED	25%	On	15.5
IV	None	0%	Off	8.4
IV	None	0%	On	8.8
XI	HPS	100%	Off	31.6
XI	HPS	100%	On	31.8
XI	HPS	50%	Off	22.3
XI	HPS	50%	On	23.9
XI	HPS	25%	Off	17.1
XI	HPS	25%	On	18.0
XI	LED	100%	Off	42.9
XI	LED	100%	On	44.6
XI	LED	50%	Off	30.3
XI	LED	50%	On	30.3
XI	LED	25%	Off	18.2
XI	LED	25%	On	18.5
XI	None	0%	Off	9.5
XI	None	0%	On	9.6

or type of sign lighting. Headlamps were used in the analysis described below, and the vehicle location was kept constant at 640 ft from the guide sign. Therefore, the only influencing factors were the sheeting, type of sign lighting, intensity of sign lighting, and use of roadway lighting.

An analysis of variance (ANOVA) was performed on the 28 data points from Table A-2 to model the effects of sign sheeting, type and intensity of sign lighting, and roadway lighting on legend luminance. Interactions between all the variables were tested. The interaction of sign sheeting and sign lighting was significant. The effects of the model are identified in Table A-3. A regression model produced from the effects is shown in Equation A-1, with some model estimates provided in Table A-4. The predicted luminance values closely matched the actual values, as illustrated by the plot in Figure A-2. The root mean square error of this model was 1.0 cd/m², and the adjusted R² value was 0.99.

Table A-3. Parameter effect tests.

Parameter	F Ratio	Pr > F
Legend Sheeting Type	0.864	0.370
Sign Lighting	198.8	<0.001
Roadway Lighting	14.21	0.002
Legend Sheeting × Sign Lighting	5.063	0.007

Table A-4. Values for $f(\text{Sign Lighting})$ in Equation A-1.

Sign Lighting	Type IV	Type XI
None	0	0
HPS, 150 lx	7.6	8.0
HPS, 300 lx	9.5	13.6
HPS, 600 lx	18.7	22.2
LED, 150 lx	6.8	8.8
LED, 300 lx	14.3	20.7
LED, 600 lx	30.6	34.2

$$L_{640} = 7.9 + 0.9 \times I_{\text{TypeXI}} + f(\text{Sign Lighting}) + 1.4 \times I_{\text{Road Lighting}} \quad (\text{Eq. A-1})$$

Where

L_{640} = legend luminance (cd/m^2) measured at 640 ft;

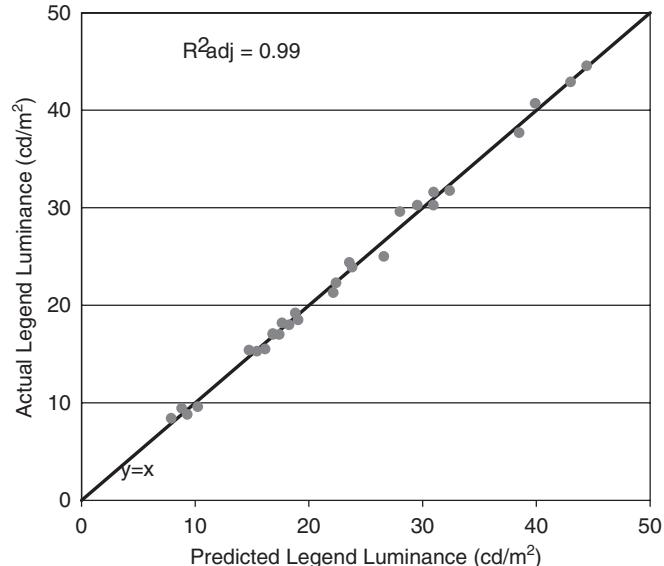
I_{TypeXI} = 1 for Type XI sheeting, 0 for Type IV;

$f(\text{Sign Lighting})$ = function of the main effect of Sign Lighting and its interaction with Legend Sheet Type, shown in Table A-4; and

$I_{\text{Road Lighting}}$ = 1 for using roadway lighting, 0 for no roadway lighting.

Discussion

From the variables in Equation A-1, the effect of roadway lighting is relatively small (increasing luminance by $1.4 \text{ cd}/\text{m}^2$). Nearly $8 \text{ cd}/\text{m}^2$ are provided when using Type IV sheeting, and luminance increases by nearly $1 \text{ cd}/\text{m}^2$ with Type XI sheeting. The values for the use of sign lighting with the two types of sheeting in Table A-4 show that luminance can typically increase by 8 to $34 \text{ cd}/\text{m}^2$, depending on the type and intensity of the lighting used. The different values in the table indicate that the two types of sign lighting and their three intensity levels uniquely interact with the two types of sheeting, which should be expected. Even though the amount of illuminance is nearly identical, the resulting luminance is different, possibly a result of the color of the lighting and the position of the luminaires.

**Figure A-2. Actual-by-predicted plot for model of luminance at 640 ft.**

The model estimating luminance of overhead guide sign legends is useful for agencies that need to ensure drivers are provided adequate sign luminance. At 640 ft, representing a 40 ft/in. index when reading a 16-in. legend, the combination of headlamps, the brightest sheeting, and the highest intensity of sign lighting produce over $40 \text{ cd}/\text{m}^2$ of luminance. The different effects in the model show that agencies have options to provide luminance that is adequate for a given situation.

One of the limitations of this analysis is that the only lighting sources were the single vehicle in front of the sign, the sign lighting (when used), and the roadway lighting (when used). In suburban and urban areas, light from additional sources may provide more illumination than what is accounted for here. The most additional illuminance will be from other vehicles on the road. The lighting conditions at specific sites, including light from multiple vehicles, should be considered when evaluating the performance of a sign and determining the potential benefits of using sign lighting or a specific type of sheeting.

APPENDIX B

Assessment of Background Complexity Using Digital Images of Roadway Scenes by Image Processing

This appendix contains information about assessing the complexity of a roadway scene based on images captured by mobile photometric equipment at night. The procedure that produced a complexity rating from a combination of parameters for each image was applied to generate a complexity rating for each sign in the open-road study described in Chapter 4. The material presented in this appendix is also published in an article in *Transportation Research Record: Journal of the Transportation Research Board*, No. 2384 (1).

Background

The open-road study included the development of a tool for quantifying visual complexity based on calibrated photometric images taken while approaching the signs of interest. The tool calculates a value from elements within a digital image that are attributed to a driver's perspective of visual complexity based on surveys of ratings from drivers using images from the open-road study sites. The process for evaluating the visual complexity with the image processing tool is described herein.

It was anticipated during the initial stages of the research that the image processing tool would be made available to departments of transportation and other interested agencies through a Web-powered interface or software. To use the tool, a practitioner would capture an image of a target sign at night and then upload the digital picture to the online tool, which would compute the visual complexity based on the components of the image discussed in Appendix B. The calculated visual complexity would be used to determine an appropriate amount of legend luminance.

As the project was coming to an end, it was decided that a simpler approach would be to use images that had been run through the tool to show what the various visual complexity levels look like and include those images in the guidelines for easier implementation. There is a need for less expensive and easier-to-use equipment to capture the necessary calibrated photometric images.

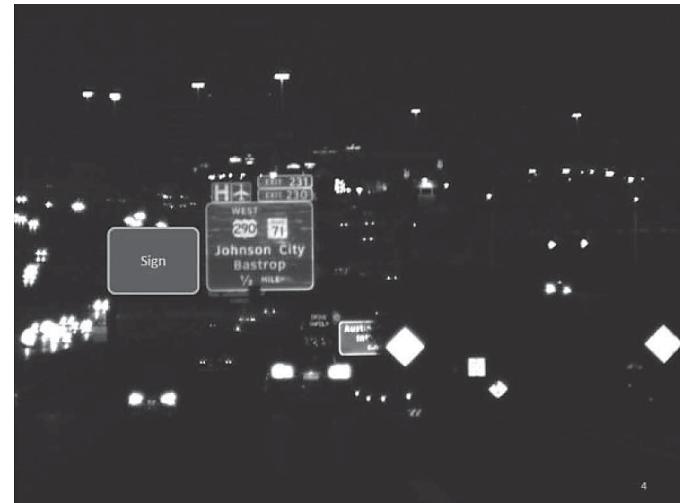
Introduction

The visibility of traffic signs is a critical component to transportation safety. All nighttime traffic control devices that are intended to provide visibility in terms of the roadway scene are developed, deployed, and tested in isolation. Effective traffic signing provides drivers with the information they need to make safe, appropriate, and timely decisions, while also maintaining a certain level of driver comfort, especially at nighttime. The existing sign placement guidance is meant to help practitioners install signs where they will be visible to the driver while not being a hazard. For the most part, the guidance focuses on the installation of an isolated sign and does not effectively take into context the background and other adjacent signs that add to the visual complexity and may impair a driver's ability to detect and obtain information from a particular sign. Figure B-1 contains images of test signs poised in images of varying background complexity.

Overhead guide and street name signs can be difficult to detect and obtain information from because of the background complexity, particularly in urban conditions where the background can be very complex. While the *Manual on Uniform Traffic Control Devices* does discuss sign visibility, the consideration of background complexity and the potential impact of background complexity are not expressly mentioned or discussed (2). The concept of and concern for background complexity has been developing over the years as state practitioners adapt to expanding urban environments. While there have been various studies indirectly related to the concept of background complexity, NCHRP Project 05-20: "Guidelines for Nighttime Visibility of Overhead Guide Signs," was initiated to specifically address growing practitioner concerns over the dilemma of whether overhead guide signs need lighting, especially in complex urban environments. Therefore, it is necessary to develop a new method or system independent of human perception to assess the background complexity of traffic signs at nighttime environments with high accuracy.



(a) Low-Complexity Overhead Guide Sign



(b) High-Complexity Overhead Guide Sign



(c) Low-Complexity Street Name Sign



(d) High-Complexity Street Name Sign

Figure B-1. Examples of signs in scenes of varying levels of complexity.

and consistency. This study aimed to design a system that automatically evaluates the background complexity of overhead traffic signs from digital images of nighttime roadway scenes by using image-processing techniques and multiple linear regression. The proposed system has the potential to be combined with the current system for measuring the visibility of traffic signs in practice.

Previous Studies

Previous studies analyzing the effects of background complexity of traffic signs did not provide a numerical model to assess the complexity but studied the effects of background complexity on a driver's ability to recognize signs (3). Hence, the focus of the review of literature was on the evaluation of two-dimensional (2D) image processing in terms of complexity.

Image processing of 2D signals has a wide application in several fields, such as automatic target recognition, traffic surveillance, pavement crack estimation, remote sensing, and medical applications. The background complexity from a driver's perspective has the potential to be evaluated using image processing techniques. The information theory, which has been widely used in data analysis for clustering, feature selection, blind signal separation, and so forth, is the most frequently used method in image complexity analysis.

Work conducted by Okawa focused on the color picture complexity measure considering six factors, such as the distribution of color variance, the total number of regions, and the color distribution of the regions (4). The six factors were mathematically defined and measured using a computer. Five students were invited to grade the complexity of 251 realistic images. Finally, the image complexity was expressed by a

linear combination of the six factors, and their weights were determined by the least-squares method. It was found that the structural factor of a color picture and the color variance could significantly affect the image complexity.

In a study by Mario et al., a novel fuzzy approach was developed to determine the complexity of an image mainly based on an analysis of edge level percentages in the image (5). The developed method did not depend on a priori human evaluation of complexity for the analysis. The complexity for all images was defined by the classes of Little Complex, More or Less Complex, and Very Complex. Each class could be determined by the in-class membership functions developed in the study. The developed method performed well in the determination of the image complexity based on testing 150 real images.

Cardaci et al. applied a fuzzy mathematical model to evaluate the image complexity via a specific entropy function based on local and global spatial features of the image, because it was more perceptible and appropriate to describe the complexity (6). The classic entropic distance function was adopted in the study. After a comparison with subjective estimation results for the image complexity, the developed model was correlated with the subjective model, which proved that such a model was capable of determining the complexity of the image.

Rigau et al. introduced a new information-theoretical method to analyze the image complexity based on the segmentation of the image (7). The information channel that goes from the histogram to the regions of the partitioned image to maximize the mutual information was applied to partition the image. In the study, the authors took into account the entropy of the image intensity histogram as well as the spatial distribution of pixels. The final complexity analysis was conducted by two measures: the number of partitioning regions needed to extract a given ration of information from the image and the compositional complexity from the partitioned image.

Perkio and Hyvarinen presented a novel information theory method to determine the single image and the pair-wise image complexity based on independent component analysis (8). Based on the experimental results, the developed model was shown to be reliable and more responsive to textures than two other compared methods.

Patel and Holt (9) conducted an experiment to determine image complexity by applying the Klinger-Salingaros algorithm (10) that was developed for a quantitative pattern measure of harmony, temperature, life, and complexity. In the study, the authors tested the Klinger-Salingaros algorithm using the realistic images for the complexity analysis and explored how well the complexity values calculated by the algorithm correlated with human ratings of the same images. A high correlation value was shown to support that the Klinger-Salingaros algorithm was useful in estimating image complexity with respect to human perception of complexity.

Methodology

Input Factors

The researchers used several image processing techniques to extract seven different intrinsic properties from nighttime roadway images for the development of a background complexity model. The seven intrinsic properties describing the image texture were entropy, contrast, energy, homogeneity, number of saturation pixels, edge ratio, and number of objects in the image. All these properties are considered as input factors to develop the complexity model for nighttime images of roadway scenes. These factors are derived from the gray-level co-occurrence matrix (GLCM) defined over an image to be the distribution of co-occurring values at a given offset. An N -bit image could produce an $N \times N$ matrix. In the GLCM, the value denoted as $p(i, j)$ is equal to the number of occurrences of two pixels that have the gray levels i and j , respectively, with a constant distance. The texture of the image can be measured by the GLCM, which is typically large and sparse. Various metrics of the GLCM are usually taken to get a more useful set of features. As shown in Figure B-2, images with different complexity levels can have significantly various co-occurrence matrices.

Number of Objects

In general, the number of objects denoted by O in an image is capable of directly reflecting the degree of complexity. Commonly, the more objects that appear in the image, the more complicated the image is (and vice versa). The number of objects in an image is automatically computed from labeled connected components in the binary image. Nevertheless, some fine textures in the large object, such as words on commercial billboards, were counted as isolated objects in this study. It is reasonable that an object that possesses complicated textures can more negatively affect drivers, as demonstrated in Figure B-3.

Number of Saturation Pixels

In this study, saturation pixels denoted by S were defined as ones whose grayscales reached the highest values (e.g., 255 for 8-bit image, and 65,535 for 16-bit image). In theory, the center areas of lighting sources are so bright that pixels of corresponding areas in the image will be given by the highest gray level, because they exceed the scale capability of the image. In practice, the threshold is usually equal to approximately 90 to 95 percent of the highest grayscale value for the scale of an image, as shown in Figure B-3, which applied the percentage of 95 percent. More saturation pixels appearing in the image implies that drivers likely view a more complex background of guide signs with a large number of

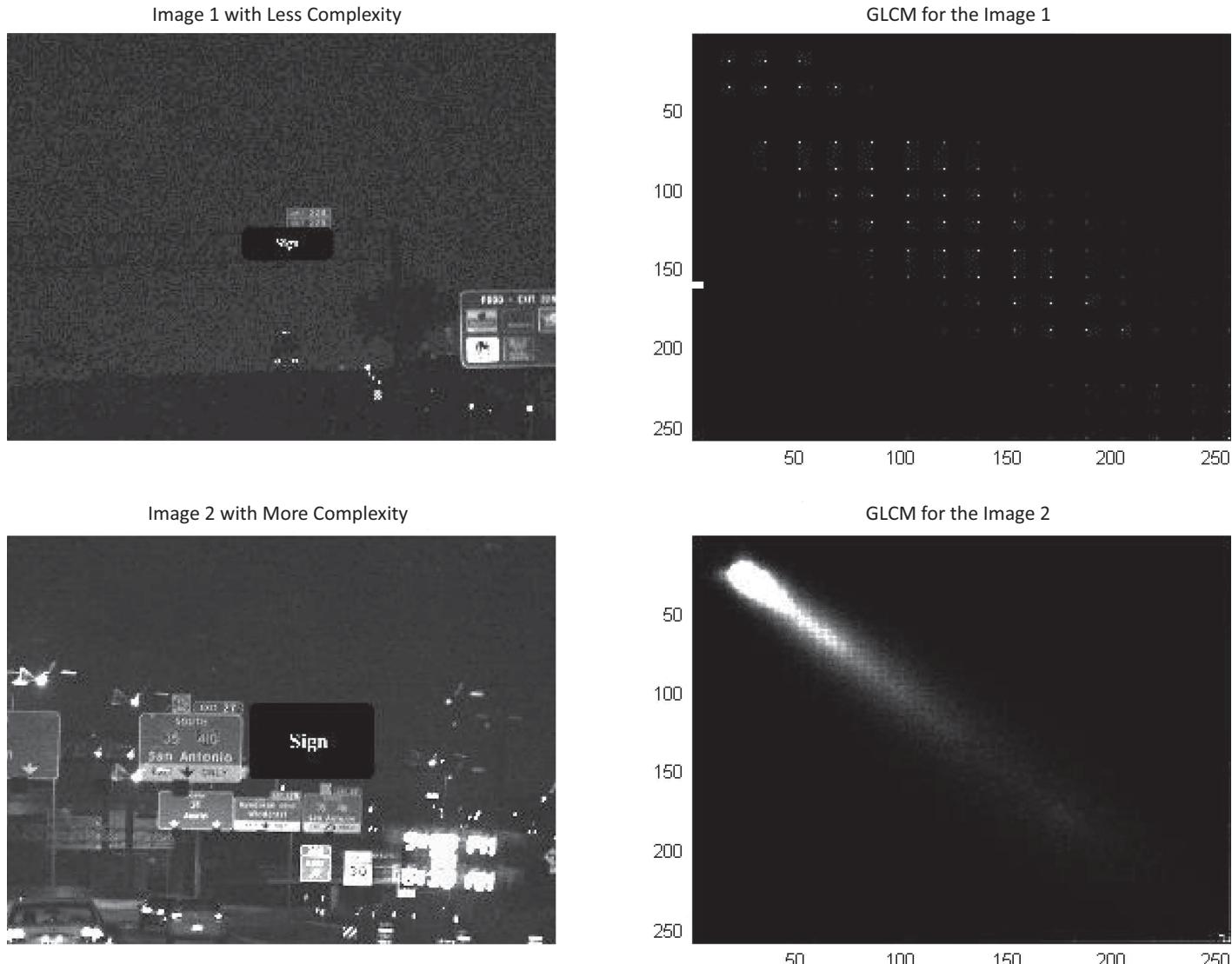


Figure B-2. GLCMs of images of varying complexity.

objects, such as lighting sources, commercial billboards, and oncoming vehicles, all of which could strongly affect drivers' observations.

Contrast

Contrast is a measurement used to represent the degree of difference in the grayscales between a pixel and its neighbor over an image. Contrast is capable of assessing the amount of local variations in the image. Human beings are more sensitive to contrast than to absolute grayscales in images. Similar to entropy and energy, the contrast of an image can also be derived from the GLCM, as demonstrated in the following equation.

$$G = \sum_{i=1}^N \sum_{j=1}^N (i-j)^2 p(i,j)$$

The focus of this work was on the nighttime roadway scene, and the contrast in the background of nighttime images has the potential to provide encoded information in terms of the complexity. The higher contrast means that there are likely more lighting sources in the background. The perfect circumstance for clearly viewing the guide signs for drivers is a completely black background, which has a zero contrast. The viewing experience for drivers could be significantly changed as the contrast increases, which is why contrast was considered an important factor in modeling the background complexity of traffic signs in this study.

Entropy

Entropy, denoted by E , is a quantity normally used to statistically measure the randomness of an image. In the information theory, entropy is used to measure the degree

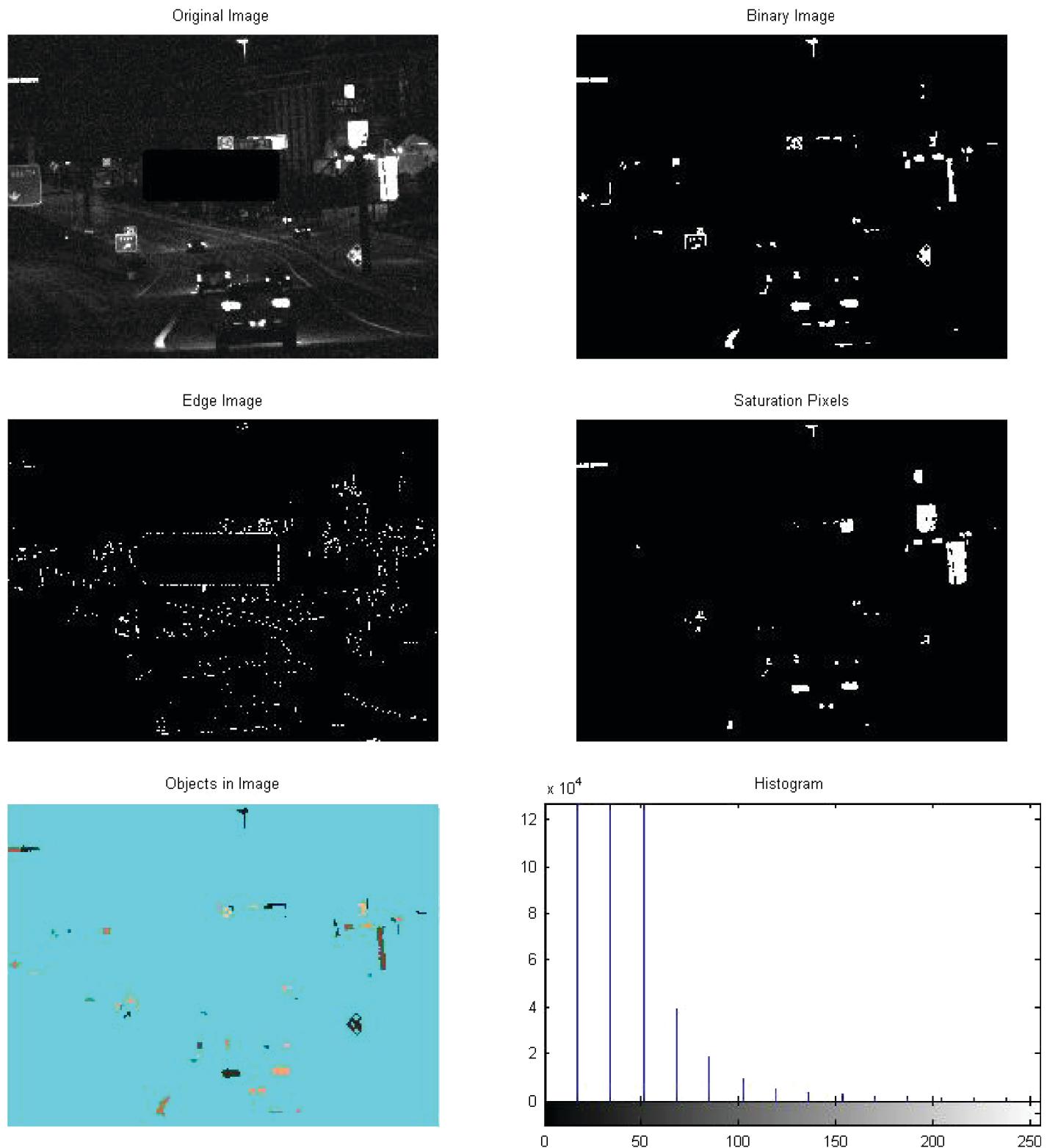


Figure B-3. Example of image properties.

of uncertainty associated with random variables, considered a statistical measure of complexity (11). It can be calculated based on the following equation.

$$E = - \sum_{i=1}^N \sum_{j=1}^N p(i, j) \log(p(i, j))$$

where $N \times N$ is the dimension of the GLCM.

Low-entropy images, such as those containing regular pixels or regions, have very little contrast and very similar grayscale values. High-entropy images, such as one with heavily cratered areas like on Mars or the Moon, have very large contrast between pixels. Hence, entropy has the potential to be used to provide information with respect to the complexity of images. It is likely that entropy is greater with the increase of image complexity.

Energy

Energy is a measure of uniformity of grayscale values in an image. It is denoted by J and calculated by the following equation.

$$J = \sum_{i=1}^N \sum_{j=1}^N (p(i, j))^2$$

High-energy images have gray-level distributions with either constant or periodic forms. A homogenous image usually consists of coarser texture with very few dominant gray peaks. Therefore, the co-occurrence matrix for such an image will have few large magnitudes resulting in large values for the energy feature. In contrast, the co-occurrence matrix with a large number of small entries produces small values of energy in an image. Hence, the coarser the texture is, the larger the energy is, and vice versa.

Homogeneity

Homogeneity is used to measure the spatial closeness of the distribution of elements in the GLCM. Its calculation formula is as follows.

$$H = \sum_{i=1}^N \sum_{j=1}^N \frac{p(i, j)}{1 + |i - j|}$$

As the extreme case, when the distribution of the GLCM is uniform, the homogeneity of such an image is equal to 0. Contrarily, it is equal to 1 when the distribution of the GLCM lies only on the diagonal of the matrix.

Edge Ratio

Edge, as a crucial characteristic of object, is used to describe the texture of objects as well as their shape information.

Hence, the occurrence of objects in images can be represented by the edge ratio, which is defined as follows.

$$R = \frac{N_{edge}}{N_{total}}$$

where N_{edge} is denoted by the number of pixels located at the edges of all objects in an image, and N_{total} is the total number of pixels in an image.

The edge of objects is the place where the grayscales of an image significantly change. Generally, the edge can be calculated by the difference algorithm depending on edge detection operators. An image with a large number of edge pixels is commonly complicated by more objects in the image. This is the reason for employing the edge ratio as a factor to evaluate the background complexity of nighttime images of roadway scenes. However, the edge ratio is sensitive to noise and accuracy of selected edge detection operators. In this work, Canny edge detection, as one of the most famous multi-stage edge detection algorithms, was adopted to extract edge pixels of the background image (12).

Modeling of Complexity

As stated above, all seven properties derived from an image are considered factors for analyzing the background complexity of nighttime images of roadway scenes. In this study, the research team assumed that the complexity is linearly related with these factors. Therefore, the multiple linear regression (MLR) model was employed to model the background complexity (13–15). MLR is a multivariate statistical technique used to examine the linear correlations between multiple independent variables and a single dependent variable. It can be demonstrated as follows:

$$\begin{aligned} y_i &= \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} \\ &\quad + \beta_5 x_{i5} + \beta_6 x_{i6} + \beta_7 x_{i7} + \varepsilon_i \end{aligned}$$

where y_i is the i -th observation of the dependent variable, which was the complexity rate in this work; x_{ij} is the i -th observation of the j -th independent variable, which is one of the properties introduced previously; β_i is the parameter to be estimated for the j -th independent variable factor; and ε_i is the error following the independent identically normal distribution.

It also can be expressed by the matrix format illustrated below.

$$Y = XB + Err$$

where $Y = (y_1, y_2, \dots, y_m)^T$ is a matrix with measurements of the dependent variable, X is a matrix with a series of multivariate measurements from input factors, $B = (\beta_0, \beta_1, \dots, \beta_7)^T$ is a parameter matrix that needs to be estimated, and Err is the noise matrix.

The noise is usually assumed to follow a multivariate normal distribution. The ordinary least square (OLS) method is employed to estimate parameters $(\beta_0, \beta_1, \dots, \beta_7)^T$ of the model of background complexity for nighttime images of roadway scenes (16).

The ability of any visual background complexity model will only be as good as the human factors data used to calibrate it. The sample size available for this analysis was such that it was decided to use bootstrapping, a common resampling method, to improve the performance of MLR (17). The general procedure of bootstrapping is as follows.

1. Plug the original samples of size N into the multiple linear regression model.
2. Compute the desired estimation of parameters in the model.
3. From the original samples, resample *with a replacement* bootstrap sample with the same size of N as the original samples. The meaning of “replacement” is that some datasets in the original samples may be drawn several times in a bootstrap sample, and some may be excluded.
4. Plug the bootstrap sample produced in the previous step into the multiple linear regression model and obtain new estimation of parameters.
5. Repeat Steps 3 and 4 many times and store all results. The number of iterations needs to be set at an appropriate value since it affects the performance of bootstrapping in the regression. Most of the time, 200 times is sufficient.
6. Each estimated parameter is the mean of stored bootstrap estimates. The estimated standard error is the standard deviation of bootstrapping estimates.

Data Description

Human factors rating data of nighttime images taken by the Basler Scout Camera with a 35 mm Fujinon lens were collected from 30 participants and used with bootstrapping to calibrate the MLR. The survey was designed to rate images of nighttime roadway scenes based upon the background complexity of the target traffic sign, overhead guide sign, or street name sign. A total of 33 images were rated individually by each of the participants. The rating of the background complexity for each image was based on a scale of 1 through 5, with 1 = *low complexity* and 5 = *high complexity*. The participants were told that high complexity was defined as difficulty detecting the test sign in each image. Two randomized image presentation orders were developed. Half of the participants, referred to as Group A, viewed one of the presentations, and the other half, Group B, viewed the second presentation. Before conducting the survey, each participant was given five images to rank in order to introduce the rating concept and the type of images he/she would be rating. Participants were also instructed to comment on any factors that seemed to increase or decrease the background complexity of the target traffic sign.

Table B-1 contains the results of the survey, with the average and standard deviation for the rate of each sign by group as well as overall rating. The results of the rating by each group for each sign were compared using a t-test. Furthermore, an independent paired sample t-test was conducted to determine whether the survey results by Groups A and B were different. The results showed there was not enough evidence to reject the null hypothesis, and the groups were the same since the p-value was equal to 0.48. According to the survey results in Table B-1, and as shown in Figure B-4, Images 12 and 28 were rated by the participants as the two least complex images. Images 15 and 17 were rated the two most complex images among all 33 images. The participants commented that the reason they selected Image 15 as the most complex one was due to the busy background, small size of the sign, and multiple signs and lights close to the sign.

Another dataset collected from a previous survey with a different group of 21 participants focused on 16 different nighttime images of roadway scenes was also used in this study. This dataset, as given in Table B-2, was mainly used to validate the proposed model to evaluate its fitting performance. Before applying image processing techniques to obtain image properties, the target traffic sign in each image was removed manually and replaced with a totally black area to eliminate the effects of the sign on the analysis of the background complexity. This way the complexity was analyzed only for the background, not for the image that also included the sign.

Results and Analysis

Parameter Estimation of Multivariate Regression Model

Using image processing, the properties of all 33 images were automatically computed. These properties included entropy, energy, contrast, homogeneity, number of saturation pixels, edge ratio, and number of objects. These values are given in Table B-3.

The parameter estimations of the multivariate linear regression model by OLS from the original small samples and 1,000 bootstrapping samples are presented in Table B-4, along with the corresponding standard error for each estimated parameter.

The root mean square error (RMSE), as shown below, was applied as the model fit index to compare the estimates from the original small samples and 1,000 bootstrap samples.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (Y_i - \hat{Y}_i)^2}$$

where Y_i is the rating of background complexity from the survey, and \hat{Y}_i is the predicted value from the proposed multivariate linear regression model.

Table B-1. Background complexity results: Survey 1.

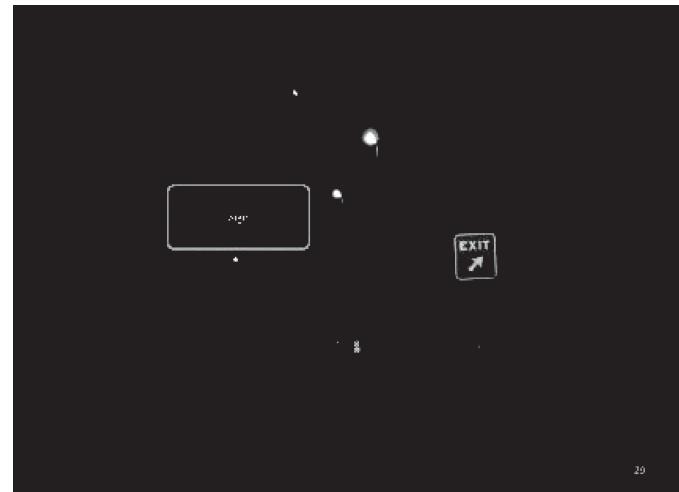
Images	Group A		Group B		Overall Average	Overall Std. Dev.	P-Value	Overall Rating
	Average	Std. Dev.	Average	Std. Dev.				
1	4.4	0.74	3.5	1.19	3.9	1.08	0.02	4
2	2.6	0.94	2.2	0.56	2.4	0.78	0.2	2
3	4.5	0.65	3.6	0.83	4	0.87	0	4
4	3	0.96	2.6	1.12	2.8	1.05	0.31	3
5	2.9	1.14	3.3	1.05	3.1	1.09	0.33	3
6	2.4	0.84	2.1	0.74	2.2	0.79	0.45	2
7	2.6	0.93	3.1	1.16	2.9	1.06	0.29	3
8	2.7	0.73	2.3	0.62	2.5	0.69	0.14	3
9	2	0.39	2.4	0.83	2.2	0.68	0.11	2
10	1.9	0.95	1.9	0.74	1.9	0.83	0.98	2
11	2.7	0.99	3.5	1.19	3.1	1.14	0.08	3
12	1.1	0.27	1.1	0.26	1.1	0.26	0.96	1
13	3.1	0.83	3.3	1.18	3.2	1.01	0.5	3
14	2.7	0.73	2.8	0.77	2.8	0.74	0.76	3
15	4.8	0.43	4.7	0.82	4.7	0.65	0.63	5
16	2.1	0.73	1.5	0.52	1.8	0.68	0.03	2
17	4.4	0.84	4.1	1.06	4.2	0.95	0.54	4
18	1.6	0.51	1.5	0.64	1.6	0.57	0.86	2
19	2.7	0.47	2.9	0.74	2.8	0.62	0.52	3
20	1.8	0.89	1.5	0.64	1.6	0.78	0.28	2
21	2.7	0.99	2.6	0.91	2.7	0.94	0.75	3
22	1.1	0.36	1.3	0.46	1.2	0.41	0.43	1
23	2.3	0.73	2.2	0.68	2.2	0.69	0.74	2
24	1.6	0.65	1.6	0.51	1.6	0.57	0.9	2
25	1.2	0.43	1.5	0.64	1.4	0.56	0.13	1
26	4	0.88	4.1	0.83	4.1	0.84	0.68	4
27	1.8	0.89	1.5	0.52	1.6	0.73	0.25	2
28	1	0	1.1	0.35	1.1	0.26	0.17	1
29	3.4	0.93	3.6	0.91	3.5	0.91	0.48	4
30	1.4	0.63	1.2	0.41	1.3	0.53	0.43	1
31	1.5	0.52	1.9	0.74	1.7	0.66	0.14	2
32	2.2	0.58	1.9	0.74	2	0.68	0.17	2
33	3.6	0.93	3.7	1.1	3.7	1	0.81	4

No. 12 Image



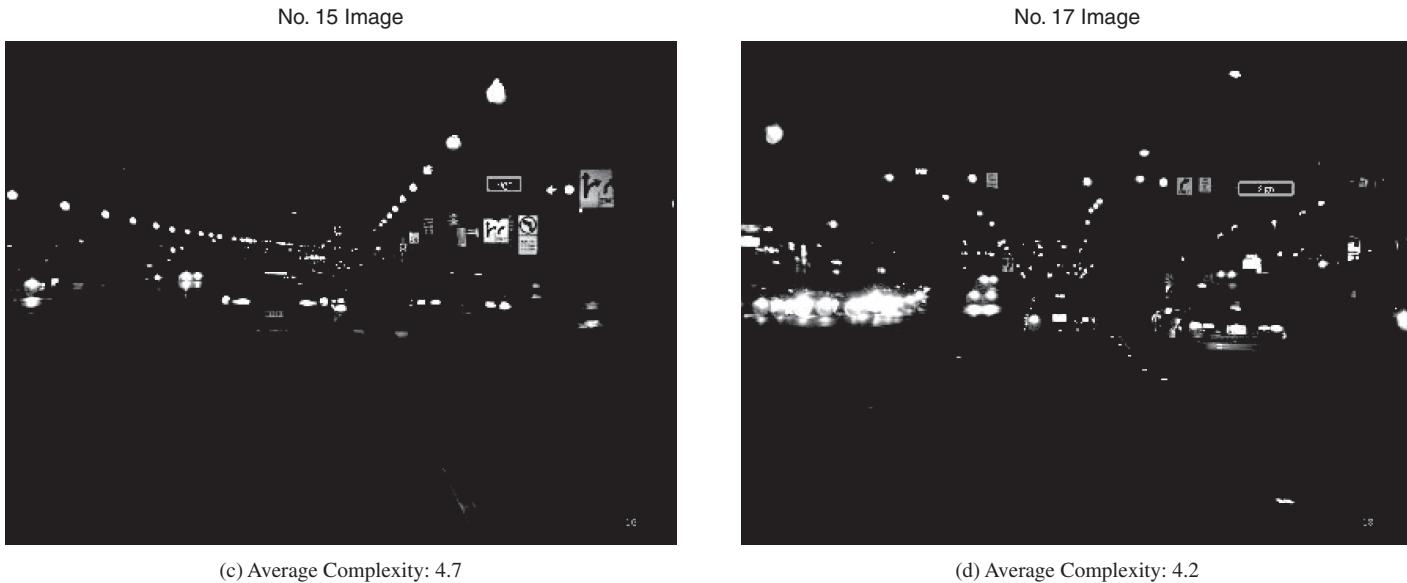
(a) Average Complexity: 1.1

No. 28 Image



(b) Average Complexity: 1.1

**Figure B-4. Survey images: (a) Image 12, (b) Image 28, (c) Image 15, and (d) Image 17.
(continued on next page)**

**Figure B-4. (Continued).**

The RMSE for the original small samples was 0.393094, and the RMSE for the bootstrap samples was 0.372485. As shown, these two models had similar performance, but estimates from the bootstrap samples were slightly downward biased for the analysis of background complexity of nighttime roadway scenes in the empirical surveyed data. The dependent

Table B-2. Background complexity results: Survey 2.

Images	Overall Average	Overall Std. Dev.	Overall Rating
1	1.3	0.23	1
2	4.3	1.13	4
3	3.3	0.90	3
4	3.3	1.03	3
5	3.3	1.20	3
6	2.3	0.73	2
7	1.7	0.98	2
8	3.0	0.94	3
9	2.0	0.51	2
10	1.3	0.37	1
11	2.3	0.88	2
12	3.0	1.08	3
13	1.7	0.61	2
14	5.0	0.84	5
15	2.0	0.82	2
16	3.7	1.10	4

variable employed in the regression was the average value of ratings from 30 participants as a continuous variable. However, the background complexity of traffic signs in the nighttime roadway scenes was defined as five levels, from 1 (least) through 5 (most), all of which were integers. Therefore, it was necessary to take a look at the performance of the proposed multivariate linear regression model with rounded values (integers). The results can be found in Figure B-5. Apparently, there were only three images (No. 16, 26, and 27) in which predicted ratings of complexity derived from the proposed multivariate linear regression model deviated from the ones from the survey. Nevertheless, these differences were ± 1 in all cases, as shown in Figure B-5. It can be tolerated in practice with such bias in the analysis.

Model Validation

After building up the multivariate linear regression model, there was a need to validate the performance of the proposed model. The leave-one-out cross validation (LOOCV) was employed to evaluate the proposed model. As its name implies, LOOCV uses a single observation from the original datasets as the validation data, and other data as the training data. The whole process continues until all observations have been used once as the validation data. The validation results are illustrated in Figure B-6.

Table B-3. Statistical summary for image properties.

Image Property	No. of Objects	No. of Saturation Pixels	Homogeneity	Edge Ratio	Contrast	Energy	Entropy
Mean	40.29	8.50	0.87	0.0056	45.21	0.16	3.61
Std. Dev.	16.47	1.02	0.11	0.0023	43.75	0.19	1.25

Table B-4. Multivariate regression results.

Parameters	Ordinary Least Square		Bootstrap for OLS	
	Estimation Value	Standard Error	Estimation Value	Standard Error
Intercept	-7.1612	1.7524	-6.1491	2.6007
Entropy	0.2422	0.3651	0.1907	0.4276
Contrast	0.0138	0.0049	0.0128	0.0088
Energy	0.3789	2.8844	0.0543	3.4869
Homogeneity	3.9557	1.361	2.7531	2.8927
No. of Saturation Pixels	0.4068	0.1691	0.4414	0.1888
Edge Ratio	92.9387	57.5493	102.1324	61.2105
No. of Objects	0.0197	0.0056	0.0196	0.0080

As shown in this figure, the fit of the model was very good and certainly acceptable, as the largest biases were 1.17 for the averaged ratings and 1 for the rounded ratings, respectively. Based upon such results, the error with respect to average ratings for background complexity in the validation was computed with a mean of 0.3182 and a standard deviation of 0.2951. Additionally, the error of ± 1 in the rounded ratings was reasonable since the survey was a subjective procedure in which it was difficult for participants to accurately distinguish the difference in the background complexity of two nighttime images, especially when they had close complexity ratings (e.g., 4 and 5).

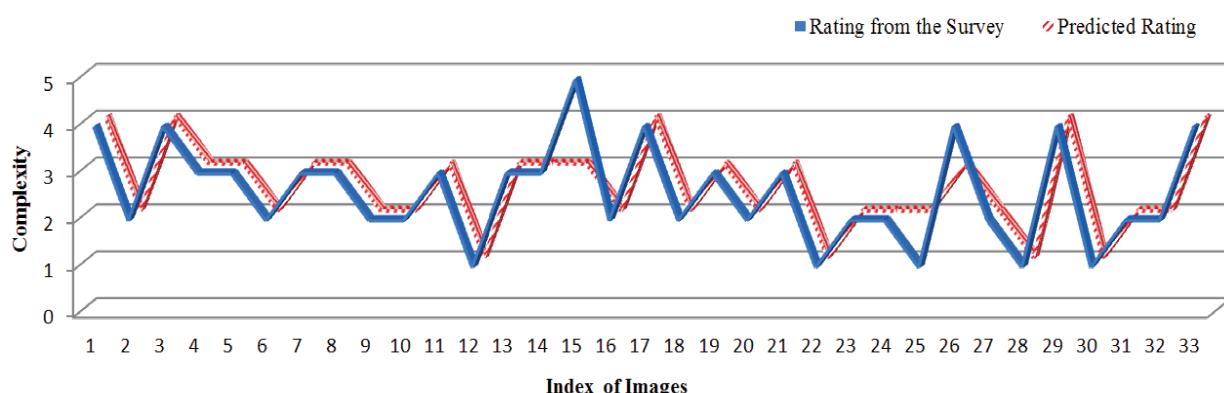
To further validate the multivariate linear regression model proposed, data were used from a preliminary survey that consisted of 16 nighttime images of overhead guide signs rated by 21 participants using a similar methodology. Figure B-7 demonstrates the performance of the proposed model in such datasets.

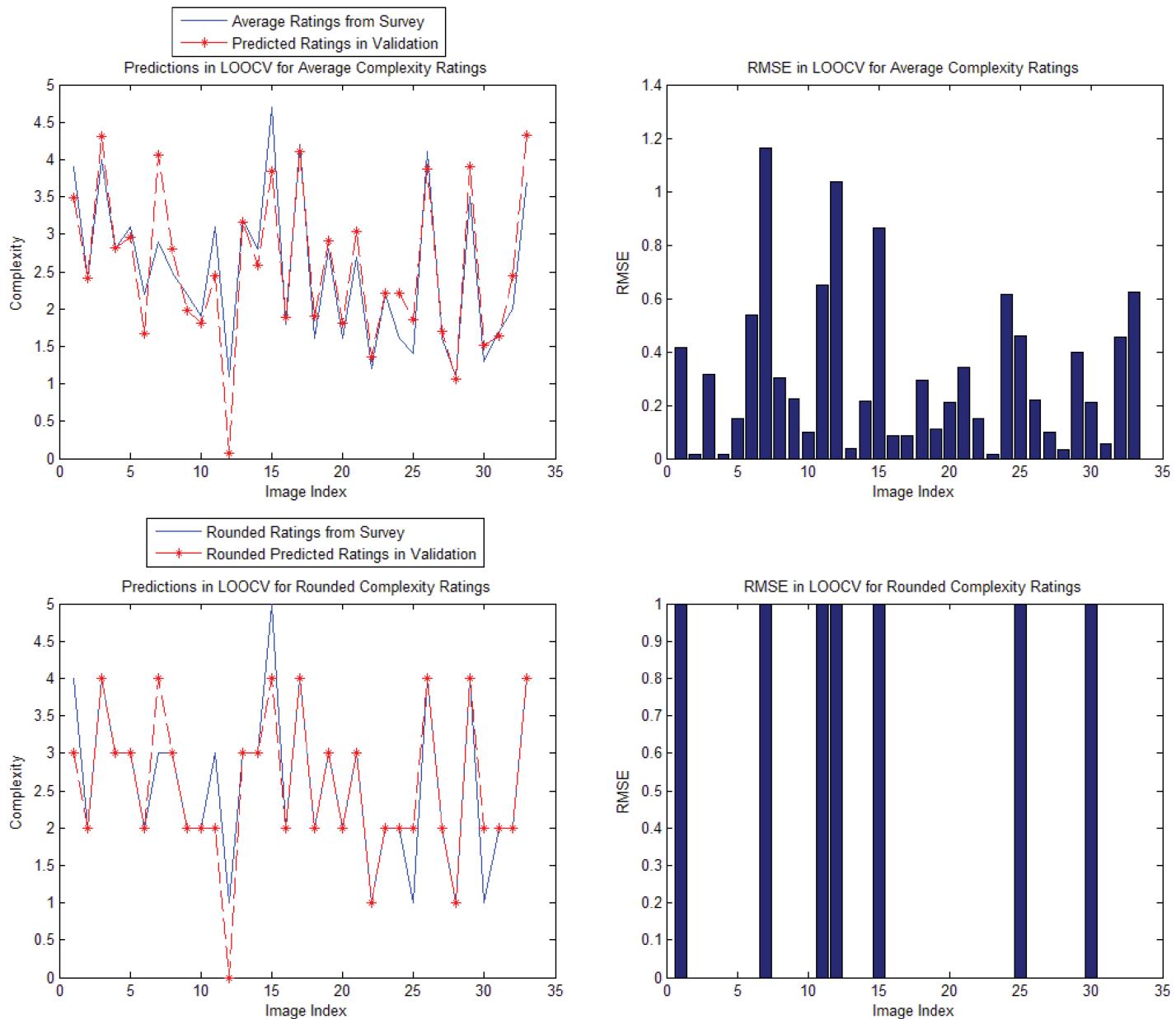
Based on the validation datasets, it is apparent that the proposed model performed well, as the largest error was less than 1.5 for the averaged ratings and 1 for the rounded ratings. In the rounded ratings, differences occurred in only 3 of 16 images with the bias of 1. As mentioned previously, the error of ± 1 was acceptable since the procedure of rating

complexity was subjective, and the differences were difficult to accurately distinguish. This validation with the second dataset was particularly important, because the model is trained from a different dataset from a different survey. This validation effort shows that the developed model is robust and has strong potential to be used to rate the background complexity of any digital image of a roadway scene.

Conclusions

The goal of this study was to assess the background complexity of overhead traffic signs using nighttime images of roadway scenes via image processing techniques. A multivariate linear regression model considering entropy, contrast, energy, homogeneity, the number of saturation pixels, edge ratio, and the number of objects as input properties is proposed. These input properties are all directly derived from images by image processing techniques. Image rating data collected from 30 participants from one survey and 21 from another survey were used to train and validate the model. The predicted ratings from the model with respect to the background complexity were consistent with ones from the surveys. It is believed that this model can be used to effectively rate nighttime images for background complexity with respect to overhead guide and street name

**Figure B-5. Results of rounded values in multivariate linear regression model.**

**Figure B-6. Results of validation by LOOCV.**

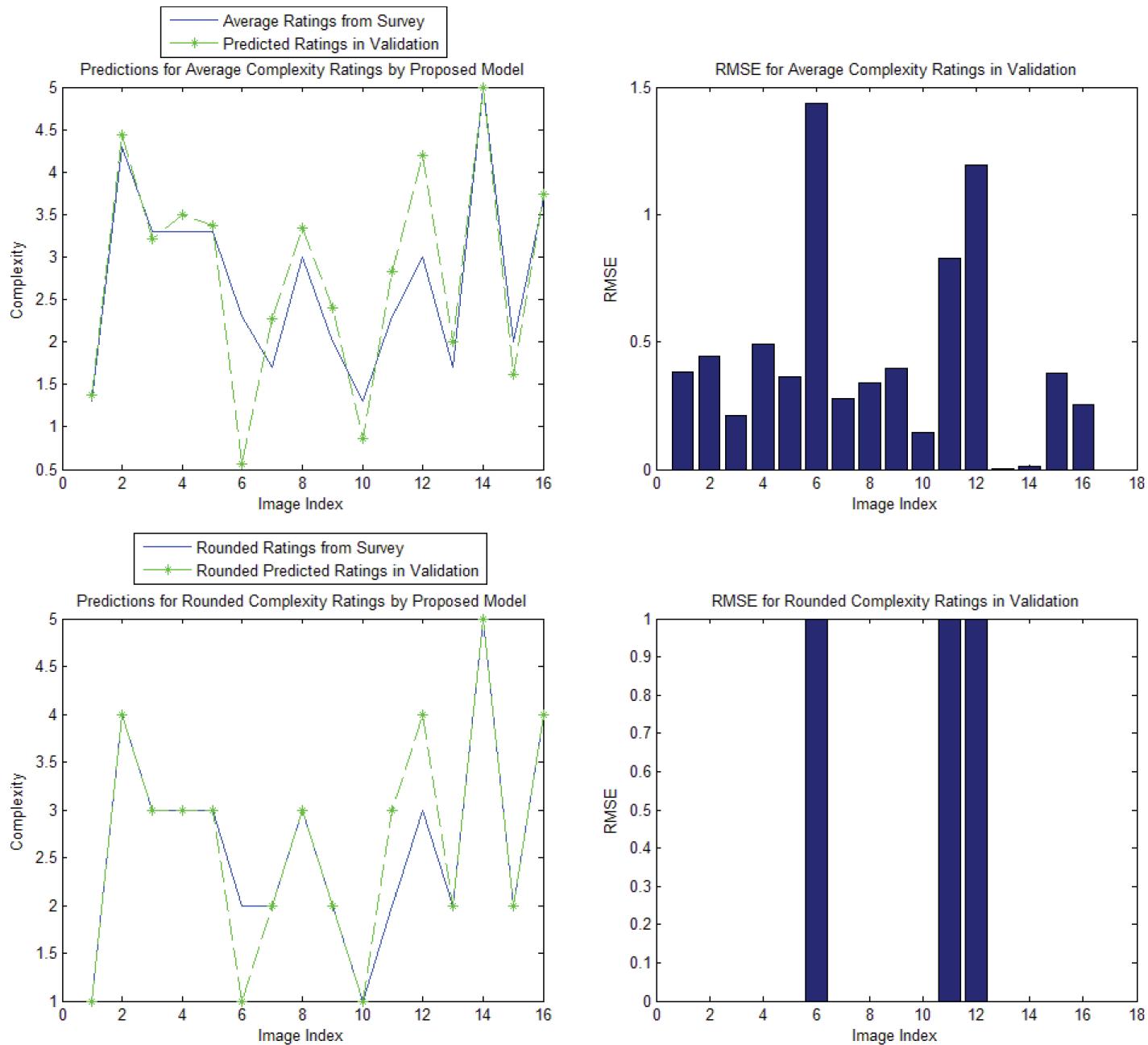


Figure B-7. Performance of proposed model by validation datasets.

signs, and those ratings can be used to more accurately assess the visibility of the signs.

Suggestions for future research include extending the work to measure other important characteristics of nighttime images, such as 2D spectrum information and relative localization of traffic signs. This model should also be validated with respect to other types of signs, such as warning and regulatory signs. It is also suggested to further develop the technique by automating the detection of all signs in the image and individually rating the background complexity of each and to collect new and more

comprehensive image samples to further train and validate the proposed model.

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APPENDIX C

Open-Road Study Details

This appendix contains details of the open-road study that supplement the material in Chapter 4. Table C-1 identifies the number of participants recruited from each location and the average ages of the participants. The sections that follow identify the specific routes used for data collection with the participants on the open road and the instructions given to the participants while driving the selected route.

Routes

The routes selected for each of the sites are shown in Google Maps images in Figure C-1 through Figure C-3.

Instructions to Participants

In each of the three locations, the researchers used a written script to instruct the participants where to drive and which signs to search for. An example of the script from Orlando, Florida, follows. Overall, the researcher provided turn-by-turn directions and asked the participants to call out each instance they saw a sign with the corresponding street and identify when they were confident in their response. The participants were asked to obey all traffic laws. To maintain some uniformity in the study, and because luminance data were recorded from one lane position, the researcher instructed the participant on which lane to drive in when multiple lanes were present.

Instructions to be read before entering the vehicle:

You will be driving our vehicle on a pre-determined route near this location. The vehicle is specially equipped to record and measure various driving characteristics, but drives just like a normal vehicle. A researcher will be in the car with you at all times and will direct you when, where, and how fast you will need to drive.

You are to obey all traffic laws at all times and you must agree to wear a safety belt at all times. As you travel you will encounter several overhead signs. Clearly tell the researcher

verbally what the sign says when you can read the words on the sign. In some cases, the researcher may give you a word and ask you to let the researcher know when you have clearly identified that particular sign and where it was located. Some signs may be repeated, so please let the researcher know when you can read each sign, and every time the sign reappears. Also note the location of the signs may be different. They may be overhead signs or signs on the side of the road to your left or to your right. In addition, please provide any comments about what you see that makes a sign easier or harder to find or read. At the end of the study the researcher will ask you a few follow-up questions.

While we want you to focus on your driving tasks, your most important job is to drive safely, always paying attention to the road ahead and keeping the vehicle under control. Do you have any questions? If no, we will begin.

Instructions to be read inside the vehicle (target signs are in **Bold**):

- Take the access road onto I-4 West, and merge into the next left lane when it is safe to do so. When the Lee Rd exit passes, please merge back into the upcoming right lane when it is safe to do so.
- Let me know when you can clearly identify any sign mentioning **Fairbanks Ave**. There may be more than one.
- Take the Fairbanks Ave exit and make a left hand turn at the light. Please stay in the right left-turning lane on Fairbanks. Let me know when you can read the sign **Formosa Ave**.
- Now that you have identified Formosa Ave, let me know when you can read the sign for **Orlando Ave**.
- Now that you have identified Orlando Ave, let me know when you can read **Denning Dr**.
- Now that you have identified Denning Dr, let me know when you can read **Pennsylvania Dr**.
- Now that you have identified Pennsylvania Dr, let me know when you can read **Park Ave**.

Table C-1. Number of participants and their average ages.

Location	Younger (Avg = 23.9 yr)	Older (Avg = 68.1 yr)	Total
Bryan/College Station, TX	7 (23.8 yr)	16 (71.9 yr)	23
San Antonio, TX	9 (23.4 yr)	16 (68.8 yr)	25
Orlando, FL	8 (24.6 yr)	16 (64.9 yr)	24

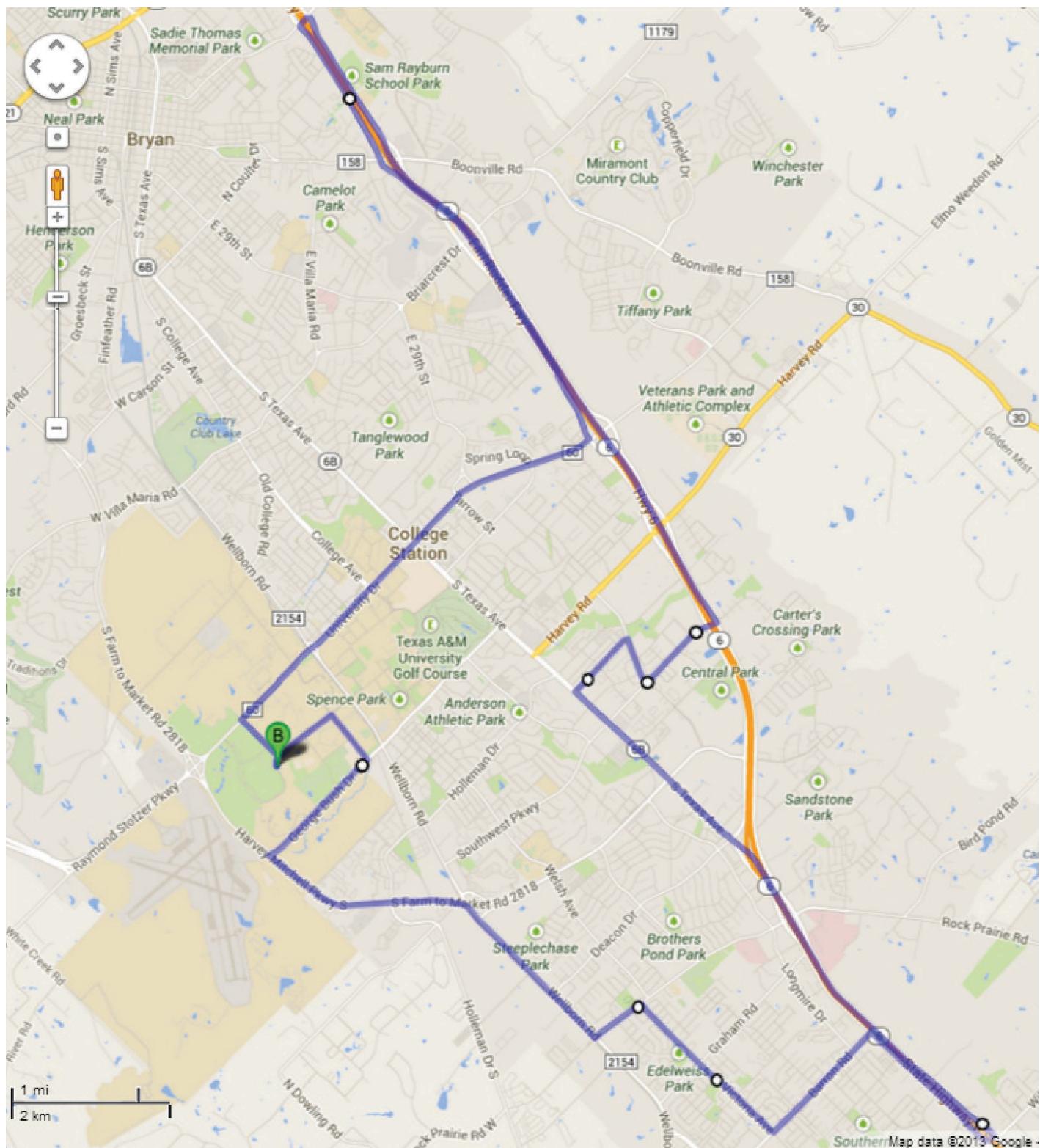


Figure C-1. Bryan/College Station, Texas, route (map data: Google).

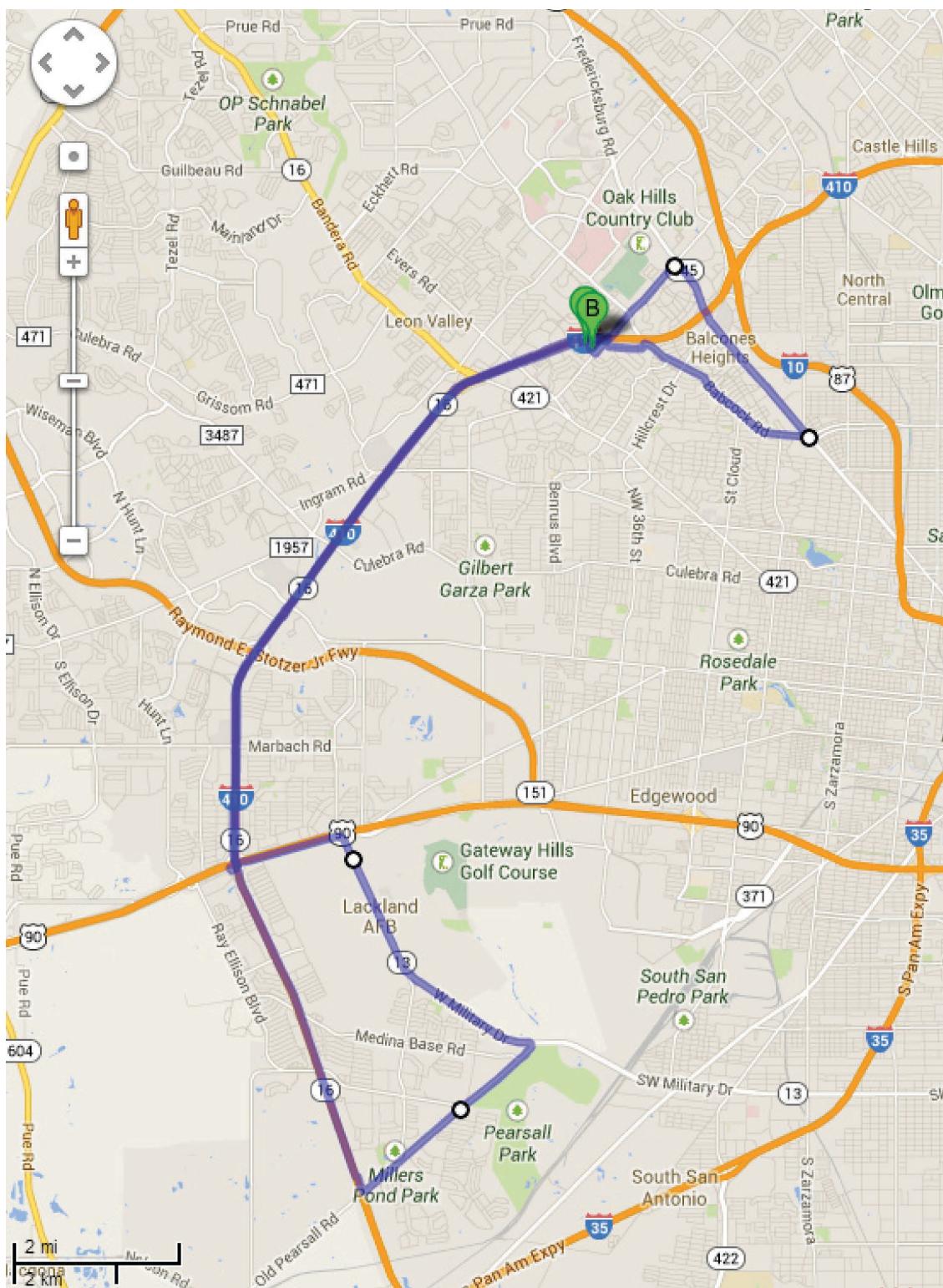


Figure C-2. San Antonio, Texas, route (map data: Google).

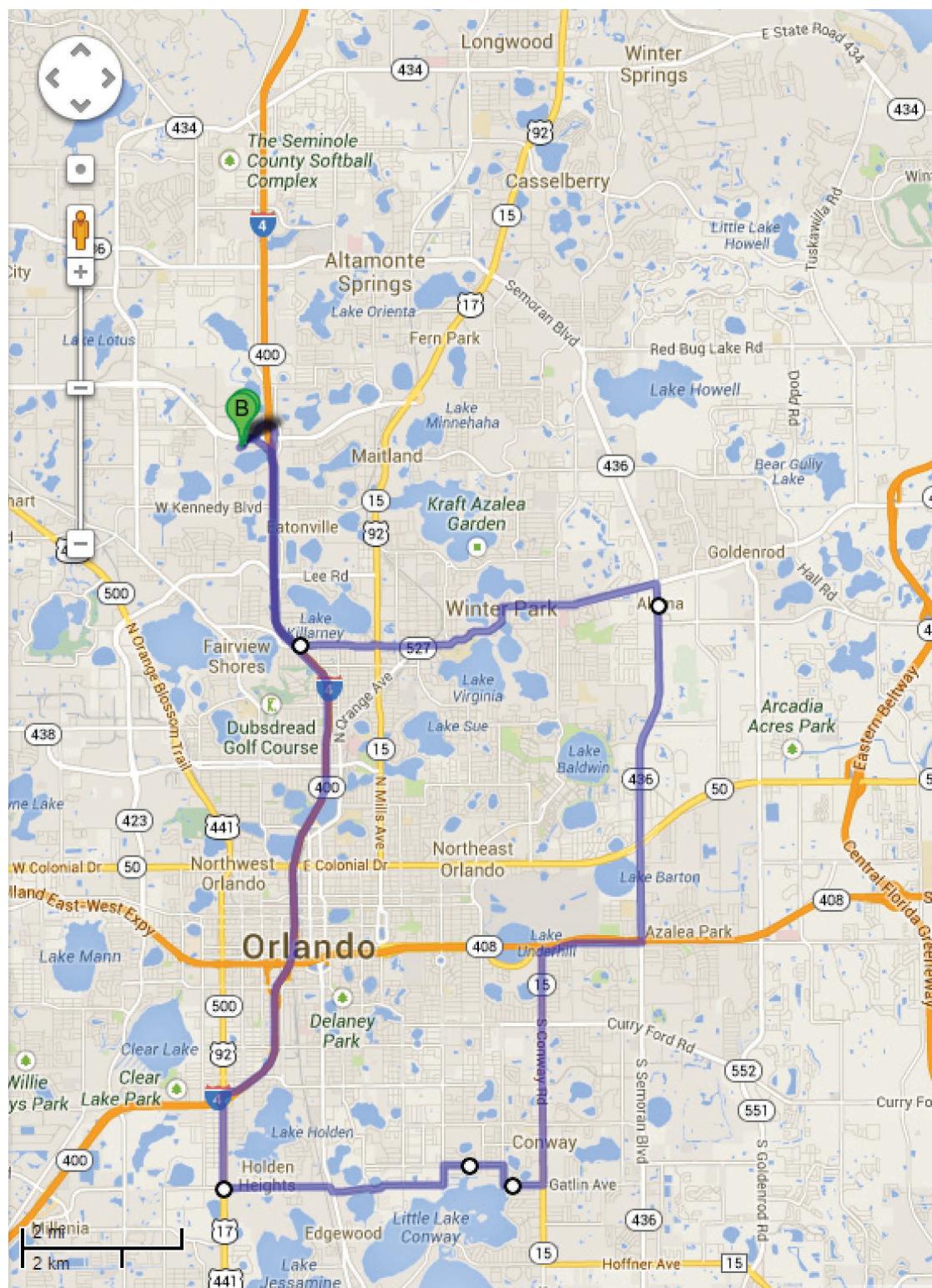


Figure C-3. Orlando, Florida, route (map data: Google).

- Now that you have identified **Park Ave**, let me know when you can read any sign related to **Henkel Cr**. There may be more than one.
- Now that you have passed Henkel Cr, let me know when you can read **Phelps St**.
- Now that you have identified Phelps St, let me know when you can read **Balfour St**.
- At the light please make a right hand turn and stay in the right hand lane. Let me know when you can read any signs related to **Scarlet Rd**. There may be more than one.
- Now that you have identified Scarlet Rd, please let me know when you can read any signs related to **Hanging Moss Rd**. There may be more than one sign.
- Let me know when you can read any signs related to **Old Cheney Hwy**.
- Now that you have identified Old Cheney Hwy, please let me know when you can read any signs related to **Oleander Dr**.
- Now that you have identified Oleander Dr, please let me know when you can read any signs related to **Yew Dr**.
- At the next signal please make a right hand turn. Please let me know when you can read **Andes Ave**. At Conway/FL 15 please make a left hand turn, and proceed in the right hand lane when it is safe to do so.
- Please let me know when you can read the sign **Kasper Dr** with a K.
- Now that you have identified Kasper, please let me know when you can read **Curry Ford Rd**.
- Now that you have identified Curry Ford Rd, please let me know when you can read the sign **Michigan St**.
- Now that you have identified Michigan St, please let me know when you can read **Anderson Rd**. At the next signal make a right hand turn.
- Please let me know when you can read **Pershing Ave**. At the next stop sign make a left hand turn.
- Please let me know when you can read the sign **Crystal Lake Dr**. At the next stop sign make a left hand turn.
- Please let me know when you can read the sign **Fern Creek Ave**.
- At the next signal make a right hand turn and turn into the left hand lane. At that light make a left hand turn and stay in the right hand lane. Please let me know when you can read the sign **Bradley Ave**.
- Now that you have identified Bradley, let me know when you can read **Raymar Dr**. At the next signal make a right hand turn.
- Please let me know when you can read the sign **I-4 East**. Stay in the right hand lane and follow the road to merge onto the interstate. Please merge one lane left when it is safe to do so.
- Please let me know when you can read any signs related to **South St**. There may be multiple signs.
- Now that you have identified South St, please let me know when you can read any signs related to **Amelia St**. There may be more than one.
- Please let me know when you can read any signs related to **Fairbanks Ave**. There may be multiple signs. Now that you have identified Fairbanks Ave, the study is now over. When it is safe to do so, please merge into the right lane and take Exit 90B.

APPENDIX D

Guidelines for Nighttime Overhead Sign Visibility

This appendix contains recommendations for revised material specifically for the *AASHTO Roadway Lighting Design Guide*. The latest edition (2005) includes a chapter focused on roadway sign lighting (Chapter 10). For ease of implementation, the key research findings have been integrated into the chapter from the *AASHTO Roadway Lighting Design Guide*. The revised chapter is shown below.

Chapter 10

Overhead Sign Lighting

10.1 OVERVIEW

Introduction

Traffic signs are placed along the roadway in strategic locations and are used to convey specific, consistent messages to motorists. The standards used in the design of traffic signs are described in the *Manual on Uniform Traffic Control Devices* (MUTCD). The intent of these standards is to ensure that all traffic signs are designed and maintained to provide information that can quickly and accurately convey the necessary information and to provide national sign design consistency. The MUTCD states “signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night” (1).

Nighttime sign legibility can be achieved in one of two ways:

- Using retroreflective sheeting materials for the legend and background.
- Using either internal or external sign illumination.

Almost all signs are made with retroreflective sheeting materials. Only some signs are illuminated, and generally those are overhead guide signs and overhead street name signs. The added sign illumination helps compensate when the vehicle headlamps and retroreflective properties of the sign sheeting materials are inadequate by themselves.

A sign designed to be legible under daylight conditions can be illuminated to fulfill its basic purpose at night. A properly designed sign lighting system can aid motorists with the rapid and accurate recognition of the sign’s shape, color, and message. This serves to improve safety

by reducing the possibility that motorists will significantly reduce their speed at locations where signs may be otherwise difficult to read. Overhead sign lighting is generally considered under the following locations:

- Signs in areas having a high level of visual complexity.
- Signs beyond sag vertical curves and outside the influence area of vehicle headlamps.
- Signs in horizontal curves that are outside the influence area of vehicle headlamps.
- Signs in areas where atmospheric conditions create condensation or frost on the sign face and reduce the effectiveness of the retroreflective sheeting.

Key Visibility Considerations for Overhead Sign Lighting

The following considerations should be addressed to assess nighttime sign visibility.

- Visual Complexity—Traffic signs are designed to be easy to read, but they also have to be conspicuous so that they are quickly recognized. The nighttime conspicuity of signs depends on the surrounding visual environment, which includes all other competing visual stimuli such as roadway lighting, vehicle lighting, other signs, and especially the roadside development and associated lighting. In this document, the term visual complexity is used to describe the surrounding visual environment. Visual complexity in the scene surrounding the sign impacts the sign luminance needed for nighttime motorists. If the visual complexity is high, then retroreflective material alone may not provide enough luminance, and therefore sign lighting may be needed.
- Sign Luminance—Sign luminance is a measure of the brightness of a sign. Sign luminance can be defined as either the legend luminance or the background luminance. The legend luminance is generally used as a key performance metric of guide sign visibility.
- Retroreflectivity of the Sign Legend and Background—The retroreflective material used for the legend as well as the background should be carefully considered. In many conditions, the proper selection of retroreflective sheeting materials can provide adequate visibility for nighttime motorists. The MUTCD contains minimum maintenance levels for sign retroreflectivity.
- Sign Contrast—The contrast between the sign legend and the sign background is an important factor to maintain adequate visibility. Generally speaking, adequate contrast is provided if the signs are fabricated using the color combinations as specified in the MUTCD and with materials meeting the color specifications established in 23 CFR Part 655, Traffic Control Devices on Federal-Aid and Other Streets and Highways; Color Specification for Retroreflective Sign and Pavement Marking Materials (*1*).

10.2 GUIDELINES FOR OVERHEAD SIGN VISIBILITY

The guidelines for overhead sign visibility are designed to accommodate the needs of nighttime motorists by establishing a threshold level of legend luminance based on specific levels of visual complexity (defined later). The contrast of the sign legend and sign background is accounted for with the matching of retroreflective legend and background materials. The

guidelines incorporate five unique levels based on the latest research, which links sign legend luminance needs to visual complexity (2). For each level of visual complexity, there is an associated minimum legend luminance. The minimum level of luminance for the lowest visual complexity level (i.e., Level 1) has been appropriately matched with the Federal Highway Administration's research that was used in the MUTCD to establish minimum retroreflectivity levels (since that work was completed in a dark, rural environment with low visual complexity). The recommended minimum maintained luminance levels for overhead signs are provided in Table D-1.

Table D-1. Luminance Levels for Overhead Signs.

Visual Complexity Level	Minimum Legend Luminance	
	Candelas per Square Meter	Candelas per Square Foot
1	2.5	0.23
2	8	0.75
3	14	1.31
4	20	1.87
5	25	2.34

The minimum luminance levels in Table D-1 are meant to be applied at a distance of 40 ft per inch of letter height. Thus, if the uppercase letters on a guide sign are 16 in., then these recommendations would apply at a distance of 640 ft ($16 \times 40 = 640$ ft).

For the highest visual complexity rating, Level 5, analyses of overhead sign legend luminance based exclusively on retroreflective sheeting materials available in 2015 indicate that additional luminance is needed beyond what can typically be provided by headlamps alone. In other words, for signs in areas with a visual complexity level of 5, sign lighting should be considered. For signs in areas with a visual complexity rating of 4 and below, the use of ASTM D4956-13 Type XI retroreflective sign sheeting materials can provide sufficient legend luminance in nearly all conditions. The exceptions are along horizontal curves in rural areas with radii of 880 ft or less and horizontal curves in urban areas with radii of 2,500 ft or less. In these conditions, sign lighting should be considered. For visual complexity ratings of 3 and below, the use of ASTM D4956-13 Types VIII and IX retroreflective sign sheeting materials can accommodate nearly all conditions with the same geometry restrictions as noted for visual complexity ratings of 4 and below. For visual complexity ratings of 1 and 2, the use of retroreflective sheeting ASTM D4956-13 Types IV, VIII, IX, and XI will provide adequate legend luminance. The analyses supporting this paragraph are based on an assumed 20 percent loss of retroreflective performance due to the impacts of sign weathering.

Visual Complexity Levels for Overhead Guide Signs

The level of visual complexity approaching a sign has a large impact on the visibility of the sign. Areas with high visual complexity dictate higher sign luminance levels in order to maintain adequate nighttime visibility. Although visual complexity can be computed from calibrated digital images of the nighttime scene, doing so requires a high level of expertise and expensive equipment. Therefore, the images in Figures D-1 and D-2 were developed and tested to show five levels of visual complexity. It is intended that these images be used to determine the visual complexity that best represents a jurisdiction or specific section of highway.



Level 1 Visual Complexity:
Minimal objects and light sources. Low traffic.



Level 2 Visual Complexity:
Low commercial activity, some nearby light sources and signs.
Low traffic.



Level 3 Visual Complexity:
Illuminated commercial signs, moderate number of other signs
and light sources. Low to moderate traffic.



Level 4 Visual Complexity:
Moderate commercial activity with illuminated signs and
businesses. Moderate to heavy traffic.



Level 5 Visual Complexity:
Heavy commercial activity with illuminated signs and
businesses. Heavy traffic and glare from vehicle lights.

Figure D-1. Five levels of visual complexity for Overhead Guide Signs (Set 1).



Level 1 Visual Complexity:
Minimal objects and light sources. Low traffic.



Level 2 Visual Complexity:
Low commercial activity, some overhead lighting.
Low to moderate traffic.



Level 3 Visual Complexity:
Moderate commercial activity with illuminated signs. Some other signs and light sources. Low to moderate traffic.



Level 4 Visual Complexity:
Moderate commercial activity with illuminated signs and businesses. Moderate to heavy traffic.



Level 5 Visual Complexity:
Heavy commercial activity, advertising signs and businesses. Heavy traffic and glare from vehicle lights.

Figure D-2. Five levels of visual complexity for Overhead Guide Signs (Set 2).

Visual Complexity Levels for Overhead Street Name Signs

The images in Figures D-3 and D-4 were developed and tested to show five levels of visual complexity for overhead street name signs (at signalized intersections). It is intended that these images be used to determine the visual complexity that best represents a jurisdiction or specific intersection.



Level 1 Visual Complexity:
Minimal light sources, signs, and objects.
Low traffic.



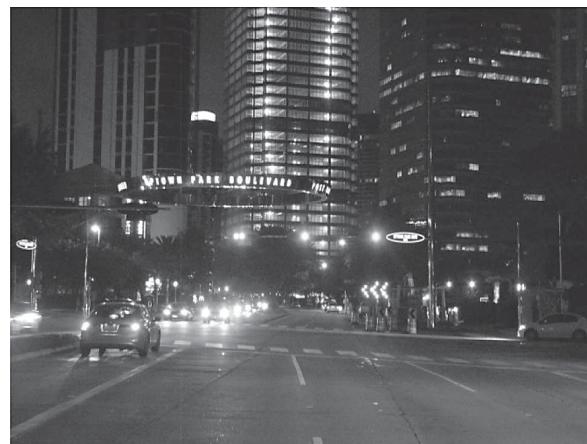
Level 2 Visual Complexity:
Some lighting, signs, or other objects.
Low traffic.



Level 3 Visual Complexity:
Minor commercial and roadway lighting. Some objects in view.
Low to moderate traffic.



Level 4 Visual Complexity:
Moderate commercial and roadway lighting. Several
illuminated objects in view. Moderate traffic.



Level 5 Visual Complexity:
Several light sources from commercial activity and roadway lighting.
Several illuminated objects in view. Heavy traffic.

Figure D-3. Five levels of visual complexity for Overhead Street Name Signs (Set 1).



Level 1 Visual Complexity:
Minimal light sources, signs, and objects.
Low traffic.



Level 2 Visual Complexity:
Some lighting, signs, or other objects.
Low traffic.



Level 3 Visual Complexity:
Minor commercial and roadway lighting. Some objects in view.
Low to moderate traffic.



Level 4 Visual Complexity:
Moderate commercial and roadway lighting. Several
illuminated objects in view. Moderate traffic.



Level 5 Visual Complexity:
Several light sources and heavy commercial activity.
Several illuminated objects in view. Heavy traffic.

Figure D-4. Five levels of visual complexity for Overhead Street Name Signs (Set 2).

10.3 ILLUMINATED SIGN TYPES

Signs can be illuminated in a variety of different ways in order to make the sign message visible and legible to the passing motorist during the hours of darkness. The two main ways of providing illumination to a static sign are as follows:

- Externally Illuminated—Externally illuminated signs are static traffic signs that are uniformly illuminated by a source of light that is mounted external to the sign. This technique is generally used for overhead guide signs.
- Internally Illuminated—Internally illuminated signs are static traffic signs that are illuminated by a source of light that is enclosed within the sign and the sign message becomes visible when illuminated from within because of the difference of color and transparent nature of the material that makes up the sign face. This technique is generally used for overhead street name signs.

10.4 SIGN LIGHTING RECOMMENDATIONS

Once it has been determined that sign lighting is warranted, the lighting engineer should select a light source that will light the sign so that it exhibits similar color rendering properties during the hours of darkness as it did under daylight conditions. The amount of light that is required to adequately light the sign during the hours of darkness is defined in Table D-1.

Several different types of light sources that can be used to light roadway signs are available. Each light source has its own set of unique characteristics that may make it more desirable than others for a given sign installation. Energy consumption is a major factor in choosing a light source and should be considered. However, there are other factors such as color rendering, operating temperature, efficiency, and maintenance ease that are equally important and should also be evaluated.

The light source that is selected should be able to adequately light the face of the sign without interfering with the contrast between the letters that make up the legend and the background of the sign that they are installed on. The contrast between the letters and the background will determine how quickly and accurately a passing motorist can recognize the shape and color of the sign as well as the interpretation of the message that is being displayed.

Lighting Uniformity

Uniformity of lighting is an indication of the quality of illumination and can be defined as either the average-to-minimum, maximum-to-minimum, or maximum-to-average ratios of light levels that are present on the face of the sign. In performing sign-lighting calculations, the maximum-to-minimum ratio has been established as the standard means of determining the uniformity of light levels that appear on the face of a sign.

The uniformity of the light levels that appear on the face of the sign should be controlled if the sign is to be effective in conveying the sign message to motorists at night. Suitable uniformity over the entire face of the sign will provide consistent and proportional contrast that is similar to daytime conditions. Maximum and minimum points that are spaced too close

together will provide poor contrast between the letters that make up the legend and the background of the sign, making it more difficult to read.

A maximum-to-minimum uniformity ratio of 6 to 1 is recommended as an acceptable ratio of lighting levels on the face of the sign. Since lower ratios will produce a more pleasing appearance and a more legible sign, lower maximum-to-minimum uniformity ratios are preferred.

Light Source Selection

There are several options for the light source selected to light a sign. Each of the sources has individual characteristics that can be desirable for the sign lighting application. The two primary considerations for lighting are energy consumption and the color characteristics. Other characteristics such as temperature of operation and ease of maintenance are secondary but should also be considered.

The standards that are used as a basis for sign colors are coded in the MUTCD. The colors have been standardized nationwide so it is essential that the face of the sign be properly illuminated in order to retain the colors for identification purposes. The lighting can impact these color appearances as shown below:



High-Pressure Sodium Lighting



LED Lighting

Sign faces should be lighted to maintain these color appearances through the selection of a light source that has a high enough color rendering index to maintain the color index (recommended CRI > 70). Of special note is the advent of solid state lighting. This newer technology allows for a light source that provides both higher energy efficiency and good color rendering. This source is an attractive choice for a light source on a sign. However, LED luminaires typically emit less heat and as such, melting of snow or frost may be different with LED and may present a maintenance issue.

Placement of Lighting Units

The location of the lighting units impacts the distribution of light on the sign, affecting the amount of illuminance on different areas and the resultant uniformity across the sign face. The lighting units that illuminate the face of a sign may be located on either the top of the sign,

the bottom of the sign, or an adjacent support. The lighting engineer should evaluate the following considerations before selecting the mounting arrangement that is to be utilized.

- The luminaire housing should not obstruct the view of the sign message.
- The reflected light should not reduce the visual performance of the sign message.
- Contribution to sky-glow should be limited as much as is practicable.
- The spill light should not be directed into the eyes of motorists.
- The luminaire mounting arrangement should not create maintenance problems.

Locating the lighting units on the bottom of the sign, if practical, is generally the preferred alternative for the following reasons.

- The reflected light is less likely to reduce the visual performance of the sign message or produce reflected glare into the eyes of motorists.
- The lighting units do not produce daytime shadows and reflections from the sun on the face of the sign.
- The lighting units are easier to access for maintenance.
- The lighting units may collect snow and dirt but may also be cleaned by rain.
- The face of the sign may only partially shield the light that spills onto traffic approaching from the rear of the sign. However, a separate shielding mechanism that will minimize this effect can be provided on the lighting units.
- Excess sky-glow or light pollution may be inherent. However, a separate shielding mechanism can be provided on the lighting units or optical control equipment can be utilized in order to minimize these effects.
- The lighting units may obstruct the view of the sign message at some viewing angles. However, proper placement and installation of the lighting units can minimize this problem.

In addition to the above considerations, the lighting engineer should also verify that the adjacent roadway lighting system, if present, does not adversely impact the lighting levels on the face of the sign or physically block the face of the sign. The adjacent roadway lighting system is not intended to perform the lighting of the adjacent overhead retroreflective signs.

10.5 REFERENCES

1. *Manual on Uniform Traffic Control Devices* (MUTCD). Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2009.
2. Carlson, P. J., B. K. Brimley, J. Miles, S. Chrysler, R. B. Gibbons, and T. Terry. *NCHRP Report 828: Guidelines for Nighttime Visibility of Overhead Signs*. Transportation Research Board, Washington, DC, 2016.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI-NA	Airports Council International—North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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