Minimum Retroreflectivity Levels for Overhead Guide Signs and Street-Name Signs

PUBLICATION NO. FHWA-RD-03-082

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
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Foreword

Report FHWA-RD-03-082 presents the results of a study that investigated the nighttime visibility needs of drivers for viewing overhead guide signs and street name signs. This effort reviewed past research and current practices to design a series of field tests. Field experiments were conducted with drivers 55 years and older in which the headlight illumination was incrementally increased until they could correctly read the messages on the overhead signs. The results from these experiments provided the data needed to determine threshold levels of demand luminance necessary to meet driver needs. The researchers back calculated minimum sign retroreflectivity levels using information about the supply luminance associated with the various retroreflective sign materials and amounts of illumination provided. The research indicated that some combinations of sign materials were inadequate to meet driver needs given changes in the headlight design, legibility requirements, viewing position from larger vehicles, and other factors. Tables of recommended minimum retroreflectivity levels for overhead guide and street name signs were formulated from the data gathered in the research. These tables cover a subset of signs that had not been addressed in previous research.

It is important to note that this research was initially completed before the need for updates to the other previously developed tables of minimum levels of traffic sign retroreflectivity became apparent. Subsequently, another research effort was undertaken to determine the factors needing updating and to generate new tables. Following that updating effort, the contractor for this project reanalyzed the minimum levels for overhead guide and street name signs using updated inputs for vehicle dimensions, headlight characteristics, driver age, material performance, legibility, and other factors. The revised set of the tables for minimum retroreflectivity for overhead guide and street name signs is provided in Chapter 8 of this report.

Sufficient copies of this report have been produced to allow distribution to FHWA division offices, resources centers and each state highway agency. Copies can be requested from the FHWA Office of Safety or the Office of Safety R&D. In addition, this report is available on-line through the FHWA electronic library at http://www.tfhrc.gov/safety/.

Michael Trentacoste
Director, Office of Safety R&D

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-03-082		

4. Title and Subtitle
MINIMUM RETROREFLECTIVITY LEVELS FOR OVERHEAD GUIDE SIGNS AND STREET-NAME SIGNS

5. Report Date
December 2003

6. Performing Organization Code

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8. Performing Organization Report No.

9. Performing Organization Name and Address
Texas Transportation Institute
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTFH61-99-Q-00053

12. Sponsoring Agency Name and Address
Office of Safety Research and Development
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101-2296

13. Type of Report and Period Covered
Final Report
February 2000-June 2001

14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officer's Technical Representative (COTR): Ken Opiela, Office of Safety Research and Development, HRDS-05

16. Abstract
In 1993, the Federal Highway Administration (FHWA) published research recommendations for minimum retroreflectivity (MR) levels for traffic signs. The recommendations included overhead signs, but not street-name signs. In revisions to the recommended MR levels in 1998, the overhead signs were removed because of unresolved headlamp issues. Since then, there have been changes in U.S. headlamp specifications that prompted FHWA to initiate research to address MR levels for overhead guide signs and, in order to fill a somewhat related void, street-name signs. The intent of the research was to develop recommendations compatible with the 1998 revised recommendations. This report describes the research activities and consequent findings related to the development of MR levels for overhead guide signs and street-name signs.

The research included a literature review of the pertinent studies and available photometric models. This review initiated the development of an analytical model to develop MR for overhead guide signs and street-name signs. Using the findings from the literature review and a state-of-the-practice survey, an initial set of MR levels was developed. After an analysis of the initial recommendations, a field investigation was initiated to determine the minimum luminance needed to read overhead guide signs and street-name signs. Special emphasis was devoted to accommodating older drivers. Once the minimum luminance values were determined, the analytical model was used to develop a set of recommendations. The sensitivity of key factors was studied to determine the most appropriate conditions under which to establish MR levels. Once these analyses were completed and the values of the key factors were established, the MR model was executed for the final runs.

The initial results are summarized in three tables: one for overhead guide signs, one for post-mounted street-name signs, and another for overhead (mast-arm-mounted or span-wire-mounted) street-name signs. However, these tables were superseded by additional research conducted after this project was terminated. This additional research is summarized and the final recommendations, which were consolidated into one table of MR levels for all white-on-green signs, are presented.

17. Key Words
Traffic control devices, overhead signs, street-name signs, retroreflectivity, visibility, luminance.

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION

The development of minimum inservice levels of retroreflectivity (end-of-service-life values) for signs is a critical step in the evolution of providing a safe and efficient road transportation system. Recent activity in this arena began in 1984, when the Center for Auto Safety petitioned the Federal Highway Administration (FHWA) to establish retroreflectivity standards for signs and markings. In 1993, Congress required the Secretary of Transportation to revise the *Manual on Uniform Traffic Control Devices* (MUTCD) to include "a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs which apply to all roads open to public travel."(1) Because of the work in progress, FHWA was able to develop suggested minimum retroreflectivity (MR) levels for signs in a relatively short time. Initial recommendations included overhead signs, but were later removed because of many unresolved issues with vehicle headlamp performance specifications and the difficulty of measuring overhead sign retroreflectivity.(2-3) Since the initial recommendations were made, vehicle headlamp performance specifications have been revised.(4) This research project was conducted to determine MR levels for overhead guide signs and street-name signs.

PROJECT OVERVIEW

As a direct result of the congressional mandate for minimum levels of retroreflectivity and the recently revised vehicle headlamp performance specifications, FHWA identified the need to conduct research to determine MR levels for overhead guide signs and street-name signs. The research project was awarded to the Texas Transportation Institute (TTI) in late 1999 and was started in mid-February 2000.

Goal

The purpose of the research was to develop scientifically based minimum levels of retroreflectivity for overhead guide signs and street-name signs.

Research Activities

The research project was a 15-month effort. The research activities are described below:

- **First Panel Meeting:** The initial meeting between the researchers and the Contracting Officer's Technical Representative (COTR) took place on January 12, 2000, during the Transportation Research Board's 79th Annual Meeting in Washington, DC. This meeting was held approximately 1 month before the project was officially started. In this meeting, the researchers and the COTR discussed:
  - Project objectives and the general plan for meeting the objectives.
  - Key findings from previous research.
  - FHWA's concerns and experiences.
  - Activities in which the researchers would require FHWA assistance.
  - Issues and/or factors that needed to be addressed in the research, including minimum luminance, implementation of MR levels, and headlamps.
- **Literature Review:** The research team reviewed a significant amount of previous research to assess the state-of-the-art in sign legibility and to identify experimental

procedures that might have application to the research. Chapter 2 describes the results of the literature review.

- **Current Practices Survey:** One of the initial efforts of the project was a review of traffic engineering manuals and a survey of State and local practices regarding overhead guide signs and street-name signs. Chapter 3 describes these activities and summarizes the results. Appendix A shows the survey and the detailed results.

- **Second Panel Meeting:** The second meeting took place on May 26, 2000, in College Station, TX. The meeting was held after the literature review and the current practices review were completed. This meeting included the researchers, the COTR, and FHWA engineer Greg Schertz. In this meeting, the group discussed:
    - How the findings of the literature review and current practices could be combined to develop initial recommendations for MR of overhead guide signs and street-name signs.
    - Advantages and disadvantages of using the photometric models available at that time.
    - Voids in the research that need to be addressed to complete the research.
    - Future research activities needed to satisfy the research objectives.

- **Development of TTI MR Model:** After the second panel meeting, the COTR and the researchers identified the need to develop an analytical model that can be used to determine MR levels. An overview of this model is explained in chapter 4. The details of the model are provided in appendix B.

- **Third Panel Meeting:** The third meeting took place in September 2000 at the Turner-Fairbank Highway Research Center (TFHRC). This meeting included the researchers, the COTR, and FHWA researcher Carl Andersen. The meeting was held after the researchers completed the work on the development of the analytical model. The results of the literature review and current practices review were used to develop initial MR recommendations for overhead and street-name signs. In this meeting, the group discussed:
    - Sensitivity of key modeling factors, such as headlamp luminous intensity profiles, distance, and speed.
    - Implications of the initial MR levels for overhead guide signs and street-name signs.
    - Initial recommendations for a field study to address the shortcomings of the data available through the literature review and current practices review.

- **Fourth Panel Meeting:** The fourth meeting between the researchers and the COTR took place in January 2001 at the National Committee on Uniform Traffic Control Devices (NCUTCD) meeting in Washington, DC. Like the previous meeting, Carl Andersen attended this meeting. The meeting was held after the researchers submitted their experimental design for the nighttime data collection to determine minimum luminance. In this meeting, the group discussed:
    - Dependent and independent factors to be considered in the study, including their limits.

- ◦ Anticipated timeframe for conducting the study.
  - ◦ Number and age of the subjects.
  - ◦ Procedure to be used.
  - ◦ Expected results, including how they will be used to enhance the initial recommendations (developed using findings from the literature review and current practices review).

- **Field Evaluation:** During March 2001, the researchers conducted a nighttime field study to determine the minimum luminance needed to read overhead guide signs and street-name signs. The study was designed to fill the voids found through the literature review. The signs were designed based on the current practices findings. Chapter 5 describes the field evaluation and subsequent findings.

- **Data Analysis:** Once the field studies were completed, the researchers conducted sensitivity analyses of key factors to be used for the final model runs. Factors included in the analyses were minimum luminance as a function of distance, headlamp luminous intensity profiles, driver accommodation level, sign position, retroreflective sheeting type, speed, and vehicle type. With the sensitivity analyses completed, the researchers developed their recommendations for MR levels for overhead and street-name signs. Chapter 6 describes the analyses and findings.

- **Fifth Panel Meeting:** In May 2001, the researchers presented their findings to the COTR and other FHWA personnel at TFHRC. The presentation included a summary of the research activities and findings, including final recommendations and identified areas for future research.

Chapter 7 provides the initial recommendations made as a result of the research described in the report. However, additional research was conducted that resulted in revised recommendations. This additional research was not part of this project; however, it directly affects the results. Therefore, chapter 8 was included to describe the revisions and the subsequent recommendations for overhead guide signs and street-name signs. Chapter 8 also provides a list of future research topics.

STUDY ISSUES

This section briefly describes the major study issues that impact MR levels.

Visibility Factors

The number of factors related to highway sign visibility can be overwhelming. The factors identified through the literature review can be categorized into four main headings as shown in table 1. Under each category are the corresponding design elements.

Table 1. Legibility Factors

Sign	Vehicle	Driver	Environment/Road

• Position
  o Ground-mounted
    - Right
    - Left
    - Lateral offset
  o Overhead
    - Height
    - Lane positioning
    - Tilt
• Size
• Shape
• Color
  o Background
  o Legend
• Legend
  o Symbol
  o Alphabet
    - Font
    - Size
    - Stroke width
    - Letter spacing
    - Line spacing
• Lighting
• Retroreflective material
	• Type
	  o Sports car
	  o Passenger car
	  o Pickup truck/SUV
	  o 18-wheeler
	• Headlamp
	  o Type
	    - Halogen-tungsten
	    - High-intensity discharge
	  o Illumination distr.
	  o Aim
	  o Cleanliness
	• Windshield
	  o Transmissivity
	  o Cleanliness
	• Constant voltage
		• Visual characteristics
		  o Acuity
		  o Contrast sensitivity
		  o Color deficiency
		  o Other
		• Awareness
		• Mental load
		• Alcohol/drugs
			• Atmospheric conditions
			  o Rain
			  o Fog
			  o Haze
			  o Other
			• Background complexity
			  o Urban
			    - Residential
			    - School
			    - Commercial
			    - Industrial
			  o Rural
			• Time of day
			  o Day
			  o Dusk
			  o Night
			• Horizontal alignment
			• Vertical alignment
			• Sight distance
			• Pavement reflectance

While each of the design elements listed above affect visibility on some level, not every element has the same effect and not all factors act independently. Given the limited time and resources associated with this project, it was not reasonable to explore each of the elements listed above. Furthermore, all of these elements can be reduced to three main components that impact visibility: the amount of light reaching the sign (illuminance), the efficiency of the retroreflective material (retroreflectivity), and the returned light that makes the sign appear bright (luminance). These three main components can be combined with a variety of other issues, such as the visual ability of the driver and the vehicle type, to determine the required luminance for the traffic signs. The luminance and contrast determine the legibility and recognition of highway signs. Therefore, these issues were explored using past research findings to help define and quantify those factors that are most influential in overhead and street-name sign visibility.

Materials

Traffic signs use retroreflective sheeting to help ensure that the signs communicate the same message day and night. Retroreflectivity redirects vehicle headlamp illuminance back toward the driver. There have been substantial improvements in retroreflective technology since it was first introduced using large glass beads called "cat's eyes." The currently available retroreflective technology is defined and described in American Society for Testing and Materials (ASTM) D4956.[(5)] As of 2001, ASTM has defined seven types of retroreflective sheeting approved for traffic signs. These types of sheeting can be broadly classified into two groups: one that uses microsized glass beads to retroreflect headlamp illuminance and another that uses microsized prisms to retroreflect the light. Table 2 includes a list of the currently defined retroreflective sheeting available for permanent traffic signs (according to ASTM D4956). This report uses the ASTM-type designation when referring to specific sheeting types.

Table 2. Types of Retroreflective Sheeting

Type Designation	Description
I	Medium-high-intensity retroreflective sheeting, sometimes referred to as "engineering grade," and typically enclosed-lens glass-bead sheeting. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
II	Medium-high-intensity retroreflective sheeting, sometimes referred to as "super engineer grade," and typically enclosed-lens glass-bead sheeting. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
III	High-intensity retroreflective sheeting that is typically encapsulated glass-bead retroreflective material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
IV	High-intensity retroreflective sheeting. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
VII	Super-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at long and medium road distances as determined by the R_A values at 0.1° and 0.2° observation angles. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
VIII	Super-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at long and medium road distances as determined by the R_A values at 0.1° and 0.2° observation angles. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
IX	Very-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at short road distances as determined by the R_A values at a 1.0° observation angle. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.

Vehicle Headlamps

As mentioned, in the mid-1990s, one of FHWA's greatest concerns regarding the initially proposed MR levels for overhead signs was the global harmonization efforts related to headlamp specifications. In 1997, the Federal Motor Vehicle Safety Standards (FMVSS) related to headlamp specifications for vehicles sold in the United States were revised to include harmonized headlamp specifications. The research effort used currently available headlamp profiles as identified in the literature review and recently obtained illuminance data from the roadway to identify the headlamp profile that best replicates those currently found on the roadway. The advantage of this approach is that real-world factors, such as headlamp misalignment, headlamp cleanliness, and variations in available voltage, are considered, rather than using an exclusively theoretically based headlamp profile.

Driver

In recent years, there has been a concentrated effort to accommodate the needs of older drivers. This is especially critical for the establishment of MR levels since a driver's vision generally degrades with age, thus requiring brighter signs. The research conducted as part of this study focused on accommodating the needs of older nighttime drivers.

Measuring Retroreflectivity

The establishment of minimum levels of retroreflectivity for overhead and street-name signs is only one part of the process of ensuring that these signs have adequate nighttime visibility. Once minimum levels are developed, agencies need to be able to measure their signs and compare the measurements to the minimums. This is a challenge for both types of signs as discussed below.

Overhead Signs

Because of the position of overhead signs, the measurement of the retroreflectivity of these signs introduces a significant challenge. Except for the FHWA mobile retroreflectometer and the LaserTech Impulse® retroreflectometer, measurement of overhead sign retroreflectivity requires contact with the specific part of the sign being measured. Both of the noncontact instruments require data manipulation to provide retroreflectivity measurements representing the standard measurement geometry of 0.2º and -4.0º. As a result, current measurements of overhead sign retroreflectivity require lane closures and a worker on a sign bridge or in a bucket truck.

In addition to the difficulty of measuring overhead sign retroreflectivity, the large size of these signs requires a substantial number of measurements to provide a representative sample of the overall sign retroreflectivity. The current ASTM procedure for measuring sign retroreflectivity with a portable sign retroreflectometer (ASTM E1709) states that four measurements should be made. Assuming that this applies to a typical roadside sign, this results in a general average of about one reading for every 0.1 to 0.2 square meters (m^2) of sign area. If a similar proportion were to be used on overhead signs (using an assumed sign size of 1x1 m), approximately 50 measurements of the sign background would be needed to get a reasonable representation of the overall sign retroreflectivity. Furthermore, with large guide signs, the legend also needs to be measured. There are no guidelines that indicate whether every letter in a sign needs to be measured, nor is there guidance on the number of measurements needed per sign. There are still a large number of signs in the field with button copy, and there are no field devices capable of accurately measuring the retroreflectivity of button copy. When the background and legend are both considered, the total number of retroreflectivity measurements could be 50 to 100 measurements for a typical sign.

These factors indicate that numerically based MR levels may not be an effective means of ensuring adequate retroreflectivity of overhead signs. Other procedures may also need to be developed for the minimum numbers to have any practical value. Alternative procedures should be based on the numerical minimums, but should not require actual retroreflectivity measurements. Examples of alternative procedures include minimum visibility distances or using a tracking schedule combined with sheeting-life curves and MR levels.

Street-Name Signs

Just as with overhead signs, there are some practical limitations on the ability to measure the retroreflectivity of street-name signs. Because of the height of street-name signs (i.e., above arm's reach), a pole-mounted retroreflectometer will typically be needed. However, street-name signs typically have crowded legends, leaving little open space for measuring the retroreflectivity of the background, especially if the positioning of the retroreflectometer is accomplished using a 2-meter (m) pole. The letter height and stroke width of street-name signs combine to provide a letter stroke that is too narrow for most retroreflectometers to measure without also measuring some of the background (green) retroreflectivity. Even if the legend retroreflectivity is to be measured, once again, accurately positioning the retroreflectometer on the end of a pole is a challenge. Finally, many street-name sign blanks are ribbed, with a thick section at the top and bottom of the blank to add rigidity. If the retroreflectometer is using a faceplate to help provide a flush and perpendicular position, then the unit may not be able to make proper contact with the face of the sign. Not using the faceplate may reduce the accuracy of measurements because of lack of proper alignment with the sign face.

These factors indicate that measuring the retroreflectivity of both the legend and the background of street-name signs may not be a practical undertaking. Again, alternative procedures may be needed, such as a minimum visibility distance or a maximum sign age.

From this point hereafter, the units of this report are presented using the common terminology among practicing traffic engineers and visibility experts. The photometric terms are expressed in SI units, as that is the standard in the industry. Sign size, letter height, and other sign-related dimensions (including legibility index) are expressed in English units because that is still the preferred practice by the transportation profession. Table 3 can be used to supplement the conversion table shown on page ii.

Table 3. Sign Dimension Conversions

Sign Size		**Letter Height**	
inch (in)	millimeter (mm)	inch (in)	millimeter (mm)
18	450	4	100
24	600	6	150
30	750	8	200
36	900	10	250
48	1200	12	300
		14	350
		16	400

CHAPTER 2. PREVIOUS RESEARCH

There have been numerous studies related to many different aspects of overhead guide sign visibility, including a fair number of literature reviews summarizing previous research. Rather than repeating work that has already been performed, this literature review focused on research performed within the last 15 years. A particularly thorough review of the early research was published in 1984 and is used as a starting point for this review. However, where appropriate, earlier landmark research findings have also been referenced.

OVERHEAD GUIDE SIGNING RESEARCH

In 1984, Gordon summarized the nighttime visibility research performed on overhead signing.(6) Gordon reviewed more than 100 research studies concerned with various aspects of overhead guide sign effectiveness.

The results of Gordon's review were compiled and compared against recommendations put forth through a Caltrans (California Department of Transportation) experiment of nonreflective guide sign backgrounds without lighting. (FHWA granted permission for Caltrans to conduct this study in light of the noncompliance with the then-current 1978 MUTCD guidelines for overhead guide signs.) The Caltrans study included 43 porcelain enamel overhead guide signs with button-copy retroreflectors used in the legends and borders. Fourteen observers, mostly civil engineers, ages 32 to 60, were used to evaluate the detection and legibility of the signs while traveling at speeds of 60 miles per hour (mph). The Caltrans team evaluated five aspects of the experimental guide signs: (1) detection, (2) legibility, (3) impact of roadway geometry, (4) impact of background lighting, and (5) color coding.

Recommendations from the Caltrans review team included maintaining lighting on freeway off-ramps and on lane-assignment signs calling for immediate lane changes. It was also recommended that sign lighting be used where fog and dew are frequent occurrences.

The remainder of the literature reviewed by Gordon was compared to the Caltrans findings and recommendations. Gordon reviewed sign detectability and legibility, the effect of high- and low-beam headlamp patterns, traffic stream, angular position of overhead signing, sign maintenance, roadway geometry, and other factors. The relevant findings include (findings from Gordon unless otherwise referenced):

- A white legend of 3.4 candelas per square meter (cd/m^2) should be taken as the lower limit of permitted sign luminance. Below this level, legibility rapidly decreases. Using this criterion, it was shown that illuminated button-copy legends on opaque backgrounds were adequate. However, nonilluminated signs, viewed with low-beam headlamps, were not always adequate. Legends of type III sheeting were considered marginal in that they only provided luminance values of 3.4 cd/m^2 or greater for distances of 450 to 900 ft. There was no distance where type I sheeting provided adequate luminance levels. Button copy was only sufficient at 450 to 600 ft.(7)

- While 3.4 cd/m^2 should be considered a minimum, 340 cd/m^2 should be the upper limit. Optimal legend luminance under most highway conditions is between 34 and 102 cd/m^2. A dark surround permits the use of lower legend luminance.[1]
- Under high ambient illumination conditions, legend/background luminance ratios as low as 4:1 will provide satisfactory visibility. Under low ambient illumination conditions, where the sign background is almost black, the specific legend luminance is more meaningful than one of contrast.
- Overhead guide signs viewed under low-beam headlamp illumination and wet road conditions provide 3.5 to 5.0 times the amount of luminance as compared to dry conditions.
- Drivers tend to use low-beam headlamps under most driving conditions. Traffic volumes have to be as light as 30 vehicles per hour before high-beam use increases significantly. However, because traffic volumes on roadways with overhead guide signs are not typically this low, the sign is usually illuminated by more than one set of headlamps and can increase the luminance returned to any one vehicle approaching the sign. As a result of this common occurrence, some researchers have recommenced studying overhead guide sign performance under high-beam headlamp illumination.(7) This thought is believed to counter the condition of research where there is usually one test vehicle compared to the field where multiple vehicles are usually illuminating guide signs.
- Some research has shown that the optimal sign position should be defined as within a 4° vertical and 6° horizontal displacement. However, other research shows that vertical displacements forward or back as much as 5 percent do not affect the luminance enough to have an impact on legibility.(8)
- Under most normal highway conditions, nonilluminated button-copy signs with opaque backgrounds will function satisfactorily if properly maintained, despite the absence of the color-coding redundancy feature that is built into other sign designs. However, auxiliary illumination may be required on curved roads, areas of high and spotted illumination, conditions of frequent fog and dew, and at action situations such as at highway exits.
- Color can be seen only at a luminance above 0.043 cd/m^2 and then just barely. Other research, subsequently documented, reports substantially higher luminance levels for color recognition.

In 1989, Stein et al., reported nighttime performance of overhead guide signs constructed from button copy and retroreflective sheeting on opaque and retroreflective backgrounds.(9-10) The project was a planned followup to Gordon's literature review and included:

- Investigation of then-current signing practices throughout the United States.
- Development of a set of in-use luminance values for guide sign materials.
- Development of life-cycle costs for signing material available then.
- Determination of driver response characteristics for these overhead guide sign systems.(6)

[1]Reported findings in foot-lamberts (ft-L) were converted to cd/m^2 (1 ft-L = 3.426 cd/m^2).

Legend and background luminance values were recorded for a variety of overhead guide signs in four different regions of the United States: Virginia, New Mexico, and Southern and Northern California. The findings suggest that regional differences do not exist, but that background complexity (defined as low, cluttered, distracting, and high) does have an impact on overhead sign visibility. The purpose of this effort was to establish a range of luminance levels representing real-world conditions to be used in a laboratory study. Unfortunately, the data showed little difference between sign material or location. There were many confounding factors present when the data were collected that perhaps explain this lack of difference between material types and location. For instance, the data were measured from the shoulder, adding complexity in that the normal viewing angles were not used; traffic flow from site to site was different; atmospheric conditions were not the same; and sign installation requirements varied from site to site. An example is the New Mexico practice of installing overhead signs at a 5º tilt, while other locations used a 0º tilt. In support of the lack of difference, other researchers have attempted to do the same type of study and have ended up with the same results—no differences between material types.[(11-13)]

Stein et al., also tested new materials at the 3M™ test track in St. Paul, MN. The types of materials that were tested are listed below:

- Type III sheeting (white and green).
- Type I sheeting (white and green).
- Prismatic lens sheeting, green (two earlier versions of the prismatic materials available now).
- Prismatic lens sheeting, white (two earlier versions of the prismatic materials available now).
- Type III sheeting on a 12-year-old sign (white and green).
- Porcelain sign material (nonreflective).
- Button-copy legend.
- Reference light source.

Luminance measurements were taken twice, once with standard U.S. headlamps (200-millimeter (mm) sealed halogen beams) and again with standard European headlamps (165-mm H-4 halogen low beams). Of all the materials tested, button copy was the brightest. Type III sheeting was brighter than type I sheeting, which was brighter than the porcelain sign material. From the data reported, and assuming a minimum legend luminance of 3.4 cd/m^2 for legibility, the new type III sheeting performed adequately from 1500 to 500 ft; however, at 250 ft, the luminance fell to about 1.5 cd/m^2. Interestingly, the 12-year-old type III sheeting performed slightly better than the new type III sheeting for all distances, although it was still below the assumed 3.4-cd/m^2 threshold at 250 ft. The type I sheeting never reached a value of 3.4 cd/m^2. The maximum luminance for type I sheeting occurred at 750 ft, with a value of 2.7 cd/m^2. The European headlamps provided luminance values far below those reported from the standard U.S. headlamps. At distances of 1500, 1000, and 500 ft, the luminance provided by the European headlamps was 2.0, 3.0, and 5.5 percent of that provided by the U.S. headlamps.

The researchers also conducted a laboratory study to explore conspicuity issues. This study consisted of a static and a dynamic element. The static element included slide presentations of 120 different stimuli. The main factors under investigation were the impact of a driver's age, sign type, distance, color and luminance, and the level of obscurity of the sign. The same independent variables were used in the dynamic study. The following results were found to be statistically significant:

- Green signs provide greater detection distances than black or gray signs.
- As signs become brighter, detection distances increase.
- Increasing the amount of obscurity of a sign decreases its ability to be detected.
- More complex backgrounds compete with the signs for the driver's attention.
- As the driver's age increases, detection distance decreases.

The practical findings that were derived from the statistical results presented above include:

- The differences between sign colors, luminance levels, and obscurity were found to be within one standard deviation. In other words, there is no practical difference between any of these findings.
- The older driver is not helped by any particular sign configuration. When reaction distance was compared for the color/luminance variable, the difference between the best and worst configurations was about 60 ft. Even at 45 mph, the best configuration allows the driver less than 1 second (s) of additional detection time.

In 1986, Mace et al., provided an excellent literature summary based on the determination of minimum brightness standards for sign legibility.(14) The findings related to minimum luminance requirements for legibility (MLRL) for overhead signs were:

- MLRL increase as the ratio of letter stroke width to letter height decreases.
- MLRL increase as the level of internal contrast decreases.
- Published data are inconsistent regarding the effects of sign luminance and ambient luminance.
- MLRL are not influenced by glare, unless the glare source is very bright and immediately adjacent to the sign.
- MLRL increase with the age of the observer.

In 1994, Mace performed another study that included research on guide signs.(15) He concluded that the driver's age had the greatest impact on conspicuity and legibility. Other factors that were determined to be significant were retroreflectivity, letter series, and letter height. For high-contrast signs, Mace found that a reduced stroke width improved legibility. Using letter spacing less than the standard spacing significantly reduced legibility.

Material-Based Research for Overhead Signs

One of the first field research efforts that documented different material types and their effect on legibility was conducted and published in 1966.(16) Using college-age subjects and 16-inch uppercase and 12-inch lowercase letters, the researchers evaluated the following six combinations of overhead guide sign material:

- Button copy on porcelain enamel background.
- Button copy on exposed-lens reflective background.
- “Signal” letters on reflective sheeting background.
- “Signal” letters on exposed-lens reflective background.
- Cutout reflective letters on reflective sheeting background.
- Internally illuminated sign.

Legibility distances greater than 70 ft/inch of letter height were obtained for all combinations except the cutout legend and the internally illuminated sign. The researchers concluded that satisfactory legibility might be achieved under many conditions without the use of overhead sign lighting fixtures. However, this finding is not surprising since it is based exclusively on the results from younger drivers.

Another study of signing materials was conducted 4 years later in 1970.(17) This study included a multidisciplinary team of six individuals observing overhead signs on various routes in various States. The recommendations stated that all overhead signs should be illuminated. However, at one location, the team observed an overhead sign with type III legend and background (type III sheeting was just introduced in the early 1970s). It was noted that this sign provided adequate visibility with low-beam headlamps. The researchers recommended additional research based on this observation.

Consequently, in 1976, the same researchers performed a study of the need for sign illumination when type III sheeting was used for the legend and background of overhead guide signs.(18) The researchers used previous evaluation techniques established by Forbes et al.(19-20) The study included three young subjects and two signs (with 16-inch letters). The first sign was externally lit and fabricated with button-copy legend and type I background. The second sign was unlit and fabricated with type III legend and background. The researchers evaluated sign height, angle of tilt, and approach speed.

The findings indicated that for the unlit type III on type III overhead guide sign, mounting height (from 18.5 to 22.5 ft), angle of tilt (from -5.0 to +5.0 degrees), and vehicle speed (from 35 to 55 mi/h) do not significantly contribute to differences in legibility distances. The average legibility distance for the unlit type III on type III sign was 19 percent less with low beams and 5 percent greater with high beams. The researchers concluded that unlit type III on type III overhead guide signs can be effectively used when background brightness is not excessive and when the minimum direct line of sight is at least 1500 ft.

In support of this conclusion, the Louisiana Department of Highways issued a directive that overhead signs constructed with type III on type III sheeting should not be externally illuminated. This decision was reached after a field test period of more than 3 years.(18)

Robertson conducted two research efforts directed at guide sign construction as it relates to retroreflective sheeting decisions.(21-22) At six sites, he compared two types of signs: one with illuminated type I sheeting and the other with nonilluminated type III sheeting. The luminance of the unlit type III sheeting was inferior to that of the illuminated type I sign when the signs were viewed from a single vehicle with low beams. However, Robertson believed that an individual vehicle was the atypical case. He recommended that external lighting be eliminated when overhead guide signs are constructed of type III sheeting and when the approach to the sign is straight. He suggested that overhead illumination be used on curves or where the lone driver is required to use low beams (e.g., narrow median).

The additional effectiveness of type III sheeting is also reported in Gordon's review of the literature. Two Dutch studies recommended type III sheeting for unlit overhead signs (except on curved sites) despite a decreased performance (when compared to illuminated signs with type I sheeting).[11-12] Additionally, the Dutch studies indicate that the decreased legibility of unlit signs with type III sheeting can be offset by increasing the letter height by 20 percent.

Another sheeting study summarized by Gordon was conducted for the Ohio Department of Transportation (DOT). This study included combinations of button-copy and type III legends on nonreflective, type I, and type III backgrounds.[23] In all cases, the findings show that button copy outperformed reflective cutout letters. It was also determined that the choice of legend material was more critical that the background material. Under high levels of illumination, the nonreflective background performed the worst. No significant difference was found between the type I and type III sheeting at high levels of illumination. At low levels of illumination, no advantage was found through the use of reflective backgrounds.

In 1987, McNees and Jones studied legibility distances for unlit overhead guide signs.[24] Using existing signs and disregarding the signs' age, retroreflectivity, and visual complexity, they found the legibility indices of various combinations of unlit legend/background materials to be as follows:

- Button copy on type I (59 ft/inch).
- Button copy on type III (55 ft/inch).
- Type III on type III (52 ft/inch).
- Button copy on opaque (50 ft/inch).
- Type III on opaque (48 ft/inch).
- Button copy on type II (46 ft/inch).
- Type III on type II (44 ft/inch).
- Type III on type I (40 ft/inch).

Another effort published in 1987 demonstrated the effect of different material types using compiled headlamp low-beam patterns that represent those in use circa 1975.[25] The researchers used the retroreflective properties of type I, type III, and prismatic sheeting (not defined) on two different overhead sign positions (directly above the vehicle and 12 ft left of the centerline of the vehicle). Using an assumed minimum luminance of 3.4 cd/m^2, the data show that type I sheeting does not provide adequate luminance levels for either sign position. For the centered signs, type III and prismatic sheeting appear to be adequate. For the left-side overhead sign, the type III sheeting results are marginal, while the prismatic sheeting results are adequate. The authors used Sivak and Olson's 75th percentile value of 7.2 cd/m^2 as a criterion for inadequacy, admitting that this does not account for factors such as dirt, natural weathering, or the substitution of colors having lower retroreflectance values.[26] Using the 7.2 cd/m^2 criterion, only the prismatic sheeting produced adequate luminance values.

In 1993, Arizona DOT funded research in an attempt to determine MR requirements for signs on their State system.[(27)] Through an analysis of the literature and a survey of State policies, recommendations for the types of sheeting were made. For overhead signs, the recommendations included type III signs on freeways. The recommendations also included the use of type II signs where surround complexity is low and speeds are below 55 mi/h. When speeds are below 45 mi/h, the use of type I sheeting is recommended. It is unclear whether these recommendations are for the legend or the background or both.

STREET-NAME SIGNS

Compared to overhead signs, the research related to street-name signs is rather limited. Probably one of the earliest street-name sign research efforts was published in 1970.[(28)] Unfortunately, this research did not address the retroreflectivity of street-name signs. However, it did address color combinations and letter height. For example, the researchers determined that white-on-green street-name signs are the most appropriate colors in terms of satisfying drivers' needs. With respect to letter height, the researchers found that 6-inch letters are inappropriate for operating speeds of 35 mi/h or greater. When speeds are at this level, they recommend using advance street-name signs.

In 1992, the Institute for Transportation Engineers (ITE) summarized street-name sign practices in the United States and Canada.[(29)] A total of 638 questionnaires were sent out inquiring about details such as installation location, height, size of letters and panels, use of retroreflective sheeting, and color. While many of the results are listed and discussed, those pertaining to sheeting type are not. It is interesting to learn, however, that "most agencies are primarily concerned with traffic signing categories that are related to public safety. Street-name signing receives more casual attention."

The first retroreflective sheeting-based study was conducted in 1996.[(30)] The purpose was to compare legibility distance for street-name signs using types I, III, VII, and IX sheeting. Legibility distances were measured at three intersections in St. Paul, MN. The intersections were chosen to have varied background complexity.

The data were collected at night and with older drivers (nine males with an average age of 74 and nine females with an average age of 68). Street-names signs were placed on the departure side of the intersection and were randomly mounted on either the left or right side. Legibility distances, corrected for response times, were recorded as drivers approached the intersections and read the signs.

The findings show that the type VII and IX sheeting resulted in similar legibility distances. These distances were significantly greater than that for type III sheeting, which was significantly greater than that for type I sheeting. The findings also showed that the differences in sheeting type were more pronounced at intersections with greater background complexity.

A report on Toronto street-name signing was published in 1999 by Smiley.[(31)] The study was performed in the field with actual street-name signs. The study was focused on providing adequate conspicuity for detection in urban and suburban areas and adequate legibility for safe maneuvering. Consequently, various retroreflective materials and letter heights were evaluated. Subjects' responses were recorded as they drove predetermined test courses.

The recommendations included the use of 8-inch letters in urban areas and retroreflectorized signs. The type of material was not a primary focus of the study. However, it was reported that the signs were either weathered type III sheeting or new prismatic sheeting (the specific type is not reported). Informal analyses suggest that the prismatic sheeting appeared to perform better than the type III sheeting. The research also recommended the use of the Clearview™ uppercase/lowercase series for street-name signs, a practice that is developing momentum, but is still uncommon.

PERFORMANCE MEASURES

Retroreflectivity is not a measure that independently describes the legibility of highway signs; rather, it is a property of the sign material. Luminance is the photometric measurement that best relates to legibility. However, luminance is difficult to measure in the field and is dependent on illumination (from vehicle headlamps) and retroreflectivity (which is geometry-specific). If luminance were the basis for minimum end-of-service life for highway signs, a standard light source and specifically detailed measurement geometry would be required. Furthermore, the congressional mandate calls for retroreflectivity and not luminance.

Regardless, research has focused on both luminance and retroreflectivity recommendations for optimal and end-of-service lives for traffic signs. The following review includes both types of research related to overhead and street-name signs.

Alternative Performance Measures

Many studies have been conducted with a goal of determining minimum photometric requirements of traffic signs (usually in terms of luminance or retroreflectivity). In general, the relationship between legibility and luminance and/or retroreflectivity has been a function of surround complexity, luminance and/or retroreflectivity of the legend or background of the sign, or the internal contrast ratio between the legend and the background.

Research recommendations for MR levels are currently available for most signs. Minimum luminance values have also been proposed in the last couple of decades. However, the job of determining minimum photometric values that are commonly accepted is difficult for many reasons. First, there is an absence of conclusive performance data supporting minimal luminance standards. Second, there is no practical way of measuring overhead sign retroreflectivity or luminance in the field. One particularly difficult paradigm to consider is that luminance is needed for two distinct purposes: recognition and legibility. Extremely high values of luminance increase sign conspicuity, but degrade the legibility (this is not to say that the only factor related to conspicuity is luminance; in fact, many factors play a role). There are a host of other issues that make the job difficult.

According to Mace et al., there are at least three different approaches for determining minimum brightness levels.[14] The first is to use the 50-ft/inch rule that has been somewhat erroneously accepted as a standard; however, much of this standard is arbitrary. A second method is to provide enough luminance to accommodate 85 percent of the maximum nighttime legibility distance. A third method would be to identify the level of brightness needed for a given sign on the basis of the recognition or legibility distance requirement of that sign. Mace terms this the minimum required visibility distance (MRVD) and uses McGee's decision sight-distance model as a basis for MRVD. In other words, MRVD is computed using the distance needed by a driver to detect the sign, recognize or read its message, decide an appropriate course of action, initiate a control response, and complete the required maneuver. The luminance needed at the distance defined by MRVD has been used to derive the current research recommendations on MR levels.(2)

Minimum Levels

Probably the most referenced research effort related to recommended luminance requirements for highway signs was conducted by Sivak and Olson and published in 1985.(26) Computing the geometric mean of the findings of 18 previous research efforts, Sivak and Olson recommended optimal and minimal sign luminance values for low-beam U.S. and European headlamps. For optimal values, they used the crest of the derived inverted U-shaped luminance functions shown in the research findings. To determine the minimum sign luminance needed, Sivak and Olson used legibility indices of 50 and 40 ft/inch for younger and older drivers, respectively. Their recommended values are shown in table 4. The replacement values apply to signs in dark environments.

Table 4. Replacement Luminance Values

Replacement Level	Sign Luminance (cd/m^2)	Estimated Retroreflectivity ($cd/lx/m^2$)	
		U.S. Headlamp	European Headlamp
Optimal	75.0	3547	7252
85th percentile	16.8	798	1624
75th percentile	7.2	342	696
50th percentile	2.4	114	232
Note: These values apply to various types of signs, including the legends of fully reflectorized signs with background complexity luminance of up to 0.4 cd/m^2 and a maintained internal contrast ratio of 12:1.			

While the Sivak and Olson work included the review of 18 earlier studies, there are others that were not included in their effort and there have also been a few since. These studies are summarized below:

In 1983, Morales published work related to retroreflectivity requirements for STOP signs.(32) Morales developed a process where the overall retroreflectivity is the criterion and is dependent on the approach speed and the size of the sign. To determine the overall retroreflectivity, Morales recommended multiplying the red retroreflectivity value by 0.76 and the white retroreflectivity value by 0.24 and summing the two values. For a 30-inch STOP sign on roads with approach speeds greater than 50 mph, 40 candelas per lux per square meter ($cd/lx/m^2$) is recommended as the MR value. Other values are reported for different speeds and sizes of STOP signs.

In 1985, Mace et al., investigated visual complexity and its impact on sign luminance.(33) The researchers used warning signs at three different luminance levels to determine detection and recognition distances. The major finding was that increases in visual complexity had a detrimental impact on recognition and no effect on legibility; however, brightness improved both recognition and legibility. Based on their findings, the researchers recommended warning sign retroreflectivity values of 18 $cd/lx/m^2$ for low-complexity areas and 36 $cd/lx/m^2$ for high-complexity areas.

In another effort documented in 1985, Schmidt-Clausen reported on the minimum luminance levels needed for sufficient and optimal performance.(34) The investigation was carried out on a 1:10 scale model and was compared to those values found in real-world situations. The study showed that a legend luminance of 3.5 to 10 cd/m^2 is sufficient. Luminance values between 10 and 35 cd/m^2 are optimal. The maximum luminance was determined to be about 60 cd/m^2.

In 1989, Olson reported on a study that included recommendations for minimum reflectivity for signs in urban, suburban, and rural areas.(35) His study consisted of laboratory and field evaluations. The goal was to determine the minimum luminance levels to ensure that the signs are detected and identified at adequate distances under nighttime driving conditions.

Olson made recommendations for several sign types, including overhead signs. To make his overhead signing recommendations, Olson had to make several assumptions as listed below:

- Green is equal in conspicuity to yellow in the same family of materials.
- The effect of a white border and legend on conspicuity is minimal.
- A correction for driver expectancy does not apply for guide signs. It was assumed that drivers are searching for guide signs and their emergence into the driver's field of view is expected.
- Olson used small roadside signs in the field study. Using results from his laboratory study, he assumed that a 2.4 multiplier is needed to account for the increased conspicuity of overhead signing. In other words, controlling for all factors other than location and size, overhead signs are 2.4 times more conspicuous than roadside signs.
- In an attempt to quantify the amount of headlamp illumination reaching overhead signs, Olson used the results from a computer model.
- Because of the difficulty associated with the angularity in reading overhead signs at relatively close distances and the rapid decrease in available illumination from headlamps at close distances, Olson assumed that drivers had to complete the reading task before passing 100 ft in front of the sign.
- Using the results from previous research, Olson assumed a reading time of three words per second.(36)

Olson's recommended specific intensity per unit area (SIA)[2] values for overhead signing are included in table 5. The process used to derive these numbers is summarized below:

- The illumination reaching the overhead position was calculated using a simulation program. The resulting values were typically 10 percent of the roadside signs measured in the field study at the same distance.
- Using the 10-percent finding, overhead signs would need to be 10 times more efficient in terms of the amount of luminance developed with constant illumination levels.
- Olson assumed that the conspicuity of green was equal to yellow; however, the retroreflectivity of green is about 23 percent of yellow for the same family of material. This led to a reduction factor of 2.3.

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[2]SIA is expressed as candelas of reflected light per footcandle of incidental light per square foot of target ($cd/fc/ft^2$). It is equivalent to $cd/lx/m^2$.

- As mentioned, Olson determined that a correction factor for size was needed. Based on his laboratory studies, he determined that a factor of 2.4 would be most appropriate. This factor essentially cancels the 2.3 reduction factor for the decreased retroreflectivity of green as compared to yellow.
- Consequently, Olson used his derived values for 85th percentile yellow warning sign identification distances (without correction for driver expectancy) to determine the proposed values for overhead signing.

The latest research on minimum luminance levels for highway signs was performed on yellow warning signs with two-digit, 6-inch Series E numbers used for stimuli. The findings suggest that a sign luminance greater than 40.2 cd/m^2 is needed to obtain at least 85 percent correct identification of the signs tested for a viewing distance of 90 meters (m), which correspond to the 50 ft/inch of letter height commonly used as a legibility index among traffic engineers. The recommended value was based on the results from subjects at least 65 years old (average age was 69).

Table 5. Recommended SIA Values for Green Background Areas of Overhead Guide Signs

Area Complexity		**Low**			**Medium**			**High**		
Words on Sign		**3**	**6**	**9**	**3**	**6**	**9**	**3**	**6**	**9**
Speed (mph)	70	8	15	27	13	31	70	35	82	200
	60	8	13	22	12	25	54	32	70	150
	50	7	11	17	11	20	37	28	54	100
	40	7	9	13	10	15	25	25	40	68
	30	6	8	10	8	12	17	22	33	46
Overhead sign is assumed to be 20-ft high and centered over a roadway 24-ft wide.										

A significant effort related to minimum luminance was conducted in Australia in 1991. The aim of this study was twofold: (1) to measure the retroreflectivity of road signs in the field and hence to establish their rate of degradation and the major influences affecting degradation; and (2) to establish a minimum performance criterion of retroreflectivity–a terminal value–below which a sign would become ineffective. This was determined by a literature review, a nighttime survey carried out by knowledgeable traffic engineers, and a laboratory experiment. The life performance curves of traffic signs throughout Australia were determined. The minimum luminance required of a traffic sign at night has been found from laboratory experiments to be 3.2 cd/m^2 for all signs other than warning and regulatory signs, where a higher value of 9.7 cd/m^2 is needed. The optimal luminance was found to be 18 cd/m^2 for all signs other than warning and regulatory signs, which were 23 cd/m^2. The researchers also found an internal contrast of 3:1 to be acceptable for fully reflectorized signs.

The current Australian standard for overhead signing includes the following statement: "lighting for overhead signs is usually avoided by using type III sheeting for the legend and, in some cases, the background." In other words, the Australians have concluded that the use of type III sheeting is adequate for unlit overhead signing.

CONTRAST RATIO RESEARCH

For fully reflectorized signs with almost no background complexity (i.e., values up to 0.4 cd/m^2), Sivak and Olson recommended a contrast ratio of 12:1 for optimal performance. For a background complexity greater than 0.4 cd/m^2, the retroreflectivity needs and corresponding contrast ratio become dependent on the amount of background complexity. The values reported in their literature review range from 3:1 to 45:1. Other reported minimum contrast ratios for white-on-green signs have ranged from 3:1 to 7:1. The Australian research recommended a value of 3:1. However, their guidelines call for a minimum of 7:1, but prefer 10:1.

A 1988 report examining fully retroreflective signs suggest a contrast ratio range from 4:1 to 15:1 as being appropriate for most conditions. For example, if the luminance of the green background is 5 cd/m^2, the luminance of the legend should be at least 20 cd/m^2. Lower contrast ratios reduce legibility and may not be acceptable, and contrast ratios as high as 50:1 may reduce legibility, but could be quite adequate under certain conditions.

The initially proposed FHWA sign retroreflectivity values suggest a minimum contrast ratio of 4:1, but no recommendation for maximum contrast. This 4:1 minimum contrast ratio was initially recommended for both white-on-red and white-on-green signs.

For red-and-white signs that have been screened, the minimum contrast ratio may be more difficult to maintain than the absolute MR values. According to outdoor weathering data from Arizona, the 4:1 ratio can only be maintained for 4 to 5 years with ASTM type I and type II sheeting.

Like the red-and-white signs, the initially proposed FHWA minimum contrast ratio of 4:1 was also required for white-on-green signs. However, the screening issues of white-on-red signs are not prevalent with white-on-green signs since these signs are not typically screened. In fact, FHWA later revised the initially proposed MR values and minimum contrast ratios, dropping the minimum contrast ratio for white-on-green signs.

PROPOSED MINIMUM RETROREFLECTIVITY LEVELS

When the original set of research-developed MR levels were introduced in 1993, the levels were included for overhead signs (see tables 6 and 7).[(2)] However, in a 1998 report, the values were removed. The following explanation was provided: "Given the many unresolved issues with vehicle headlamp performance specifications and the difficulty in measuring overhead sign retroreflectivity, at this time, the FHWA is not recommending that minimum levels be established for overhead-mounted signs."[(3)]

An examination of the initially proposed overhead levels reveals that minimum values for type I sheeting are at a level that may exclude its use on high-speed roadways. Type II sheeting becomes marginal when degradation is considered.[(41-43)] Other more efficient sheeting appears to perform adequately in comparison to the initially proposed levels.

Table 6. MR for White Signs

Legend Color		Black and/or Red											
Background Color		**White**											
Traffic Speed		45 mi/h or greater						40 mi/h or less					
Sign Size		≥ 48 inches		30-36 inches		≤ 24 inches		≥ 48 inches		30-36 inches		≤ 24 inches	
Mounting	**Material Type**[2]	**MR Levels (cd/lx/m²)**[1]											
		Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]
Ground	I	20	25	35	35	50	45	15	20	20	25	35	30
	II	25	30	45	45	70	55	20	25	30	30	55	35
	III	30	40	60	55	90	70	25	30	45	40	75	45
	IV & VII	40	50	80	70	120	90	35	40	60	50	100	60
Overhead	I	No levels originally proposed						40	No levels[4]	50	No levels[4]	100	No levels[4]
	II							50		75		135	
	III							65		115		185	
	IV & VII							90		150		250	

[1]Measured at an entrance angle of -4.0º and an observation angle of 0.2º.
[2]Original levels proposed by FHWA (1993).(2)
[3]Revised levels proposed by FHWA (1998).(3)
[4]Overhead signs eliminated from the revised levels.

As mentioned, the initially proposed retroreflectivity levels included overhead signs. An investigation of the Computer Analysis of Retroreflectance of Traffic Signs (CARTS) software used to develop the initially proposed levels shows that three different overhead signs were included for evaluation. Because there is no standard guide sign design, three generic signs were developed for CARTS modeling purposes. The three signs have one, two, and three lines of text.

Table 7. MR Guidelines for Signs with Green Backgrounds

Traffic Speed	45 mph or greater				40 mph or less			
Color	White		Green		White		Green	
Sign Position	**MR Levels (cd/lx/m²)**[1]							
	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]	Orig.[2]	Rev.[3]
Ground-mounted	35	35	7	7	25	25	5	5
Overhead-mounted	110	n/a[4]	22	n/a[4]	80	n/a[4]	16	n/a[4]

[1]Measured at an entrance angle of -4.0º and an observation angle of 0.2º.
[2]Original levels proposed by FHWA (1993).(2)
[3]Revised levels proposed by FHWA (1998).(3)
[4]n/a = not applicable (overhead signs eliminated from the revised levels).

The MRVD submodel of the CARTS model is made up of five time-based components: detection, reading, decision, response, and maneuver. These components incorporate many assumptions and previously developed models. While these assumptions and models are generally accepted as reasonable, they were designed to accommodate the drivers' need for *roadside* signs and were not specifically designed for *overhead* signing. Consequently, the number of assumptions related to overhead signing is increased to make up for the submodel caveats. The results, after proceeding through the CARTS assumptions for overhead signing, oversimplify the driver's task related to detecting and reading overhead signs.

Once CARTS calculates the MRVD needed for the situation entered by the user, it uses another submodel, PCDETECT, to determine the needed luminance and, ultimately, the MR. PCDETECT has been used for years and its strengths and weaknesses are well documented in the literature. It is believed to be a reasonable model for the task at hand except that it is a "cyclops" model. In other words, the model assumes that there is one illumination source and that the observer's eye is in the same plane as the illumination source. This is of particular concern when the full retroreflection system is used or needed, such as when prismatic sheeting is being considered (as will be discussed later).

In summary, while the CARTS model has been built to accommodate many different factors and may work well for small roadside signs, the overhead guide sign assumptions raise questions that decrease confidence in the overhead guide sign MR levels derived from CARTS.

VEHICLE HEADLAMPS

Headlamp placement, illumination, and intensity are all significant factors in the development of MR for overhead signs. They are related to the geometry of the viewing system (which incorporates the signing and the driver's eye position), which can be somewhat sensitive depending on the sign location and the sheeting used to construct the sign. There are also significant changes underway in terms of headlamp standards that could potentially impact the amount of light available to be retroreflected.

Standards

FMVSS 108 provides the requirements for lighting equipment and its placement on motor vehicles. This standard requires that headlamps be no lower than 22 inches (1.83 ft) and no higher than 54 inches (4.5 ft). It also requires that the headlamps be located on either side of the vertical centerline of the vehicle as far apart as practicable.

Fambro et al., collected driver's eye height and headlamp height for several thousand vehicles around the United States. Table 8 summarizes their efforts:

Table 8. Headlamp and Driver's Eye Height

Descriptive Statistic	Passenger Cars		Multipurpose Vehicles[1]		Heavy Trucks[2]	
	Driver's Eye	Headlamp	Driver's Eye	Headlamp	Driver's Eye	Headlamp
Sample size	875	1318	629	992	163	337
Mean (ft)	3.77	2.13	4.86	2.76	8.03	3.68
Standard deviation (ft)	0.18	0.13	0.43	0.31	0.35	0.29
High value (ft)	4.67	3.11	6.67	3.85	9.24	4.43
Low value (ft)	3.13	1.77	3.45	1.87	6.90	3.00
Range (ft)	1.53	1.33	3.22	1.98	2.34	1.43
5th percentile	3.48	1.94	4.15	2.27	7.56	3.19
10th percentile	3.55	1.98	4.28	2.34	7.64	3.31
15th percentile	3.59	1.99	4.37	2.39	7.68	3.35

[1]Includes pickup trucks, sport utility vehicles (SUVs), minivans, and vans.
[2]Includes tractor-trailer combinations only.

The Society of Automotive Engineers (SAE) specification for headlamps was J579; however, this has been cancelled in lieu of an effort to harmonize headlamp design worldwide.[45] The SAE standards and FMVSS 108 apply to all vehicles registered in the United States, regardless of the design of the headlamp filament or light source. The output of two- and four-headlamp systems in the United States is limited by these specifications to the following:

- Type 2 or 2A Sealed Beam.
  - Upper beam (each lamp): 20,000 to 75,000 cd.
  - Lower beam (each lamp): 15,000 to 20,000 cd.
- Type 1 or 1A Sealed Beam.
  - Upper beam (each lamp): 18,000 to 60,000 cd.

The illumination levels are for the brightest spots within the light distribution. The output decreases quickly as the beam pattern diverges from the nominal hot spot. According to Bhise, headlamp illumination levels encountered on the highway can vary by as much as a factor of two.[(47)] Low voltages and the use of in-vehicle accessories decrease illumination levels. High charging rates and overvoltages increase illumination levels; however, this is to the detriment of lamp life.

The early efforts of headlamp design harmonization are summarized in SAE J1735.[(46)] The goal of the harmonization efforts is to develop specifications for one headlamp pattern that satisfies worldwide illumination criteria. In general terms, the U.S. pattern has traditionally provided substantially more light above the horizon than the European and Japanese patterns. However, attempts to harmonize these headlamp patterns have resulted in several compromises among all three patterns. For the U.S. pattern, one of the more significant compromises has been the decreased amount of light above the horizon. In fact, with the 1997 revision to FMVSS 108 allowing visually/optically-aimed (VOA) headlamps (including both visually/optically left-aimed (VOL) and visually/optically right-aimed (VOR) designs) and a global 1999 agreement concerning harmonized headlamps (a drastic compromise between the U.S. philosophy of maximizing visibility versus the European philosophy of minimizing glare), the amount of light above the horizon will continue to decrease. A recent report shows comparisons between the U.S. conventional headlamps and the VOL, VOR, and harmonized headlamps. For overhead signs at approximately 500 ft, there are consistent trends showing decreased illumination above the horizon. Compared to the conventional U.S. headlamps, the VOL headlamp reduces overhead illumination by 28 percent, the VOR headlamp by 18 percent, and the harmonized headlamp by 33 percent.

One of the more recent headlamp research projects was published in 1999 and sponsored by FHWA. Funded because of a concern about changes in the headlamp performance of the present U.S. vehicle fleet in terms of adequately illuminating traffic signs, especially overhead guide signs, the research was charged with determining the minimum luminance requirements needed for overhead guide signs and then establishing whether the current vehicle fleet was providing enough illumination to create such minimum luminance levels.

The literature review determined that the minimum threshold luminance value for the nighttime visibility of guide signs is about 3.2 cd/m^2, while the optimal values are on the order of 75 cd/m^2. A laboratory experiment conducted as part of the project found minimum luminance values to be about 13.2 cd/m^2 for white-on-green signs with a contrast ratio of 8:1.

Field experiments were conducted with 50 different vehicles having a variety of different headlamp types. Based on an assumed minimum luminance of 3.2 cd/m^2 for the legend of overhead signs, the researchers concluded that certain cars in the vehicle fleet do not provide adequate illumination unless type III or brighter sheeting is used. The following general conclusions are based on illumination data from more than 1500 headlamp distributions:

- Right-shoulder-mounted signs receive sufficient illumination (more than 99 percent satisfaction).
- Left-shoulder-mounted signs receive barely sufficient illumination (more than 90 percent).
- Overhead signs receive marginally sufficient illumination (only about 50 percent of the vehicles provided adequate illumination to meet the legibility criteria).

Other criteria established for headlamp adequacy include a viewing distance of 500 ft, straight and flat roadways, a minimum luminance of 3.2 cd/m^2, and new type III sheeting.

FINDINGS

The review of the literature yielded the following findings related to MR levels for overhead guide signs and street-names signs:

- **Overhead Signs**
    - Measuring the retroreflectivity of overhead signs is not as practical as measuring the retroreflectivity of roadside signs.
    - The majority of the recommendations for minimum luminance or retroreflectivity levels were developed through theoretical or laboratory research efforts.
    - The minimum luminance needed for legibility is about 2.5 to 3.5 cd/m^2 for the legend, although substantial variability exists in the research. These findings are for young drivers and low background complexity. Older drivers and more complex backgrounds may increase the minimum luminance needed for the legibility of overhead signs.
    - Type III sheeting viewed under low-beam conditions provides marginal luminance for the legibility of overhead signs.
    - Types I and II sheeting do not provide adequate luminance for legibility on overhead signs.
    - There appears to be some support for the need for a minimum internal contrast ratio. A minimum ratio of 3:1 or 4:1 has been recommended most frequently. For background areas with high visual complexity, the minimum internal contrast is critical; however, for backgrounds with low visual complexity, the legend luminance is more important.

- **Street-Name Signs**
    - The literature review has shown that minimum photometric requirements for street-name signs have not been researched or recommended. In fact, street-name signs are usually an afterthought or at least not a primary concern.
    - The legibility of street-name signs depends on many factors; however, the location is most important. Left-shoulder-mounted signs will require a significantly greater amount of retroreflectivity because of headlamp beam patterns.

- **Headlamps**
    - A substantial difference in headlamp beam patterns exists between U.S. and European standards.

Based on a random sample of 1500 vehicles passing under an underpass on an Interstate highway in Kansas, headlamps in use on today's roadways provide marginal illumination for overhead signs. Research shows that only about 50 percent of the 1500 randomly sampled vehicles provided enough illumination to satisfy the assumed criteria of a viewing distance of 500 ft, type III sheeting, and a minimum luminance of 3.2 cd/m^2.

CHAPTER 3. CURRENT PRACTICES

This chapter describes the activities and findings associated with a review of current State and local agency practices related to overhead guide signs and street-name signs. This task was conducted to establish a fundamental understanding of the design and application practices for those types of signs.

ACTIVITIES

The activities associated with this effort included a review of State and national versions of the MUTCD and a survey of State and local agency personnel. The results of the MUTCD reviews and the survey of transportation agencies are divided by subject into overhead signs and street-name signs.

Review of National and State MUTCDs

The MUTCD establishes the guiding principles for the use of traffic control devices, including overhead and street-name signs. When this review was conducted, the 1988 MUTCD was the current edition of the national manual. However, FHWA has since developed and published a new edition. In the first effort of this task, the researchers reviewed the applicable portions of the 1988 MUTCD and then proposed a Millennium Manual (it had not been published when this review occurred) to establish the basic principles for the design and placement of overhead signs and street-name signs.

The MUTCD issued by the Federal Government is referred to as the national MUTCD and it is intended to promote national uniformity of traffic control devices. However, because the Federal Government does not build and maintain roadways (with a few exceptions, such as forest roads), the Federal Government is not responsible for placing and maintaining traffic control devices. Federal and State laws require each State to adopt a traffic control device manual that meets or exceeds the requirements of the national manual. These State manuals can take one of three different forms: the national MUTCD, the national MUTCD with a State supplement, or a State manual. Almost half of the States have adopted the national MUTCD as a complete document without any changes. But more than half of the States have made changes to the national MUTCD through a State supplement or a State version of the MUTCD. Despite the existence of a national MUTCD, the fact that there are different versions of the MUTCD in the various States can lead to important differences from one part of the United States to another. Therefore, as part of this activity, the researchers also reviewed several State MUTCDs for information regarding the design of overhead and street-name signs. The State MUTCDs, or their equivalents, that were reviewed included:

- Caltrans *Traffic Manual*.[52]
- *Maryland Supplement to the Manual on Uniform Traffic Control Devices*.[53]
- *Minnesota Manual on Uniform Traffic Control Devices*.[54]
- PennDOT *Handbook of Approved Signs*.[55]
- *Texas Manual on Uniform Traffic Control Devices*.[56]

In some cases, the documents reviewed may not be completely up to date. This is a particular issue for the legend height in the street-name signs. The national MUTCD was revised in 1997 to increase the size of the legend. This may not be reflected in all of the State documents.

Survey of Practitioners

The MUTCD establishes minimum standards and guidelines, which are often exceeded in common practices. Furthermore, other than the courtroom, there is no enforcement mechanism for the MUTCD. Therefore, it is not uncommon for MUTCD principles to be violated (knowingly or unknowingly) in actual practice. In order to assess the differences between the MUTCD principles and actual practices, researchers conducted an e-mail survey of practitioners at State and local transportation agencies.

The survey was distributed to five State and five local agencies. Table 9 lists the nine agencies that responded. Figure 1 presents the questions submitted to the practitioners. The complete survey as sent to the practitioners is included in appendix A. Appendix A also contains the complete responses as received from the agencies for overhead signs and street-name signs. The results from the surveys are summarized and discussed in the sections addressing overhead signs and street-name signs.

Table 9. List of Transportation Agencies That Responded

Type of Agency	Agencies
State	California
	Florida
	Maryland
	Minnesota
	Pennsylvania
Local	City of Austin, TX
	City of Pueblo, CO
	Montgomery County, MD
	Pierce County, WA

OVERHEAD SIGNS
What size is the legend (typical letter height)?
What alphabet is used for the legend (Series E (Modified), other)?
What sheeting material(s) do you use for overhead signs (background and legend)?
Do you use a higher grade of sheeting for overhead signs compared to ground-mounted signs?
What is the typical height to the bottom of an overhead sign?
Do you have any agency guidelines for the design of overhead signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)

STREET-NAME SIGNS
What is your agency's policy for providing street-name signs (under what conditions are street-name signs provided and where are they located)?
How high are the street-name signs mounted?
What colors are your street-name signs?
What size is the standard blank/blade (do you use other sizes)?
What size is the legend?
What alphabet is used for the legend (Series D, Series E (Modified), other)?
What sheeting material(s) do you use for street-name signs (background and legend)?
Do you have any agency guidelines for the design of street-name signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)

Figure 1. Questions Included in Transportation Agency E-Mail Survey

OVERHEAD SIGNS

Overhead signs are any signs that are mounted in a manner that allows vehicles to drive under the signs. These signs are typically placed on sign bridges or cantilever sign supports. Overhead signs can also be placed on traffic signal mast arms. The most common type of overhead sign is the freeway guide sign. For this research study, the researchers were concerned about overhead guide signs, overhead street-name signs, and post-mounted street-name signs.

Other types of signs may also be placed overhead. The researchers have observed regulatory, warning, construction, and services signs mounted overhead. Commonly used overhead regulatory signs include signal-related signs (LEFT TURN SIGNAL, LEFT TURN YIELD ON [green ball], NO LEFT TURN, etc.), lane-use control signs, hazardous cargo signs, and others. Examples of warning signs that may be mounted overhead include a LANE ENDS sign, an advisory exit speed sign, an EXIT ONLY panel, and others. The initial minimum levels published by FHWA did not address yellow, orange, or red signs mounted in the overhead position.

There are a number of factors that have a significant effect on the nighttime visibility of overhead signs. The most significant of these is the lower level of illumination reaching signs in the overhead position. Other factors include, but are not limited to, variations in signing materials (including button copy), variations in legend size and design, and variations in mounting height.

Previous Efforts on MR Levels

MR levels for overhead signs were included in the original FHWA recommendations for white background signs and green background signs only. There were no levels proposed for yellow or red background overhead signs. When the MR levels were revised, the levels for overhead signs were eliminated. The original MR recommendations for white-and-green overhead signs are shown in tables 6 and 7. These tables also include the revised levels where the minimum levels for the overhead signs were eliminated.

Review of MUTCD Principles

As indicated previously, the overhead sign portion of this project is focusing upon overhead guide signs. In conducting the review of MUTCD principles for overhead guide signs, the researchers reviewed the expressway and freeway chapters of the MUTCD. MUTCDs, or the equivalent manuals, were evaluated from the following States: California, Maryland, Minnesota, and Texas. The following provides some of the key findings from the review as they relate to the visibility or retroreflectivity aspects of overhead signs:

- **Overhead Sign Height**
  - 1988 National MUTCD: Overhead signs should be mounted to provide a vertical clearance of at least 17 ft over the entire length of the roadway (including the shoulders). This height may change where other structures use lower clearances and under special circumstances (tunnels, double-decker bridges, etc.).
  - Other States: Same as the national MUTCD except as noted below:
    - Overhead signs are to have a minimum vertical clearance of 18 ft. Overhead signs shall be placed 30 ft from any light standards.
    - Overhead signs are to be mounted with a minimum vertical clearance of 17 ft-6 inches over the entire length of the roadway. The height of the sign should not initially exceed 23 ft. When the height is reduced to less than 16 ft-6 inches, consider raising the sign.

- **Mounting Issues (number of sign panels)**
  - 1988 National MUTCD: No more than three overhead signs at one location.
  - Other State MUTCDs: Same as the national MUTCD.

- **Amount of Legend**
  - 1988 National MUTCD: Legend is fixed at a maximum of two destination names or street names. Directional copy should not exceed three lines. When two or more signs are used together, it is desirable to limit destinations or names to one per sign.
  - Other State MUTCDs: Same as the national MUTCD.

- **Legend Size**
  - 1988 National MUTCD: For both rural and urban areas, lettering should be a minimum of 8 inches high. Uppercase letters are used for all word legends. Lowercase letters with an initial uppercase letter are used for all places, streets, and highways. The uppercase lettering shall be 1.33 times the loop height of the lowercase lettering. Table 10 contains letter heights based on the type of overhead sign. These range from 10 to 18 inches on overhead signs. For example, numerals (15 inches) are larger than words (10 inches) and single letters are also 15 inches.
  - Other State MUTCDs: Same as the national MUTCD.

- **Type of Alphabet**
    - 1988 National MUTCD: Not specified for expressways; however, for freeways, the initial alphabet will be Series E (Modified).
    - Other State MUTCDs: Same as the national MUTCD.

Survey of Agency Practices

As mentioned previously, the researchers also conducted a survey of five State and five local agencies to identify the actual practices related to overhead signs. Table 9 lists the agencies that responded to the survey. Figure 1 presents the questions that were part of the survey. The complete responses to the overhead sign questions from each agency are contained in appendix A. Tables 10 and 11 provide a capsule summary of the survey responses from each agency.

STREET-NAME SIGNS

There are several different types of street-name signs. The most common is the post-mounted horizontal rectangular sign. This type of street-name sign is often mounted above another type of sign, such as a STOP sign. Another common type of street-name sign is mounted on traffic signal mast arms or span wire. Street-name signs are also used in advance of intersections, alone or in combination with other types of signs (such as a crossroad warning sign, W2-1).

There are great variations in the type, design, and placement of street-name signs. The most common is the white on green with 6-inch letters. There are also great variations in the type of legend used on street-name signs. Some agencies simply provide the street name. Others include the street classification (Rd, St, Blvd, Ave, etc.) and/or a block number. The legend may be in capitals or in uppercase/lowercase letters. There are many agencies that use colors other than white on green.

Table 10. State Agency Responses to Overhead Sign Questions

Question	State 1	State 2	State 3	State 4	State 5
General Comments	None	None	None	None	None
1. What is the legend (typical letter height)? (uppercase/lowercase, inches)	16/12	MUTCD Section 2F	16/12 20/15 fry-fry signs	MUTCD Standard	16/12
2. What alphabet is used for the legend (Series E (Modified), other)?	Series E (Modified)	Series E (Modified)	Series E (Modified)	Series E (Modified)	Series E (Modified)
3. What sheeting material(s) do you use for overhead signs (background and legend)?	Type III or IV (high-intensity or microprismatic)	Type III	Type III	Visual Impact Performance (VIP) microprismatic	Type III
4. Do you use a higher grade of sheeting for overhead signs compared to ground-mounted signs?	No	No	No (all overhead signs are lighted)	See question 3.	No
5. What is the typical height to the bottom of an overhead sign?	18 ft	17 ft-6 inches	20 ft-9 inches	17 ft-4 inches	17 ft
6. Do you have any agency guidelines for the design of overhead signs that are different from that contained in your State's MUTCD?	No	No	No	Uses SignCAD program	Yes

Table 11. Local Agency Responses to Overhead Sign Questions

Question	City 1	City 2	County 1	County 2
General Comments	Except for mast-arm signs, rarely install overhead signs. Answers based on street-name mast-arm signs.	Do not use overhead signs other than standard highway sign designs.	None	None
1. What is the legend (typical letter height)? (uppercase/lowercase, inches)	10	See general comment.	8/6	6
2. What alphabet is used for the legend (Series E (Modified), other)?	Series B and C	See general comment.	Series C	Series E (Modified)
3. What sheeting material(s) do you use for overhead signs (background and legend)?	Green electronic cuttable (EC) film on white type III (high-intensity)	See general comment.	Type III (high-intensity)	VIP microprismatic
4. Do you use a higher grade of sheeting for overhead signs compared to ground-mounted signs?	No	See general comment.	Experimenting with VIP microprismatic	Type III for red and yellow ground signs and type I for white, green, and blue ground signs
5. What is the typical height to the bottom of an overhead sign?	17 ft-6 inches	See general comment.	16 ft minimum, 19 ft preferred	16 ft-6 inches to 17 ft-0 inches
6. Do you have any agency guidelines for the design of overhead signs that are different from that contained in your State's MUTCD?	No	See general comment.	Policies are consistent with State agency.	No

There are a number of factors that have a significant effect on the nighttime visibility of street-name signs. These signs are often mounted on only one corner of an intersection, presenting a disadvantaged (left side) position for two of the four approaches. They may also be as high as 10 ft or more if they are mounted above a STOP or YIELD sign. These factors reduce the illumination reaching the signs, thereby reducing the luminance of the signs. Because of the length of many street names, a narrow stroke-width alphabet (Series B or C) is often used, reducing the legibility of the signs.

Previous Efforts on MR Levels

MR levels for street-name signs were not specifically excluded from the original FHWA recommendations. However, a review of the CARTS model indicates that street-name signs were not in the sign library and were therefore probably not addressed in the development of MR levels. Street-name signs were specifically excluded when the MR levels were revised.

Review of MUTCD Principles

In conducting the review of MUTCD principles for street-name signs, the researchers reviewed the conventional guide sign chapter of the MUTCD. MUTCDs, or the equivalent manuals, were evaluated from the following States: California, Maryland, Minnesota, Pennsylvania, and Texas. The following provides some of the key findings from the review as they relate to the visibility or retroreflectivity aspects of street-name signs:

- **Sign Color**
  - 1988 National MUTCD: Legend and background shall be of contrasting colors, specifically a white legend and border on a green background. The sign should also be reflectorized or illuminated. When paired with an advance warning sign, colors will be black on a yellow background.
  - Other State MUTCDs: Same as the national MUTCD except as noted below:
    - Post-mounted signs are to have color combinations visible to 150 ft during the day and under normal weather conditions.
    - Legend and background shall be of contrasting colors.
    - White legend on a green background, black legend on a white background, or other contrasting combination.

- **Sign Legend (street name, block number, direction, symbol)**
  - 1988 National MUTCD: Legend consists of street name and street designation (avenue, street, etc.). The legend may also have cardinal directions and a symbol identifying the governmental jurisdiction. The sign may use conventional abbreviations; however, the street name may not be abbreviated.
  - Other States: Same as the national MUTCD.

- **Legend Size**
  - 1988 National MUTCD: The legend shall be a minimum of 4-inch lettering. Supplemental lettering shall be at least 2 inches in height. Any symbols will be to the left of the street name and will be less than or equal to the height of the sign.
  - 1988 National MUTCD Revision 5: The 1988 MUTCD was revised to require the legend on street-name signs to be at least 6 inches high. If uppercase and lowercase

letters are used, then the uppercase letters should be 6 inches, with 4.5-inch lowercase letters. Abbreviated lettering to indicate the type of street or section of the city (e.g., Ave., N.W., etc.) may be in smaller lettering (at least 3 inches high). However, for local roads with speed limits 25 mph or less, the lettering may be a minimum of 4 inches, with 2-inch letters for street abbreviations or city sections.
  - Other State MUTCDs: Same as the national MUTCD except as noted below:
    - The lettering for urban streets and less important rural roads shall be 4 inches high. When using lowercase letters, the uppercase letter height will be 1.33 times the loop height of the lowercase letters. Supplemental lettering shall be at least 2 inches high. Any symbols will be to the left of the street name and will be less than or equal to the height of the sign.
    - Open capital letters shall be no greater than 4 inches high. Capital letters are to be 4 inches high when used with 3-inch lowercase lettering. The street designation shall be no greater than 2 inches high. Mast-arm-mounted signs are to use a minimum height of 6 inches for uppercase letters and 4.5 inches for lowercase letters.
    - In rural districts, the letter height is 6 inches or more on the principal legend. On urban streets and less important rural roads, the letter height is 4 inches or greater.
    - Use lettering at least 4 inches high. Supplementary lettering uses a 3-inch height.

- **Legend Alphabet**
  - 1988 National MUTCD: Sign lettering shall be in uppercase letters. The Series B alphabet shall be restricted to limited breadth and width signs (street-name signs).
  - Other State MUTCDs: Same as the national MUTCD.

- **Sign Placement**
  - 1988 National MUTCD: In business districts and on principal arterial streets, at a minimum, signs shall be placed on diagonally opposite corners such that they are on the far right-hand side of the major traffic flow. In residential areas, there shall be a minimum of one street-name sign at each intersection. There shall also be signs naming both streets at each location. The sign face should be parallel to the street it names.
  - Other State MUTCDs: Same as the national MUTCD except as noted below:
    - Street-name signs at all street intersections in urban areas.
    - At signalized intersections along State highways with mast arms or span wires, street-name signs shall be installed on the mast arm or span wire for all approaches. At all other signalized intersections, street-name signs should be installed. All intersections without overhead signs shall have at least one street-type D-3 name sign facing each major approach. Also, there shall be one sign facing each major approach and nonmajor approaches that are not the only exits from private streets, cul-de-sacs, and residential developments. These other approaches should have a street-name sign facing them.
    - Street-name signs are required at all signalized intersections and must be visible from all directions. Two street-name signs, visible from each approach, are required in retail business districts. Signs may be post- or mast-arm-mounted.

        - Street-name signs shall be placed at all street intersections regardless of other route markings already present. In business districts, signs are to be placed on diagonally opposite corners so that the sign will be on the far right-hand side of the major traffic. In residential districts, there will be a single sign for each intersection. Signs may also be placed in a vertical position on a wooden post.

- **Sign Height**
    - 1988 National MUTCD: Minimum of 5 ft from the bottom of the sign to the near edge of the pavement. Minimum of 7 ft when pedestrians and vehicles may cause a sight obstruction.
    - Other State MUTCDs: Same as the national MUTCD except as noted below:
        - Minimum height of 7 ft over the top of the curb. Two street-name signs on the same pole are to be mounted in the cross position, one over the other. On wooden post signs, the legend is to be at least 5 ft above the road surface.

Survey of Agency Practices

As mentioned, the researchers also conducted a survey of State and local agencies to identify the actual practices related to street-name signs. Table 9 lists the agencies that responded to the survey. Figure 1 presents the questions that were part of the survey. The complete responses to the overhead sign questions from each agency are contained in appendix A. Tables 12 and 13 provide a capsule summary of the survey responses from each agency.

SUMMARY

Based on the activities associated with the review of current practices, the researchers developed the following findings and scenarios related to the overhead signs and street-name signs that were later used in the development of the MR levels.

Findings

The review of MUTCD principles and the survey of agency practices led to the following findings related to the current use of overhead signs and street-name signs:

- **Overhead Signs**
    - The minimum clearance to the bottom of the overhead signs varies by agency; however, it is typically 17 to 21 ft.
    - There should be no more than three sign panels at a single overhead sign location.
    - There should be no more than two destinations or three lines of legend on a single sign panel.
    - The minimum legend size for destinations is 16-inch uppercase and 12-inch lowercase Series E (Modified) alphabet. The minimum legend for cardinal directions, distances, and other information ranges from 10 to 18 inches.
    - High-intensity (type III) or microprismatic (type IV or Visual Impact Performance (VIP)) sheeting is typically used in new overhead signs.

- While button-copy legend was once the most common type of legend for overhead signs, it is not being used on new signs to any significant extent. However, there are still many button-copy signs in the field.
- The use of sign lighting with overhead signs is decreasing.

- **Mast-Arm Street-Name Signs**
  - Both State and local agencies use mast-arm-mounted street-name signs at major signalized intersections.
  - The height of these signs ranges from 16 to 19 ft.
  - The legend size ranges from 6 to 10 inches.
  - Several different alphabets are used for mast-arm street-name signs, ranging from Series B to E (Modified).
  - These signs are white on green.
  - High-intensity (type III) or microprismatic (type IV or VIP) sheeting is typically used in mast-arm street-name signs.

- **Post-Mounted Street-Name Signs**
  - Street-name signs are located on both the right and left sides of the road. On major roads, street-name signs are more likely to be found on the right side of the major road at opposing corners.
  - Post-mounted street-name signs are often 9 to 10 ft high because of their being mounted above STOP and YIELD signs.
  - While a recent revision of the 1988 MUTCD increased the minimum size of the legend on street-name signs to 6 inches, there are many existing signs with 4-inch legends and agencies that still use 4-inch legends. Some of the 6-inch legends use the Series E (Modified) alphabet, with a 4-inch loop height for the lowercase letters.
  - Street-name signs commonly use Series C and D alphabets. Some local agencies use Series E (Modified) uppercase/lowercase letters. Local agencies also use the Series B alphabet in some cases. The choice of an alphabet to be used is often based on the size of the street name. A long street name will use a narrower stroke-width alphabet.
  - White on green is the most common color. Other colors are allowed; however, the use of other colors does not appear to be widespread.
  - Retroreflective sheeting used on street-name signs ranges from type I to microprismatic.

Table 12. State Agency Responses to Street-Name Sign Questions

Question	State 1	State 2	State 3	State 4	State 5
General Comments	None	None	None	None	None
7. What is your agency's policy for providing street-name signs (under what conditions are street-name signs provided and where are they located)?	State puts street-name signs (SNS) at signalized intersections only. Local agencies are responsible for all others.	State puts mast-arm SNS at signalized intersections. For nonsignalized intersections, State replaces local sign in kind.	Local agencies install SNS at far right and near left corners. Signalized and major streets have overhead and/or advance SNS.	State does not install slat SNS. Only mast-arm SNS are installed by State.	SNS are local responsibility.
8. How high are the street-name signs mounted?	Mast arm: 15 ft Post: 5-12 ft	Mast arm: 17 ft Post: MUTCD	Mast arm: 17 ft Post: 7 ft minimum	See response to question 7.	Post: 7 ft
9. What colors are your street-name signs?	White on green	Mast arm: White on green Post: Varies, typically on green or blue background	White on green	See response to question 7.	White on green, black on white, or other contrasting colors
10. What size is the standard blank/blade (do you use other sizes)? (inches)	Mast arm: 96 by 18	Mast arm: 84 by 18	Mast arm: Variable by 16 Post: Variable by 8	See response to question 7.	36 by 10
11. What size is the legend? (uppercase/lowercase, inches)	6/4.5	Depends on street name	Mast arm: 8/6 Post: 4	See response to question 7.	6
12. What alphabet is used for the legend (Series D, Series E (Modified), other)?	Series E (Modified)	Mast arm: Series E (Modified) Post: Series D	Mast arm: Series D Post: Series C	See response to question 7.	Varies, Series D typical
13. What sheeting material(s) do you use for street-name signs (background and legend)?	Type III or IV	Type III	Type III	See response to question 7.	Varies, type I typical
14. Do you have any agency guidelines for the design of street-name signs that are different from that contained in your State's MUTCD?	No	See appendix.	No	No	No

Table 13. Local Agency Responses to Street-Name Sign Questions

Question	City 1	City 2	County 1	County 2
General Comments	None	None	None	None
7. What is your agency's policy for providing street-name signs (under what conditions are street-name signs provided and where are they located)?	On mast arm or at one corner minimum	On mast arm for all signalized intersections, on STOP sign post at all nonsignalized intersections	Major streets: On diagonal quadrants Minor streets: Far right corner of one major street approach	SNS for intersection street only
8. How high are the street-name signs mounted?	7 ft	7 ft minimum, 9.5 ft typical above STOP sign	Approximately 10 ft	7 ft nominal
9. What colors are your street-name signs?	White on green	White on green	White on green	White on green
10. What size is the standard blank/blade (do you use other sizes)? (inches)	Mast arm: 18 Post: 9	Mast arm: 18 Post: 12 Used to be 9 and 6	9	Arterials: 30 by 9, 36 by 12 Local: 24 by 6, 30 by 6
11. What size is the legend? (uppercase/lowercase, inches)	Mast arm: 10 Post: 6	8/6 Reduce 1 inch if descender in name	5/3.75	4 on 6-inch blank 6 on 9-inch blank 5 on 12-inch blank with two lines
12. What alphabet is used for the legend (Series D, Series E (Modified), other)?	Series B and C	Series C	Series C	Series B or C
13. What sheeting material(s) do you use for street-name signs (background and legend)?	Green EC film on white type III	Green EC film on white VIP prismatic sheeting	Type III	Type I
14. Do you have any agency guidelines for the design of street-name signs that are different from that contained in your State's MUTCD?	No	No	Updating 1988 policy	No

Scenarios

Based on these findings, the researchers developed the following scenarios that represent best-case, typical, and worst-case situations for nighttime visual performance of overhead guide signs and street-name signs:

- **Overhead Signs**
  - Best Case: 17 ft high, 16-inch uppercase and 12-inch lowercase Series E (Modified) legend, single sign panel with minimal copy, appropriate sign lighting.
  - Typical Case: 18 ft high, 16-inch uppercase and 12-inch lowercase Series E (Modified) legend, two sign panels with one or two destinations per sign panel, no sign lighting, and panel is located directly ahead or to the right of the vehicle.
  - Worst Case: 21 ft high, 16-inch uppercase and 12-inch lowercase Series E (Modified) legend, three sign panels with complicated copy, no sign lighting, and sign panel of interest is located to the left of the vehicle.

- **Mast-Arm Street-Name Signs**
  - Best Case: Right side, 16 ft high, 10-inch Series E (Modified) legend, white on green.
  - Typical Case: Right edge of lane, 17 ft high, 8-inch Series E (Modified) legend, white on green.
  - Worst Case: Head on, 19 ft high, 6-inch Series C legend, white on green.

- **Post-Mounted Street-Name Sign**
  - Best Case: Right side, 7 ft high, 6-inch Series E (Modified) legend, white on green.
  - Typical Case: Right side, 9 ft high, 6-inch Series C or D legend, white on green.
  - Worst Case: Left side, 10 ft high, 4-inch Series B legend, white on brown.

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CHAPTER 4. MR MODEL

MODEL DESCRIPTION

To develop MR recommendations, the researchers developed a computational model that considers the relationships between the headlamps (source), sign (target), and the geometric relationship between these and the driver (receptor). The TTI model is a combination of ideas from other models such as CARTS and Exact Roadway Geometry Output (ERGO), with refinements to address shortcomings in the previously developed models. The elements (source, target, receptor, and vehicle) of the model were addressed in the following manner:

- **Headlamps:** External databases are used to accommodate different headlamp profiles such as CARTS50 or others, such as those published by the University of Michigan Transportation Research Institute (UMTRI).

- **Sheeting:** The model includes external retroreflectivity matrices for all types of sheeting. The data were obtained from the ERGO model with the permission of the model developer. The researchers conducted goniometer evaluations (on the TxDOT goniometer) of several materials to confirm the accuracy of the ERGO data and found it to be accurate.

- **Driver:** The model does not incorporate any human factor elements for driver considerations beyond the minimum luminance needed to read a sign at a specific distance. For this research, a field study (described in chapter 5) was conducted to determine the minimum luminance needed to read overhead guide signs and street-name signs.

- **Vehicle:** External databases are used to allow various vehicle designs to be studied. The database includes information about the location of the headlamps and the driver's eyes.

Once the driving scenario is defined by the user in Cartesian coordinates, the TTI model makes transformations in order to take advantage of vector algebra. Once unit vectors have been defined, the model determines the exact magnitude and direction of the vectors needed to fully define the three-dimensional retroreflective space. These calculations are made separately for each headlamp. Multipoint quadratic lookup features are then applied to the headlamp and retroreflectivity data files to obtain accurate values for the headlamp intensity and the retroreflective properties of the sign material. The luminance from each headlamp is then determined and totaled to arrive at the total luminance.

Up to this point, the TTI model performs similarly to ERGO. However, after ERGO outputs sign luminance, its usefulness in terms of establishing MR levels has ended. This is where the TTI model expands the current state-of-the-art by being able to determine the retroreflectivity needed to provide a user-defined threshold luminance.

The concept used to determine MR is provided below. The terminology introduced will be used throughout the remainder of this report.

$$\text{Minimum } R_{A} = \text{New } R_{A,SG} \times \left(\frac{\text{Demand } R_{A,NSG}}{\text{Supply } R_{A,NSG}}\right) \quad (1)$$

where,

Minimum R_A	=	MR at standard measurement geometry (α = 0.2E, β = -4.0E) needed to produce assumed threshold luminance, cd/lx/m^2
New $R_{A,SG}$	=	Averaged retroreflectivity of new sheeting at standard geometry, cd/lx/m^2
Demand $R_{A,NSG}$	=	Retroreflectivity needed to produce the minimum luminance at the nonstandard geometry (backcalculated and determined for each scenario), cd/lx/m^2
Supply $R_{A,NSG}$	=	Retroreflectivity of new sheeting at nonstandard geometry (determined for each scenario), cd/lx/m^2

If the Demand $R_{A,NSG}$ > New $R_{A,NSG}$, then the material cannot provide the threshold luminance for the given scenario. As shown below, the Demand $R_{A,NSG}$ is determined from the illuminance falling on the sign, the viewing geometry, and the assumed threshold luminance needed for legibility.

$$\text{Demand } R_{A,NSG} = \frac{\text{Minimum Luminance} \times \cos(\upsilon)}{\text{Illuminance}} \quad (2)$$

The Supply $R_{A,NSG}$ is found through a lookup table for each type of material. Nu is the viewing angle for the sign, using the driver as the observation point. The lookup tables contain almost 200,000 retroreflectivity values, depending on the applications system's four angles that are used to fully describe the performance of the retroreflective sheeting.

Appendix B provides additional information pertaining to the details of the development of the MR levels. A step-by-step example is provided for additional clarification.

MODEL ASSUMPTIONS

Several assumptions are associated with this methodology. For instance, this methodology assumes that the retroreflective characteristics for each type of sheeting degrade uniformly as the sheeting weathers. Figure 2 shows an illustrative example of this concept. The concept of uniform degradation for beaded materials (i.e., types I, II, and III) is a reasonable assumption. However, for microprismatic sheeting (i.e., types VII, VIII, and IX), the researchers acknowledge that this assumption has not been validated. For these microprismatic materials, the weathering may cause the microprisms to change shape, which may produce different retroreflectivity characteristics. Some sheeting may actually get brighter with age, but only to a point, and even then, the change may not be consistent along the full dynamic range. However, no data currently exist in the public domain that can be used to develop weathered curves that illustrate how microprismatic sheeting characteristics change over time. Efforts are currently underway at FHWA to measure the retroreflectivity of weathered microprismatic sheeting to determine the validity of this assumption and to make changes if needed.

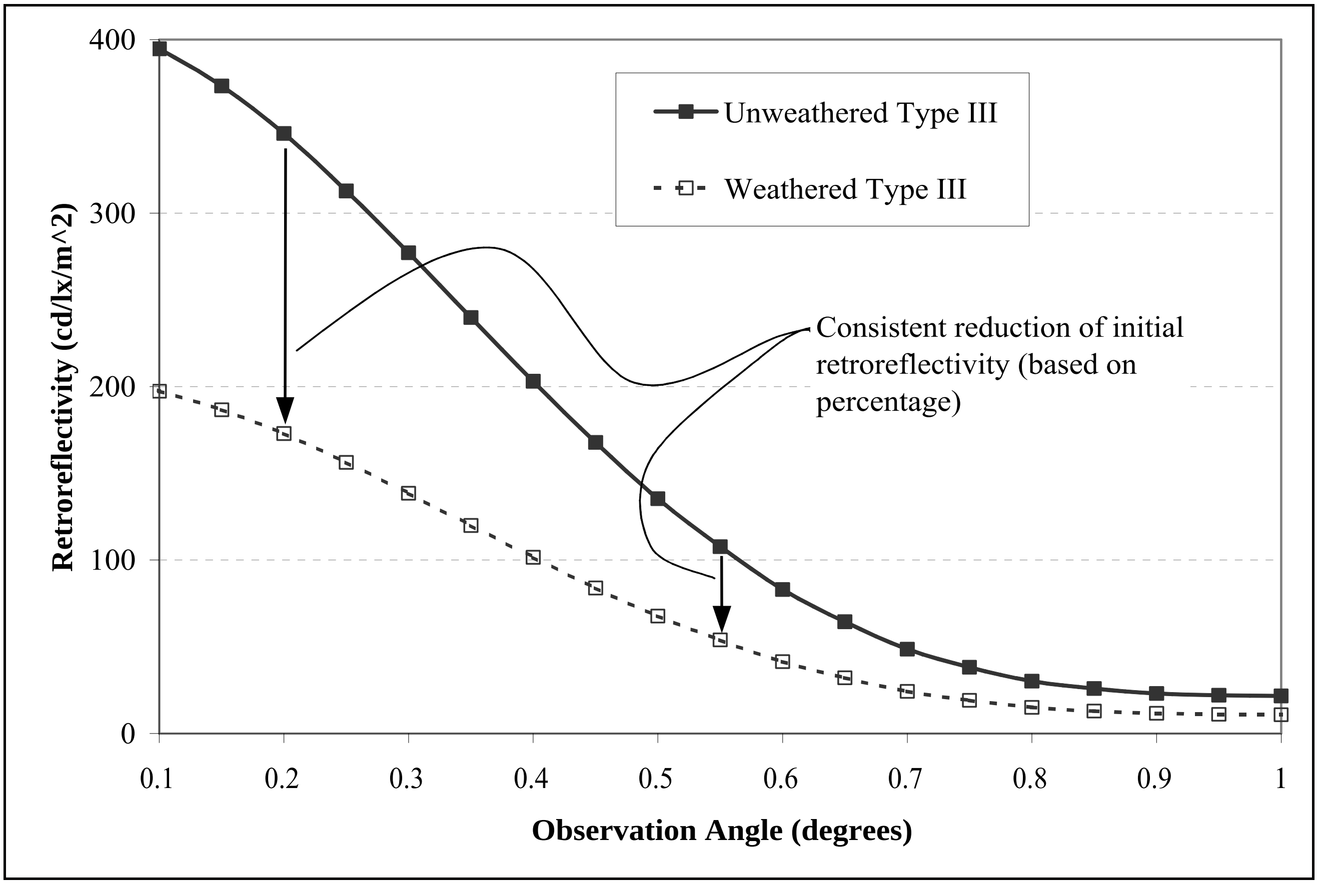

Figure 2. Weathering Degradation of Retroreflective Sheeting

The modeling methodology also assumes that the retroreflectivity of new sheeting at the standard measurement geometry can be generalized with one value per ASTM type of material (even though there are several manufacturers of certain types of sheeting). The values shown in table 14 were determined by averaging the retroreflectivity values for each type of material at α = 0.2E, β = -4.0E, ε = +180E to -180E in 15E intervals and ω = +180E to -180E in 15E intervals. The sheeting data from the ERGO model were combined with measurements made by the researchers to develop the values shown in table 14.

A final modeling assumption is that the photometric relationships used in the model provide accurate estimates of the illuminance falling on a sign and the returned luminance directed toward the driver's eyes. Real-world factors such as pavement glare and ambient lighting are not considered in the model, or in any other available model. However, atmospheric and windshield transmissivity are considered.

Table 14. Average R_A of New White Sheeting

ASTM Type	Retroreflectivity ($cd/lx/m^2$)
I	100
II	175
III	315
VII	1100
III	800
IX	450
R_A values at α = 0.2º and β = -4.0º	

CHAPTER 5. FIELD EVALUATION

The objective of the field evaluation was to determine the minimum luminance needed to read overhead and street-name signs (as a function of distance). As described in chapter 2, there is a wide range of research findings related to legibility luminance requirements. More precise minimum luminance values were needed to determine the retroreflectivity that will produce those luminance values. The retroreflectivity values that produce the minimum luminance values are the MR levels that will be used to generate recommendations.

To obtain the minimum luminance values, an experiment was designed that involved nighttime viewing of overhead and street-name signs. Essentially, drivers were positioned in a closed-course, real-world driving scenario and were asked to read different retroreflective signs. The luminance of the signs was controlled so that they were initially too dim to read and then the brightness (i.e., luminance) was systematically increased until the words were read correctly. The remainder of this chapter summarizes the experimental procedure and findings.

RESEARCH STIMULI

For the overhead sign testing, two words were shown simultaneously on each overhead sign. There are three advantages associated with this approach. First, overhead signs usually contain more than one word. Second, this approach increases the efficiency of the data collection procedure, allowing more data to be collected in a shorter amount of time. Finally, by using the two-word configuration proposed, the resolution of the findings was increased (the top word had different luminance than the bottom word). Similar to the real world, only one street-name sign was displayed at a time.

This research was based on the legibility of words rather than other visual testing icons such as the Landolt ring or grating patterns. Each word contained six letters. These words were “everyday” or common words and were not associated with the name of a city or destination. In all, 15 different words were used for the overhead signs. The words were developed for and used in another TxDOT-TTI study where both the legibility and the recognition distances of overhead signs were determined for various ages of drivers (luminance was not controlled in this study). The words included seven neutral words and eight words with both one ascender and one descender. Table 15 lists the words.

The street-name evaluations were conducted during the same session as the overhead signs, but not simultaneously. To avoid potential learning effects, the majority of the street-name signs were made with different test words than the overhead signs. The street-name sign words used are also listed in table 15.

Table 15. Test Words

Overhead Guide Signs		Street-Name Signs	
Neutral Words	**Ascender/Descender Words**		
Nerves	Bishop	AIRPLANE	MICHIGAN
Nurse	Dearly	ALABAMA	MILKMAN
Ounces	Eatery	ALASKA	MISSOURI
Season	Felony	ARIZONA	MONTANA
Senior	Flange	KICKOFF	MOUNTAIN
Sensor	Forget	KANSAS	SEASON
Series	Plunge	MARATHON	SENSOR
	Shapes	MAXIUM	STREAM

All sign backgrounds and sign legends were fabricated with type III sheeting. The street-name signs were constructed with new type III sheeting that consistently measured approximately 320 cd/lx/m^2 for the legend and 55 cd/lx/m^2 for the background. The overhead signs were fabricated for another study that was conducted approximately 5 years ago; therefore, there was some loss of retroreflectivity for the words in the overhead signs. To determine the extent, each letter of each word was measured six times. The average scores ranged from 230 to 290 cd/lx/m^2 and are shown in figure 3. The green overhead background measured 40 to 45 cd/lx/m^2.

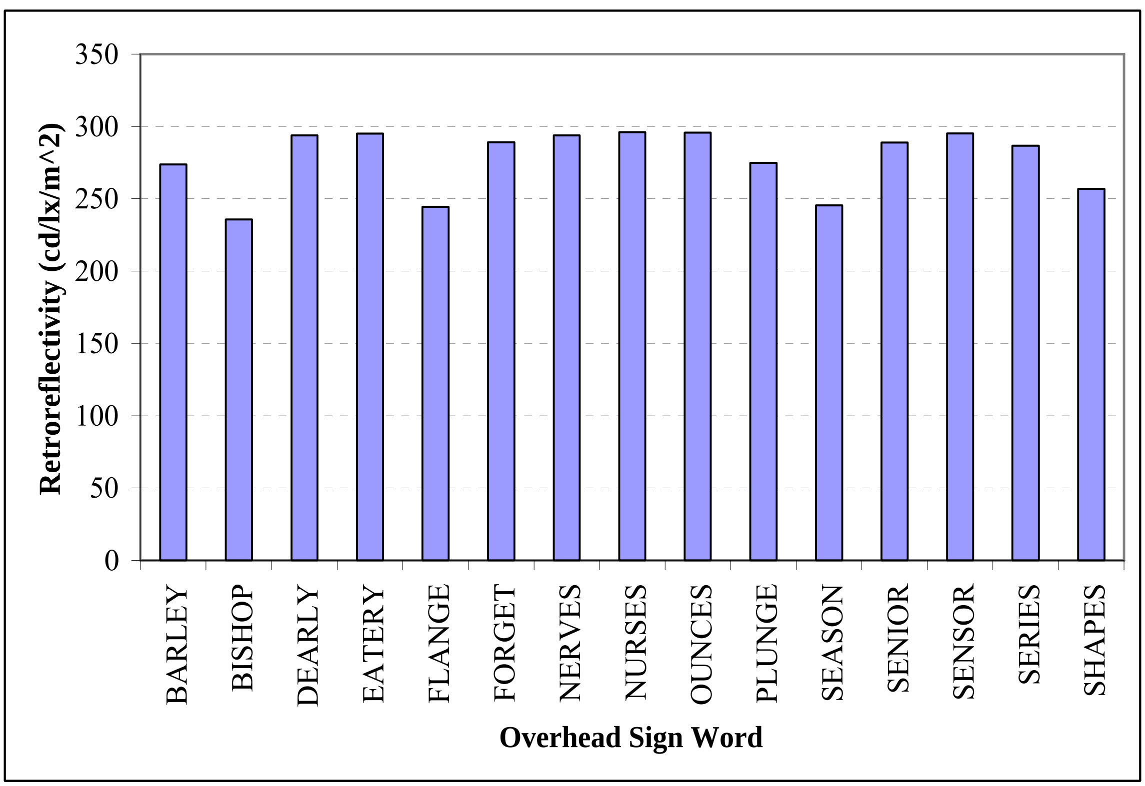

Figure 3. Overhead Sign Retroreflectivity Values

The overhead signs were made with white Series E (Modified) 16-inch uppercase and 12-inch lowercase words on a green background. The street-name signs were made with white Series C 6-inch uppercase words on a green background.

Spacing between letters was in accordance with the standard highway alphabet as recommended by FHWA. For the overhead signs, two words were shown on the overhead sign. The spacing between the words was 34 inches (see figure 4). Only one street-name sign at a time was shown.

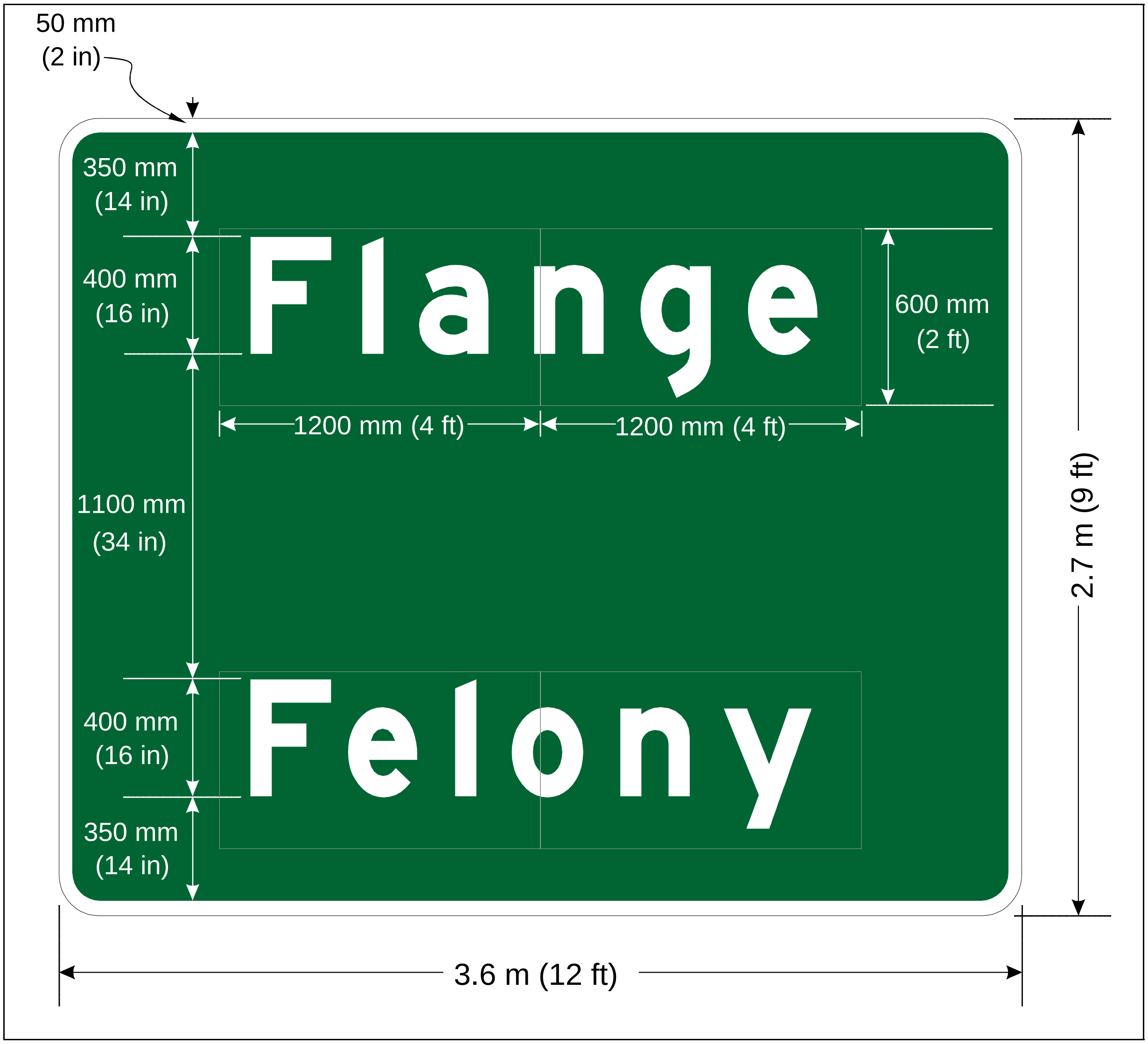

Figure 4. Layout of Overhead Sign Panel and Legend

SIGN POSITIONING

Using the literature review and current practices survey described in chapters 2 and 3, sign positions were selected to represent typical sign locations. The bottom of the overhead sign was positioned 18 ft above the road surface. Figure 4 illustrates the precise positioning of the test words. The bottom of the street-name sign was positioned 9.5 ft above the roadway surface. This height was selected to simulate the practice of installing street-name signs on the top of STOP signs.

The MR modeling research addressed lateral positioning issues associated with various viewing geometries and various headlamp profiles. For the field study, the overhead targets were centered above the travel lane and the left edge of the street-name sign words was mounted 6 ft to the right of the right edgeline of the travel lane.

STUDY VEHICLE

The same vehicle was used throughout the entire data collection effort–a 2000 Ford Taurus, Model SE. The Taurus headlamps were the tungsten-halogen VOA style. Specifically, the driver’s side headlamp was HB5 VOR LH DOT SAE AHRT5P2P 00T2 and the passenger’s side headlamp was HB5 VOR RH DOT SAE AHRI5P2P 00T2. VOR means that the headlamp is to be visually/optically aimed using the right side of the cutoff, which is to be adjusted such that it is on the horizon line (at the same height as the center of the headlamp) when shown at a wall 25 ft away. In general, the VOA headlamp design (which includes VOR and VOL subclassifications) casts a relatively small amount of light above the horizon, not unlike the European headlamp specification.

All subjects were tested from the driver’s seat of the test vehicle. A researcher was in the passenger’s seat at all times during data collection.

SUPPLIED LUMINANCE LEVELS

Using both the low beams and the high beams, the researchers were able to provide 32 different, but precisely controlled, headlamp illumination levels to vary the luminance of the test words. The headlamp illuminance levels produced sign luminance values ranging from near zero (i.e., too dim to read) to that allowed by the maximum output with high beams (actual maximum sign luminance levels varied as the distance from the test signs varied). An attempt was made to control the headlamp illuminance levels so that the intervals producing sign luminance values near the standard threshold value of 3.4 cd/m^2 would be small. However, as the headlamp illumination level increases, thereby increasing the sign luminance, the size of the intervals increased. A nearly constant legend:background luminance contrast ratio of 5:1 was maintained throughout the luminance range. Table 16 summarizes the luminance values that were supplied for each sign position. Figure 5 illustrates the luminance curves for each sign type and position.

Table 16. Supplied Legend Luminance Values (cd/m²)

Dial Position	Upper Overhead Word			Lower Overhead Word			Street Name		
	640 ft	480 ft	320 ft	640 ft	480 ft	320 ft	640 ft	480 ft	320 ft*
Low 1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.09
Low 2	0.2	0.2	0.2	0.3	0.3	0.3	0.5	0.2	0.18
Low 3	0.3	0.3	0.3	0.5	0.5	0.4	0.8	0.4	0.29
Low 4	0.5	0.4	0.4	0.6	0.6	0.5	1.1	0.5	0.38
Low 5	0.6	0.6	0.5	0.8	0.8	0.7	1.4	0.7	0.48
Low 6	0.7	0.7	0.6	1.0	1.0	0.9	1.8	0.9	0.50
Low 7	0.9	0.9	0.7	1.2	1.2	1.0	2.1	1.0	0.73
Low 8	1.1	1.0	0.8	1.4	1.5	1.2	2.6	1.3	0.86
Low 9	1.2	1.2	0.9	1.7	1.7	1.4	3.0	1.4	0.86
Low 10	1.4	1.3	1.0	1.9	1.9	1.6	3.3	1.7	1.13
Low 11	1.5	1.5	1.1	2.1	2.1	1.7	3.7	1.8	1.24
Low 12	1.9	1.8	1.4	2.5	2.5	2.0	4.5	2.2	1.50
Low 13	2.0	2.0	1.5	2.8	2.7	2.3	4.8	2.4	1.62
Low 14	2.2	2.1	1.6	3.0	3.0	2.4	5.3	2.6	1.77
Low 15	2.3	2.2	1.7	3.2	3.2	2.6	5.7	2.8	1.89
Low 16	2.7	2.5	2.0	3.5	3.6	2.9	6.4	3.2	2.13
High 1	0.8	0.4	0.2	1.6	1.0	0.3	2.6	0.5	0.15
High 2	1.6	0.7	0.4	3.3	2.0	0.7	5.3	1.1	0.29
High 3	2.6	1.1	0.7	5.3	3.1	1.2	8.6	2.0	0.46
High 4	3.4	1.4	0.9	7.0	4.1	1.5	11.5	2.6	0.60
High 5	4.4	1.8	1.1	9.1	5.3	1.9	15.0	3.5	0.77
High 6	5.7	2.3	1.4	11.7	6.6	2.4	19.0	4.6	0.98
High 7	7.0	2.8	1.7	14.2	7.9	3.0	22.8	5.4	1.17
High 8	8.3	3.3	2.0	17.0	9.5	3.5	27.1	6.4	1.40
High 9	9.2	3.8	2.3	19.7	10.8	4.0	30.5	7.8	1.60
High 10	10.6	4.4	2.6	22.4	12.3	4.5	34.5	8.7	1.83
High 11	11.8	4.7	2.8	24.3	13.5	4.9	38.0	9.9	2.01
High 12	14.4	5.8	3.5	30.4	16.5	6.0	45.6	12.1	2.45
High 13	15.7	6.3	3.8	33.0	17.8	6.6	50.6	13.2	2.65
High 14	17.1	6.9	4.1	35.9	19.6	7.2	56.3	14.4	2.89
High 15	17.8	7.3	4.3	38.6	20.8	7.6	59.1	15.5	3.06
High 16	20.4	8.3	4.9	43.9	23.8	8.4	68.3	17.1	3.50

*The luminance of the street-name signs (at this distance) was measured with more precision than other target/distance combinations because of the aperture limitations of the LMT1009.

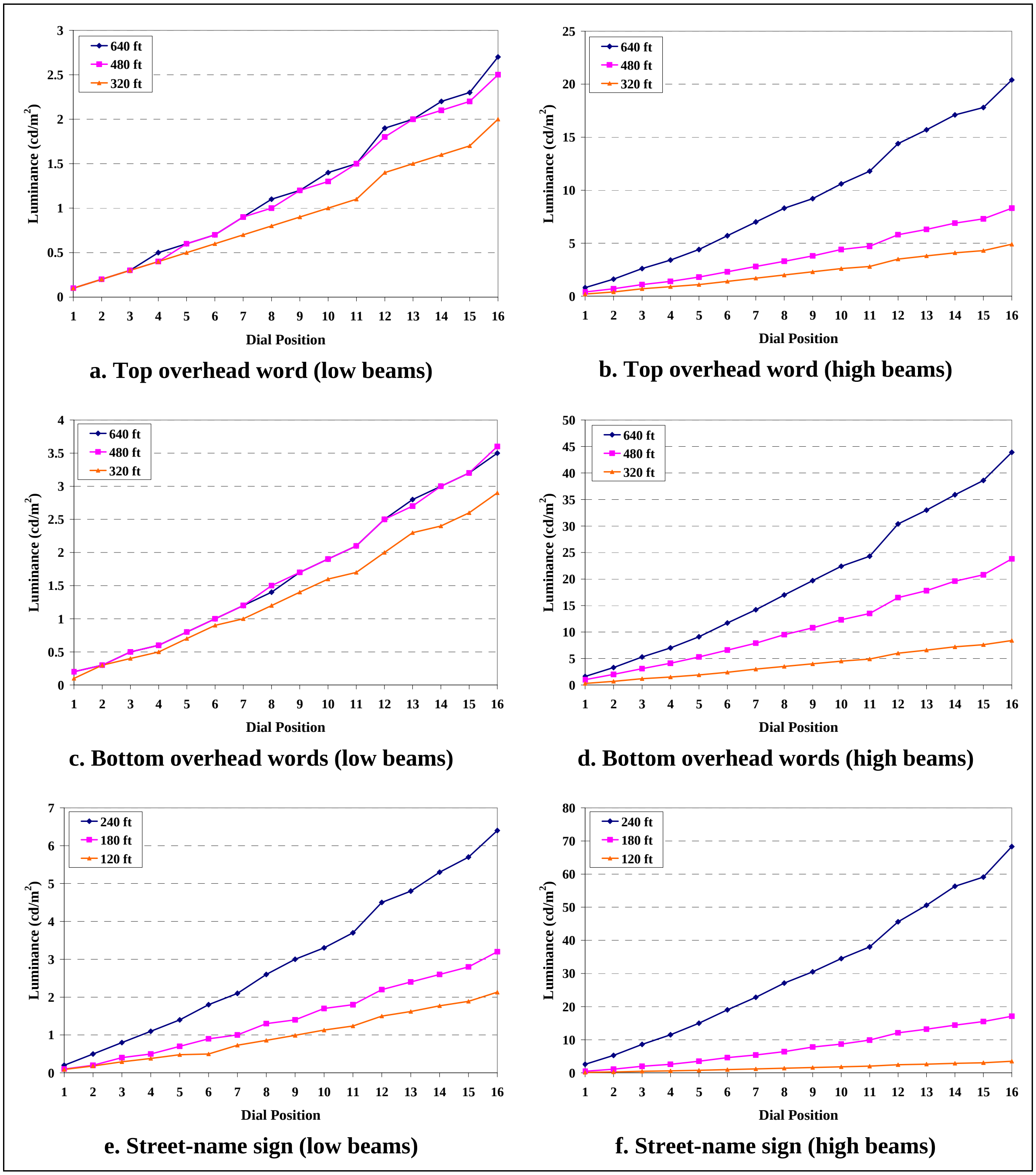

Figure 5. Supplied Legend Luminance Graphs

Dimmer Switch

Several methods of reducing the output of automobile headlamps are available. One method uses a variable resistor to dissipate a portion of the voltage as heat, with the remainder powering the headlamps. This would allow from 0- to 100-percent control of the light; however, the values in between would be nonlinear and would be difficult to replicate. Also, up to 100 watts (W) of power would need to be dissipated as heat. Another method used to control the light output is pulse-width modulation (PWM). This method applies full voltage to the headlamps at all times, but is interrupted at rapid and controllable rates. With the voltage turning on and off 2000 times per second, the ratio between the on-time and the off-time controls the brightness of the lamps. For example, if the voltage to the lamps was on for 50 microseconds (µs) and off for 450 µs, repetitively, the overall effect would be that the lamp is only receiving power for 10 percent of the time. This second method was chosen for this project.

Since we are now dealing with numbers, precise control of the light output is possible with a numeric processor or imbedded microcontroller. For this purpose, a Parallax BASIC Stamp 2 (BS2) was used. The BS2 contains a computer chip, serial input and output, 16 binary input/output lines, data storage, and memory. The BS2 is programmed with a standard laptop computer and retains the program until programmed again. To control headlamp output, a 16-position, binary rotary switch was used. The four-line output from the switch is sensed by the BS2 and, using a lookup table, produces the required PWM signal to the headlamp drivers. Since the percentage of *on* time does not easily equate to the percentage of light output as shown in figure 6, a switch position versus light output table was generated empirically with a laptop and a Tektronix J16 light meter and was programmed into the BS2. This method produces a highly repeatable set of test conditions than can easily be reprogrammed if necessary. The BS2, selector switch, and power switches are located in a small box that is held by the experimenter (figure 7).

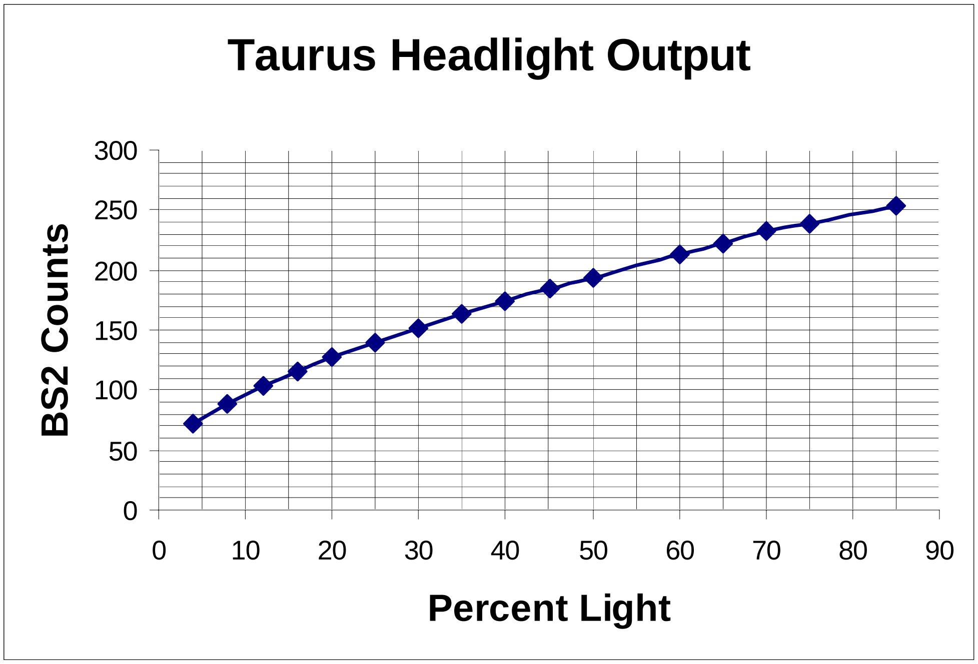

Figure 6. Ford Taurus Headlamp Output

Special transistors were used to switch the headlamps on and off at 2000 times per second. These were power Metal-Oxide-Semiconductor Field Effect Transistors (MOSFETs), one for each headlamp. The common wire to each headlamp was cut and run to the drivers located on each fender. Since the common wire to the headlamp is normally connected to the plus side of the battery, a special “high side” driver circuit was used. By controlling the common wire to the headlamps, dimming is achieved on both the low and high beams. The internal resistance of these MOSFETs is very low (0.02 ohms), so there is little heat generated and there is very little voltage dropped across them, allowing nearly normal full voltage to the headlamps.

To allow operation of the vehicle at night without the controller turned on, a relay was added to each driver box. This relay, through the normally closed contacts, bridges across the power MOSFET to provide full voltage to the headlamp. This relay is actuated when power is applied at the control box, allowing the headlamp voltage to pass through the power MOSFET.

Finally, a solid-state 4-milliwatt (mW) red laser was powered from the control box through a switch. This laser, located in the vehicle’s grill area and pointing forward, provided a means of vehicle (headlamp) alignment each time it is returned to the test course. Figure 8 shows a picture of the aiming laser.

Figure 7. Control Box

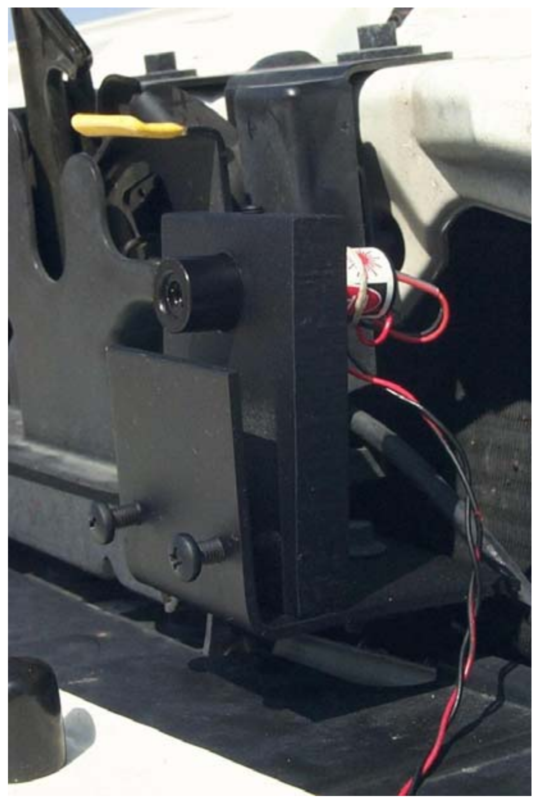

Figure 8. Aiming Laser

The aiming laser was installed in the grill area of the test vehicle as shown in figure 9. Then the laser could be used to aim the vehicle as it was positioned for each evaluation. Figure 10 shows how the vehicle was aimed.

Figure 9. Laser Location

Figure 10. Use of Laser for Aiming

Figure 11 shows how the luminance values for each setting were measured. Using an LMT1009, the researchers measured the luminance of each sign position using 24-inch by 24-inch panels of white type III retroreflective material. A 24-inch square was needed to fill the aperture of the LMT at 640 ft using the 6-minute aperture. Very precise control was needed to accurately reproduce the luminance values from one night to another. For example, the researchers had to be in the same position (e.g., front seats), there could be no substantial difference in the weight distribution throughout the car (e.g., another observer in the backseat or substantial differences in fuel levels), and the contents of the trunk were removed. The headlamp lens and windshield were cleaned each night before the evaluations were begun. The researchers also kept the fuel topped off after each night of data collection. Also, it was important to keep the LMT at the same height for each reading.

Figure 11. Luminance Readings

The researchers also learned that the vehicle used during the evaluation would periodically run an engine fan. When the fan would start and quit, there was a moment of unstable luminance readings. However, the luminance readings would return to their previous state within 1 s of the fan either starting or quitting. The luminance change was so slight that only after many subject runs were the researchers able to notice it with their naked eyes and it did not appear to impact the subjects' evaluations of the legibility of the test words.

Color Shift

Sealed-beam halogen headlamps are generally known for having a substantial color shift phenomenon when the voltage is decreased from the standard operating voltage. However, the test vehicle used herein did not have sealed-beam headlamps and the voltage was not reduced. Still, the impact of the chosen method to vary luminance was not known. Consequently, before the researchers fully implemented the experimental plan, chromaticity and color temperature readings were taken to determine the color shift patterns of the Taurus headlamps (which were tungsten-halogen replacement bulbs). This was a critical issue since a substantial color shift would add severe confounding to the legibility analyses.

Figures 12 and 13 show the chromaticity shift from the brightest setting to the least bright setting using the Commission International d'Eclairage (CIE) 1931 color space (ASTM E308). Figure 14 shows the corrected color temperature (CCT) shift. A Photo Research PR®-650 was used to take both the chromaticity and color temperature readings. Both of the trends were determined to be inconsequential and the procedure was implemented.

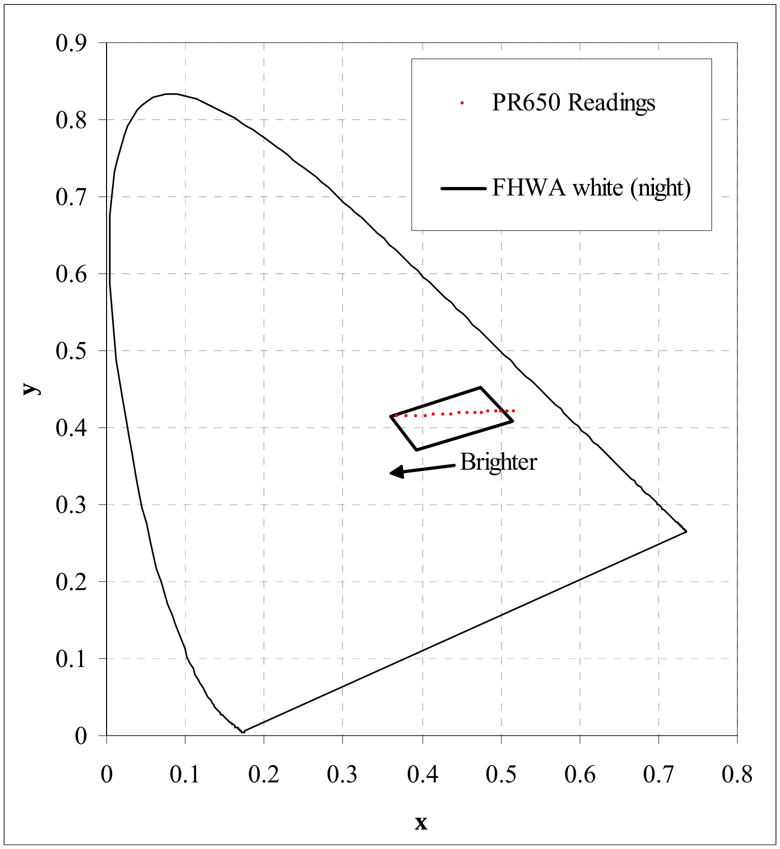

Figure 12. Chromaticity Color Shift (CIE, 1931)

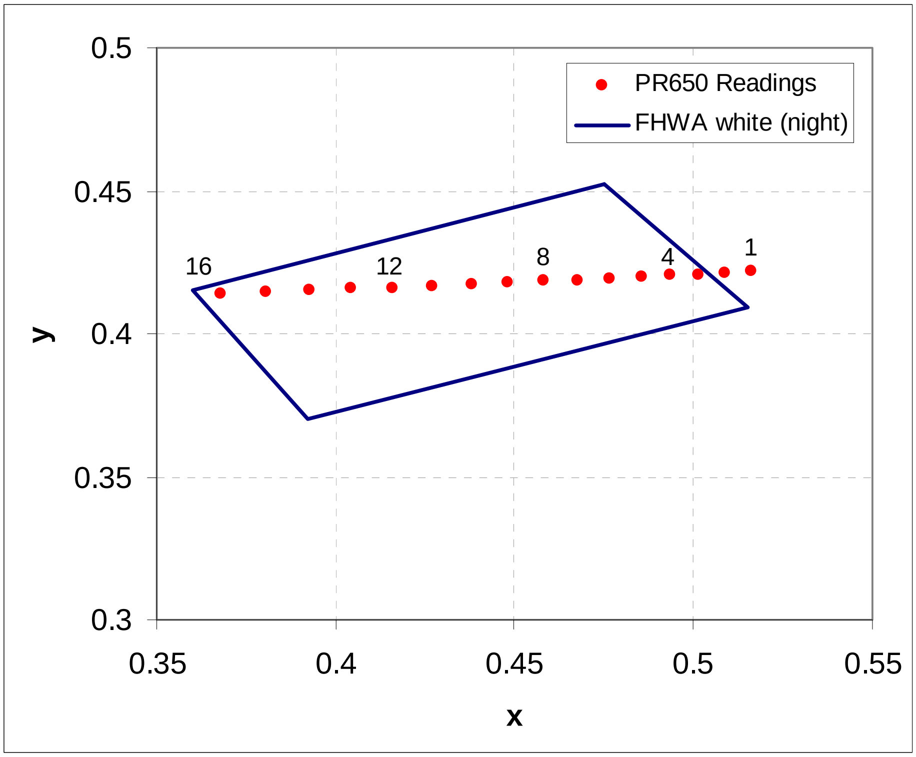

Figure 13. Closeup Chromaticity Color Shift (CIE, 1931)

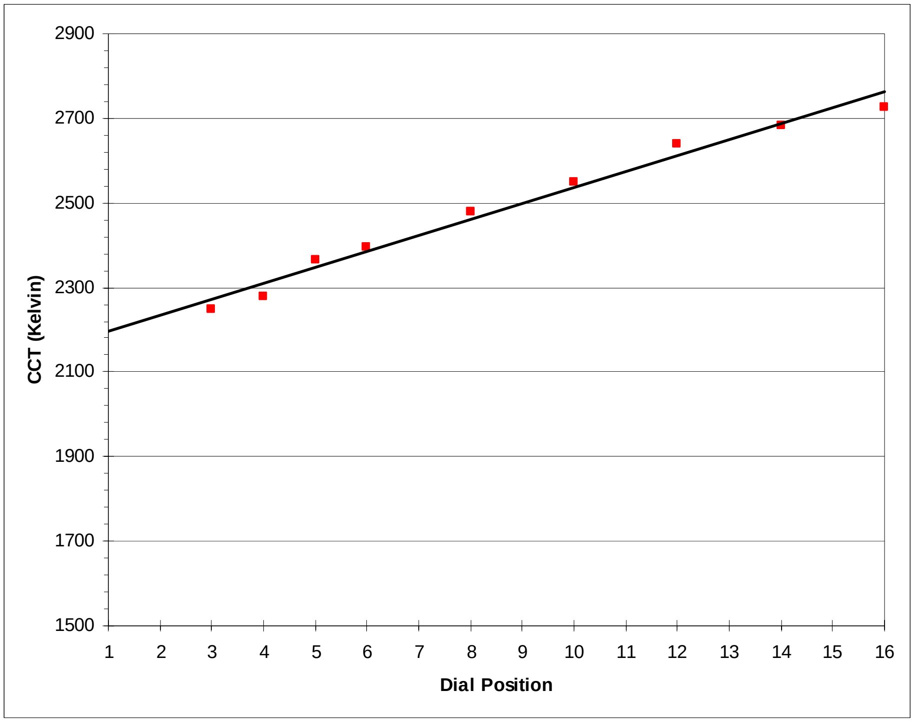

Figure 14. Color Temperature Shift

TEST SUBJECTS

Thirty subjects were recruited from the Brazos Valley, TX, area using advertisements at local senior centers. Subjects received financial compensation of $30. Each driver was required to have a current Texas driver's license without nighttime restrictions. Table 17 lists the subject data.

Table 17. Subject Information

Subject #	Age (years)	Gender	Driving Restrictions	Self Restriction	Miles Driven per Year	Snellen Visual Acuity	VisTech Visual Acuity
1	59	F	Corrective lens	N	1000	20	20
2	75	F	Corrective lens	N	3000	50	30
3	69	M	Corrective lens	N	30000	30	30
4	66	M	N	N	14000	25	30
5	68	F	N	Do not drive at night	NR	40	25
6	68	F	Corrective lens	Dislike nighttime driving	5000	20	20
7	70	M	Corrective lens	N	20000	25	30
8	81	M	N	NR	6000	30	25
9	69	M	Mirrors on both sides	N	13000	30	30
10	54	F	Corrective lens	N	5000	20	40
11	76	M	Corrective lens	Avoid nighttime driving	10000	40	25
12	74	M	N	Only drive at night on familiar roads	14000	30	25
13	64	F	N	N	15000	25	25
14	59	F	N	N	2000	20	30
15	64	M	Corrective lens	Use glasses at night	12000	40	30
16	72	M	NR	NR	NR	20	25
17	69	F	N	N	NR	40	20
18	71	F	Corrective lens	N	1000	40	30
19	66	M	Corrective lens	N	10000	40	30
20	60	F	N	N	12000	40	40
21	69	F	N	N	15000	25	20
22	76	F	N	N	13000	25	25
23	72	M	Corrective lens	N	15000	25	20
24	68	F	Corrective lens	N	15000	20	25
25	63	M	Corrective lens	N	20000	20	25
26	61	F	Corrective lens	N	15000	40	25
27	64	M	N	N	18000	15	25
28	63	F	N	N	6000	15	20
29	63	M	N	N	12000	20	20
30	62	M	N	N	25000	30	25

All 30 subjects were at least 55 years of age. Twelve were between ages 55 and 65. The remaining 18 were age 66 or older, with the oldest subject being 81 years of age.

Because legibility is a function of vision, the visual acuity of each test subject was measured using a standard Snellen eye chart at a distance of 20 ft. Two subjects had visual acuity better than 20/20. Nineteen subjects had visual acuity of 20/20 to 20/30. The remaining nine subjects had visual acuity greater than 20/30, but none had visual acuity worse than 20/40.

Contrast sensitivity tests were also conducted using a VisTech VCTS® contrast sensitivity chart at a distance of 3.1 m (10 ft). An advantage of using contrast sensitivity as an independent variable is that it provides a comprehensive measure of visual function across a range of sizes and contrasts that appear in the roadside environment. Only 7 of the 30 subjects were classified as having marginal contrast sensitivity. The remaining 23 were classified as having normal contrast sensitivity.

ENVIRONMENTAL CONDITIONS

No external sign lighting (the type of lighting designed to illuminate overhead signs) was used in this experiment. This area in which the study was performed can be considered rural with low ambient light. No glare sources were present other than that produced from the instrument panel inside the vehicle, which was maintained at the highest setting throughout the experiment. All data were collected under dry conditions (i.e., no rain or dew on the signs).

RESEARCH PROTOCOL

The objective of the experimental plan was to determine the minimum luminance needed to read overhead and street-name signs at legibility indices ranging from 40 ft/inch to 20 ft/inch, in 10-ft/inch intervals. The minimum luminance was needed to accurately determine the MR.

Subjects participating in the study were asked to meet the researchers at Texas A&M University's Riverside Campus. Subjects were asked to wear corrective lenses if they normally wear them while driving.

Upon arriving at the Riverside Campus, the researchers explained the study in general terms and asked the subjects to sign an informed consent waiver. Once the waiver had been signed, the researchers evaluated the subjects' visual acuity and contrast sensitivity at normal indoor luminance levels. These activities occurred inside a building at the Riverside Campus where a room was set up to perform the visual assessments.

Upon completion of the vision tests, the subject drove the test vehicle to the testing area with a researcher in the passenger's seat guiding the subject (approximately 1 mi through the decommissioned air force base). Upon arrival, the researcher read the test instructions and conducted a trial run. This allowed the subject to develop a familiarity with the testing procedure and allowed his/her vision to approach complete adaptation to the darkness.

The testing began with overhead signing. The subject was asked to drive to a specified starting location 640 ft from the sign (legibility index = 40 ft/inch) while using the laser to aim the vehicle. After arriving at the first test location and putting the vehicle in park, the researcher took control of the headlamps using the control box. The headlamps were turned off and the first set of words was installed on the sign. The researcher turned the headlamps on using the lowest illumination setting. The subject was then asked to read the words. If the subject could not read both words correctly, the illumination level was increased one level and the subject was asked to read the words again. This procedure continued until the subject read both words correctly two consecutive times. At this point, the researchers asked the subject to move the test vehicle forward to the next specified testing location associated with a reduction of 10 ft/inch of legibility index (in this case, the distance would be 480 ft or 30 ft/inch). The headlamps were turned off and two new words were installed (the selection of the test words was performed randomly throughout the experiment). The increasing illumination procedure was repeated until the subject consecutively read both words correctly. This procedure was repeated for the specified distances corresponding to legibility indices of 40, 30, and 20 ft/inch. After all of the specified distances corresponding to all of the legibility indices had been tested, the complete procedure was repeated two more times (using a unique randomization of a 15-word set for each subject) to build repetition and thus decrease variability.

After the overhead signs were tested, the same procedure was used to evaluate street-name signs. The one difference was the specified distances associated with the legibility indices. The letter height on the street-name signs was 6 inches and therefore the testing distances were closer than for the overhead sign evaluation. The total evaluation time took about 90 minutes. Figure 15 shows an illustration of the test course. Figures 16 and 17 show pictures of the data collection stimuli for overhead and street-name signs, respectively.

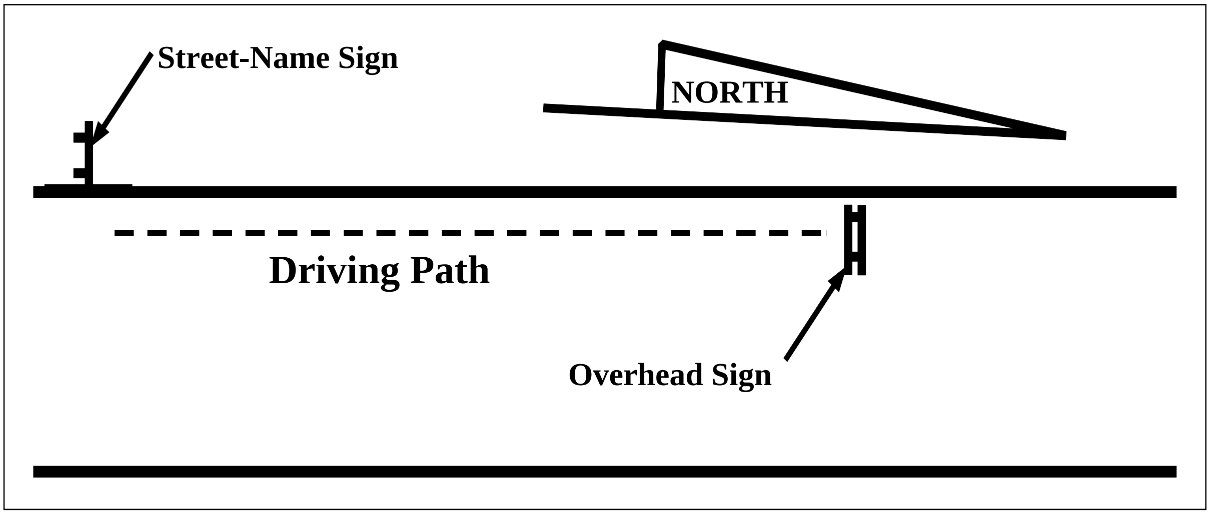

Figure 15. Test Course

Figure 16. Overhead Sign

Figure 17. Street-Name Sign

The researchers recorded the responses at each illumination level, regardless of whether the subject could read the word(s) or not. The researchers also recorded all errors that the subjects made in reading the words.

Once the subjects completed the legibility evaluation, they were escorted back to the vision testing room. The researchers then conducted a brief exit interview and paid the subject for his/her time.

To ensure experimental control, the researchers remeasured the supplied luminance values to verify the repeatability of the initial luminance readings and to ensure that nothing had changed during the evaluations. The readings provided the confidence that nothing had changed during the evaluations.

In other efforts to obtain the best experimental control possible, the test vehicle was dedicated exclusively to this project throughout the duration of the data collection activities. No other individual was permitted to use the vehicle. Furthermore, the test vehicle did not leave the research site. These precautions were implemented to avoid the possibility of anything happening to the vehicle that could have caused headlamp misalignment. In addition, every test subject who participated in the study received the same set of instructions. This included directions to not guess at the legibility of a word. Rather, subjects were asked only to respond when they were reasonably confident in their answer.

RESULTS

In all, 30 subjects completed the study. All but one subject read 18 overhead signs and 9 street-name signs. The one exception was that one subject only read 12 overhead signs (because of time constraints associated with the subject's personal schedule). In total, there were 534 overhead sign observations and 270 street-name sign observations.

The most efficient way to illustrate the resulting data is by cumulative distribution graphs showing how much luminance is needed to accommodate the various percentages of the study sample. Figures 18 and 19 show these cumulative distribution plots for overhead signs and street-name signs, respectively.

Using figures 18 and 19, it is relative easy to develop the luminance values needed to accommodate the various percentages of the study sample (at distances corresponding to the different legibility indices). Table 18 shows the results.

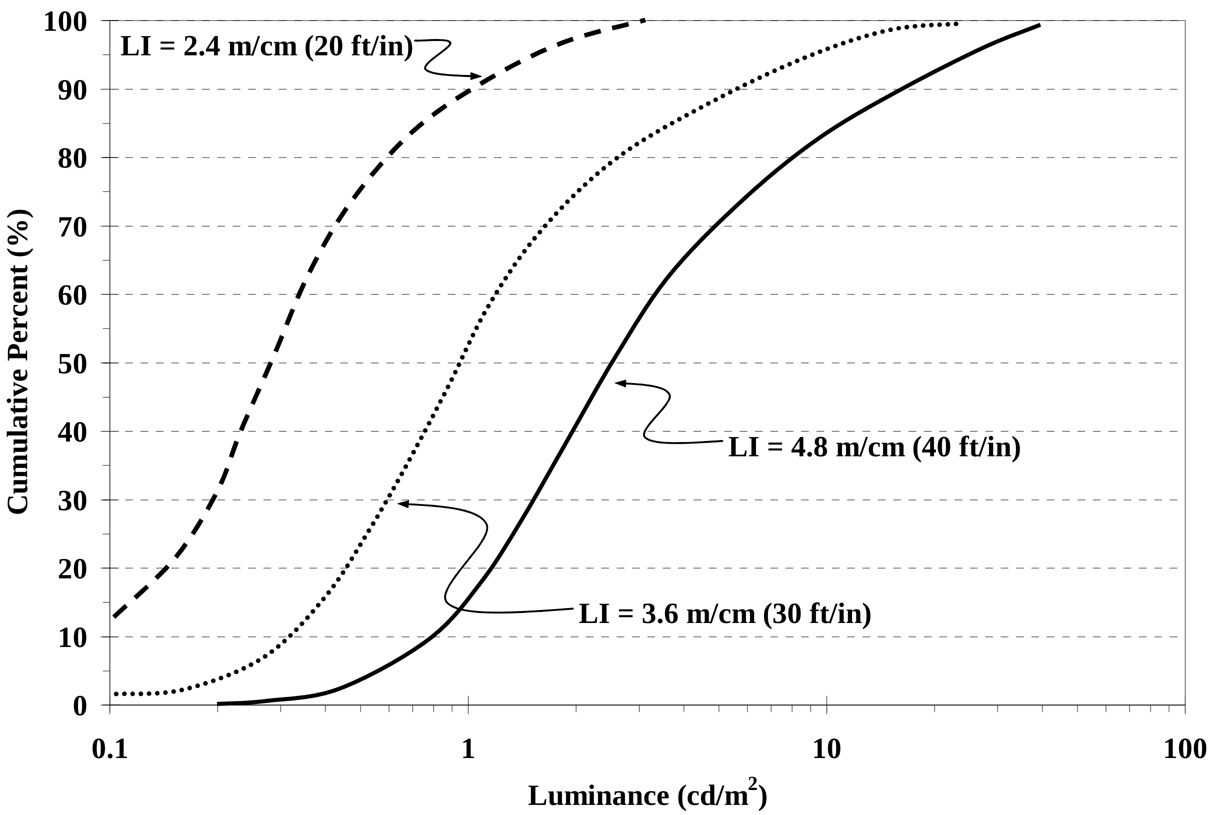

Figure 18. Overhead Sign Results

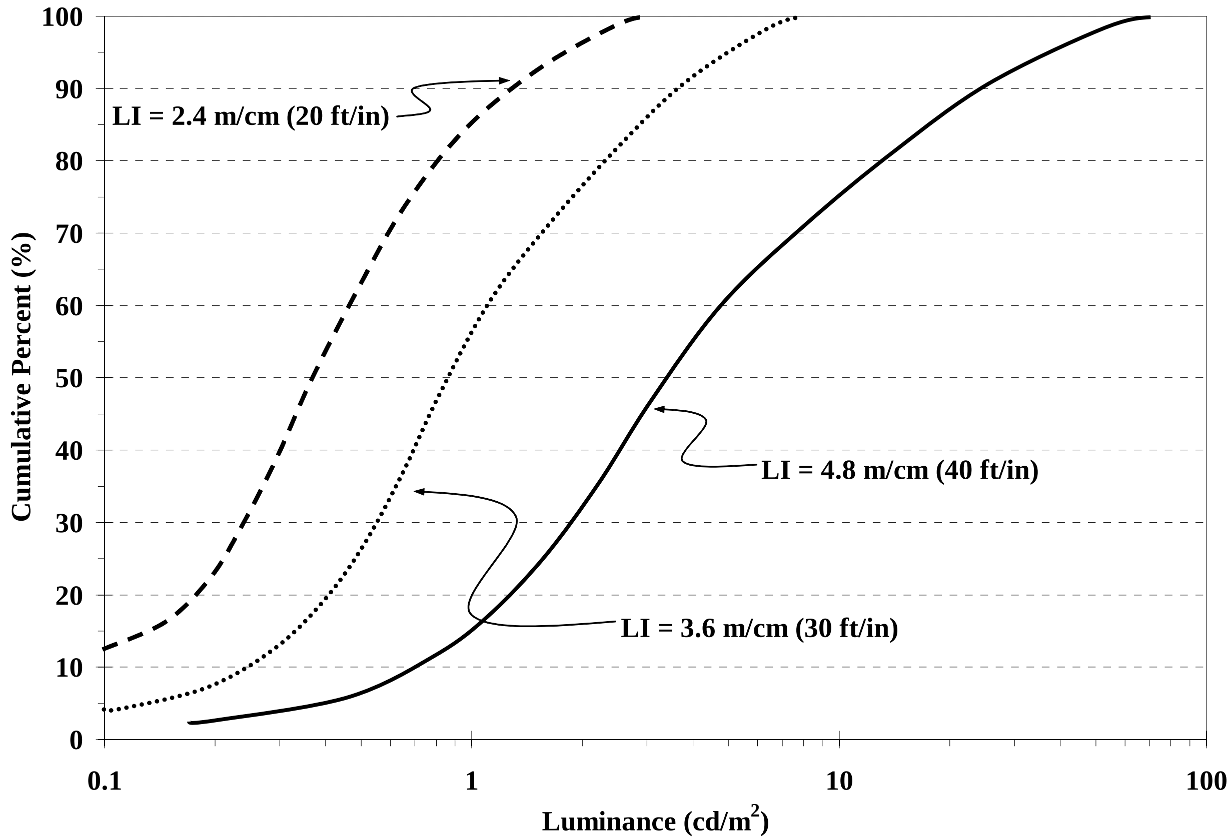

Figure 19. Street-Name Sign Results

Table 18. Threshold Luminance Values by Accommodation Level (cd/m^2)

Accommodation Level (percent)	Overhead Signs[1]			Street-Name Signs[2]		
	Legibility Index (ft/inch)			Legibility Index (ft/inch)		
	20	30	40	20	30	40
10	0.1	0.3	0.8	0.1	0.2	0.8
25	0.1	0.5	1.2	0.3	0.5	1.8
50	0.3	0.9	2.3	0.4	1.0	3.9
75	0.5	1.9	5.7	0.7	1.8	14.1
85	0.8	3.8	11.7	1.0	2.5	20.0
95	1.6	11.7	19.2	1.6	4.7	32.7
98	1.7	16.5	31.5	1.9	5.8	38.0

[1]For white Series E (Modified) 16-inch uppercase and 12-inch lowercase words on a green background
[2]For white Series C 6-inch uppercase words on a green background

However, the data in table 18 are shown as discrete (categorized by the distance corresponding to the legibility index and the letter height) rather than continuous. To determine the minimum luminance at other distances, the data were plotted as a function of distance. This allows interpolation of any distance within the range studied, which corresponds to the legibility index and the letter height. For overhead signs, this corresponds to a range of 320 to 640 ft. For street-name signs, the range is from 120 to 320 ft. Figures 20 and 21 show the results.

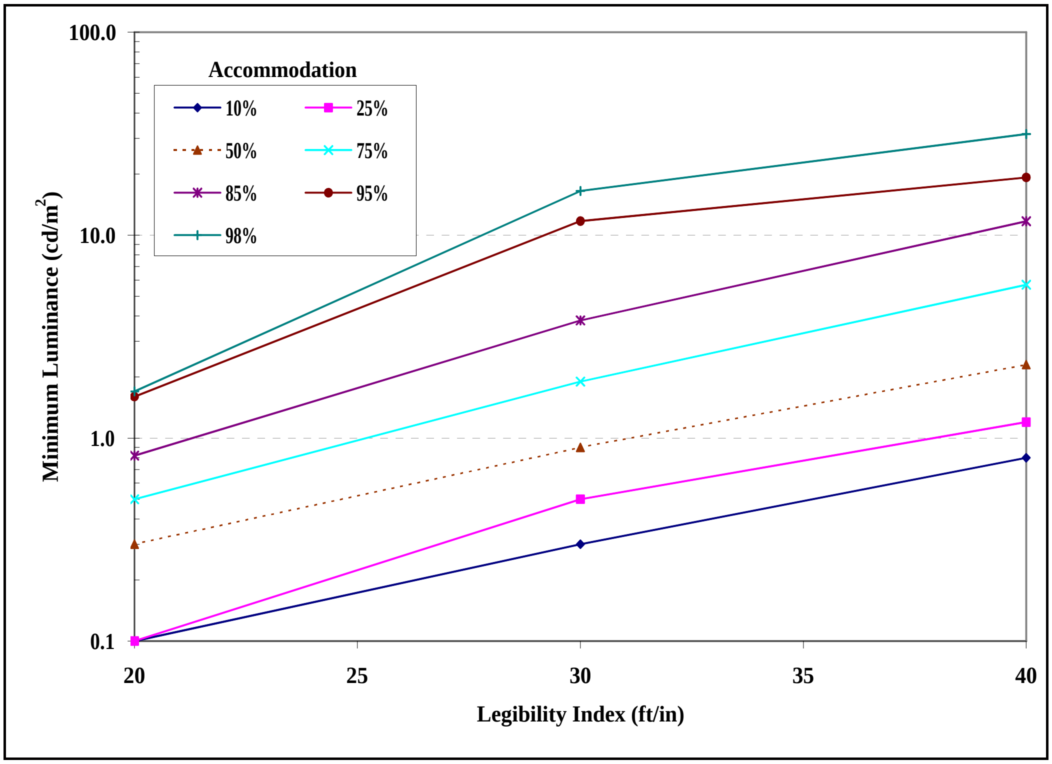

Figure 20. Results for Overhead Signs

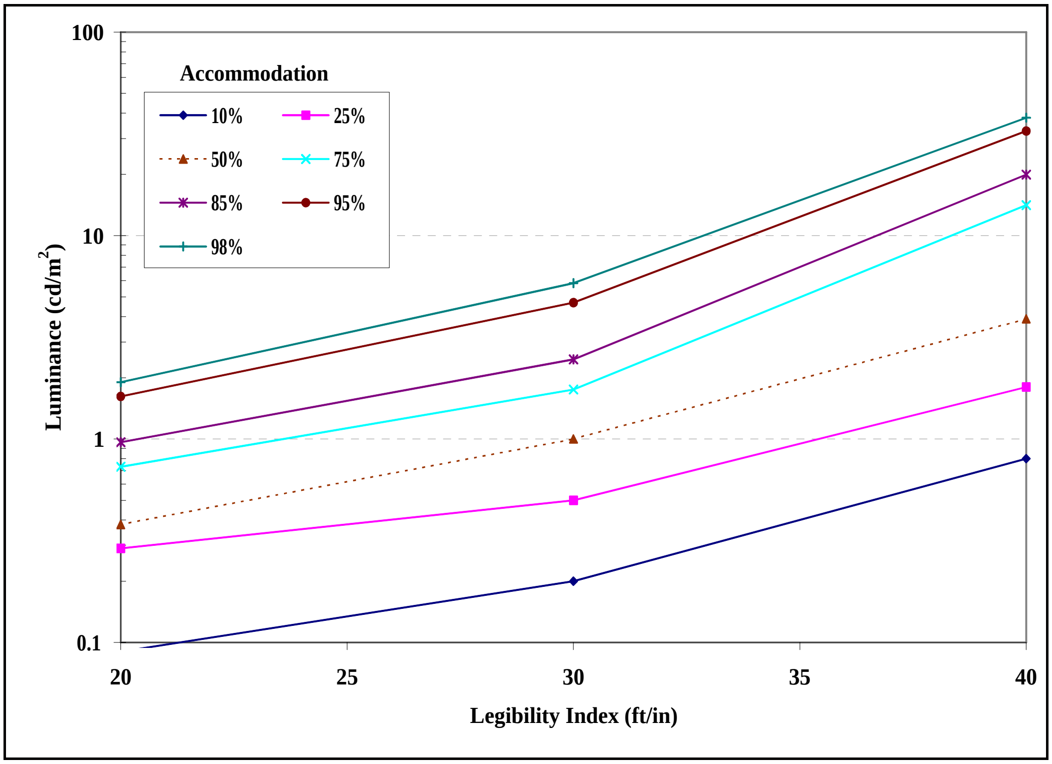

Figure 21. Results for Street-Name Signs

COMPARISON

Probably the most referenced publication related to minimum luminance was by Sivak and Olson, published in 1985.[26] Their work included the geometric means of various luminance studies that had been previously published. They assumed legibility indices of 50 and 40 ft/inch of letter height for younger and older drivers, respectively. Their recommended minimum luminance values are shown in table 19 with the 40-ft/inch results of this study.

Table 19. Replacement Luminance Values

Replacement Level	Sign Luminance (cd/m^2)		
	Sivak & Olson	TTI Overhead	TTI Street Name
85th percentile	16.8	11.7	20.0
75th percentile	7.2	5.7	14.4
50th percentile	2.4	2.3	9.0

The results from the Sivak and Olson work compare well to the findings found herein. For all three replacement levels, the Sivak and Olson luminance criteria fall between the overhead and street-name criteria found as a result of the field studies.

Interestingly, for street-name signs, the results of the study are generally higher than for overhead signs or what Sivak and Olson have recommended. One possible explanation of this was that many subjects repeatedly commented on the difficulty they had reading the street-name signs because of a perceived letter spacing that was too close. They also commented that the all-uppercase design of the street-name signs made it more difficult to read because of the similarity in the word footprints. Had the street-name signs been made with an initial uppercase letter followed by lowercase letters, the threshold luminance values may have been lower.

CHAPTER 6. DATA ANALYSIS

There are a variety of factors that may impact the MR levels for overhead guide signs and street-name signs. Some of the key factors include minimum luminance, the distance which that minimum luminance represents, sign position relative to the driver, type of retroreflective sheeting, headlamp illumination, the accommodation level represented by the minimum luminance, vehicle speed, and vehicle type. Other factors also include the internal contrast of the sign (all signs under study are positive-contrast signs), ambient lighting conditions, and background complexity. This section includes an analysis of these key factors as they relate to MR levels for overhead and street-name signs.

The objective of these analyses is to identify which variables have the most significant impact on the determination of the MR needs. This effort is needed to determine which variables should be considered in the development of the MR levels and, for those variables identified as needing to be considered, which values should be used to develop the MR recommendations.

DISTANCE, SIGN POSITION, AND RETROREFLECTIVE SHEETING

The results of the field evaluations show how sensitive minimum luminance is as it pertains to the distance between the observer and the sign. Specifically, less luminance is needed to read signs as the viewing distance decreases. However, countering the decreased luminance are two factors: increased observation angles and decreased headlamp illumination. Therefore, an understanding of the relationship between these variables is needed to determine where the critical distance is related to MR. For example, at the farthest distance to be studied, the observation angle is small and most signs fall near the hotspot of the headlamp illumination pattern. However, the luminance needed to read the sign at this farthest distance is high. On the other hand, at the shortest distance to be studied, the observation angle is greater and most signs will receive less headlamp illumination. Countering these issues, however, is the decrease in luminance needed to read a sign.

Also, since the sign position is critical to where the sign falls within the headlamp illumination pattern, it is convenient to include sign position in the same analysis as distance. Likewise, it is also convenient to include the different type of retroreflective sheeting in the analysis.

To conduct these analyses, various scenarios were studied for overhead signs, post-mounted street-name signs, and overhead street-name signs. For these analyses, the 50th percentile luminance accommodation level was used as determined from the data collection task (other accommodation levels could be used as well; however, for measuring the sensitivity of the variables under study, it is convenient to use one constant accommodation level). The MR levels shown in these analyses are not final recommendations; rather, they are for the purposes of determining the sensitivity of distance, sign position, and retroreflective sheeting as they relate to MR levels.

Overhead Signs

Table 20 summarizes the MR results for overhead guide signs to accommodate 50 percent of the experimental sample. In all cases and for all types of retroreflective sheeting, the most critical distance is the farthest distance. At this point, even though the observation angle is very small and the sign is located near the hotspot of the headlamp illumination pattern, the distance is overpowering. This is not surprising since light intensity diminishes with the square of the distance between the vehicle and the sign. It should be noted, however, that if one were to consider the required retroreflectivity needed to maintain the threshold luminance levels at a very short distance, there would be a point where the shorter distance would need more retroreflectivity than the longer distance. However, research has shown that drivers last look at a sign about 2.5 to 3.0 s before passing the sign.

Table 20. Initial MR Levels for Overhead Guide Signs (50-Percent Accommodation)

Sign Lateral Position	Distance (ft)	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material					
		I	II	III	VII	VIII	IX
Above inside lane	300	15	15	16	19	13	9
	470	37	37	38	42	37	28
	640	n/a	n/a	119	129	98	85
Above center lane	300	12	12	13	16	11	7
	470	31	32	32	35	32	24
	640	n/a	100	100	100	81	72
Above shoulder lane	300	11	10	11	14	10	6
	470	29	29	30	32	29	22
	640	n/a	89	89	96	73	65

- Sign centroid 9.5 ft above roadway
- Based on modeling performed with CARTS50 headlamps (right and left)
- Straight and level roadway
- Passenger car in center lane

Also, as expected, the most critical overhead signing position shown is when the vehicle is in the center lane of a three-lane highway (with 12-ft lanes) and the sign is positioned above the leftmost lane. If the vehicle were in the rightmost lane, then the MR for an overhead sign above the leftmost lane would be higher than those levels shown. Also, as the number of lanes increase (i.e., offset distance), so does the retroreflectivity needed to maintain the threshold luminance.

The MR levels for different types of sheeting show trends that may indicate that the columns can be collapsed. However, the researchers felt that the different types of sheeting should be kept separate until all of the factors have been considered and the MR model is executed for the final MR runs. At that time, the trends shown in the MR levels were considered for simplification by collapsing the columns.

Post-Mounted Street-Name Signs

Table 21 summarizes the MR results for post-mounted street-name signs to accommodate 50 percent of the experimental sample. For post-mounted street-name signs on two-lane roadways, the most critical distance is the farthest distance (for almost all cases and for all but one type of retroreflective sheeting). Again, as the study distances grow shorter, the retroreflectivity needs will eventually become more demanding because of the increasing severity of the viewing geometry. In fact, there is a good example of this phenomenon shown for the study scenarios for four-lane roadways. More specifically, for type VII sheeting, the shortest distance (120 ft) requires more retroreflectivity than the intermediate distance (180 ft) and the farthest distance (240 ft). However, for all other types of retroreflective sheeting, the farthest distance is the most critical. The exception of type VII sheeting can be explained by its photometric performance under severe viewing geometries. Particularly, the type VII performance falls off rather quickly as the observation angle increases. This is exactly what is happening as the distance between the vehicle and the sign decreases.

Table 21. Initial MR Levels for Post-Mounted Street-Name Signs (50-Percent Accommodation)

Roadway	Sign Lateral Position	Distance (ft)	MR (cd/lx/m²) for Specific ASTM Retroreflective Signing Material					
			I	II	III	VII	VIII	IX
Two-lane	Right side (12 ft from center of travel lane)	120	7	10	19	31	27	6
		180	13	15	20	31	27	8
		240	40	49	55	69	52	26
	Left side (24 ft from center of travel lane)	120	27	30	43	100	52	11
		180	31	31	36	43	45	17
		240	n/a	98	108	130	96	66
Four-lane	Right side (24 ft from center of travel lane)	120	21	15	29	118	60	11
		180	24	24	33	51	42	11
		240	64	70	79	106	77	35
	Left side (36 ft from center of travel lane)	120	36	47	65	195	111	19
		180	68	46	55	69	67	27
		240	n/a	n/a	150	178	133	93

- Sign centroid 9.5 ft above roadway
- Based on modeling performed with CARTS50 headlamps (right and left)
- Straight and level roadway

For both the two-lane and four-lane scenarios, the left shoulder-mounted signs require more retroreflectivity than the right shoulder-mounted signs. Since headlamps are generally aimed to the right, this is not surprising.

Overhead Street-Name Signs

Table 22 summarizes the MR results for overhead street-name signs to accommodate 50 percent of the experimental sample. Similar to the overhead guide signs, for all cases and for all type of retroreflective sheeting, the most critical distance is the farthest distance.

Table 22. Initial MR Levels for Overhead Street-Name Signs (50-Percent Accommodation)

Sign Lateral Position	Distance (ft)	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material					
		I	II	III	VII	VIII	IX
Center of travel lane (0 ft)	195	8	9	11	17	14	5
	260	11	12	13	16	11	8
	320	46	51	53	62	45	36
Right edge of travel lane (6 ft)	195	7	8	10	14	12	5
	260	9	11	12	14	10	6
	320	29	43	45	54	38	29
Right edge of adjacent travel lane (18 ft)	195	10	11	14	18	15	5
	260	13	14	15	19	13	7
	320	43	49	51	65	44	31

- Sign centroid 17 ft above roadway
- Based on modeling performed with CARTS50 headlamps (right and left)
- Straight and level roadway
- Forced to use 195 ft because of vertical limit of CARTS50 headlamp profile (+5.0º)

The aiming of the headlamps slightly to the right causes the overhead street-name sign directly above the vehicle to require more retroreflectivity than signs mounted closer to the shoulder. From the data shown, it can be seen that the sign mounted above the right edgeline is closest to the headlamp illumination hotspot since the retroreflectivity needs are less restrictive. However, as the sign is positioned farther to the right (i.e., closer to the shoulder), the retroreflectivity needs increase, but not to the level that is required when the sign is directly above the vehicle. Again, if the sign were positioned even farther to the right, or to the left of the vehicle centerline, the retroreflectivity needs would be even higher than the levels shown. However, overhead street-name signs are generally not mounted in these locations.

Summary of Sensitivity of Distance, Sign Position, and Retroreflective Sheeting

The sensitivity analyses for distance show that the farthest distance is most critical for nearly all of the scenarios. The only exception is for type VII left-shoulder, post-mounted street-name signs; however, the difference between the retroreflectivity needed at the shorter distance is not that much different from the retroreflectivity needed at the largest distance. Therefore, only the farthest distance needs to be considered in the final development of retroreflectivity recommendations.

Realistic sign positions were tested to determine the impact on MR. As expected, the signs in disadvantaged locations require more retroreflectivity than the signs falling closer to the headlamp illumination hotspot. Therefore, for the final analyses, sign position was maintained as a key variable. After the final analyses were performed, the MR tables were analyzed to determine whether consolidation by sign position was feasible.

All currently available types of retroreflective sheeting were analyzed. While the results show distinguishing trends that indicate that certain types of sheeting can be collapsed into a broader class, it may be useful to keep the sheeting types separate until the final analyses are performed. Then, similarly to sign position, the tables were analyzed to determine whether simplification by sheeting type was feasible. Appendix B provides additional information pertaining to the need to have different retroreflectivity levels for different types of sheeting.

HEADLAMP ILLUMINATION

The previous MR levels for shoulder-mounted signs (excluding street-name signs) were developed based on the CARTS50 headlamp isocandela profile for both the left and right headlamps.[2] Since retroreflectivity levels are directly impacted by headlamps, it is worth investigating how the CARTS50 headlamp profile compares to other published U.S. headlamp profiles and how the isocandela profiles of headlamps from the same vehicle compare.

Left Versus Right Headlamps

One of the first things to consider is the difference between the left and right headlamps. In order to compare the consistency of the light-output distributions for lamps built for the same side of a vehicle and lamps built for the two different sides of a vehicle, UMTRI measured two left headlamps and one right headlamp for each of six vehicles (three in each category). Their results show a high level of consistency for both left versus left and left versus right comparisons, with the maximum correlation for each pair of headlamps being 0.936 or greater. However, the maximum coefficients for the left versus right comparisons (the range over the six vehicles being 0.936 through 0.988) were consistently lower than those for the left versus left comparisons. These results suggest that it is easier to produce similar headlamps of the same design (for a given side of a vehicle) than it is to produce similar headlamps with different designs required by the constraints of available space on different sides of the vehicle. Nonetheless, the UMTRI research indicates that the intensity and distribution differences between the left and right headlamps of the same vehicle are statistically negligible.[61] Consequently, hereafter, it is assumed that there is no significant difference between the left and right headlamps. However, the TTI MR model does have the capability of accounting for the unique left and right headlamp profiles.

Intensity Comparisons

The CARTS50 headlamp profile was developed as part of a National Highway Traffic Safety Administration (NHTSA) study and includes a sample of 26 sealed-beam and replaceable-bulb headlamps commonly used in the United States. It represents the 50th percentile of the bulbs' photometric tables. Most of the vehicles used to develop this profile were manufactured in the late 1980s, with one vehicle from 1990. Although no mention is made in the report by Paniati and Mace, from the isocandela diagram provided in the report, researchers are fairly confident that their profile represents low beams.[2]

Another source of U.S. headlamp profile data is a 1997 UMTRI report.[61] The UMTRI profiles include a sample of 35 low-beam headlamps manufactured for 23 of the best-selling passenger cars, light trucks, and vans for the 1997 model year. At the time, these 23 vehicles represented 45 percent of all vehicles sold in the United States. The photometric information for each lamp was weighted by 1997 sales figures for each corresponding vehicle.

In order to compare how the CARTS50 headlamp performs versus the UMTRI headlamp profiles, tables 23 through 25 were developed for typical overhead, right shoulder-mounted, and left shoulder-mounted sign locations, respectively.

Table 23. Comparison of Headlamp Profiles for Overhead Signs

Headlamp Vector Angles		Left	Right	Centroid height = 25 ft Centroid offset = 0 ft Sign distance = 470 ft	
Headlamp angle: Vertical (degrees)		2.8016	2.8016		
Headlamp angle: Horizontal (degrees)		0.2435	-0.2435		
Headlamp Profile		Illumination (lx)			Source
		Left	Right	Sum	
CARTS50		0.0179	0.0171	0.0350	Doug Mace
Passenger Cars	UMTRI 25th percentile	0.0091	0.0089	0.0180	UMTRI-97-37
	UMTRI 50th percentile	0.0121	0.0129	0.0249	UMTRI-97-37
	UMTRI 75th percentile	0.0156	0.0152	0.0308	UMTRI-97-37
Vans & Light Trucks	UMTRI 25th percentile	0.0091	0.0085	0.0176	UMTRI-97-37
	UMTRI 50th percentile	0.0101	0.0098	0.0199	UMTRI-97-37
	UMTRI 75th percentile	0.0177	0.0176	0.0353	UMTRI-97-37

Table 24. Comparison of Headlamp Profiles For Right-Shoulder-Mounted Signs

Headlamp Vector Angles		Left	Right	Centroid height = 7 ft Centroid offset = 10 ft Sign distance = 375 ft	
Headlamp angle: Vertical (degrees)		0.7639	0.7639		
Headlamp angle: Horizontal (degrees)		2.7478	2.1379		
Headlamp Profile		Illumination (lx)			Source
		Left	Right	Sum	
CARTS50		0.0917	0.0956	0.1873	Doug Mace
Passenger Cars	UMTRI 25th percentile	0.0467	0.0451	0.0918	UMTRI-97-37
	UMTRI 50th percentile	0.1217	0.1167	0.2384	UMTRI-97-37
	UMTRI 75th percentile	0.1916	0.1715	0.3631	UMTRI-97-37
Vans & Light Trucks	UMTRI 25th percentile	0.0813	0.0667	0.1480	UMTRI-97-37
	UMTRI 50th percentile	0.1008	0.0952	0.1960	UMTRI-97-37
	UMTRI 75th percentile	0.1234	0.1562	0.2796	UMTRI-97-37

Table 25. Comparison of Headlamp Profiles for Left-Shoulder-Mounted Signs

Headlamp Vector Angles		Left	Right		
Headlamp angle: Vertical (degrees)		0.7639	0.7639	Centroid height = 7 ft Centroid offset = 11 ft Sign distance = 375 ft	
Headlamp angle: Horizontal (degrees)		-4.1178	-4.7253		
Headlamp Profile		Illumination (lx)			Source
		Left	Right	Sum	
CARTS50		0.0338	0.0320	0.0658	Doug Mace
Passenger Cars	UMTRI 25th percentile	0.0250	0.0228	0.0478	UMTRI-97-37
Passenger Cars	UMTRI 50th percentile	0.0296	0.0274	0.0570	UMTRI-97-37
Passenger Cars	UMTRI 75th percentile	0.0416	0.0370	0.0786	UMTRI-97-37
Vans & Light Trucks	UMTRI 25th percentile	0.0204	0.2017	0.2221	UMTRI-97-37
Vans & Light Trucks	UMTRI 50th percentile	0.0304	0.0280	0.0584	UMTRI-97-37
Vans & Light Trucks	UMTRI 75th percentile	0.0360	0.0318	0.0678	UMTRI-97-37

For overhead signs, the CARTS50 headlamp profile produces illuminances considerably higher than the UMTRI 75th percentile passenger car. Based on an assumption of normally distributed data for the UMTRI headlamps, it can be shown that the CARTS50 headlamp profile produces an UMTRI passenger car profile of approximately 85 percent. For vans and light trucks, the CARTS50 headlamp profile is almost identical to the UMTRI 75th percentile profile. Therefore, for overhead signs, the CARTS50 profile is equal to about a 75th or 85th percentile UMTRI profile, which is interesting since the CARTS50 profile represents a 50th percentile headlamp (albeit, from earlier headlamps).

Discovering that the CARTS50 headlamp provides more overhead illumination than expected (using the UMTRI profiles as measures) may not be surprising since there have been several attempts to harmonize world headlamp profiles, specifically the U.S., European, and Japanese patterns. The goal of the harmonization effort is to develop specifications for one headlamp pattern that satisfy worldwide illumination criteria. In general terms, the U.S. pattern has traditionally provided substantially more light above the horizon than the European and Japanese patterns. However, attempts to harmonize these headlamp patterns have resulted in several compromises among all three patterns. For the U.S. pattern, one of the more significant compromises has been the decreased amount of light above the horizon. In fact, with the 1997 revision to FMVSS 108 allowing VOA headlamps (including both VOL and VOR designs) and the 1999 agreement from the Working Party on Lighting and Light-Signaling of the World Forum for Harmonization of Vehicle Regulations (WP.29) concerning harmonized headlamps (a drastic compromise between the U.S. philosophy of maximizing visibility versus the European philosophy of minimizing glare), the amount of light above the horizon will continue to decrease. A recent report shows comparisons between U.S. conventional headlamps and the VOL, VOR, and harmonized headlamps.[48] For overhead signs at approximately 500 ft, there are consistent trends showing decreased illumination above the horizon. As mentioned in chapter 2, compared to the conventional U.S. headlamps, the VOL headlamp reduces overhead illumination by 28 percent, the VOR headlamp by 18 percent, and the harmonized headlamp by 33 percent.

The data from table 24 for right shoulder-mounted signs indicate that the CARTS50 headlamp profile comes closer to the UMTRI 50th percentile headlamps (compared to the overhead illuminance data). For passenger cars, the CARTS50 illuminance falls between the UMTRI 25th and 50th percentile levels, but is closer to the 50th percentile level. For vans and light trucks, the CARTS50 illuminance is just below the respective UMTRI 50th percentile levels.

The left-shoulder data in table 25 indicate that the CARTS50 headlamp profile represents something between the UMTRI 50th and 75th percentile passenger car headlamp profiles. For vans and light trucks, the CARTS50 illuminance value is nearly the same as the UMTRI 75th value. Therefore, for left shoulder-mounted signs, there appears to be a reasonably good correlation between the CARTS50 headlamp profile and more recent headlamp profiles for passenger cars, vans, and light trucks.

However, it should be noted that none of these headlamp profiles include the latest headlamp designs. For instance, high-intensity discharge (HID) headlamps (such as the xenon headlamps generally found on today's luxury vehicles) were not measured for either the CARTS50 profile or any of the UMTRI profiles. Furthermore, they do not include samples from the newer headlamp styles that have a distinct vertical cutoff designed to aim vehicle headlamps (such as the VOA-style headlamp found on the Taurus used as part of the minimum luminance data collection). Furthermore, these headlamp profiles can be considered ideal. In other words, the headlamps were perfectly aimed when measured under ideal conditions with constant voltage supplies. They do not consider variations introduced from headlamp misalignment, headlamp cleanliness, and vehicle sprung-mass orientation caused by an infinite number of vehicle loads and distributions (such as a passenger car with an overloaded trunk).

Real-World Headlamp Illumination

All of the headlamp analyses presented and discussed thus far have assumed ideal conditions. In other words, the headlamps were new and tested on a goniometer with a constant power supply. Also, the alignment was controlled to be as near perfect as possible. Unfortunately, this does not represent real-world conditions very well.(62) Furthermore, all of the headlamp profiles shown are weighted averages made from a number of headlamp measurements. Therefore, the real-world nature of misaligned and dirty headlamps is not considered, nor are comparisons to individual vehicles or headlamp designs made.

Fortunately, Russell et al., recently completed a study on the need for headlamp illuminance in terms of overhead signs, in which special care was taken to control for pavement glare illuminance.(49) As part of this study, they used 50 known vehicles to measure the illuminance falling on three locations that were typical of overhead-mounted, left shoulder-mounted, and right shoulder-mounted signs. For all vehicle passes, low beams were used. Illuminance data were collected by two illuminance meters (per sign position) equipped with optical occluders to eliminate the illuminance caused by glare off of the pavement surface. The data were collected at distances of 500 and 375 ft. Table 26 summarizes their findings and shows how the modeled CARTS50 and UMTRI headlamp profiles compare.

Table 26. Roadway Illuminance Measurements (in lux)

Distance (ft)	Statistic	Overhead		Right Shoulder		Left Shoulder	
		Meter #1	Meter #2	Meter #1	Meter #2	Meter #1	Meter #2
375	No. of readings	163	66	199	199	197	198
	Minimum	0.021	0.018	0.092	0.063	0.055	0.063
	Average	0.047	0.054	0.205	0.202	0.096	0.101
	Maximum	0.195	0.135	0.413	0.411	0.207	0.349
	Std. dev.	0.034	0.033	0.081	0.082	0.037	0.035
	CARTS50	0.0434		0.1873		0.0658	
	UMTRI 25th PC	0.0246		0.0918		0.0479	
	UMTRI 50th PC	0.0309		0.2384		0.0571	
	UMTRI 75th PC	0.0358		0.3631		0.0787	
	UMTRI 25th V&LT	0.0223		0.1480		0.0406	
	UMTRI 50th V&LT	0.0252		0.1960		0.0584	
	UMTRI 75th V&LT	0.0412		0.2506		0.0678	
500	No. of readings	165	64	198	198	196	199
	Minimum	0.011	0.009	0.058	0.050	0.034	0.049
	Average	0.035	0.042	0.143	0.142	0.068	0.073
	Maximum	0.245	0.081	0.349	0.343	0.150	0.142
	Std. dev.	0.040	0.027	0.066	0.065	0.028	0.027
	CARTS50	0.0330		0.1492		0.0459	
	UMTRI 25th PC	0.0166		0.1056		0.0351	
	UMTRI 50th PC	0.0231		0.1966		0.0434	
	UMTRI 75th PC	0.0299		0.2703		0.0649	
	UMTRI 25th V&LT	0.0160		0.1200		0.0302	
	UMTRI 50th V&LT	0.0193		0.1725		0.0479	
	UMTRI 75th V&LT	0.0334		0.2323		0.0616	

Meter pairs were located at the same position relative to vehicles.
PC = passenger cars, V&LT = vans and light trucks

To determine which of the seven headlamp profiles best replicates the measured illuminance data collected by Russell et al., the percentage differences were calculated. These percentage difference calculations were based on the average of the two mean measured values for each sign position and each respective modeled headlamp value for that position. The percentage differences were then ranked. For both distances shown in table 26, the CARTS50 headlamp was ranked first (i.e., it does the best job of replicating the measured illuminance data provided by Russell et al.). However, it is important to note that there is a poor correlation between the modeled headlamp illuminance and the measured illuminance falling on left shoulder-mounted signs. If the measured data were accurate, then the low CARTS50 data would result in unnecessarily high MR levels for left-shoulder roadside signs (such as left-shoulder, post-mounted street-name signs). This issue is revisited later.

Russell et al., also provide specific headlamp illuminance data for 4 of the 50 known vehicles. These values are shown in table 27 with the CARTS50 values for the same scenarios. For reference, the Mercedes headlamps produced the lowest overhead illumination of the 50 known vehicles, while the 1984 Mazda produced one of the highest overhead illuminance readings. These data provide additional evidence that the CARTS50 headlamp profile does a reasonable job of simulating the 50th percentile headlamp of vehicles found in the United States.

Table 27. Comparison of Specific Vehicles

Distance (ft)	Sign Location[1]	Measured Illuminance (lx)				CARTS50 Illuminance (lx)
		1996 Mercedes[2]	1994 Acura Integra[3]	1996 Ford Taurus[4]	1984 Mazda[5]	
275	Overhead	0.0392	0.0506	0.0578	0.1614	0.0567
	Right shoulder	0.1370	0.1870	0.3470	0.5740	0.2668
	Left shoulder	0.1060	0.0880	0.1460	0.2010	0.1223
375	Overhead	0.0198	0.0327	0.0439	0.1253	0.0433
	Right shoulder	0.0930	0.1290	0.2500	0.4090	0.1943
	Left shoulder	0.0620	0.0610	0.1080	0.1590	0.0805
500	Overhead	0.0108	0.0240	0.0349	0.0798	0.0329
	Right shoulder	0.0610	0.0890	0.1690	0.3460	0.1359
	Left shoulder	0.0420	0.0430	0.0780	0.1380	0.0551

[1]Overhead = center of travel lane, 25 ft height; right shoulder = 10-ft lateral offset from right edgeline, 7 ft height; left shoulder = 11-ft lateral offset from left edgeline, 7 ft height
[2]Xenon composite headlamps
[3]Projector-style headlamps
[4]Halogen composite headlamps
[5]Sealed 2B1 headlamps

Again, the same illuminance trends that existed with the aggregated data (shown in table 26) also exist for the four vehicles shown in table 27. More specifically, the illuminance from the CARTS50 headlamp profile compares well for signs in the overhead and right-shoulder positions, falling between the boundary illuminance values. However, for left-shoulder signs, the CARTS50 headlamp provides illuminance values similar to the minimum values of the four vehicles shown in table 17.

To provide an assessment of how different headlamp profiles and real-world data compare for left shoulder-mounted signs, table 28 was developed using the TTI MR model and available headlamp data.

Table 28. Illuminance Data for Left-Shoulder-Mounted Signs

Headlamp Profile		Distance (ft) 375	Distance (ft) 500	Source
CARTS50		0.0658	0.0459	Doug Mace
Passenger Cars	UMTRI 25th percentile	0.0479	0.0351	UMTRI-97-37
	UMTRI 50th percentile	0.0571	0.0434	UMTRI-97-37
	UMTRI 75th percentile	0.0787	0.0649	UMTRI-97-37
Vans & Light Trucks	UMTRI 25th percentile	0.0406	0.0302	UMTRI-97-37
	UMTRI 50th percentile	0.0584	0.0479	UMTRI-97-37
	UMTRI 75th percentile	0.0678	0.0616	UMTRI-97-37
Real-World Data	Minimum	0.055	0.034	FHWA-RD-98-135
	50th percentile	0.096-0.101	0.068-0.073	FHWA-RD-98-135
	Maximum	0.349	0.150	FHWA-RD-98-135

The illuminance data shown in table 28 provide additional information pertaining to the poor correlation for left-mounted signs between the CARTS50 modeled illuminance and the measured illuminance. For both distances, the CARTS50 illuminance is above the minimum measured values, but not near the lower bounds of the measured 50th percentile. In fact, even the 75th percentile UMTRI illuminance values fall short of the lower bounds of the measured 50th percentile.

Summary of Headlamp Sensitivity

Researchers at UMTRI have studied the differences between the left and right headlamp profiles. They have concluded that there is a strong correlation among headlamps of the same vehicle. Therefore, the same headlamp profile was used for the left and right headlamps in the final runs of the TTI MR model.

Comparisons of various headlamp profiles demonstrate the age of the CARTS50 headlamp profile. For right and left shoulder-mounted signs, the CARTS50 profile performs similarly to the UMTRI passenger car profile and the van and light truck profile. However, for overhead signs, the CARTS50 headlamp provides substantially more illumination above the horizon. In terms of the UMTRI profiles, the CARTS50 profile is equivalent to approximately an 85th percentile passenger car profile and a 75th percentile van and light truck profile. The international headlamp harmonization efforts that are currently underway will probably reduce the amount of overhead illumination even further, especially as the U.S. vehicle fleet turnover rate begins to increase the number of VOA and harmonized headlamps on the road.

On the other hand, comparison of the CARTS50 illuminance values to the real-world data collected by Russell et al., shows that the CARTS50 headlamp profile does an impressive job of simulating real-world illumination values for overhead and right shoulder-mounted signs.

However, for left shoulder-mounted signs, a poor correlation exists between the measured illuminance values and any of the headlamp profiles (including the CARTS50 headlamp profile and the UMTRI profiles).

The consistent results of the CARTS50 headlamp profile as compared to the UMTRI headlamp profiles indicate that there is little reason to suspect that the CARTS50 is outdated, other than perhaps for overhead signs. However, the headlamp used for modeling purposes should replicate real-world data rather than weighted data from more recent headlamp designs. This philosophy accounts for headlamp misalignment, headlamp cleanliness, and variations in the sprung-mass of the vehicles. The data show that the CARTS50 does a good job of replicating the average real-world illuminance measurements for overhead and right shoulder-mounted signs. For left shoulder-mounted signs, CARTS50 compares well with the UMTRI profiles. However, all seven of the headlamp profiles tested produce illuminance values substantially less than the average values measured by Russell et al.

Several options are available to account for the differences in left shoulder-mounted signs. For instance, the difference between the measured illuminance and the modeled illuminance can be used to weight a headlamp profile so that it better replicates the measured values. This modified headlamp profile would only be used for the determination of MR levels for left shoulder-mounted signs. Another option would be to use the headlamp profile that comes closest to the measured illuminance values for left shoulder-mounted signs. In this case, the UMTRI 75th percentile passenger car profile would be the best. However, this profile still falls short of the average of the measured illuminance values. Another option would be to assume that the UMTRI profiles are normally distributed, estimate a standard deviation, and then use that and the 50th percentile profile to develop a profile that better replicates the average measured values. A quick analysis shows that an UMTRI 85th percentile passenger car profile would come close to matching the average measured illuminance. However, all of these methods introduce an element of inconsistency by using different headlamp profiles for signs in different positions.

There is a benefit of using one headlamp profile to determine MR levels. Also, there is evidence for dismissing the measured illuminance values for left shoulder-mounted signs. In particular, for overhead and right shoulder-mounted signs, the average of the measured illuminance values fall within realistic boundaries for all of the headlamp profiles tested. Furthermore, for overhead and right shoulder-mounted signs, there is consistency between the modeled illuminance values from all of the headlamp profiles tested. For left shoulder-mounted signs, the same consistency exists between the modeled illuminance values from all of the headlamp profiles; however, the measured illuminance values are substantially higher than expected. Therefore, these trends can be interpreted to suggest that the measured illuminance values for left shoulder-mounted signs are unreasonably high. If the illuminance meters used by Russell et al., had been rotated from position to position, then additional data would be available to support the reported measurements. However, without additional data, there is no way to verify the accuracy of the measurements. Given the position presented above, it was concluded that the CARTS50 headlamp profile was the most appropriate headlamp to determine the MR levels. It has good correlation with recently measured real-world illuminance values for overhead and right shoulder-mounted signs. Despite the difference between the CARTS50 and the measured real-world illuminance values for left shoulder-mounted signs, there are indications that the measured real-world values may be unreasonably high.

Headlamp technology and specifications are changing. Consequently, the selection of the most appropriate headlamp is dynamic in nature. While the analysis shows that the CARTS50 headlamp does the best job of replicating the measured illuminance values reported by Russell et al. (of the seven headlamp profiles considered), it is important to note that newer headlamps and revised headlamp specifications will eventually lead to the need to reevaluate MR levels. Evidence is provided in the literature that shows a decreased amount of illumination provided to overhead signs with newer headlamps. Furthermore, the data presented in table 23 also indicate the same trend.

For example purposes only, the researchers reran the TTI MR model with the CARTS50 and UMTRI 25th percentile passenger car headlamp profiles for an overhead sign scenario to demonstrate how sensitive the MR levels can be to different headlamp isocandela distributions. The isocandela plots of these headlamps are shown in figure 22 (with the CARTS50 headlamp on top). The MR results are shown for an accommodation level of 50 percent in table 29.

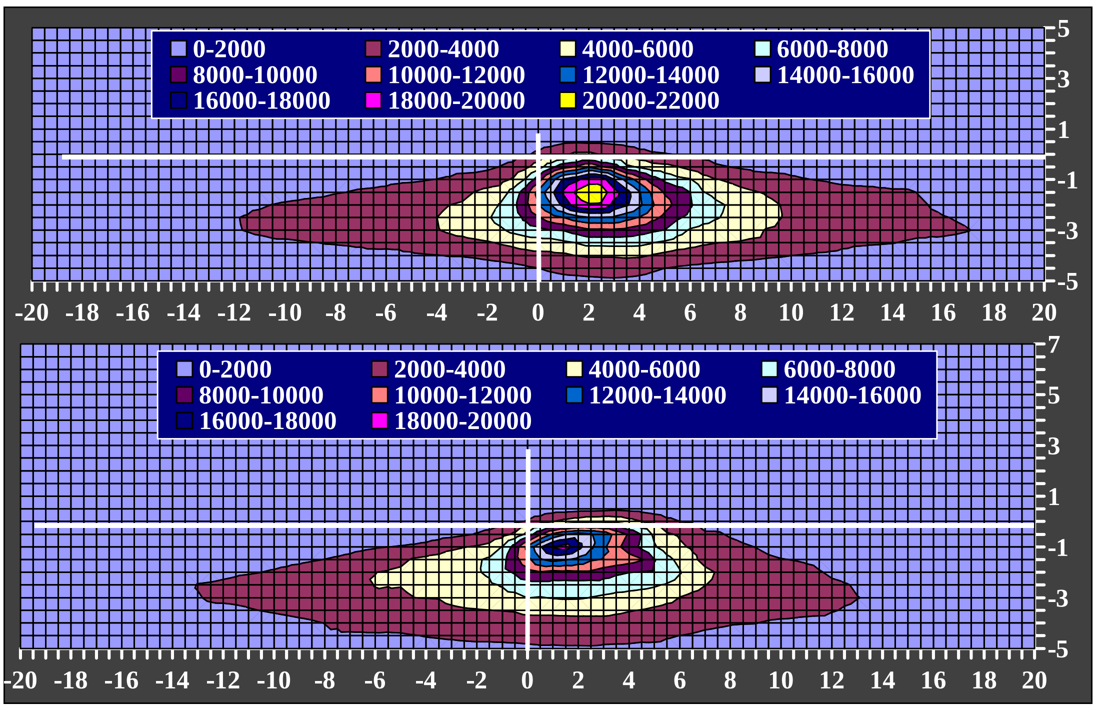

Figure 22. Isocandela Plots of CARTS50 (Top) and UMTRI25PC Headlamp

Table 29. Minimum Overhead Retroreflectivity Levels (50-Percent Accommodation)

Sign Lateral Position	Headlamp Profile	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material					
		Type I	Type II	Type III	Type VII	Type VIII	Type IX
Above inside lane	CARTS50	n/a	n/a	119	129	98	85
	UMTRI 25th PC	n/a	n/a	n/a	245	187	161
Above center lane	CARTS50	n/a	100	100	100	81	72
	UMTRI 25th PC	n/a	n/a	214	230	174	153
Above shoulder lane	CARTS50	n/a	89	89	96	73	65
	UMTRI 25th PC	n/a	n/a	197	213	162	145

- Sign centroid 25 ft above roadway
- Sign 640 ft from vehicle (40 ft/inch of letter height)
- Straight and level roadway
- Passenger car in center lane

This example shows that the impact of the vehicle headlamp can be significant in terms of MR levels. As the vehicle fleet turnover rate catches up with the newer headlamp styles, the MR for signs will need to be reevaluated.

VEHICLE SPEED

Vehicle speed also needs to be considered for the determination of MR levels. Signs have to be bright enough to accommodate typical operating speeds. However, depending on the position of the signs and the maneuver required, final speed and deceleration rates also play an important role.

Since overhead guide signs are typically found on expressways and freeways with operating speeds of 55 mph or greater, the researchers assumed that low-speed roadways would not generally have overhead guide signing. The researchers also decided that the maneuvers are not required from overhead guide signs, because they generally are designed using a series of signs providing ample time to move into the appropriate lane. Therefore, the speed factor for overhead signs was not considered to be a critical factor. However, since retroreflectivity is a function of luminance and luminance is a function of distance, one has to decide at what distance the signs should be legible. The Millennium MUTCD provides a legibility guideline of 40 ft/inch of letter height.[(51)] Using 16-inch uppercase and 12-inch lowercase letters, a distance of 640 ft is reasonable. Therefore, the MR derived for overhead signs was based on providing enough retroreflectivity to read overhead signs at 640 ft. Depending on the approach speed, this philosophy provides different reading times. For the worst-case scenario, an operating speed of 70 mph was assumed. With a last-look distance based on 3.5 s, the process provides the driver with 280 ft of legibility, or 2.7 s to read an overhead sign. For 55-mph approach speeds, drivers will have approximately 4.4 s to read an overhead sign. It should be noted that legibility distances associated with 40 ft/inch of letter height is generally unobtainable with older subjects, as many studies have shown. However, younger drivers normally exceed the legibility distances equivalent to 40 ft/inch of letter height.

For street-name signs, a supply-and-demand analysis was used. A range of distances was considered that were derived from approach speeds ranging from 20 to 70 mph in 5-mph increments. This exercise was done in order to study the sensitivity of MR as a function of approach speed.

The concept for post-mounted street-name signs included an "expected event" PIEV time (or total time required to perceive and react to a situation as referred to in the MUTCD as the combination of the perception, identification, emotion, and volition times) for older drivers of 0.66 s.[44] It was also assumed that the motorist does not stop, but rather decelerates to a speed of 5 mph to negotiate the turning maneuver. The stopping sight-distance deceleration rate of 11.2 ft/s^2 (for all speeds) from the 2001 American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets, 4th Edition* (Green Book) was used to determine the distances needed based on the approach speed. These distances are the demand distances; in other words, this is the distance needed, based on the provided assumptions, to negotiate the maneuver.

For overhead street-name signs, the process was the same as for the post-mounted street-name signs except that the assumptions were modified. The PIEV time was raised to 1.0 s to account for the visual clutter associated with the signal head's proximity to the sign and the usual urban conditions in the background. Because mast-arm signs are usually located at signalized intersections, the assumed maneuver was a stop. Therefore, the demand distances were based on the approach speed and the deceleration rate needed to come to a complete stop.

The supply distances were determined using typical letter heights of 6 inches for post-mounted street-name signs and 8 inches for overhead street-name signs, and a legibility index of 40 ft/inch of letter height. Using this basic philosophy, post-mounted street-name signs supply 240 ft of legibility distance and overhead street-name signs supply 320 ft of legibility distance.

Next, for each 5-mph increment, the demand and supply distances were compared. For higher approach speeds, the demand distances needed to decelerate and make a turning maneuver are greater than what can be supplied (assuming a legibility index of 40 ft/inch of letter height). For those speeds, the researchers used the same philosophy as that used for the design of MR for overhead guide signs. Specifically, determine the MR that will provide the legibility equivalent to a legibility index of 40 ft/inch of letter height. This results in a distance of 240 ft for post-mounted street-name signs and 320 ft for overhead street-name signs.

The breakpoint in the supply-and-demand relationship differs between post-mounted and overhead street-name signs. For post-mounted street-name signs with speeds of 30 mph and less, the supply distance is greater than the demand distance. For overhead signs, the breakpoint is 35 mph.

For approach speeds that result in demand distances that are less than the supply distances of 240 or 320 ft (for post-mounted and overhead signs, respectively), the researchers determined the critical distance by taking the average demand distance of all speeds equal to and less than the breakpoint. This philosophy ultimately reduces the retroreflectivity requirements for street-name signs on lower speed roadways. For post-mounted signs, a distance of 140 ft was used to model the MR, instead of 240 ft for speeds of 35 mph and greater. For overhead street-name signs, the breakpoint was 35 mph with a distance of 200 ft.

VEHICLE TYPE

A surface that is retroreflective (e.g., the face of traffic signs) directs light back to its source. However, there is some dispersion of the light. Besides the small amount that is either absorbed or diffusely reflected as the light enters and then exits the protective film on the outside of retroreflective sheeting, the majority is directed back toward the source. The intensity of the redirected light varies as the observation angle is increased. Near the source, with a small observation angle, the redirected light is very intense. However, as the observation angle increases, the redirected light gradually diminishes. Furthermore, each type of retroreflective sheeting has unique performance curves associated with observation angles.

One of the factors that controls the observation angle is the type of vehicle from which a traffic sign is viewed. The vehicle type can have a strong impact on the headlamp height and the driver's eye position. FMVSS 108 specifies a vertical headlamp range with which all vehicles sold in the United States must comply. However, there are limited controls on how the cabins of vehicles are designed. For instance, the cabins (more specifically, the driver's seat position) of passenger cars are generally designed to be low to the ground. This results in a relatively small vertical difference between the headlamp and the driver's eyes, depending on the size of the driver. Vehicles such as light trucks and sport utility vehicles (SUVs) are designed to ride higher than passenger cars. The vertical difference between the headlamps and the driver's eyes is somewhat greater than that for passenger cars. The worst-case scenario is large trucks. They also have to satisfy FMVSS 108's headlamp height requirements. However, their cabin is designed to sit relatively high. Therefore, the difference between the headlamps and the driver's eyes is also great.

This means that a driver with specific visual capabilities, and all else constant, will receive decreased amounts of redirected (retroreflected) light from a traffic sign as they move from a vehicle with small differences between the headlamp and the eye height to a vehicle with large differences between the headlamp and the eye height. In other words, for a given scenario, that same driver may be able to easily read a sign in a passenger car. For the same driver and scenario, the driver may just barely be able to read the sign in an SUV. Again, for the same conditions, the driver may not be able to read the sign from a large truck.

There have been numerous attempts to define specific measurements for typical vehicles of different classifications (e.g., passenger cars, light trucks, large trucks, motorcycles, etc.). Table 30 illustrates the various headlamp and driver's eye height dimensions used by previous research (other dimensions needed for retroreflectivity modeling include the lateral distance from the headlamp center to the vehicle centerline, the lateral distance from the driver's eye location to the vehicle centerline, and the longitudinal distance between the headlamps and the driver's eye).

For the MR numbers shown thus far, the CARTS passenger car dimensions have been used. To demonstrate the impact of other vehicles, we executed the TTI MR model using two additional vehicles (UMTRI's light truck and Sivak's heavy truck). The results are shown in table 31.

Table 30. Vehicle Dimensions

Source	Headlamp Height (ft)	Driver's Eye Height (ft)
Passenger car [2]	2.00	3.50
Passenger car [62]	2.03	3.64
Passenger car [44]	2.13	3.77
Light trucks and vans [62]	2.72	4.66
Multipurpose vehicle [44]	2.76	4.86
Heavy truck [44]	3.68	8.03

Table 31. Vehicle Impacts on Overhead Guide Sign MR Levels

Sign Lateral Position	Vehicle Type	MR (cd/lx/m^2) for Specific ASTM Retroreflective Signing Material					
		Type I	Type II	Type III	Type VII	Type VIII	Type IX
Above inside lane	PC	n/a	n/a	119	129	98	85
	V&LT	n/a	n/a	153	173	132	110
	HT*	n/a	n/a	n/a	407	329	141
Above center lane	PC	n/a	100	100	100	81	72
	V&LT	n/a	n/a	127	143	108	91
	HT	n/a	n/a	n/a	338	273	118
Above shoulder lane	PC	n/a	89	89	96	73	65
	V&LT	n/a	110	112	126	95	80
	HT	n/a	n/a	n/a	299	243	103

- Sign centroid 25 ft above roadway
- Sign 640 ft from vehicle
- Based on the 50th percentile luminance accommodation level for overhead signs (2.3 cd/m^2)
- Straight and level roadway
- Vehicle in center lane

*HT = heavy truck

As expected, the retroreflectivity demand increases as the distance between the headlamp and the driver's eye height increases, which is controlled by vehicle type. For large trucks, only the microprismatic materials are able to provide the 50th percentile threshold luminance of 2.3 cd/m^2. However, for passenger cars and overhead signs located above the travel lane, type II sheeting provides adequate luminance, albeit, just barely.

Of course, retroreflectivity is exclusively a nighttime element of traffic signs. Therefore, in order to adequately select a design vehicle, one would need to know the distribution of vehicles on the road at night. To be even more precise, it would be nice to know the ages of the drivers in those nighttime vehicles. For instance, there is probably little doubt that older drivers are more likely to be found driving passenger cars than large trucks. However, these data are not currently available. Without such data, it is difficult to select the most appropriate design vehicle.

The CARTS passenger car was used for the final runs of the TTI MR model. There is little evidence to indicate the use of something other than the CARTS passenger car. The other referenced dimensions for passenger cars (shown in table 30) indicate that the CARTS passenger car is a reasonable replication of passenger cars. Furthermore, the previous MR levels developed by research under Paniati and Mace used the CARTS passenger car.[2] When larger vehicles are used (e.g., a light truck or a heavy truck), the MR levels increase. These data may prove to be useful for an agency wishing to design signs for a facility with a large proportion of truck traffic.

LUMINANCE ACCOMMODATION LEVELS

As shown by the results of the data collection (see figures 18 and 19), the minimum luminance needed to read signs is highly dependent on the level of accommodation chosen. Because MR is a direct function of luminance, the MR levels will also be highly dependent on the level of accommodation chosen.

It should be noted, however, that the data collection included only older drivers (age 55 and older). Therefore, the accommodation levels shown as a result of the data collection are somewhat misleading. For instance, when the minimum luminance levels of the 85^{th} percentile are shown, this is really the minimum luminance needed to accommodate 85 percent of drivers age 55 and older. However, there is little doubt that the largest population of drivers found on unfamiliar roads at night (when the legibility of road signs is of the utmost importance) is younger than age 55.

There are numerous research reports showing that younger drivers need less luminance to read traffic signs at night than older drivers, all else being constant.[63-65] Although the correlation varies with age and individual visual capabilities, in general, younger drivers need about 70 to 75 percent of the luminance required by older drivers (to read traffic signs). Therefore, it can be assumed that luminance levels that accommodate a driver of a certain age also accommodate younger drivers.

An example is provided to show how the accommodation levels acquired herein can be misleading. If one assumes that 75 percent of the nighttime drivers are younger than age 55 and the remainder are age 55 or older, and the MR levels are based on the 85^{th} percentile luminance levels derived herein, then a more accurate accommodation level is actually $75 + [(85/100) \times 25] = 96.25$ percent.

Unfortunately, data related to nighttime driver age are unavailable, especially data for nighttime drivers on unfamiliar roads. Furthermore, there has been a substantial effort in recent years to accommodate the aging population in the United States. Therefore, the accommodation levels acquired through the data collection effort conducted as part of this research project will be used to generate MR levels. This will ensure that the older population is duly considered and will provide actual accommodation levels that surpass the design levels. Additionally, a margin of safety will be inherently introduced into the determination of the MR levels.

CHAPTER 7. INITIAL RECOMMENDATIONS

Using the results of the data analysis described in chapter 6, the final runs of the TTI MR model were made. These runs resulted in a total of five tables that included the factors considered in this research. The sensitivity analyses demonstrated that there were three particular factors that could not be comfortably narrowed down. Therefore, for the convenience of field use, the tables were consolidated.

One of the first items considered was the accommodation level. As explained in the sensitivity analyses, the accommodation levels used herein represent drivers age 55 and older. Because of this, the accommodation levels do not represent the entire population of nighttime drivers. However, data are not available that detail the age distribution of nighttime drivers. With the assumptions that 75 percent of nighttime drivers are younger than age 55 and that younger drivers need less luminance than older drivers to read traffic signs, an accommodation level of 50 percent for the data collected herein actually translates to an accommodation level of $75 + [(50/100) \times 25] = 87.5$ percent for the population of nighttime drivers. This correlates well with the 85th percentile accommodation level for which the previous MR levels were designed. Therefore, the consolidation efforts are based on an accommodation level of 50 percent for older drivers.

Another item considered for consolidation was the sign position relative to the vehicle position. For overhead signs, the MR levels were chosen to represent a sign positioned above the left adjacent lane of the travel lanes. It was assumed that low-speed, post-mounted street-name signs are mostly found on local, two-lane roads. For high-speed, post-mounted street-name signs, it was assumed that the driver turning right was in the appropriate lane and used the two-lane road levels. However, for the driver turning left on a high-speed roadway, it was assumed that the road is either a two-lane highway with shoulders or a four-lane arterial/collector without shoulders, both cases providing substantial offset, justifying the use of the multilane levels. Finally, for overhead street-name signs, the MR levels were chosen to represent a sign positioned directly above the travel lane. It was assumed that most drivers realize that they are in the vicinity of where they need to turn and are therefore in the appropriate lane.

Other consolidation efforts included rounding the MR levels for overhead and street-name signs to the nearest integer divisible by five, again for convenience in field applications. Once the rounding off was completed, an effort was made to consider the feasibility of consolidating the various types of retroreflectivity sheeting. In general, the MR requirements for beaded sheeting increase slightly, but consistently, as the sheeting type is increased from types I through III. Therefore, for beaded sheeting, the levels for type II sheeting were used to represent all beaded sheeting (with the few exceptions indicated in the following tables). For microprismatic materials, the trends are less uniform and less consistent. Therefore, consolidation among microprismatic materials was not conducted.

MR levels for the green backgrounds were obtained by calculating the percentage difference between the retroreflectivity of new unweathered white sheeting and the minimum levels as determined through this research for each type of sheeting. The percentage difference was then applied to the retroreflectivity of new unweathered green sheeting. The value was then rounded to the nearest integer divisible by five. This allows the legend and the background of signs made of the same sheeting to degrade at the same rate, allowing agencies to schedule sign replacement activities based on the degradation of one single material. Table 32 shows the values used for new unweathered sheeting.

Table 32. Average R_A of New Unweathered Sheeting

ASTM Type	Retroreflectivity ($cd/lx/m^2$)	
	White	**Green**
I	100	20
II	175	34
III	315	55
VII	1100	145
VIII	800	120
IX	450	80
Note: R_A values at $\alpha = 0.2^o$ and $\beta = -4.0^o$		

The MR levels presented are meant to be applied to typical roadway sections. They would need to be adjusted for areas with complex backgrounds, roads with a high predominance of large trucks, or frequent severe road curvature; however, there has not been a sufficient amount of research conducted to determine the extent of these adjustments. The MR levels are shown in $cd/lx/m^2$ and represent the standard measurement geometry of an observation angle of 0.2º and an entrance angle of -4.0º.

Table 33 presents the initial recommendations for overhead guide signs, table 34 presents the initial recommendations for post-mounted street-name sign levels, and table 35 presents the initial recommendations for overhead street-name levels. The following chapter summarizes additional research that resulted in recommendations that superseded those in tables 33 through 35.

Table 33. Overhead Guide Signs

Color	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material				
	I or II	**III**	**VII**	**VIII**	**IX**
White	Do not use	120	130	100	85
Green	15	20	20	15	15
Recommendations in this table are superseded by those in table 40.					

Table 34. Post-Mounted Street-Name Signs

Speed (mph)	Sign Lateral Position	Color	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material			
			I, II, or III	VII	VIII	IX
> 35	Right side	White	50	70	55	25
		Green	10	10	10	5
	Left side	White	155*	180	140	100
		Green	25*	25	20	20
< 35	Right side	White	15	45	30	10
		Green	5	5	5	5
	Left side	White	30	65	50	15
		Green	5	10	10	5
*Types I and II should not be used for this scenario.						
Recommendations in this table are superseded by those in table 40.						

Table 35. Overhead Street-Name Signs

Speed (mph)	Color	MR ($cd/lx/m^2$) for Specific ASTM Retroreflective Signing Material			
		I, II, or III	VII	VIII	IX
> 40	White	50	65	45	40
	Green	10	10	10	10
< 40	White	10	15	15	10
	Green	5	5	5	5
Note: Includes street signs mounted on a mast arm or span wire.					
Recommendations in this table are superseded by those in table 40.					

CHAPTER 8. FOLLOWUP RESEARCH

The completion of the research activities and findings described in the previous seven chapters convinced the researchers that a significant amount of work was still needed before the MR levels were ready for implementation. During the American Traffic Safety Services Association (ATSSA) Traffic Expo in Fort Lauderdale, FL, in 2001, the researchers presented their concerns to FHWA. The concerns were focused on the investigation and sensitivity of updated factors such as the driver's age, headlamps, vehicle type, and an inventory of available retroreflective sheeting materials and their performance levels. By summer 2001, the researchers were under contract to address the identified concerns. Since then, the researchers have addressed the concerns and developed an updated set of MR levels for traffic signs.[66-67] This chapter summarizes the research that was conducted from summer 2001 to the end of 2002. However, it is specifically focused on the updated MR levels for overhead guide signs and street-name signs.

UPDATED FACTORS

The work that was done to update the MR levels was based on the concerns mentioned above. A summary of the decisions that were made is included in this chapter. The complete details are discussed elsewhere.[66-67]

One of the first issues that was addressed during the research to update the MR levels was the assumed visual capabilities of the driver. After studying the effect of changing the assumed nighttime needs of the driver, the researchers and FHWA decided that the thresholds assumed in the earlier chapters of this report are reasonable. More specifically, it was decided that the assumed demand minimum legibility luminance thresholds derived from the median accommodation levels of drivers age 55 and older were reasonable in terms of defining a visibility metric. The additional research also led to the discovery of additional data, which allowed the researchers to generate a better estimate of the actual accommodation level of nighttime drivers that is inferred by the previously stated assumptions. The result of the additional data revealed that the actual nighttime accommodation level corresponds to levels well above 90 percent (89 percent of the nighttime driving population plus 50 percent of the nighttime drivers older than the age 55 threshold). Generally, this process results in visual capabilities approximating a 62- to 65-year-old nighttime driver.

Additional analysis on headlamp profiles and their effect on nighttime sign luminance led the researchers to recommend an updated headlamp for modeling MR levels. The updated headlamp profile takes into account many of the changes that have occurred in the headlamp and automotive industries over the past decades. The researchers also studied additional headlamp sources, including the latest headlamp trend–HID headlamps. Based on the inconclusive results of some of the analyses and the slow implementation of HID headlamps on new vehicles sold in the United States, UMTRI's U.S. low-beam 50th percentile profile for the 2000 model year vehicles was selected for establishing updated MR levels for traffic signs.[68] However, it is important to note that as the technologies, specifications, and the composition of the vehicle fleet evolve, there will be a need to revisit the headlamp issues associated with the development of MR.

Prior to the work described herein to update the MR levels for traffic signs, all MR research used vehicle dimensions representing a large passenger sedan. However, U.S. model year 1999 vehicle sales statistics show that for the first time since records have been maintained, trucks (defined as pickups, SUVs, and minivans) outsold cars. (For that year, trucks had about 50.1 percent of the new vehicle market versus 49.9 percent for cars.) This trend has continued through 2001 (the last year of available data). The most recent data from J.D. Power and Associates representing vehicle sales in the United States for the first quarter of 2003 show that the trend for larger vehicles still continues in the United States.[(69)] The top three best-selling vehicles were full-size pickup trucks and less than 50 percent of the combined vehicle sales were passenger cars. Over the last decade, the number of registered passenger cars decreased by 0.1 percent, while the percentage of trucks has increased more than 60 percent.[(70)] Based on these data, the researchers decided to use an updated vehicle that better represents the trends in the U.S. vehicle fleet. This decision was also made because it provides no compromises in terms of reducing nighttime visibility. Vehicles such as passenger cars generally have headlamp and seating arrangements that result in smaller observation angles compared to larger vehicles such as trucks, and the performance of retroreflective sheeting increases as the observation angle decreases.

In November 2001, researchers measured the pertinent dimensions of the top 10 best-selling light trucks, minivans, and SUVs for model year 2000. The results were averaged to develop a set of dimensions representing a typical light truck/minivan/SUV that could be used to develop MR levels. The overall impact of this change is a larger observation angle associated with the vehicle dimensions (see table 36).

Table 36. Updated Vehicle Dimensions

Vehicle Description	Headlamp Height	Driver's Eye Height	Headlamp Separation	Driver's Eye Setback	Driver's Eye Offset
Averaged truck/minivan/SUV (inches)	33.5	58.1	52.6	86.4	15.8
CARTS passenger car (inches)	24	42	48	54	18

Additional work was completed to determine the assumptions related to retroreflective sheeting performance as it weathers. Preliminary analyses indicated that the assumption of constant degradation rates in observation profiles within specific sheeting types was only valid for materials using glass beads as their retroreflective element. The findings for materials using microprisms as their retroreflective elements were inconclusive, but did show the need for additional research. Ultimately, it was decided that the retroreflectivity data from the computer program ERGO would be the most reasonable and complete set of data to use in the calculations of the MR levels. However, it is clear that additional retroreflectivity data sets need to be available in the public domain.

DATA ANALYSIS

This section describes the analyses that were conducted to develop a preliminary set of updated MR levels for guide signs and street-name signs. It includes the demand luminance criteria and other related conditions that were used to establish the MR levels.

Overhead Guide Signs

Using the updated factors as described above, overhead guide signs were assumed to be located at fixed positions corresponding to typical State DOT practices. The overhead sign was positioned with a centroid 25 ft above the pavement surface and offset 18 ft to the left of the right edgeline of the travel lane (i.e., centered above the left adjacent lane).

Using the demand luminance data determined from the human factors task of this research, the MR levels for overhead guide signs were based on demand luminance values of 2.3 and 3.2 cd/m^2 for the 55-year-old and 65-year-old driver data sets, respectively. The corresponding MR levels needed to satisfy these demand luminance values are shown in table 37. It is important to note that the demand luminance values and, therefore, the MR levels shown in table 37 represent the white legend for white-on-green signs.

The MR levels for the green background were determined by first calculating a white-to-green color ratio using the retroreflectivity standards shown in ASTM D4956.[(5)] Then, the white-to-green color ratio was multiplied by the MR levels shown in table 37, which are for the white part of the guide signs. This same process was used for all positive-contrast signs.

Table 37. Initial MR Levels for Overhead Guide Signs ($cd/lx/m^2$)

Position	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Overhead	Any	55			290	290	250	230
		65				400	350	320

- Retroreflectivity ($cd/lx/m^2$) at observation angle = 0.2E and entrance angle = -4.0E
- Represents only the white legend of white-on-green signs
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

Street-Name Signs

Because street-name signs are installed in somewhat unique positions compared to other white-on-green signs, the researchers felt that they warranted a dedicated analysis. Two street-name sign positions were analyzed. One was a right-shoulder mounting and the other was an overhead mounting.

The size of the legends of the street-name signs was varied depending on the speed of the roadway under consideration. In general, FHWA's proposed recommendations for the second revision of the Millennium MUTCD were used to select letter height as a function of speed. Table 38 provides a summary of the letter heights used for different speed ranges and the distances resulting from the application of the 40 ft/inch of letter height legibility concept.

Table 38. Assumed Characteristics and Criteria for Street-Name Signs

Position	Ground	Ground	Ground	Overhead
Speed (mph)	>40	30–40	#25	Any
Letter height (inches)	8	6	4	12
MRVD (ft)	320	240	160	480

Both types of street-name signs were assumed to be located at positions corresponding to typical practices. The centroid height of the ground-mounted street-name sign was assumed to be 9 ft above the pavement surface (which is based on the assumption that it is located on top of a STOP sign) with an offset of 6 ft from the right edgeline of the travel lane. The overhead street-name sign was assumed to be located on a signal mast arm or span wire and was therefore positioned 18 ft above the pavement surface and centered above the travel lane.

The TTI demand luminance data for street-name signs were used to determine the initial MR levels for street-name signs. Therefore, the demand luminance values were 3.9 and 6.9 cd/m^2 for the 55-year-old and 65-year-old driver data sets, respectively. Table 39 shows the preliminary set of updated MR levels associated with these criteria.

Table 39. Initial MR Levels for Street-Name Signs (cd/lx/m^2)

Position	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Ground	>40	55		140	145	180	140	70
		65			255	315	245	120
	30-40	55			240	290	285	80
		65		170	210	255	250	70
	#25	55				710	660	135
		65						240
Overhead	Any	55			265	290	225	195
		65				510	400	340

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E
- Represents only the white legend of white-on-green signs
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

RECOMMENDATIONS

During summer 2002, FHWA conducted a second round of national workshops dedicated to the MR concept (the first set of workshops was held in 1995). A total of four workshops were held in Lakewood, CO; Hudson, WI; College Station, TX; and Hanover, MD.[71] The goal of the workshops was to solicit comments from public agencies regarding the implementation of minimum inservice retroreflectivity guidelines for traffic signs. During the workshops, draft MUTCD language for section 2A.09 was presented and revisions were suggested by the workshop participants. The workshops also included a nighttime demonstration of a variety of signs at various levels of retroreflectivity. The most current research recommendations regarding the MR levels were presented and discussed (as the workshops were conducted, the research regarding the updated MR levels progressed). One of the most consistently and frequently heard comments during the four national MR workshops held during summer 2002 was that the MR levels need to be easy to manage and implement. The results of the workshops will be used by FHWA to draft the MUTCD language used in the rulemaking process for the MR levels.

The recommended MR levels resulting from the work summarized in this chapter are shown in table 40. Table 40 also includes consideration of other white-on-green signs such as destination and distance signs and shoulder-mounted guide signs. The MR levels shown in table 40 represent the most current research recommendations, but are limited to the current knowledge of the nighttime requirements for traffic signs. It should be noted that, because of the limitations that are described below, there will be conditions where the levels shown in table 40 will not provide adequate retroreflectivity levels. It should also be noted that if the worst-case scenario were chosen for the analyses, there would be no type of retroreflective sheeting that could provide adequate luminance levels to achieve detection and legibility for all drivers. Furthermore, environmental conditions such as dirt accumulation, dew, and/or frost were not necessarily considered in the development of the MR levels.

Table 40. Research Recommendations for Updated MR Levels

Sign Color	Position	Sheeting Type (ASTM D4956-01a)					
		I	II	III	VII	VIII	IX
White-on-green guide signs or street-name signs	Overhead	(* 7	(* 15	(* 25	250 * 25		
	Shoulder	(* 7	120 * 15				

Note: The levels in the cells represent legend retroreflectivity * background retroreflectivity (for positive-contrast signs). Units are cd/lx/m^2 measured at an observation angle of 0.2E and an entrance angle of -4.0E.

The development of the updated MR levels consisted of many different scenarios, including a variety of practical and typical speeds, roadway cross sections, vehicle types, sign positions, sign sizes, headlamp types, etc. Ultimately, the MR levels were derived from the equilibrium point of the demand and supply luminance levels, which also vary as a function of the aforementioned factors. (It is important to note that luminance and retroreflectivity are not synonymous terms. *Luminance* is the perceived brightness of a sign and *retroreflectivity* is a property of the sign that describes its ability to return headlamp illuminance back toward the driver.) Technically, each specific scenario for each specific driver has a unique minimum luminance and therefore a unique MR level associated with that situation. However, from a practical point of view, the MR levels need to be easy to manage and implement. This requires that the infinite number of MR levels associated with the infinite number of driving scenarios be consolidated to a practical and manageable number. The level of complexity of the framework of the MR levels of 1993 and 1998 was a particularly significant issue according to the AASHTO Retroreflectivity Task Force. As the research effort to update the MR levels was nearing completion, the researchers focused on consolidating the recommendations into an easy-to-use format. In consolidating the MR levels, certain decisions were made regarding the resolution of the levels. For example, factors such as sign size and roadway speed were collapsed into one level representing the majority of typical driving scenarios for a given sign type. The consolidation efforts ultimately resulted in some degree of compromise between the precision and the brevity of the MR levels. The final research report provides a detailed description of how the MR levels were consolidated into an implementable format.(66)

ASSUMPTIONS

The recommended updated MR levels presented in this chapter represent the most recent results of a series of dedicated research studies that have been undertaken over the past two decades. They also represent the latest efforts in a long series of safety considerations related to providing safe and efficient roadways. The key assumptions that are associated with the updated MR levels are described below:

Demand Luminance

- Demand luminance levels used to derive the updated MR levels were based on the field data described in this report. These studies were performed in an environment representing dark rural conditions with essentially no ambient lighting, no glare except from the vehicle instrument panel, and no visual complexity. The luminance contrast of the test signs was approximately 5:1.
- Assumed threshold levels equivalent to accommodating legibility or recognition for 50 percent of drivers more than 55 years of age.
- Required legibility distances were based on a legibility index of 40 ft/inch of letter height.
- Under conditions where the required threshold luminance levels were below 1.0 cd/m^2, a minimum of 1.0 cd/m^2 was assumed for maintenance of sign conspicuity.

Supply Luminance

- Supply luminance was modeled assuming that the only contribution of illuminance originated from the design vehicle. In other words, no contribution from other vehicles in the proximity of the design vehicle was considered. There was also no consideration of pavement reflection adding to the luminance of the sign.(72)
- Supply luminance did consider windshield transmissivity (0.72) and atmospheric transmissivity (0.86/km).
- The headlamp luminous intensity matrix used for developing the MR levels representing a market-weighted model year 2000 passenger car. The data are derived from measurements made with perfect aim (no scattering of light caused by lens wear or dirt) and a voltage of 12.8 volts (V).

- Retroreflectivity data used for the analysis and modeling were the same as that included in the ERGO2001 program. While the retroreflective sheeting materials used throughout this report are classified using the ASTM D4956-01a classification scheme, it is important to note that the retroreflectivity data from the EGRO2001 model do not necessarily represent all manufacturers' sheeting performances within each ASTM type designation. For instance, there are several manufacturers of high-intensity retroreflective material (ASTM type III). Each brand performs differently. However, the retroreflectivity data from the ERGO2001 program represent only one manufacturer's retroreflective sheeting performance. It is also important to note that the retroreflectivity data in ERGO2001, while comprehensive in nature, are nearly 5 years old. There is a need to provide an updated set of retroreflectivity data for modeling purposes.
- Other key modeling factors related to the supply luminance were straight and flat roadways (i.e., no curves), vehicle dimensions representing a contemporary-styled SUV, and signs installed normal to the roadway.

FUTURE RESEARCH NEEDS

While significant progress has been made in the last couple of decades regarding the nighttime visibility requirements of traffic signs, there is a need for additional research. The following research topics, which are based on the assumptions and limitations associated with the proposed MR levels, are recommended by the research team:

- One of the key voids associated with the MR levels is a direct link to safety in terms of reduced crashes. There is even a void in the research related to identifying relationships between retroreflectivity and crash surrogates. Research is needed to develop a link between retroreflectivity and safety.
- Research is needed that identifies a set of retroreflective sheeting material measurement geometries that better represents the driving task. Such an effort would preferably lead to a more meaningful classification scheme than that used herein (the classification defined in ASTM D4956-01a was used for this report).
- A more recent study regarding the economic impact of the MR levels needs to be completed. The last one was completed in 1998; however, many of the factors that were considered have either changed drastically or are no longer valid.[(73)]
- In order for transportation agencies to choose or design an efficient process that reasonably satisfies the MR levels, there needs to be research done to identify and develop methods to manage nighttime sign visibility. There should also be research done to investigate new technologies or procedures to measure nighttime visibility, such as the development of an on-the-fly sign luminance van.
- A carefully formulated study is needed to validate the MR levels from a driver's point of view. This type of study would provide the first direct validation of the MR levels.
- Research is needed to better understand the impact of using different sizes of signs, horizontal and vertical curves, large trucks, sources of glare, various levels of ambient lighting, and various levels of background complexity.
- Research should address the implications of using various combinations of retroreflective sheeting materials on positive-contrast signs (e.g., guide signs fabricated

with legends made with microprismatic retroreflective materials on backgrounds made with high-intensity retroreflective materials).

- Long-term weathering research is needed to determine the validity of the uniform degradation assumption (over a practical range of observation angles). This research should also address the performance of retroreflective sheeting relative to the rotational aspects of retroreflectivity measurements made with point-source instruments.
- A study is needed to determine the distribution of vehicle type and their drivers on the roadways at night. This study should include different functional classifications of roadways and possibly different geographical areas. It should also include rural, suburban, and urban areas since the nighttime travel patterns in these areas may be substantially different. The data can be used to determine the most appropriate design vehicle and design driver on which to base the development of minimum retroreflectivity levels. Weighted values for vehicles and/or drivers would also be able to be developed using the data. This would allow the development of MR to be more precise in terms of accommodating a specified level of nighttime driver, such as the 85th percentile.
- The modeling efforts used to develop the MR levels recommended in this report are based almost exclusively on theoretical relationships, except for the consideration of windshield and atmospheric transmissivity. There has been no calibration or validation of the model. Earlier photometric models have suffered the same drawback. However, Russell et al., went to great extremes to eliminate pavement glare when they made their illuminance measurements. However, pavement glare is not eliminated when a motorist approaches a sign. A future research activity should include the calibration and validation of the photometric modeling efforts that go into the development of MR levels. This research should include precise measurement of illuminance and luminance in a controlled, full-scale environment. Comparisons should be made between the measured values and the modeled values. Appropriate real-world factors should then be integrated into the modeling process as needed.

APPENDIX A. SURVEY OF CURRENT PRACTICES

Figure 23 presents the complete e-mail message sent to the State and local transportation agencies. The survey was sent to five State agencies, three city agencies, and two county agencies. All but one responded. In the detailed responses below, "State" refers to a comment from a State agency, "city" refers to a city response, and "county" refers to a county response.

From: Hawkins, Gene
Sent: Tuesday, March 14, 2000
To:
CC: Carlson, Paul
Subject: Minimum levels of retroreflectivity for overhead and street-name signs

The Texas Transportation Institute is conducting research for the FHWA on minimum levels of retroreflectivity for overhead signs and street-name signs. These types of signs were not included in the FHWA's previous MR values. I would be extremely grateful if you or one of your staff could take a few minutes to answer the following questions to the extent that they apply to your agency.

OVERHEAD SIGNS
1. What size is the legend (typical letter height)?
2. What alphabet is used for the legend (Series E (Modified), other)?
3. What sheeting material(s) do you use for overhead signs (background and legend)?
4. Do you use a higher grade of sheeting for overhead signs compared to ground-mounted signs?
5. What is the typical height to the bottom of an overhead sign?
6. Do you have any agency guidelines for the design of overhead signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)

STREET-NAME SIGNS
7. What is your agency's policy for providing street-name signs (under what conditions are street-name signs provided and where are they located)?
8. How high are street-name signs mounted?
9. What colors are your street-name signs?
10. What size is the standard blank/blade (do you use other sizes)?
11. What size is the legend?
12. What alphabet is used for the legend (Series D, Series E (Modified), other)?
13. What sheeting material(s) do you use for street-name signs (background and legend)?
14. Do you have any agency guidelines for the design of street-name signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)

Thank you for your cooperation. Please feel free to contact Paul Carlson or me if you have any questions.

H. Gene Hawkins, Jr.
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Figure 23. E-mail Survey Sent to State and Local Transportation Agencies

OVERHEAD SIGN SURVEY RESPONSES

This section provides the detailed responses submitted by respondents to each question in the overhead sign portion of the e-mail survey.

General Comments

1. State: None.
2. State: None.
3. State: None.
4. State: None.
5. State: None.
6. City: With the exception of signs on signal mast arms, we rarely install overhead signs. Answers to this category of questions are based on street-name signs on signal poles.
7. County: None.
8. County: None.
9. City: We do not use "overhead signs" in the usual sense. The only overhead signs installed in the city would be those installed on our overhead traffic signal mast-arm poles. These would include street-name signs, ONE WAY signs, and lane-use control signs. We generally use standard layouts for these and historically have used engineering-grade sheeting (except as noted below).

1. **What size is the legend (typical letter height)?**
    1. State: Typical letter height for the legend is 16-inch uppercase and 12-inch lowercase.
    2. State: We use the table in section 2F of the MUTCD.
    3. State: 16-inch uppercase and 12-inch lowercase. The legend on freeway-to-freeway guide signs and freeway exit direction signs is 20-inch uppercase and 15-inch lowercase.
    4. State: Standard legend (letter height) sizes specified in the Federal MUTCD.
    5. State: 16-inch uppercase and 12-inch lowercase.
    6. City: 10 inches.
    7. County: 8-inch uppercase and 6-inch lowercase.
    8. County: 6 inches.
    9. City: See general comment.

2. **What alphabet is used for the legend (Series E (Modified), other)?**
    1. State: Alphabet is Federal alphabet Series E (Modified).
    2. State: Series E (Modified) since this is the only series with uppercase/lowercase lettering. What happen to the 3M research for the new letter series (Clearview or something like that)?
    3. State: Series E (Modified).
    4. State: Series E (Modified).
    5. State: Series E (Modified).
    6. City: Series B and C.
    7. County: Series C.
    8. County: Series E (Modified).
    9. City: See general comment.

3. **What sheeting material(s) do you use for overhead signs (background and legend)?**
    1. State: Materials for legend and background are high-intensity, type III or IV.
    2. State: Type III.
    3. State: Type III for both.
    4. State: On March 1, 1999, our agency adopted the Wide-Angle Prismatic Retroreflective Sheeting for Visual Impact Performance (VIP) manufactured by 3M (sole-source specification) for ALL permanent regulatory, warning, guide, and supplemental guide signs, except for Adopt-A-Highway signs, snowplow markers, and the blue background of logo signs (Federal Specific Service signs). These three exceptions use type III (high-intensity reflective sheeting). Note: VIP sheeting requires that any overhead signs made of extruded aluminum need to be covered with 0.063-inch sheet aluminum with Direct Applied sheeting for legends and backgrounds. Note: Since brown is not available in VIP sheeting, we specify white VIP sheeting for the background material and brown electronic cuttable (EC) film manufactured by 3M (with the legend cut out of the EC film. Also: On route markers attached to overhead guide signs, the sign legend materials for colors other than black may be screen-processed painted legend. Black legend may be either screen-processed painted legend or pigmented plastic film legend.
    5. State: Type III for both.
    6. City: Green EC film on white high-intensity sheeting.
    7. County: High-intensity.
    8. County: VIP for both.
    9. City: See general comment.

4. **Do you use a higher grade of sheeting for overhead signs compared to ground-mounted signs?**
    1. State: Same material is used on all guide signs, both overhead and ground-mounted.
    2. State: No.
    3. State: No, however it is our policy to light all overhead signs.
    4. State: See response to question 3.
    5. State: No.
    6. City: No.
    7. County: We are experimenting with diamond-grade and VIP sheeting.
    8. County: Yes, we use high-intensity on red/yellow background ground mount, and engineering grade for white/green/blue ground mount.
    9. City: See general comment.

5. **What is the typical height to the bottom of an overhead sign?**
    1. State: Typical height to bottom of sign is 18 ft.
    2. State: Our minimum height is 17 ft-6 inches.
    3. State: 20 ft-9 inches from the high-point elevation of the traveled roadway
    4. State: 17 ft-4 inches to the bottom of the low steel of the sign truss or to the bottom of the tallest sign panel (on monotube unlit sign structures).
    5. State: 17 ft.
    6. City: 17 ft-6 inches.
    7. County: Minimum 16 ft, preferred 19 ft.
    8. County: 16 ft-6 inches to 17 ft-0 inches.
    9. City: See general comment.

6. **Do you have any agency guidelines for the design of overhead signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)**
   1. State: No, we conform to the Federal MUTCD.
   2. State: No
   3. State: No other than as noted in question 1 above. The only other related design guideline is the application of message dividers.
   4. State: We developed (in conjunction with a private vendor) and beta tested the SignCAD guide sign design program. The SignCAD guide sign design program is Windows®-based and was designed using the parameters from an old (FORTRAN-based) design program from the 1960s. At this time, more than 25 State DOTs have adopted SignCAD as their guide sign design program (States are dropping GuideSign and replacing it with SignCAD.) DOT has purchased more than 100 copies of SignCAD.
   5. State: Our manual (not a State MUTCD) references other standards.
   6. City: No.
   7. County: Our policies are generally consistent with our State agency.
   8. County: No.
   9. City: See general comment.

STREET-NAME SIGN SURVEY RESPONSES

This section provides the detailed responses submitted by respondents to each question in the street-name sign portion of the e-mail survey.

General Comments

1. State: None.
2. State: None.
3. State: None.
4. State: None.
5. State: None.
6. City: None.
7. County: Incidentally, we estimate as much as 40 percent of our total number of signs are street-name signs, so take it easy on us when it comes to any proposed changes or retroreflectivity requirements!
8. City: None.

7. **What is your agency's policy for providing street-name signs (under what conditions are street-names signs provided and where are they located)?**
   1. State: We provide advance street-name sign for all intersections. We place street-name signs only at signalized intersections. Local agencies will install ground-mounted street-name signs at nonsignalized intersections under the encroachment permit.
   2. State: For all signalized intersections, we place street-name signs on the signal support over the roadway between the support pole and the right-lane signal for each direction. If it intersects a road with two names, one to the right and one to the left, we mount the left street-name sign on the left side of our highway and the right street-name sign on the right side of our highway. For nonsignalized intersections, we replace the existing

street-name signs installed by the local agency and replace "in kind" what was existing.

3. State: All roads have corner street-name signs typically installed by the local jurisdiction (located near left and far right corners of an intersection). This was a statewide initiative effort by the 911 emergency coordinators. All signalized intersections, multilane streets, and/or streets leading to major traffic generators have additional advance and/or overhead street-name signs.
4. State: Our agency does not fabricate or install "slat" street-name signs. These signs are installed by local road authorities within incorporated areas. In rural areas where street-name signs are installed for the 911 emergency telephone system, the authority in charge of the road intersecting the State highway is responsible for fabricating, installing, and maintaining the signs (we have a written guideline for 911 signing). Street-name signs (slat signs) may be made from type I, type III, or VIP sheeting, depending on how progressive communities are and how tight their budgets are. The size of the lettering varies from community to community. DOT does not regulate legend size, although the Federal MUTCD adopted (in a final rule) the 6-inch capital or 6-inch uppercase/4.5-inch lowercase FULLY REFLECTORIZED sign guidelines more than 2 years ago. The only street-name signs at intersections that our agency installs are overhead traffic signal mast-arm-mounted signs. These signs use VIP reflective sheeting with 8-inch uppercase and 6-inch lowercase Series E (Modified) letters. We use an 18-inch-high sign panel when the posted speed is less than 45 mph and a 24-inch-high sign panel for posted speeds of 45 mph or greater.
5. State: Street-name signs are a local responsibility.
6. City: Provided at all intersections at one corner of the intersection or on signal mast-arm poles.
7. County: In residential areas, we install a combination street-name sign assembly on the far right-hand quadrant in one direction of the major street. At major intersections, we often install street-name signs on two quadrants diagonally opposite.
8. County: Street-name signs are provided at intersections and along roads where name changes occur. On our local roads (non-arterials), we typically only install the street-name sign for the intersecting street, not the street you are traveling on if you have already seen that street name. This minimizes the amount of double street-name signing at intersections. We are complying with the MUTCD requirement for 6-inch letters on roads with speed limits greater than 25 mph. We are also using 6-inch letters on 25-mph arterials, but are still using 4-inch letters for local (non-arterial) roads.
9. City: We require that street-name signs be installed at every intersection. At signalized intersections, we install 18-inch-deep signs on the mast arm. The length varies with the number of letters. At nonsignalized intersections, we try to install the signs over the STOP signs to eliminate the intrusion of an extra post on a person's property and to help us out by saving a post. We install 12-inch-deep signs at all of these locations. We now use diamond-grade VIP sheeting on all street-name signs. They are made in our shop by cutting green vinyl over silver sheeting.

8. **How high are street-name signs mounted?**
    1. State: Street-name signs at signalized intersections are overhead, at a minimum height of 15 ft. Ground-mounted advance street-name signs are 7 ft where pedestrians may be present, otherwise 5 ft. Street-name signs placed by the locals are approximately 11 to 12 ft.
    2. State: Minimum of 17 ft for signalized intersections. For nonsignalized intersections, used the MUTCD requirements.
    3. State: 7-ft minimum for ground-mounted signs. Height may vary depending on whether the corner signs are combined with STOP signs on the same support. 17-ft minimum for overhead applications on signal structures.
    4. State: See response to question 7.
    5. State: 7 ft above the sidewalk or pavement.
    6. City: 7 ft.
    7. County: Approximately at a 10-ft mounting height.
    8. County: 7 ft nominal to bottom of sign.
    9. City: A minimum of 7 ft, if installed alone on a separate post. If above a STOP sign, the minimum height would be approximately 9.5 ft, and if on a mast arm, approximately 20 ft.

9. **What colors are your street-name signs?**
    1. State: The standard color is a green background with a white border and legend.
    2. State: Our agency uses a green background for signalized intersections. For nonsignalized intersections, we use the existing color. Green or blue background, or special color for historical areas.
    3. State: Typically, a white legend on a green background. They are black legend on yellow background when placed in combination with advance warning signs.
    4. State: See response to question 7.
    5. State: Our regulations allow white on green, black on white, or other contrasting colors. I'd have to say that most are white on green.
    6. City: White legend on green background.
    7. County: White on green.
    8. County: White letters on green background.
    9. City: Green background with white border and letters.

10. **What size is the standard blank/blade (do you use other sizes)?**
    1. State: Standard blank size for overhead street-name sign is 18 by 96 inches (maximum width).
    2. State: For signalized intersections, the maximum sign panel height is 18 inches and the length is 7 ft.
    3. State: Typically 8 inches high by a variable width depending on the street name for the corner blades. Typically 16 inches high by a variable width for advance and overhead street-name signs on signal structures.
    4. State: See response to question 7.
    5. State: 36 by 10 inches.
    6. City: 9 inches (18 inches on signal mast arm).
    7. County: 9 inches.
    8. County: 24 by 6 inches and 30 by 6 inches on local/residential roads, 30 by 9 inches and 36 by 12 inches on arterials and all roads intersecting with arterials.

9. City: 12 inches for ground mount, 18 inches for mast-arm mount (24 inches if two street names). We just changed to the 12-inch minimum standard last year. Prior to that, we used 9 inches for arterials and 6 inches for locals.

11. **What size is the legend?**
    1. State: The legend letter height is 6-inch uppercase and 4.5-inch lowercase.
    2. State: Depends upon the length of the street name to fit the panel size.
    3. State: Typically 4 inches for corner street blades. Typically 8-inch uppercase and 6-inch lowercase for advance and overhead street-name signs.
    4. State: See response to question 7.
    5. State: 6 inches.
    6. City: 6 inches (10 inches).
    7. County: 5-inch uppercase and 3.75-inch lowercase (will be modified to 6-inch uppercase in near future).
    8. County: 4 inches on 6-inch blanks, 6 inches on 9-inch blanks, 5 inches on 12-inch blanks that require two lines of text.
    9. City: The legend is usually 8-inch capital letters and 6-inch lowercase letters. We always use uppercase and lowercase layouts. The size will be reduced approximately 1 inch if the street name contains a drop in letter.

12. **What alphabet is used for the legend (Series D, Series E (Modified), other)?**
    1. State: The alphabet is the Federal alphabet, Series E (Modified).
    2. State: Overhead use Series E (Modified). Ground-mounted street-name signs typically use Series D.
    3. State: Series C for the corner blades. Series D for the advance and overhead street-name signs.
    4. State: See response to question 7.
    5. State: Varies, generally Series D.
    6. City: Series B and C.
    7. County: Series C.
    8. County: Series B or C.
    9. City: We use Series C. (We did experiment with the Clearview font; however, we saw no significant difference in appearance or legibility and decided not to pursue FHWA permission.)

13. **What sheeting material(s) do you use for street-name signs (background and legend)?**
    1. State: The background and legend reflective sheeting is high intensity, type III or IV.
    2. State: Type III
    3. State: Type III
    4. State: See response to question 7.
    5. State: Varies, but personally I believe the bulk of them are type I.
    6. City: Green electronic cuttable (EC) film on white high-intensity sheeting
    7. County: High intensity.
    8. County: Engineering grade.
    9. City: When we adopted a 12-inch panel size standard, we also adopted a diamond-grade VIP sheeting standard with green acrylic overlay film.

14. **Do you have any agency guidelines for the design of street-name signs that are different from that contained in your State's MUTCD? (If so, please send us a copy at your convenience.)**
    1. State: No, we conform to the current Federal MUTCD.
    2. State: Elder Road User Program requires use of 18-inch height panel, so the letter height varies depending upon the length of the street name. Common for overhead-mounted street names. Not sure how common or practical this practice is for ground-mounted street-name signs.
    3. State: Yes. Standard street-name sign details from the agency's Sign Book will be forwarded to you.
    4. State: See response to question 7.
    5. State: No, except we require a larger size for overhead street-name signs at signalized intersections.
    6. City: No response.
    7. County: Policy of 1988 is being updated.
    8. County: No.
    9. City: No.

APPENDIX B. MODELING PROCESS

This section of the report was provided to further document the details pertaining to the development of the MR levels. By going through the process, this section also provides a good example of why different sheeting types require different MR levels.

For ease of explanation, it is helpful to consider a specific example. For instance, table 40 shows the MR levels for overhead guide signs. For the white sheeting, there are sheeting types that are not allowed, and of the sheeting types that do have MR numbers, the levels depend on the sheeting type. The development of these findings is detailed in the following discussion.

The first issue to be considered is the position of the sign relative to the driver. For the conditions under which the MR levels were developed, the overhead guide sign was 640 ft from the vehicle. The centroid of the sign was located 25 ft above the pavement surface and was centered above the left adjacent lane of the travel lanes (both lanes were 12 ft wide). The vehicle used was a passenger car. Both the right and left headlamps were the CARTS50 headlamps.

Table 41. Overhead Sign Example

Descriptor	Left Headlamp	Right Headlamp
Observation angle (degrees)	0.152	0.352
Entrance angle (degrees)	2.24	2.41
Presentation angle (degrees)	-38.02	33.91
Rotation angle (degrees)	14.50	-65.21
Orientation angle (degrees)	-23.50	-31.33
Vertical headlamp angle (degrees)	2.06	2.06
Horizontal headlamp angle (degrees)	-0.90	-1.25
Viewing angle (degrees)	2.13	
Headlamp intensity (cd)	413	404.6
Illuminance (lx)	0.01084	0.01061

This is enough information to determine the angles and the amount of light reaching the sign. Table 41 shows the important levels.

As seen from table 41, the observation angle for the left headlamp is 0.152º and the entrance angle is 2.24º. These are obviously not the same as the standard measurement geometry of 0.2º and -4.0º (for the observation and entrance angles, respectively). Instead, these are the exact angles of the scenario defined above. In other words, they can be considered nonstandard geometry.

As noted in chapter 4, there are only two basic equations needed to determine the MR. They are shown below:

$$\text{Demand } R_{ANSG} = \frac{\text{Minimum Luminance } \times \cos(\upsilon)}{\text{Illuminance}} \qquad (3)$$

$$\text{Minimum } R_A = \text{New } R_{A,SG} \times \left(\frac{\text{Demand } R_{A,NSG}}{\text{Supply } R_{A,NSG}} \right) \qquad (4)$$

where,

Minimum R_A	=	MR at standard measurement geometry (α = 0.2°, β = -4.0°) needed to produce assumed threshold luminance, cd/lx/m^2
New $R_{A,SG}$	=	Averaged retroreflectivity of new sheeting at standard geometry, cd/lx/m^2
Demand $R_{A,NSG}$	=	Retroreflectivity needed to produce the minimum luminance at the nonstandard geometry (backcalculated and determined for each scenario), cd/lx/m^2
Supply $R_{A,NSG}$	=	Retroreflectivity of new sheeting at nonstandard geometry (determined for each scenario), cd/lx/m^2

One of the most significant unknowns prior to this research was the minimum luminance needed in equation 3. The field evaluations conducted as part of this study were designed to determine the minimum luminance for overhead guide signs and street-name signs, with an emphasis on accommodating older drivers. The results are summarized in table 18. For the 50^{th} percentile accommodation level, the minimum luminance for overhead signs was 2.3 cd/m^2.

The next step is to determine how much retroreflectivity is needed to produce a luminance of 2.3 cd/m^2. There are two key issues to be considered. First, the vehicle in this scenario is 640 ft from the sign and, as shown, the angles associated with the scenario do not correspond to the standard measurement geometry. Therefore, the retroreflectivity needed to produce a luminance value of 2.3 cd/m^2 at 640 ft from the sign is termed the demand retroreflectivity at the nonstandard measurement geometry (Demand $R_{A,NSG}$).

Second, the minimum luminance (which can also be thought of as the demand luminance because that is what is being demanded of the sheeting) is really the total luminance. In other words, it is a combination of the luminance provided by both the left and right headlamps. However, it cannot be simply halved for each headlamp because each headlamp contributes differently to the total luminance. The difference is explained by the different angles for each headlamp, which impact the following factors:

1. Amount of light directed to the sign (luminous intensity).
2. Amount of light reaching the sign (illuminance).
3. Performance of the sheeting (retroreflectivity).

To determine the contribution that each headlamp makes toward the demand luminance, the supplied luminance of the sign is determined for new sheeting. First, the luminance provided by each headlamp is determined (row 3 of table 42), then the total luminance is found by summing the luminance of each headlamp (row 4 of table 42). Using these values, the contribution of each headlamp can be determined. This is shown in row 5 of table 42.

Using the contribution from each headlamp and the demanded luminance value (2.3 cd/m^2 in this case), one can determine the demand retroreflectivity at the nonstandard measurement geometry (Demand $R_{A,NSG}$). This is done using equation 3. The results are shown in row 6 of table 38.

The next step is to determine the supplied retroreflectivity at the nonstandard geometry. Using the angles shown in table 41 and the large databases of sheeting performance (one for each type of sheeting), it is possible to determine the retroreflectivity levels of each type of sheeting at the nonstandard geometry. This was done for each headlamp geometry. The values are shown in row 7 of table 42.

The next step is to determine whether the sheeting provides enough luminance to meet the desired or demanded luminance (in this case, 2.3 cd/m^2). This step includes several substeps. The first is to use the luminance produced by each type of new sheeting (row 8 of table 42). The summed luminance can be considered the raw luminance. This is the ideal luminance. However, at least two factors reduce the luminance as viewed by a driver. The first is the windshield. A typical value for windshield transmissivity is 0.72, although this can vary slightly with different windshields. The second reduction factor is caused by the atmosphere. An atmospheric transmissivity of 0.86/km was used here, which represents a typical dry day. The result of these reductions in luminance is the luminance supplied to the driver (row 10 of table 42). Finally, in row 11 of table 42, a check is made to ensure that the different types of sheeting supply enough luminance to meet the demand. If a particular type of sheeting does not meet the demand luminance, then it cannot provide sufficient luminance for the scenario even when unweathered. In this case, sheeting types I and II cannot supply enough luminance to meet the demand of 2.3 cd/m^2.

Now that the adequate sheeting types are identified, the next step is to determine the MR needed for each sheeting type. This is accomplished using equation 4. The results are shown in row 13 of table 42. Because headlamp contribution was accounted for earlier in the process, the retroreflectivity for each headlamp is the same.

The final step was a simple rounding of the numbers to the nearest value divisible by five. The results, shown in row 14 of table 42, are the MR levels for overhead guide signs at the standard measurement geometry. When the sheeting falls to these values, the luminance provided to a motorist at 640 ft from an overhead sign positioned as indicated will be 2.3 cd/m^2.

Retroreflectivity values higher than those shown in row 14 of table 42 will produce luminance values higher than 2.3 cd/m^2. The highest luminance value a sheeting can supply a driver when the sheeting is unweathered is shown in row 10 of table 42 (for the conditions given in this example).

Table 42. Example MR Calculations

1	ASTM sheeting designation	Type I		Type II		Type III		Type VII		Type VIII		Type IX	
2	Headlamp position	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
3	Luminance per headlamp with new sheeting (cd/m^2)	1.13	0.77	1.97	1.26	3.66	2.30	13.21	7.45	11.31	7.75	7.30	4.68
4	Total RAW supplied luminance (cd/m^2)	1.90		3.23		5.97		20.66		19.06		11.98	
5	Contribution from each headlamp (%)	59.4	40.6	61.1	38.9	61.4	38.6	64.0	36.0	59.3	40.7	60.9	39.1
6	Demand R_A @ NSG ($cd/lx/m^2$)	125.1	87.4	128.8	83.6	129.4	83.0	134.8	77.5	125.0	87.5	128.3	84.1
7	Supply R_A @ NSG ($cd/lx/m^2$)	104.2	72.86	182.1	118.1	337.8	216.8	1218.2	701.0	1043	730.0	672.7	440.9
8	Total RAW supplied luminance (cd/m^2)	1.90		3.23		5.97		20.66		19.06		11.98	
9	Reduction: Windshield transmissivity (0.724) and atmospheric transmissivity (0.86/km)	0.74		1.26		2.34		8.08		7.45		4.69	
10	Total supplied luminance (cd/m^2)	1.16		1.97		3.63		12.58		11.61		7.29	
11	Check: Luminance adequacy (2.3 vs. row 10)	Inadequate		Inadequate		Adequate		Adequate		Adequate		Adequate	
12	New R_A @ SG ($cd/lx/m^2$)	97.1	97.1	169.6	169.6	314.4	314.4	1190.1	1190.1	822.6	822.6	433	433
13	Minimum R_A @ SG ($cd/lx/m^2$)					120.4	120.4	131.6	131.6	98.6	98.6	82.6	82.6
14	Rounded Minimum R_A @ SG ($cd/lx/m^2$)					120		130		100		85	

Note: NSG = nonstandard measurement geometry ($\alpha \neq 0.2^\circ$ and $\beta \neq -4.0^\circ$)
SG = standard measurement geometry ($\alpha = 0.2^\circ$ and $\beta = -4.0^\circ$)

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