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16. Abstract
This project was conducted to determine the legibility of the Clearview alphabet on freeway guide signs constructed with microprismatic retroreflective sheeting. The Clearview legibility results were compared to the legibility of freeway guide signs constructed with the Series E(Modified) alphabet. Also included in the analysis were legibility distances of freeway guide signs constructed with Type III sheeting.

A total of 60 subjects divided into three age groups participated in this nighttime study. The findings indicate that the Clearview alphabet provides statistically longer legibility distances than the Series E(Modified) alphabet. The findings also show that microprismatic sheeting provides statistically longer legibility distances than Type III sheeting. Sequentially, the differences between Type III guide signs with Series E(Modified) legends, microprismatic guide signs with Series E(Modified) legends, and microprismatic guide signs with Clearview legends were modest. However, the combined effect of switching from Type III guide signs with Series E(Modified) legends to microprismatic guide signs with Clearview legends were noteworthy. For overhead signs, the combined effect resulted in an overall mean legibility distance improvement of 70 ft, or 11.9 percent. For shoulder-mounted guide signs, the improvement was 74 ft, or 12.0 percent. Furthermore, the largest legibility distance improvements of the Clearview alphabet were associated with older drivers.

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Evaluation of Clearview Alphabet with Microprismatic Retroreflective Sheetings

by

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The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Paul J. Carlson, P.E. # 85402.

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This project was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration. It was performed by the Texas Transportation Institute (TTI) of the Texas A&M University System.

The successful completion of this research project was achieved only because of a significant degree of assistance from a large number of individuals. First and foremost, the Texas Department of Transportation's procedure for research projects includes the assignment of a project director. The assigned project director for this project was Greg Brinkmeyer of the Traffic Operations Division. Mr. Brinkmeyer provided significant guidance in the development and conduct of this research study. His ability to keep the project on course in terms of providing benefit to TxDOT was a substantial contribution to the successful completion of this research study.

Others that deserve more recognition than words can express are Andrew Holick and Todd Hausman of TTI. These gentlemen were the heart and soul of the data collection efforts, which included almost 45 consecutive nights. Mr. Holick also helped design the data collection procedure.

These acknowledgments would not be complete until we recognize Nada Trout's effort. Mrs. Trout was responsible for obtaining the Texas A&M University Institutional Review Board's (IRB) approval for conducting research with human subjects. She also was responsible for subject recruitment. Her efforts went above the call of duty. During the data collection effort, Mrs. Trout was undergoing chemotherapy and traveling. Yet she managed to schedule subjects every night. After the subjects were scheduled, Mrs. Trout also called and reminded the subjects of their commitments. Her attention to details was a significant reason for the successful completion of this research project.

This project was essentially a follow-up to an earlier Clearview project funded by TxDOT. Dr. Gene Hawkins was the research supervisor of this earlier effort. Dr. Hawkins also played a significant role in this effort, providing his expertise and experience whenever called on. By adding a link between the earlier project and this project, his role allowed the research to be completed in a relatively short time period, yet maximize the benefits.

Dan Walker and Mark Wooldridge also played critical roles. Mr. Walker helped design the data collection procedure. Moreover, he was also responsible for preparing the majority of the field equipment. Mr. Wooldridge was also a member of the earlier Clearview project. His expertise in experimental design and data analysis techniques allowed this research project to maximize the efficiency of the data collection and analysis activities.

This research project relied on the help of many student workers. In particular, Jeff Miles was extremely helpful in fabricating the test word panels and helping analyze the data. Other student workers were responsible for changing the test words after each data collection run. These students spent many nights on the runways of the Texas A&M University Riverside Campus. Their help cannot go without recognition. These students include (in no particular order):

Victoria Salgado, Luisa Ward, Andrea Kattan, Ana Zelaya, Alan Black, Dusty Rowe, Norman Hogue, and Mike Maresh.

Other organizations and individuals also contributed to the success of this project. Because the project included the use of microprismatic retroreflective sheetings, and TxDOT does not have the equipment needed to cut letters from these sheetings, other avenues had to be identified. One half of the letters were cut at the city of Houston’s sign shop. In particular, Chromatek, Inc. helped coordinate the resources at the city of Houston. The other half of the letters were cut at Interstate Signs, Inc. These organizations, and the individuals involved in helping with the research project, were largely responsible for helping meet the project’s objectives and deadlines.

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CHAPTER 1
SUMMARY

In the 1950s, national signing standards introduced the use of white on green guide signs for freeways. These signs used a lowercase alphabet (Series E(Modified)) for destination names, which was the first use of lowercase letters on U.S. highway signs. This lowercase alphabet has remained the same since it was introduced in the 1950s. The only change has been in the manner in which the letters are fabricated. The original generation of freeway sign legend used button copy letters, in which multiple retroreflector buttons were placed in an aluminum letter. Most modern legends are cut-out letters, in which the letters are cut directly from retroreflective sheeting. When these fully retroreflective letters are combined with the use of brighter sheetings (particularly, microprismatic sheeting), a phenomenon known as irradiation (also known as halation, overglow, or blooming) can occur for some drivers. In this phenomenon individual features of some letters (such as the lowercase E, A, and O) are blurred or washed out resulting in less distinct individual letter patterns which can cause reduced legibility distances.

The primary research goal of this project was to determine if the legibility of full-scale guide signs fabricated with microprismatic sheeting could be increased by using the Clearview alphabet instead of Series E(Modified). Series E(Modified) is the current U.S. standard lowercase alphabet and has been for over 50 years. Clearview is a new alphabet that was developed by Meeker & Associates and the Pennsylvania Transportation Institute to overcome the irradiation effects of bright retroreflective sheeting, such as microprismatic sheeting.

In addition to testing the legibility distance of the two alphabets, researchers also evaluated sign position (shoulder-mounted and overhead), retroreflective sheeting type, subject age, and vehicle type (passenger car and large sport utility vehicle (SUV)). The studies were conducted only at nighttime.

In the experimental procedure, test subjects driving the test vehicles would start at a distance where the signs were not legible. They would accelerate to 35 mph, set the cruise control, and begin to concentrate on reading the test word. When the subject read the word correctly, a researcher in the vehicle recorded the distance. Each subject read 56 randomly selected test words which were approximately equally distributed between the Clearview and Series E(Modified) alphabets (28 words were tested from each vehicle). Of the 56 words, 40 were located in the shoulder-mounted position and 16 were in the overhead position. A total of 60 subjects participated in the study. There were 20 young drivers, 20 middle-aged drivers, and 20 elderly drivers.

The results show that the Clearview alphabet provides longer legibility distances than Series E(Modified) for all cases studied, including shoulder-mounted and overhead guide signs. The differences in each case were statistically significant. The research findings also show that guide signs fabricated with microprismatic sheeting produce statistically longer legibility distances than guide signs constructed with Type III sheeting (TxDOT's current guide sign policy).

Sequentially, the differences between Type III guide signs with Series E(Modified) legends, microprismatic guide signs with Series E(Modified) legends, and microprismatic guide signs with Clearview legends were modest. However, the combined effect of switching from Type III guide signs with Series E(Modified) legends to microprismatic guide signs with Clearview legends were noteworthy. For overhead signs, the combined effect results in an overall mean legibility improvement of 70 ft, or 11.9 percent. For shoulder-mounted guide signs, the improvement was 74 ft, or 12.0 percent. Furthermore, for the guide signs constructed with microprismatic sheeting, older drivers benefitted the most from the Clearview alphabet. For the microprismatic overhead signs, older drivers could read the Clearview alphabet an average of 33 ft farther (6.8 percent) than Series E(Modified). For the older drivers and microprismatic shoulder-mounted signs, the average benefit of Clearview over Series E(Modified) was 30 ft or 6.0 percent.

Assuming a 70 mph highway, the overall overhead guide sign legibility improvement provides drivers an extra 0.68 second to read an overhead guide sign. For a 55 mph highway, drivers would be provided an extra 0.86 second. This extra time, however, is somewhat misleading because drivers do not attempt to read signs from the point where they can just begin to read the sign until they pass the sign. Rather, drivers focus their attention ahead. Once drivers acquire the necessary information from a sign, they shift their attention downstream. Eye scanning studies, which track the looking positions of drivers' eyes as they drive, have reported that drivers quit looking at signs approximately 3 seconds before reaching the sign, regardless of speed. This distance is referred to as the last look distance because this is the "last look" or "last glance" drivers normally take of the sign.

Assuming a last look distance equivalent to 3 seconds, the time improvements associated with the increased legibility of microprismatic guide signs with Clearview legends are even more significant. For instance, on a 70 mph highway, an extra 0.68 second would equate to a 26.4 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 21.2 percent.

Again, assuming a 70 mph highway, the overall shoulder-mounted guide sign legibility improvement provides drivers an extra 0.72 second to read a shoulder-mounted guide sign. For a 55 mph highway, drivers would be provided an extra 0.92 second. Assuming a last look distance equivalent to 3 seconds, these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.72 second would equate to a 24.1 percent increase in time to read an a shoulder-mounted guide sign. For a 55 mph highway, the increase would be 19.8 percent.

With these findings, the researchers recommend a statewide implementation of microprismatic sheetings with Clearview legends for overhead guide signs and shoulder-mounted guide signs. This policy should be implemented on a maintenance basis.

CHAPTER 2
INTRODUCTION

The Clearview alphabet for guide signing was developed to improve legibility with the newer microprismatic retroreflective sheetings that can produce relatively high luminance levels (compared to the glass-beaded retroreflective sheetings). When these high luminance levels occur, especially with fully retroreflective cutout letters like those used on guide signs, a phenomenon known as blooming (also known as halation, overglow, or irradiation) can occur for some drivers. This effect causes individual features of some letters to be washed out, resulting in a reduction of their legibility. There is at least a perception that blooming occurs with Series E(Modified) letters when fabricated from the newer microprismatic retroreflective materials. Interestingly, the Series E(Modified) alphabet has remained unchanged since its introduction in the 1950s despite the evolution of retroreflective materials, which includes several milestones since the 1950s.

To date, there have been two research studies that have reported on the visibility impacts of using guide signs made with the Clearview alphabet instead of the currently specified Series E(Modified) alphabet (1-2). Both of these projects were reviewed in detail and summarized in the Chapter 3. The results of the studies show promise but are not overwhelming. However, both studies have potentially fatal drawbacks such as small and inconsistent letter heights and the use of glass-beaded retroreflective sheeting instead of microprismatic sheeting. Therefore, no research results are available that address the legibility benefits of the Clearview alphabet when used at the appropriate size, with comparable Series E(Modified) letter heights, and with the appropriate type of retroreflective sheeting. Research was needed to evaluate the legibility impacts of using the Clearview alphabet at the appropriate size with microprismatic sheeting.

PROJECT OVERVIEW

The overall objective of this project was to perform legibility studies of Clearview and Series E(Modified) alphabets using full-scale overhead and shoulder-mounted guide signs fabricated with microprismatic retroreflective sheeting (Types VIII and IX).[1] The primary purpose was to determine if the Clearview alphabet produced longer legibility distances than the Series E(Modified) alphabet when full-scale guide signs were constructed with microprismatic retroreflective sheeting. A secondary purpose was to compare the results to an earlier but similar effort where researchers tested three alphabets (including Clearview and Series E(Modified)) using full-scale guide signs fabricated with Type III retroreflective sheeting (2). The anticipated results were to be used by TxDOT to select the most appropriate retroreflective sheeting and alphabet for overhead and shoulder-mounted guide signs.

Secondary research issues included investigations among drivers of three different age groups and investigation of performance from the perspective of two different vehicle types, a 2001 Chevy Suburban four-wheel drive (4×4) and a 1989 Ford Crown Victoria LTD.

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[1] When referring to a specific type of retroreflective sheeting, this report uses the type designations specified by ASTM in their D4956-01 specification (3).

However, soon after the project was initiated, TxDOT made a decision to begin using microprismatic retroreflective sheeting on all overhead guide signs (for both the background and legend), although an implementation date was not set (the prior policy was to use Type III sheeting on overhead and ground-mounted guide signs). Therefore, the project was slightly modified to focus more on shoulder-mounted guide signs while maintaining some focus on overhead guide signs. The research started on September 1, 2000, and ended on August 31, 2001.

Research Activities

The research project conducted by TTI was a 12-month effort. The activities that took place are described below.

- **First Research Meeting** - The initial meeting between the researchers and the project director, Greg Brinkmeyer, took place on September 22, 2000, in College Station, TX. Other TxDOT staff, Brian Stanford and Dale Picha, were also present at this meeting. This meeting served as the kickoff meeting. The project director and researchers discussed several items including:
  - the project objectives and the general plan for meeting the objectives,
  - key findings from previous research,
  - TxDOT's concerns and experiences,
  - activities in which the researchers would require TxDOT assistance, and
  - issues and/or factors that needed to be addressed in the research, including but not limited to test subject age, type of retroreflective sheeting, sign position, and test vehicle type.

- **Literature Review** - The research team reviewed the pertinent research to assess the state-of-the-art in sign legibility since the completion of the earlier TTI-Clearview project in 1999. One of the main focuses was to determine the current state of the Clearview alphabet and determine how much it had changed since the earlier TTI-Clearview project (conducted in 1997 and published in 1999). The activities also included a thorough review of the experimental procedure used in the earlier TTI-Clearview research in order to identify areas for possible improvements. Chapter 3 describes the results of these activities.

- **Second Research Meeting** - The second meeting between the researchers and the project director took place at TTI on November 15, 2000. In addition to the project director, other TxDOT participants included Rick Collins and Brian Stanford. The purpose of this meeting was to reevaluate the project objectives since TxDOT administration had recently made a decision to begin using microprismatic retroreflective sheeting on all new and refurbished overhead guide signs, although the implementation date had not been set.

  During the meeting several options in terms of refocusing the project were discussed, including terminating the project. However, because the Clearview alphabet was designed to perform better than Series E(Modified) under relatively high luminance levels, and right shoulder-mounted signs naturally produce higher luminance levels than overhead-mounted signs (because they receive more headlamp illumination), the participants decided that the project should focus on right shoulder-mounted guide signs, while maintaining some of the initial focus on overhead signs.

- **Research Preparation** - Before data collection could begin, researchers had to obtain several approvals and complete many preparation activities. These approvals and activities are summarized below.
  - *Research Procedure Approvals* - After refining the project objectives to focus on shoulder-mounted guide signs, the researchers developed an experimental plan that they submitted to the project director for approval. Once the project director granted approval, the researchers submitted the experimental plan to the Texas A&M University's Institutional Review Board (IRB) for approval. The IRB approval is a federal requirement for any experiment or research that involves human subjects. The IRB unconditionally approved the experimental plan. A final level of approval was needed from the Texas A&M University's Riverside Campus Oversight Committee. This included permission to use the runways and temporarily install raised retroreflective pavement markers on the runways (to guide the test subjects during testing). Chapter 4 describes the experimental plan in detail.
  - *Data Collection Preparation* - One of the more time-consuming tasks related to this project was cutting the letters and constructing the sign panels. Because the retroreflective sheetings used herein were microprismatic, and TxDOT does not currently have sheeting cutters that can cut most microprismatic sheetings, researchers had to identify other sources. Chapter 4 describes these activities and others related to the data collection preparation.

- **Data Collection** - During the second half of May 2001 and continuing through the end of June, researchers collected the nighttime legibility data. TTI recruited over 60 subjects, who each went through the two-hour evaluation. Accounting for equipment failure, rain, and sometimes high winds, a total of 60 subjects completed the study. Chapter 4 describes these activities.

- **Data Analysis** - Once the field studies were completed, the researchers analyzed the data using the appropriate statistical techniques. The researchers also prepared the data in a format to allow easy comparisons between the earlier TTI-Clearview project and this one. Chapter 5 presents the results from these analyses.

- **Third Research Meeting** - In July 2001, the researchers presented their findings to the project director and other TxDOT personnel. The presentation included a summary of the research activities and findings, including final recommendations and areas identified for future research.

Chapter 6 provides the conclusions and final recommendations. The references are listed in Chapter 7.

CHAPTER 3
BACKGROUND

EVOLUTION OF THE CLEARVIEW ALPHABET

The development of the Clearview alphabet has been underway for several years and, in fact, is still undergoing possible refinements. This section documents the development of the alphabet. The related legibility research is summarized in the following section.

The Clearview alphabet was developed by Meeker and Associates, Inc., a graphic design firm. The purpose of the new alphabet was to counter the blooming possibilities when signs are fabricated from bright microprismatic sheeting. The alphabet was first tested as part of a research project conducted at the Pennsylvania Transportation Institute (1). For purposes of the PTI project, researchers required the alphabet to have some relationship to the two existing federal typefaces that they were comparing (standard Series E(Modified) and Series D). To that end, they designed the new typeface in regular and condensed versions. These versions, subsequently named Clearview and Clearview Condensed, incorporate the desirable attributes of a group of typefaces studied by Meeker & Associates, but they retain the visual proportions of the existing FHWA typefaces.

Initial versions of the alphabets were improved and recreated numerous times. Comparisons of various early renditions of the alphabets were made through subjective field evaluation, objective tests of the typefaces' degradability, and objective laboratory studies using computer simulation. These comparisons resulted in the versions of Clearview and Clearview Condensed that researchers used in the PTI study.

Using a 5 inch letter height, the PTI research concluded that the Clearview alphabet provided substantially better legibility distances than either Series D or Series E(Modified) (1). Using this finding as an indication of the promise provided by the Clearview alphabet, TTI included Clearview as an alphabet for a legibility study on a full-scale basis (2).

The TTI project included a pilot study of the Clearview alphabet using 16 inch letter height. A preliminary investigation was conducted to determine the optimal stroke width and letter spacing for the Clearview alphabet. Participants included the TTI research team, the TxDOT Advisory Panel, PTI researchers, a representative from Meeker & Associates, and a 3M representative. Three height-to-stroke width versions of Clearview were prepared for the preliminary investigation (5.2, 5.7, and 6.2). The letters were prepared on individual tiles so that the letter spacing could be varied.

Researchers completed both day and night evaluations in that project. The preliminary investigation proved valuable in that the following findings were discovered:

- For the 16 inch letter sizes used in the TTI research, the optimal letter spacing for Clearview was approximately the same as the spacing for Series E(Modified). This finding was contrary to findings from the PTI project that showed that tighter letter spacing could be achieved with Clearview without sacrificing legibility.

- The full-scale study proved that additional Clearview modifications were needed.
- Clearview 5.7 provided the best daytime legibility, and Clearview 6.1 appeared to provide the best nighttime legibility. The general opinion of the participants was that Clearview 5.7 should be used in the formal data collection activities of the TTI research. However, modifications were needed to specific letters before TTI could conduct the evaluations.

Meeker & Associates made the necessary modifications to the Clearview alphabet, and TTI performed the research. Table 1 shows the refined Clearview alphabet as it stood during the initial TTI-Clearview project (2). However, after the TTI research commenced, Meeker & Associates sent the Clearview alphabet to a type foundry so that it could be converted to a True Type alphabet that could be used in sign-cutting equipment. During that process, the cartographer made additional refinements to the Clearview alphabet. Most of these refinements were made to uppercase letters that were not a part of the TTI research effort, but small changes were made to lowercase letters. As a result, the Clearview that is currently available, which is called ClearviewOne, is different from the Clearview PTI and TTI researchers evaluated (1-2).

Table 1. Clearview Used in Initial TTI-Clearview Project (2).

Clearview Style	Letter Spacing and Stroke Width	Examples of Style and Spacing	
Street	Condensed	aeshp	Highway
	Light	aeshp	Highway
	Regular	aeshp	Highway
Road	Condensed	aeshp	Highway
	Light	aeshp	Highway
	Regular	aeshp	Highway
Expressway	Light	aeshp	Highway
	Regular	aeshp	Highway

Figure 1 illustrates the current versions of the ClearviewOne alphabet. The different versions of ClearviewOne have been developed to take advantage of the flexibility provided by modern sign fabricating procedures. It is now possible to adjust the height-to-stroke width ratio of an alphabet to accommodate differences in applications such as different approach speeds or illumination condition). The range of height-to-stroke width ratio, letter width, and letter spacing available with the Clearview alphabet provides significant flexibility to custom design each sign. However, at the present time, there are no guidelines on the use of these versions of ClearviewOne to take advantage of that flexibility.

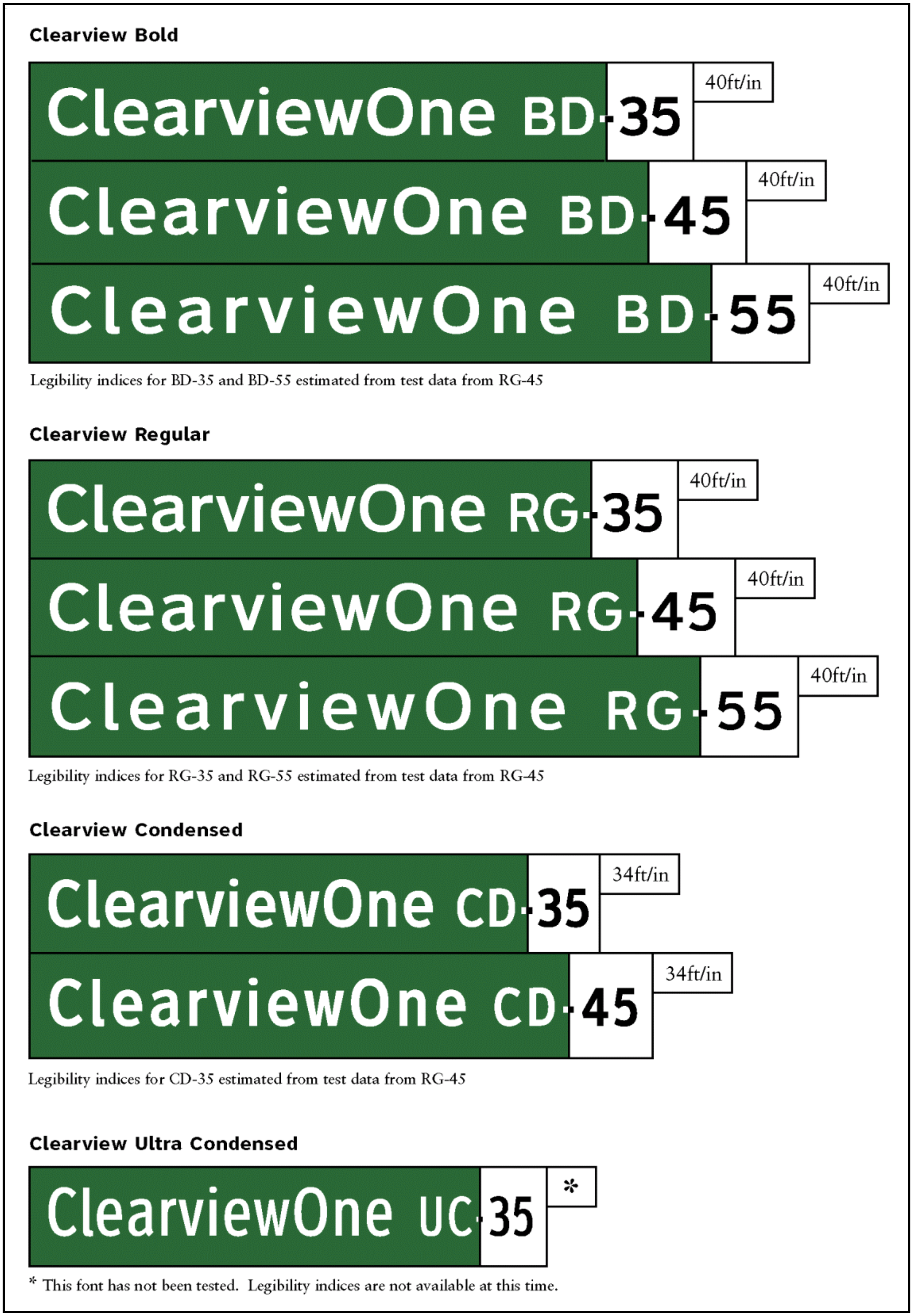


Figure 1. Current Clearview Alphabet (ClearviewOne).

The current version of ClearviewOne includes nine typefaces classified into four categories: Bold, Regular, Condensed, and Ultra Condensed. The Bold, Regular, and Condensed typefaces are roughly similar to the earlier Clearview typefaces Regular, Light, and Condensed, respectively (shown in Table 1). The number at the end of the ClearviewOne type name is the letterspace based on the approach speed. These speeds are roughly similar to the style names (expressway, road, and street) of the earlier Clearview typeface shown in Table 1. The ClearviewOne Ultra Condensed typeface is new and is intended for use on street name signs.

CLEARVIEW RESEARCH

As mentioned, two studies have been published concerning the legibility and recognition of the Clearview alphabet (1,2). The first was conducted at PTI and the second at TTI. Detailed reviews of each project follow.

Pennsylvania Transportation Institute Study

In 1997, Garvey et al. described a study of the legibility and recognition of two versions of the Clearview alphabet (Clearview and Clearview Condensed) (1). Each version of Clearview was presented in two sizes, normal and expanded. The expanded version was created by increasing the footprint of a word to fill the same area as the same word in Series E(Modified). The footprint expansion resulted in a 12 percent increase in letter size. In all, four versions of Clearview were compared to Series E(Modified) and D. The study also included two different types of retroreflective sheeting (Types III and IX). The test signs were all shoulder-mounted.

Figure 2. Clearview Alphabet for PTI Study.

Series D and uppercase Series E(Modified) letters were 5 inches high. The standard Clearview alphabet (Clearview100 as shown in Figure 2) had the same size characteristics as Series E(Modified) but Clearview112 was appropriately 12 percent larger. In other words, Clearview112 uppercase letters were 5.6 inches high.

The study included two groups of 12 subjects. The subjects were all age 65 and older with current Pennsylvania driver's license.

Both the daytime and nighttime recognition studies showed no statistical differences between Clearview and Series E(Modified). No effect on sheeting was found either. However, Clearview112 did outperform Series E(Modified).

The daytime legibility study showed a marginal effect on sheeting type (a 4 percent increase with Type IX versus Type III). There were no significant differences between the two Clearview alphabets and Series E(Modified) although Clearview112 performed the best, albeit just barely.

The nighttime legibility analysis showed that the sheeting main effect was insignificant but there was a significant sheeting-alphabet interaction. The alphabet main effect was also significant. For Type III sheeting, Clearview112 performed 22 percent better than Series E(Modified) which was significant. For Type IX sheeting, Clearview112 performed 11 percent better than Series E(Modified), which was insignificant. Unfortunately, these results are the opposite of what one might expect because of the more efficient Type IX sheeting.

While this study appears to indicate that Clearview, and more specifically, Clearview112, outperforms E(Modified), it is important to note that the increase in recognition and legibility performance can be partly attributed to the increased size of the Clearview112 alphabet.

Texas Transportation Institute Study

Before the PTI study was completed, TTI had started another evaluation of Clearview. Hawkins et al. studied the daytime and nighttime performance (both recognition and legibility) of the Clearview alphabet, comparing it to Series E(Modified) and British Transport Medium (2,4). They also considered the difference between shoulder-mounted signs and overhead signs. The project used Type III sheeting exclusively.

The project used full-scale freeway signs with 16 inch uppercase letters and appropriately sized lowercase letters. A total of 54 subjects participated in both the day and night trials. For comparisons sake, there were seven younger subjects (< 35 years of age). However, the focus was on older drivers. Two groups of older drivers were used: a young-old group identified as 55 to 64 years old (18 subjects) and an old-old group identified as 65 or older (29 subjects).

For both the daytime and nighttime overhead recognition results, Clearview consistently outperformed Series E(Modified). The percent improvement was as much as 8 percent in some cases. However, the only time the difference was statistically significant was the daytime overhead sign position. For the shoulder-mounted signs, no recognition differences were statistically significant, although a general decrease in performance with Clearview was reported.

There were no statistically significant differences found in the legibility studies. However, for the overhead position during both daytime and nighttime conditions, Clearview consistently outperformed Series E(Modified) by 0.6 to 3.3 percent. The daytime ground position results show a consistent decrease in performance with Clearview while the nighttime data slightly favor Clearview. Table 2 shows the 50th and 85th percentile legibility results of the study.

Table 2. Legibility Indices by Driver Age.

Time of Day	Alphabet	Sign Position	Mean Indices Driver Age All	<40	55-64	65+	85th Percentile Indices Driver Age All	<40	55-64	65+
			ft/in				ft/in			
Day	Transport Medium	Overhead	52.4	69.4	53.9	47.3	35.4	55.5	39.9	30.8
		Ground	50.8	67.1	53.3	45.2	33.8	52.3	39.9	29.8
	Clearview	Overhead	55.3	71.3	57.5	50.1	37.0	57.6	43.8	32.6
		Ground	50.3	68.8	52.4	44.3	33.6	53.4	39.5	28.9
	Series E(Modified)	Overhead	54.1	71.3	56.1	48.8	36.3	55.8	40.9	32.3
		Ground	52.3	69.9	54.5	46.6	35.3	55.3	41.6	31.1
Night	Transport Medium	Overhead	39.0	49.4	41.0	35.2	23.8	33.3	27.6	20.6
		Ground	40.2	50.5	42.0	36.5	24.4	34.2	27.6	21.6
	Clearview	Overhead	41.4	50.7	43.6	37.8	25.8	35.2	28.8	22.3
		Ground	40.9	51.8	42.9	37.0	25.3	34.4	29.3	22.1
	Series E(Modified)	Overhead	40.6	51.4	42.8	36.6	25.2	35.6	30.6	22.1
		Ground	40.8	51.3	42.4	37.3	24.9	35.9	27.4	22.0
Day	Minimum		50.3	67.1	52.4	44.3	33.6	52.3	39.5	28.9
	Maximum		55.3	71.3	57.5	50.1	37.0	57.6	43.8	32.6
Night	Minimum		39	49.4	41	35.2	23.8	33.3	27.4	20.6
	Maximum		41.4	51.8	43.6	37.8	25.8	35.9	30.6	22.3

The researchers concluded that the use of the Clearview alphabet introduces a small but consistent improvement for overhead signs. However, the legend and backgrounds of the signs were made from Type III sheeting, which was the TxDOT standard at the time of the research. Consequently, the researchers concluded that the expected benefits of the Clearview alphabet may be more significant if the signs were constructed with the one of the currently available microprismatic retroreflective sheetings.

STUDY ISSUES

This section of the report describes the major issues that impact studies of the visibility of retroreflective targets such as traffic control devices. This section is not meant to be comprehensive in nature, as such an endeavor would require more time and would justify a stand-alone document. Rather, this summary is intended to educate the reader of the complexities involved when performing, reporting, and interpreting results of visibility studies involving retroreflective traffic control devices. An overhead signing example is described throughout the discussion. The example ultimately concludes with results that show the expected legibility performance for different types of retroreflective sheeting viewed from different vehicle types.

Visibility Factors

The number of factors related to retroreflective sign visibility can be overwhelming. Factors identified through the literature reviews can be categorized into four main headings as shown in Table 3. Under each category are the corresponding elements.

Table 3. Legibility Factors.

Sign	Vehicle	Driver	Environment/Road
• Position 1. Ground-mounted - Right - Left - Lateral offset 2. Overhead - Height - Lane positioning - Tilt • Size • Shape • Color 1. Background 2. Legend • Legend 1. Symbol 2. Alphabet - Font - Size - Stroke width - Letter spacing - Line spacing • Lighting • Retroreflective material	• Type 1. Sports car 2. Passenger car 3. Pick-up truck / SUV 4. 18-wheeler • Headlamp 1. Bulb Type - Halogen - Tungsten - HID 2. Reflector type 3. Illumination distr. 4. Aim 5. Cleanliness • Windshield 1. Transmissivity 2. Cleanliness • Constant voltage	• Visual characteristics 1. Acuity 2. Contrast sensitivity 3. Color deficiency 4. Other • Awareness • Mental load • Alcohol / drugs	• Atmospheric conditions 1. Rain 2. Fog 3. Haze 4. Other • Background complexity 1. Urban - Residential - School - Commercial - Industrial 2. Rural • Time of day 1. Day 2. Dusk 3. Night • Horiz. Alignment • Vertical Alignment • Sight Distance • Pavement Reflectance

While each of the categorical elements listed in Table 3 effect visibility at some level, not every element has the same effect and not all factors act independently. Given the long list of elements, it would not be reasonable to explore each one individually. Furthermore, all of these elements boil down to four main components that impact nighttime visibility of retroreflective traffic control devices. These four components are:

1. the amount of light reaching the sign (illuminance),
2. the efficiency of the retroreflective material (retroreflectivity),
3. the returned light that makes the sign appear bright (luminance), and
4. the visual capabilities of the driver (i.e., human factors), which can vary substantially from driver to driver and even for each individual driver.

Illuminance

For nighttime driving, traffic control devices rely on vehicle headlamp illumination to work properly, unless they are either internally or externally illuminated. Both the *Texas* and *national MUTCDs* require that (5,6):

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

In September 1993, TxDOT implemented a guide sign policy that included the use of Type III legends on Type III backgrounds. The policy did not require external lighting except in areas where sign sight distance or geometric conditions warranted the use of sign lighting. This policy has led to inconsistent overhead guide sign lighting practices that vary from district to district and even within districts.

However, in 1999 during the 76th Texas State Legislative session, House Bill 916 was unanimously passed requiring TxDOT to modify or eliminate sign lighting unless "...for lighting of a designated highway system, the Texas Department of Transportation determines that the purpose of the outdoor lighting fixture cannot be achieved by the installation of reflective road markers, lines, warning or information signs, or other effective passive methods."

During the 1990s, a breakthrough in retroreflective sheeting occurred. Prior to the 1990s, retroreflective sheeting relied on glass beads to redirect the headlamp light back toward the driver (Types I, II, and III). However, in the 1990s three new types of retroreflective sheeting were introduced that rely on microsized prisms to redirect the light (Types VII, VIII, and IX). These three types of microprismatic sheetings were touted by the manufacturers as being brighter and better than their predecessors. Consequently, many agencies, including TxDOT, were pressured to begin using the microprismatic sheeting. TxDOT responded by installing a small number of signs throughout the state on an experimental basis.

The cumulation of these events, and others, led TxDOT to recently change its overhead guide sign policy. When implemented, the TxDOT overhead guide sign policy will be to use one of the three currently available microprismatic retroreflective sheetings. External lighting is still an option, but because of the requirements of House Bill 916, it is more difficult to install and maintain compliant lighting fixtures. Therefore, new and refurbished overhead guide signs on TxDOT's highways now rely almost exclusively on retroreflective sheeting to satisfy the previously mentioned MUTCD requirement.

Therefore, during the nighttime, guide signs are almost exclusively illuminated with vehicle headlamps. The Federal Motor Vehicle Safety Standards (FMVSS 108) includes headlamp intensity and distribution requirements for all vehicles sold in the U.S. (7). Prior to 1997, FMVSS 108 included specifications that allowed a reasonable amount of light to be emitted above the horizontal plane. This is the light that is used to "light up" overhead guide signs when no external illumination is provided. The drawback is that light above the horizontal plane can create a discomforting glare to drivers approaching from the opposite direction (i.e., on a two-lane highway).

Because of efforts to create a global headlamp specification, the FMVSS 108 was revised in 1997. The revision was made to accommodate the U.S. specification along with the European and Japanese specifications. In general terms, the U.S. pattern has traditionally provided substantially more light above the horizontal 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 horizontal. In fact, with the 1997 revision to FMVSS 108 allowing visually-optically aimed (VOA) headlamps (including both the visually-optically left (VOL) and visually-optically right (VOR) designs) and GTB's (an international group of lighting experts) 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 horizontal will decrease. A recent report shows comparisons between U.S. conventional headlamps and the VOL, VOR, and harmonized headlamps (8). For overhead signs at approximately 500 ft, there are consistent trends showing decreased illumination above the horizontal. Compared to the conventional U.S. headlamps, the VOL headlamp reduces overhead illumination by 28 percent, the VOR by 18 percent, and the harmonized headlamp by 33 percent.

To illustrate the impacts of these headlamp revisions, Figure 3 contains two headlamp profiles. The top illustration in Figure 3 shows a 50th percentile isocandela plot representing the headlamp intensity and distribution from a sample of 26 different passenger cars dating from 1986 to 1990. The bottom illustration in Figure 3 shows the isocandela plot from a 2001 Ford Explorer.

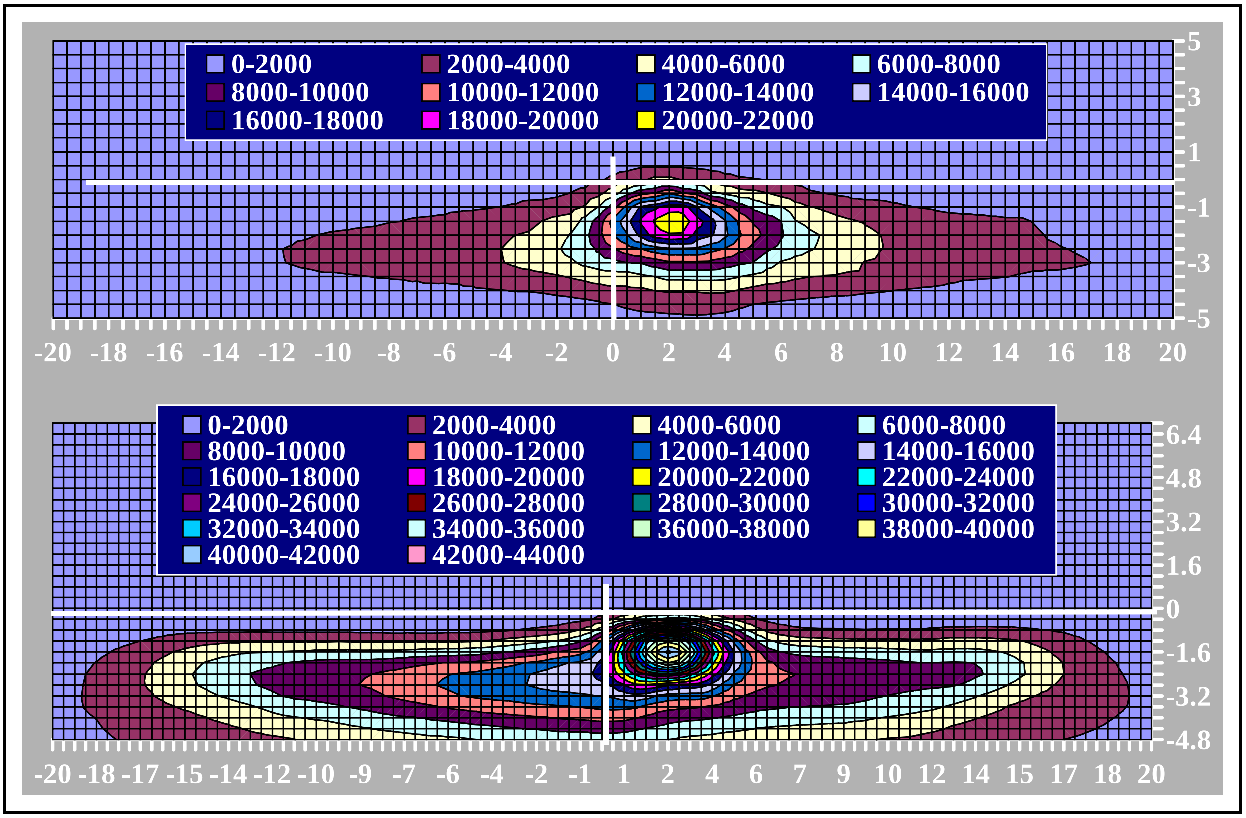


Figure 3. Isocandela Plots.

The elimination of overhead light is obvious from these two plots. However, it may be worth noting that the amount of illumination cast to the right and left of the vertical is significantly increased with the newer headlamps.

Regardless of the amount of illumination cast toward an overhead sign, one thing that is constant is the speed at which the light diminishes as it travels through the atmosphere. The determination of sign illuminance (i.e., the amount of light reaching a sign) follows the inverse-square law, which states that light diminishes with the square of the distance. Therefore, the illuminance from each headlamp can be determined as follows.

$$Left\ Headlamp\ Illuminance,\ E_L = \frac{Luminous\ Intensity_{\mathbf{L}}}{\left|\mathbf{I}_{\mathbf{L}}\right|^2}$$

$$Right\ Headlamp\ Illuminance,\ E_R = \frac{Luminous\ Intensity_{\mathbf{R}}}{\left|\mathbf{I}_{\mathbf{R}}\right|^2}$$

where: $|\mathbf{I}_{\mathbf{L}}|^2$ = the distance between the left headlamp and the sign and
$|\mathbf{I}_{\mathbf{R}}|^2$ = the distance between the right headlamp and the sign.

The total illuminance can be found by adding the illuminance from the left and right headlamps.

So as a vehicle approaches a sign and the distance constantly decreases, the illumination should increase. However, there is another factor that needs to be discussed. The equations above contain the term *Luminous Intensity*. This term refers to the output of the headlamps. The luminous intensity from each headlamp is determined from the Hh and Hv components for each headlamp (an angular convention of the Society of Automotive Engineers (SAE) type goniometer used to position and measure headlamps). Headlamp measurements are essentially a matrix of angular positions that include the output of the headlamp at each angular position. Figure 3 was created using such matrices. The matrices are generally produced from +10 above the horizontal to -7 degrees below the horizontal and 45 degrees to both sides of the vertical. Depending on the resolution of the measurements, a single luminous intensity headlamp matrix may contain as many as 30,000 cells.

As a vehicle approaches a sign, the angles from the headlamps to the sign are constantly changing as well. Therefore, the angles that specify the Hh and Hv components for each headlamp are changing. For overhead guide signs, the Hh angle remains relatively constant while the Hv angle increases at an exponential rate. Therefore, the *Luminous Intensity* is also changing as a vehicle approaches a sign. Consequently, the amount of light falling on a sign as the vehicle approaches is dynamic and constantly changing. Furthermore, the vehicle fleet using the Texas highways has a variety of headlamps that make almost every vehicle's headlamps' isocandela plots unique. Dirt on the headlamps and misalignment can also add to the variability.

Figure 4 provides an illustration of how illuminance varies as a vehicle approaches a typical overhead guide sign. This example was generated with a headlamp file representing the market-weighted, 50th percentile headlamp from passenger car sales in the U.S. in 1997. It should be noted that illuminance is not a function of the type of retroreflective sheeting used on the sign. In other words, the graph in Figure 4 only shows the amount of light hitting the sign and does not indicate how much light is redirected back toward the driver. That is a function of the efficiency of the retroreflective sheeting (discussed in the next section).

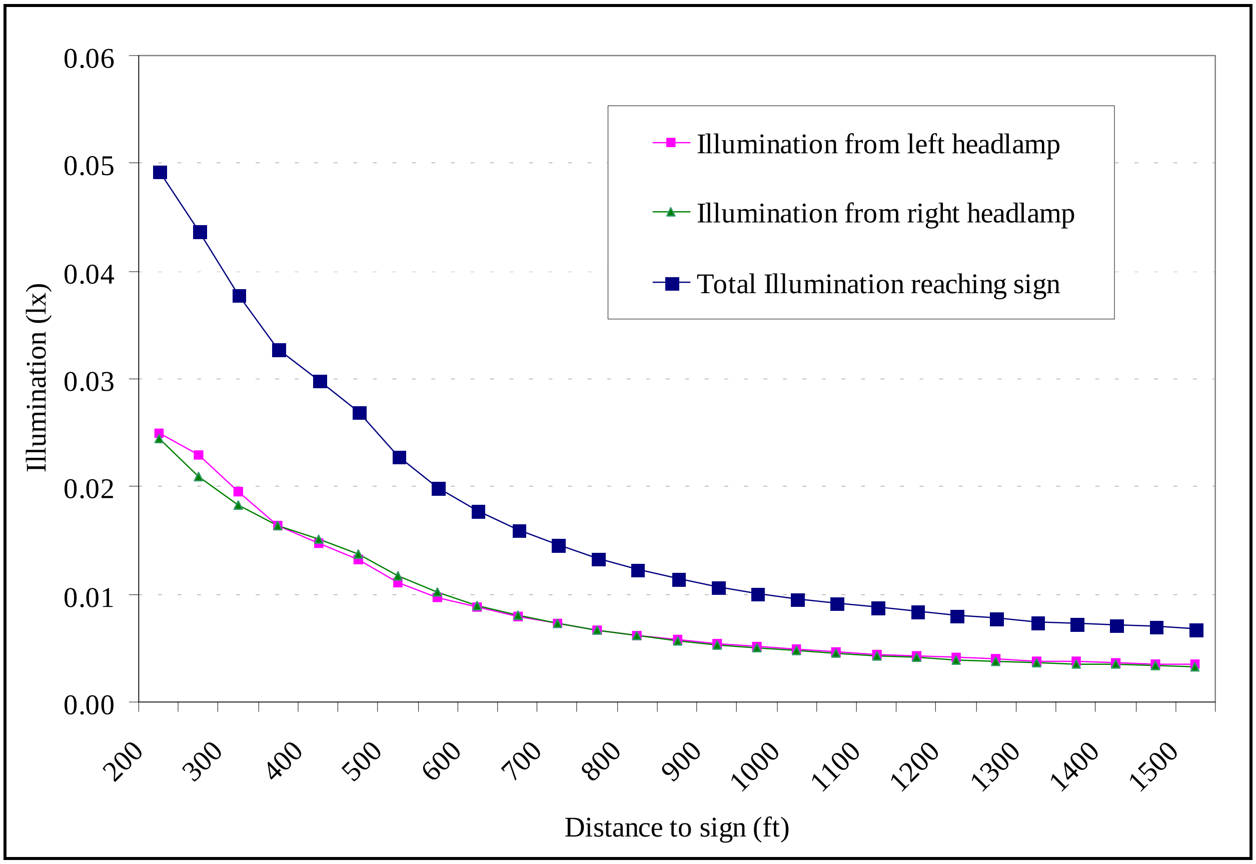


Figure 4. Example of Illumination of an Overhead Guide Sign.

Retroreflectivity

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 retroreflectivity technology since first being introduced using large glass beads, also called "cats eyes." The American Society for Testing and Materials (ASTM) defines and describes the currently available retroreflectivity sheetings in ASTM D4956 (3). 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 4 includes a list of the currently defined retroreflective sheetings available for permanent traffic signs (as per ASTM D4956).

Table 4. Types of Retroreflective Sheeting.

Type Designation	Description
I	A 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	A 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	A 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	A 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	A super-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at long and medium road distance 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	A super-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at long and medium road distance 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	A very-high-intensity retroreflective sheeting having highest retroreflectivity characteristics at short road distances as determined by the R_A values at 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.

Essentially, retroreflectivity is a way to define the efficiency of the sheeting, in other words, how well the sheeting redirects light back to the driver. However, unlike many measurements used in the civil engineering profession, retroreflectivity is not a static value. In reality, the retroreflectivity of a particular sheeting is one number that represents one of an infinite number of possible values. That is because the efficiency of retroreflective sheeting is very dependent on where the illumination source is (i.e., the vehicle headlamps), where the sign is, and where the observation point is (i.e., the driver's eyes). Theoretically, retroreflective surfaces redirect light directly back to the source. However, if retroreflective sheeting performed ideally, then all the headlamp light would be redirected back to the headlamp, and the driver would not see the sign. Fortunately, retroreflective sheeting is not perfect. Rather than redirecting all of the headlamp illumination back to the driver, the light is directed back in a conical shape and the driver's eyes generally fall within the cone. However, the cone varies with different types of retroreflective sheeting and with different viewing angles.

It takes four angles to fully describe the roadway driving environment with respect to retroreflective sheeting and the measurement of its performance. Both the International

Commission on Illumination (CIE) and the American Society for Testing and Materials have documented these systems (9,10).

Within each of these standard angular systems there are five fundamental vectors that are common to all of the systems. These vectors are shown in Figure 5.

The vector directions, that is the three components of the vector, are derived from six points in the Cartesian roadway environment. These six points are the retroreflector center (x_c, y_c, z_c), the position of the driver's eye (x_e, y_e, z_e), the position of the left and right headlamps (x_{hl}, y_{hl}, z_{hl} and x_{hr}, y_{hr}, z_{hr}), a point on the retroreflector axis (x_r, y_r, z_r), and a point on the datum axis (x_d, y_d, z_d). The axes of the five basic vectors originate on the retroreflector center. These five directions can be expressed then as vectors **E**, $\mathbf{I_R}$, $\mathbf{I_L}$, **R**, and **D** with the **i**, **j**, **k** components as follows:

E (x_e-x_c, y_e-y_c, z_e-z_c)
$\mathbf{I_R}$ (x_{hr}-x_c, y_{hr}-y_c, z_{hr}-z_c)
$\mathbf{I_L}$ (x_{hl}-x_c, y_{hl}-y_c, z_{hl}-z_c)
R (x_r-x_c, y_r-y_c, z_r-z_c)
D (x_d-x_c, y_d-y_c, z_d-z_c)

There is a fundamental restriction in the allowable direction for **R** and **D** vectors, which is that they always must be perpendicular to each other. Therefore, the dot product of **R** and **D** must equal zero.

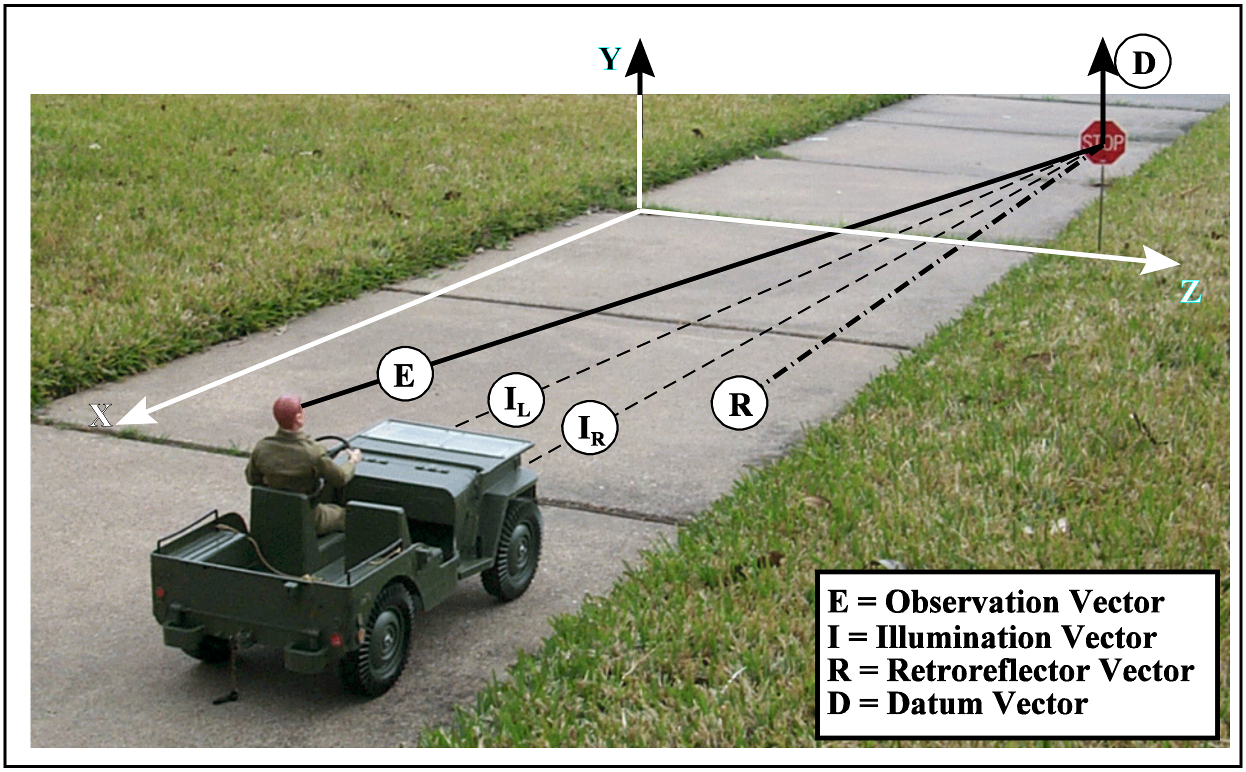


Figure 5. Basic Vectors in Roadway Environment.

For defining the angles in the application system, the basic vectors described above are required in addition to the following secondary vectors.

F	First Axis	$\mathbf{F} = \mathbf{I_x} \times \mathbf{E}$ (fixed axis on goniometer)
S	Second Axis	$\mathbf{S} = \mathbf{F} \times \mathbf{R}$ (moveable axis on goniometer)
C	Advance Axis	$\mathbf{C} = \mathbf{R} \times \mathbf{S}$ (90 degree advanced to **S**)
H	Vector	$\mathbf{H} = \mathbf{I_x} \times \mathbf{R}$ (perpendicular to entrance plane)
L	Vector	$\mathbf{L} = \mathbf{H} \times \mathbf{R}$ (in entrance plane perpendicular to **R**)

Using these secondary vectors, the angles in the application system can be determined as follows:

observation angle for left headlamp, α_L:	$\cos \alpha_L = \mathbf{E} \bullet \mathbf{I_L}$		
observation angle for right headlamp, α_R:	$\cos \alpha_R = \mathbf{E} \bullet \mathbf{I_R}$		
entrance angle for left headlamp, β_L:	$\cos \beta_L = \mathbf{R} \bullet \mathbf{I_L}$		
entrance angle for right headlamp, β_R:	$\cos \beta_R = \mathbf{R} \bullet \mathbf{I_R}$		
rotation angle, ε:	$\cos \varepsilon = \mathbf{D} \bullet \mathbf{S}$	or	$\sin \varepsilon = \mathbf{D} \bullet \mathbf{C}$
orientation angle, ω_s:	$\cos \omega_s = \mathbf{D} \bullet \mathbf{L}$	or	$\sin \omega_s = \mathbf{D} \bullet \mathbf{H}$

The most important of the angles is the observation angle, which is separately defined for the left and right headlamp. The observation angle for the left headlamp is the angle between the vectors $\mathbf{I_L}$ and **E**, as shown in Figure 5. Figure 6 shows how important the observation angle is in terms of retroreflectivity.

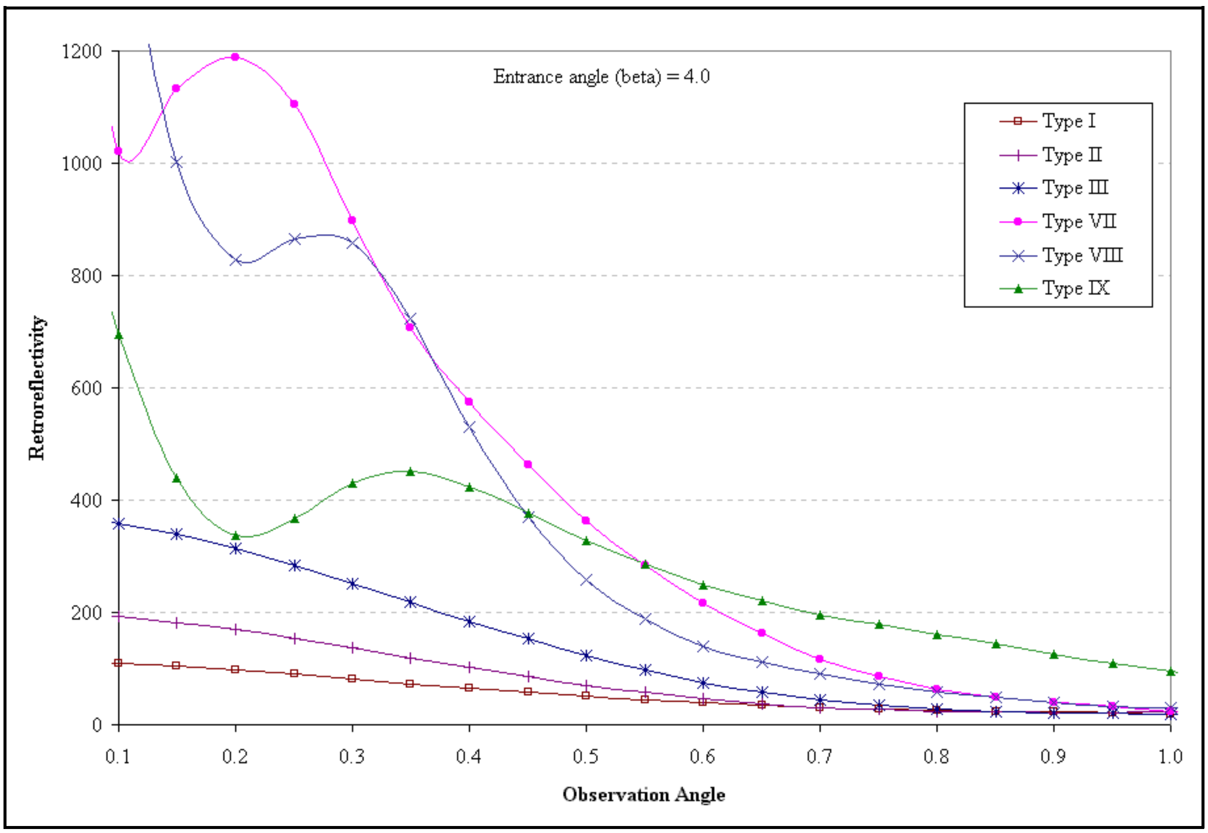


Figure 6. Observation Angle Curves for Retroreflective Sheeting.

Going back to the same overhead sign example as used in the previous section, a graph was created showing how the observation angle changes as a passenger car approaches an overhead guide sign (see Figure 7).

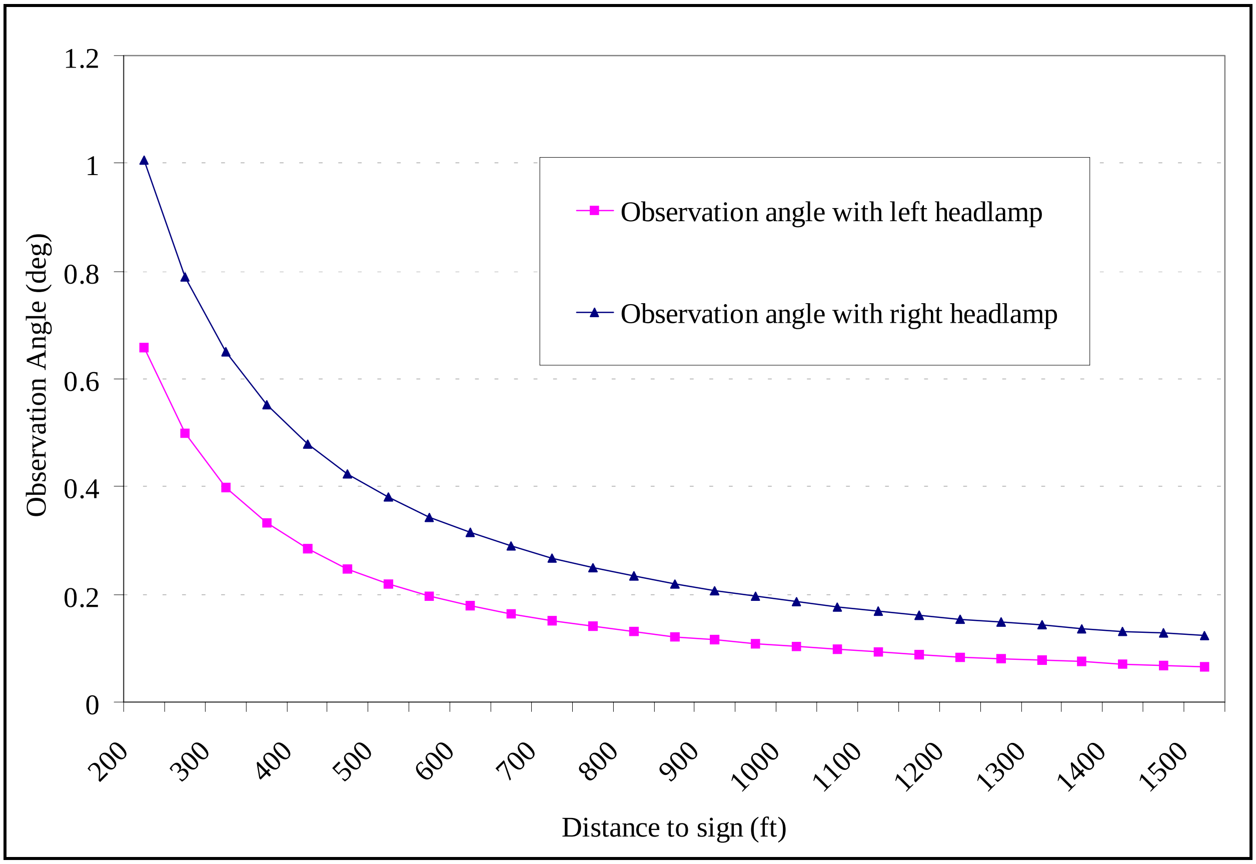


Figure 7. Example of Observation Angle Changes Approaching an Overhead Guide Sign.

Because the driver seat is not centered in a vehicle, but is positioned closer to the left side of the vehicle, there are noticeable differences between the left and right observation angles. The left headlamp is closer to the driver's eye, and, therefore the angle subtended between $\mathbf{I_L}$ and **E** is smaller than the angle subtended between $\mathbf{I_R}$ and **E**.

Using Figures 6 and 7, one can really start to see the impact of the distance between the sign and the vehicle and how the changing observation angle plays a critical role in the actual retroreflectivity as the vehicle approaches the sign. For instance, at 1500 ft, the observation is approximately 0.1 degrees. Going back to Figure 6, the retroreflectivity can vary from 100 cd/lx/m^2 with Type I sheeting to over 1000 cd/lx/m^2 with Types VII or VIII sheeting. However, as the distance between the vehicle and sign decreases, the observation angle increases and the sheeting performance decreases, although not consistently among types of sheeting.

Because of variations in the angles that define retroreflectivity, such as those shown with the observation angle, it is difficult to define the best performing sheeting for all conditions. Consequently, ASTM D4956 includes as part of the type designations, matrices of different observation and entrance angles that are used to categorize the retroreflective sheetings by products, not necessarily by performance.

The standard measurement geometry used in the U.S. is defined with an observation angle of 0.2 degrees and an entrance angle of -4.0 degrees.

Luminance

Luminance is a measure of the brightness of a sign. It includes the illuminance reaching the sign and is dependent on the retroreflectivity of the sheeting at the geometry defined by the location of the vehicle with respect to the sign. Luminance of a retroreflective sign, directed toward the driver, can be estimated as follows:

$$L = \frac{\left(R_A \times E\right)_{left} + \left(R_A \times E\right)_{right}}{\cos \upsilon}$$

$R_{A,left}$ and $R_{A,right}$ are the coefficients of retroreflection of the sign corresponding to the vehicle's left and right headlamps (as source points) with the vehicle's driver as the observation point. E_{left} and E_{right} are the separate headlamp illuminance values falling on the sign, measured on planes perpendicular to the respective illumination axis. Nu is the viewing angle for the sign, using the driver as the observation point.

However, adjustments are needed to account for those factors that impact the amount of available luminance directed from the sign. The estimated luminance can be thought of as the luminance in a perfect environment with no obstacles between the sign and the observer. However, in a driving environment there are at least two factors that have to be considered. The first is the impact of the light scatter caused by the transmission of light through the windshield. This is called windshield transmissivity and typically reduces the ideal luminance by about 30 percent. The second factor that can be considered is the atmospheric transmissivity. As light passes through the air, it is scattered by dust particles, and thus the luminance is reduced. Atmospheric reduction factors are available in most physic books and depend on not only the weather conditions, but also the viewing distance.

Again, going back to the example used previously, the ideal luminance of different retroreflective sheetings was calculated for a vehicle approaching an overhead sign. Figure 8 shows how the luminance changes as the distance to the sign decreases.

The example clearly shows that the brightness of the sign (i.e., the luminance) changes as the distance to the sign decreases. It is brightest at about 500 to 600 ft, but as the distance to the sign decreases beyond 500 ft, the luminance of the sign quickly diminishes. Also, the impact of the newer microprismatic retroreflective sheeting technologies is clearly evident.

Human Factors

In recent years research efforts have made an asserted effort to accommodate the needs of elderly drivers. This is especially critical for the establishment of policies regarding retroreflective sheeting since driver vision generally degrades with age, thus requiring brighter signs. The question becomes, how much luminance is needed to reasonably accommodate nighttime drivers, including the elderly drivers.

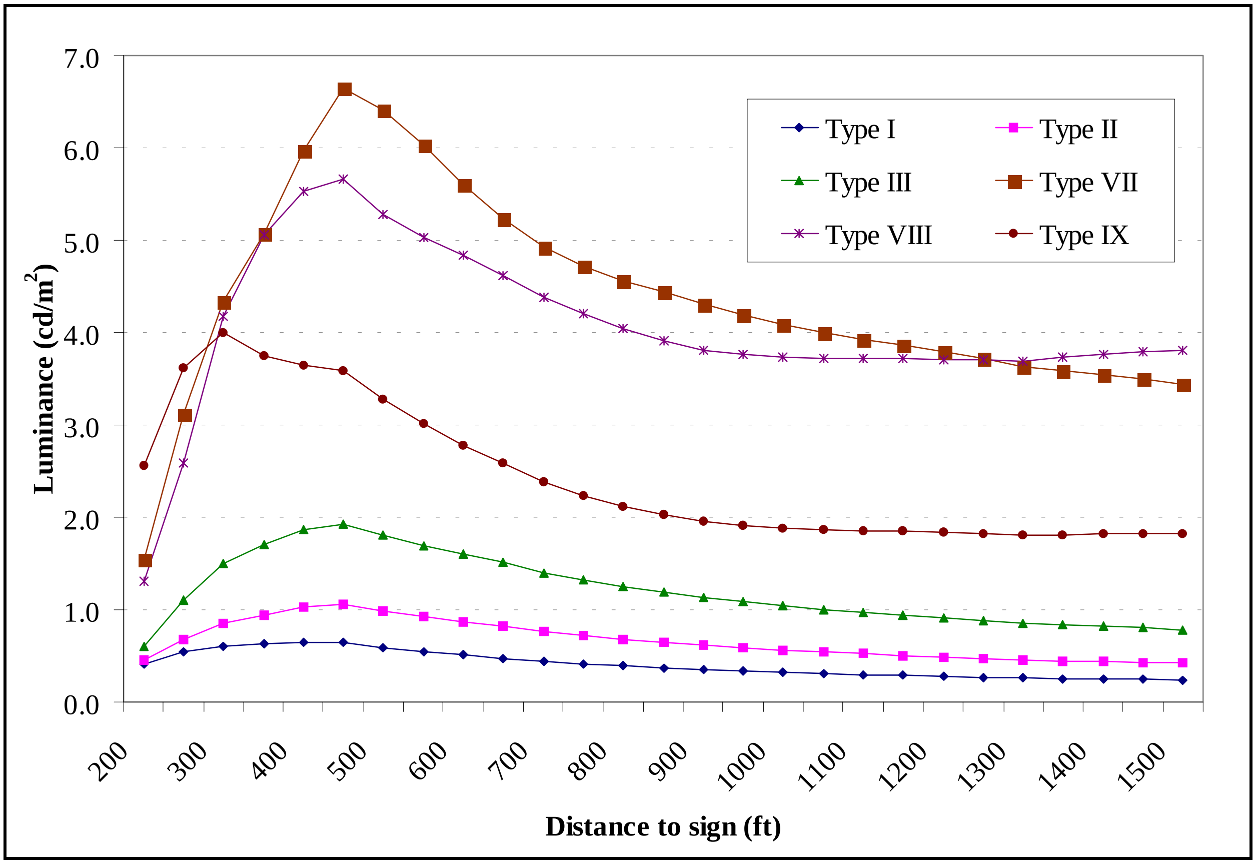


Figure 8. Example of Luminance of an Overhead Guide Sign.

Fortunately, research has been recently completed that documents the minimum luminance needs for nighttime drivers. In a recent FHWA study, Carlson and Hawkins performed a study to determine minimum guide sign luminance needs for elderly drivers (11). Figure 9 shows the cumulative distribution results for 30 drivers aged 55 to 81. These curves represent the minimum luminance needed to read overhead guide signs.

The first finding from this graph is that the luminance needed to read an overhead sign decreases as the distance to the sign decreases. At a distance of 640 ft (i.e., a legibility index of 40 ft/in of letter height), 50 percent of the elderly drivers would be accommodated with a luminance of 2.3 cd/m^2. Table 5 shows the luminance requirements depending on accommodation level and distance.

It is important to note that these values were obtained in a dark rural environment with little ambient light. Research has shown that as the background environment becomes more complex and the ambient light level rises (conditions typically found with overhead guide signs), drivers need more luminance to read signs. Therefore, these numbers represent ideal conditions and should be considered absolute minimums.

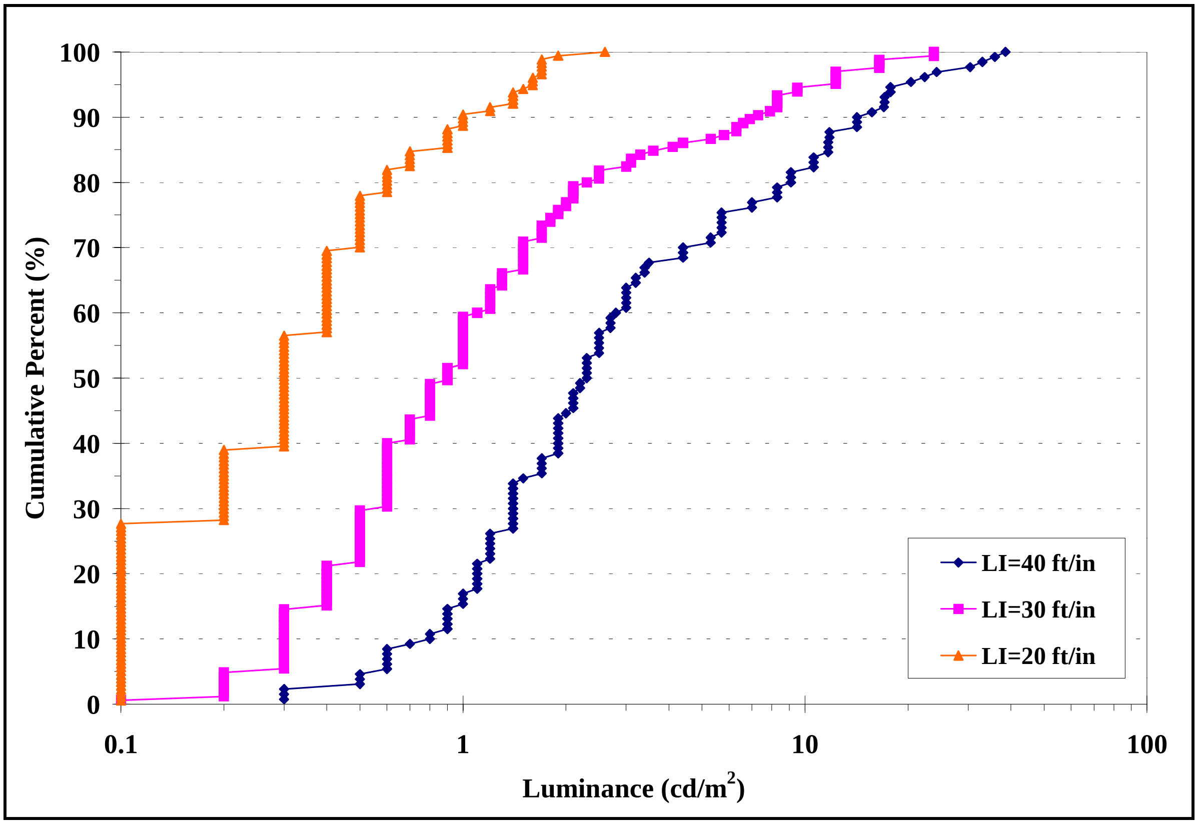


Figure 9. Minimum Luminance Required for Overhead Signs.

Table 5. Threshold Luminance Values for Overhead Signs (cd/m²).

Distance (ft)	Accommodation Level (percent)		
	50	75	85
300	0.27	0.45	0.75
470	0.80	1.63	3.05
640	2.30	5.70	11.7

Implications

Using the minimum luminance values shown in Table 5, it is possible to determine best fit curves in order to develop minimum luminance curves to accommodate other distances. The equations for each of the three accommodations levels were computed and are shown below.

- 50th percentile accommodation level: Minimum luminance = $0.0671 \times e^{(0.0081 \times \text{distance})}$
- 75th percentile accommodation level: Minimum luminance = $0.0482 \times e^{(0.0075 \times \text{distance})}$
- 85th percentile accommodation level: Minimum luminance = $0.0410 \times e^{(0.0063 \times \text{distance})}$

Now, using the luminance graph shown in Figure 8, the minimum luminance curves derived from the relationships shown above were superimposed. Figure 10 shows the results.

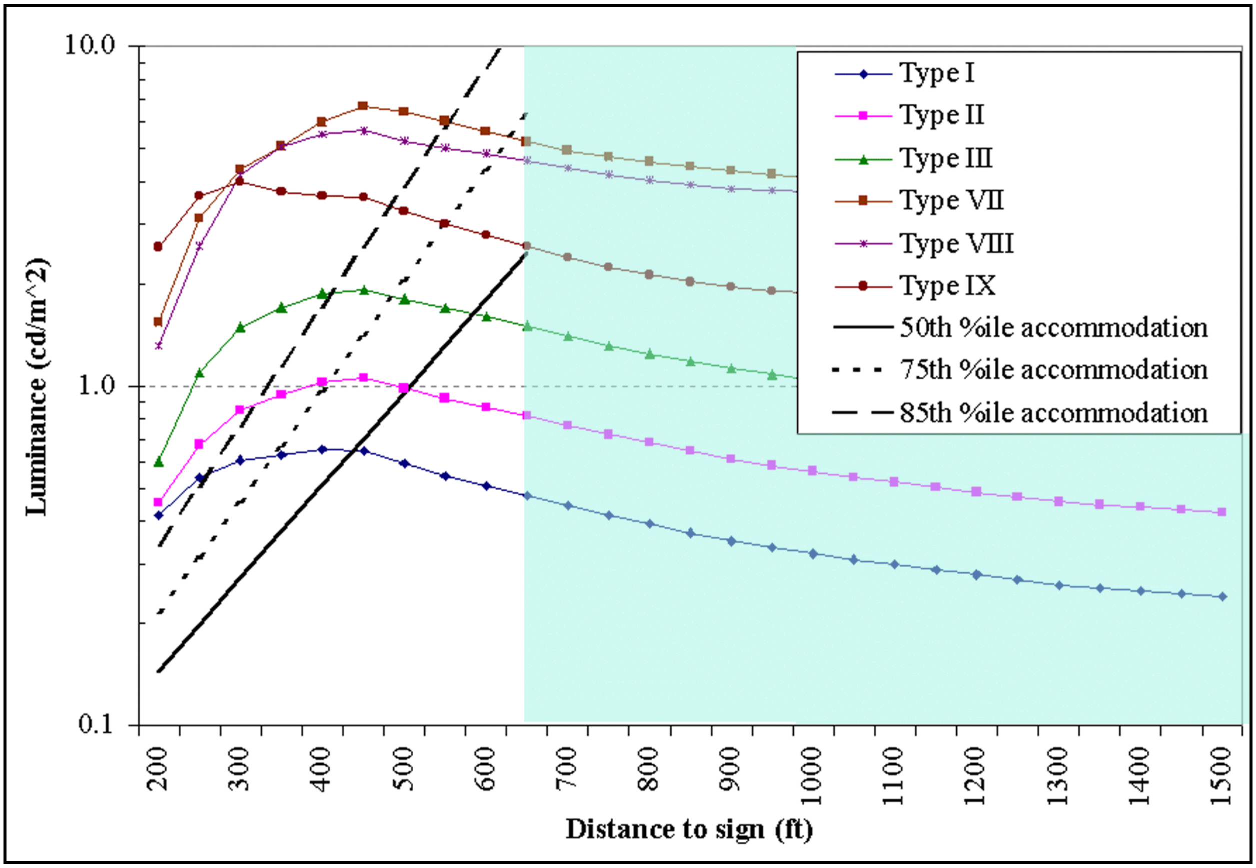


Figure 10. Passenger Car Luminance Curves.

With the minimum luminance curves superimposed on the available luminance curves, derived from the discussion above and representing a typical overhead guide sign with 50th percentile headlamps circa 1997, it is possible to estimate the actual performance of different retroreflective sheetings.

First, in the Millennium MUTCD, signs are to be designed to provide a legibility index of 40 ft/in of letter height (6). In Texas, overhead guide signs are constructed with legends of 16/12 inch uppercase/lowercase letters. Using these values to derive a criterion, overhead guide signs should be designed to be legible at 640 ft (16 in × 40 ft/in). Coincidently, numerous research reports have reported this distance as the maximum legibility distance for elderly drivers. Consequently, the grey area of Figure 10 represents distances greater than 640 ft and, therefore, non-critical distances with respect to legibility for elderly drivers (although younger drivers should be able to read signs in the gray area, and recognition distances will typically fall in the gray area).

The way to read Figure 10 is as follows. In order to design overhead guide signs to accommodate 50 percent of the elderly drivers, the luminance curve for a particular sheeting must fall above the 50th percentile accommodation curve. The point where the lines intersect is the maximum distance that a particular type of retroreflective sheeting can provide sufficient luminance to read the sign. For instance, in order to accommodate 50 percent of the elderly drivers, Type I sheeting provides sufficient luminance levels starting at about 440 ft, and Type III sheeting provides sufficient luminance levels starting at about 580 ft. Neither of those distances meets the MUTCD criterion of 40 ft/in of letter height (or 640 ft for overhead guide signs).

However, for an accommodation level of 50 percent, all three types of microprismatic material do meet the MUTCD criterion. Table 6 lists the performance of each type of retroreflective sheeting as derived using the same approach.

Table 6. Overhead Signs Retroreflective Sheeting Performance for Passenger Cars. [A]

Sheeting Type	Accommodation Level (percent)		
	50	75	85
Type I	440 ft	340 ft	250 ft
Type II	500 ft	400 ft	320 ft
Type III	580 ft	480 ft	410 ft
Type VII	≥ 640 ft [B]	640 ft [B]	550 ft
Type VIII	≥ 640 ft [B]	610 ft	530 ft
Type IX	≥ 640 ft [B]	550 ft	480 ft

A Point at which an overhead sign first becomes legible for elderly drivers in a **passenger car**
B For these conditions, the retroreflective sheeting meets the MUTCD criterion

From this hypothetical scenario, one can easily determine that for overhead guide signs there is a distinct advantage to using microprismatic retroreflective sheetings. More specifically, for the this example, Type VII sheeting performs the best, followed closely by Type VIII, and then Type IX. As expected, the worst performing sheeting is Type I. Type III sheeting, the TxDOT practice until recently, performs better than any of the glass beaded material but clearly not as well as the newer microprismatic retroreflective sheetings.

At this point, it is important to list the conditions under which this example was derived. The illuminance, observation angle, and luminance data were generated using a photometric model called ERGO (12). The following bullets list and discuss these example conditions.

- **Headlamps** - The headlamp used in this example represents the market-weighted, 50th percentile headlamp from passenger car sales in the U.S. in 1997. It is commonly referred to as UMTRI50c (13). This headlamp profile was used for both the left and right headlamps. It assumes a perfectly clean and perfectly aligned headlamp.
- **Overhead Sign** - This example used an overhead guide sign with 16/12 inch uppercase/lowercase Series E(Modified) letters. The guide sign was positioned directly above the travel lane with a centroid height of 25 ft above the pavement surface.
- **Vehicle** - This example used a passenger car (the ERGOcar) centered in a 12 ft lane.
- **Retroreflectivity** - The retroreflectivity data used were those that come with the ERGO program as defaults.
- **Luminance** - This example used what has been described herein as ideal luminance. In other words, no consideration was given to windshield or atmospheric transmissivity.

- **Minimum Luminance** - The minimum luminance used in the example represents the minimum legibility luminance for elderly drivers, as reported by Carlson and Hawkins (11). The conditions under which these minimum luminance were obtained include dark, rural environments with little ambient lighting. An accommodation level of 50 percent for older drivers probably represents something substantially higher, considering that most of the nighttime drivers are younger than 55 and younger drivers generally have better vision than elderly drivers. For instance, assuming that 75 percent of nighttime drivers are younger than 55 and younger drivers need less luminance than older drivers to read traffic signs, an accommodation level of 50 percent for the data reported by Carlson and Hawkins actually translates to an accommodation level of 75 + [(50/100)×25] = 87.5 percent for the population of nighttime drivers.

For a given roadway, there are only a couple of factors of concern. One is the type of vehicle (which helps characterize the headlamps and observation angles) and the other is the visual capabilities of the driver. Using the minimum luminance data from Carlson and Hawkins to account for the visual capabilities of the driver, and maintaining the market-weighted, 50th percentile headlamp from passenger car sales in the U.S. in 1997, two additional analyses were performed to determine the performance of the various retroreflective sheetings when different types of vehicles approach the sign. Figures 11 and 12 show the results using a pickup or large sport utility vehicle (SUV) and an 18-wheeler, respectively. Tables 7 and 8 summarize the findings.

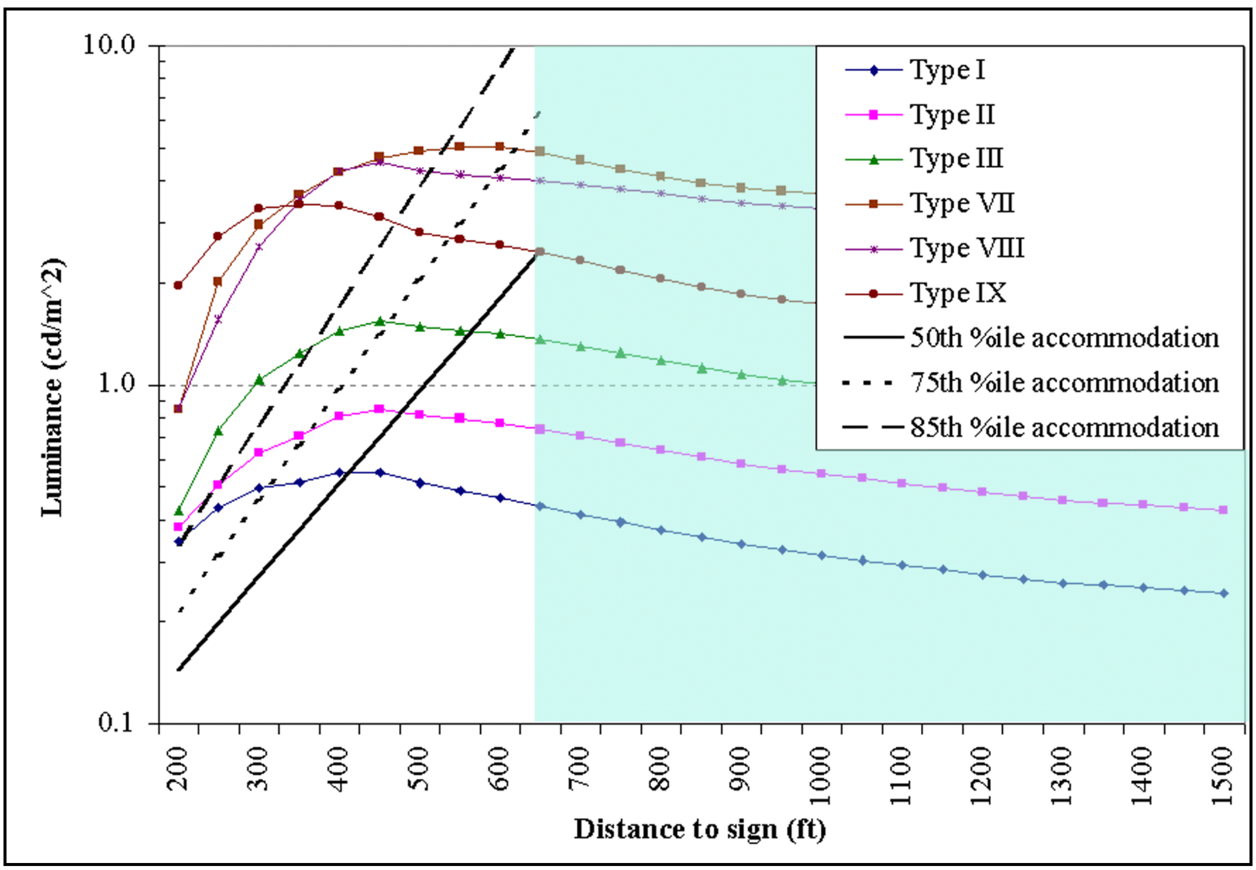


Figure 11. Pickup Truck and SUV Luminance Curves.

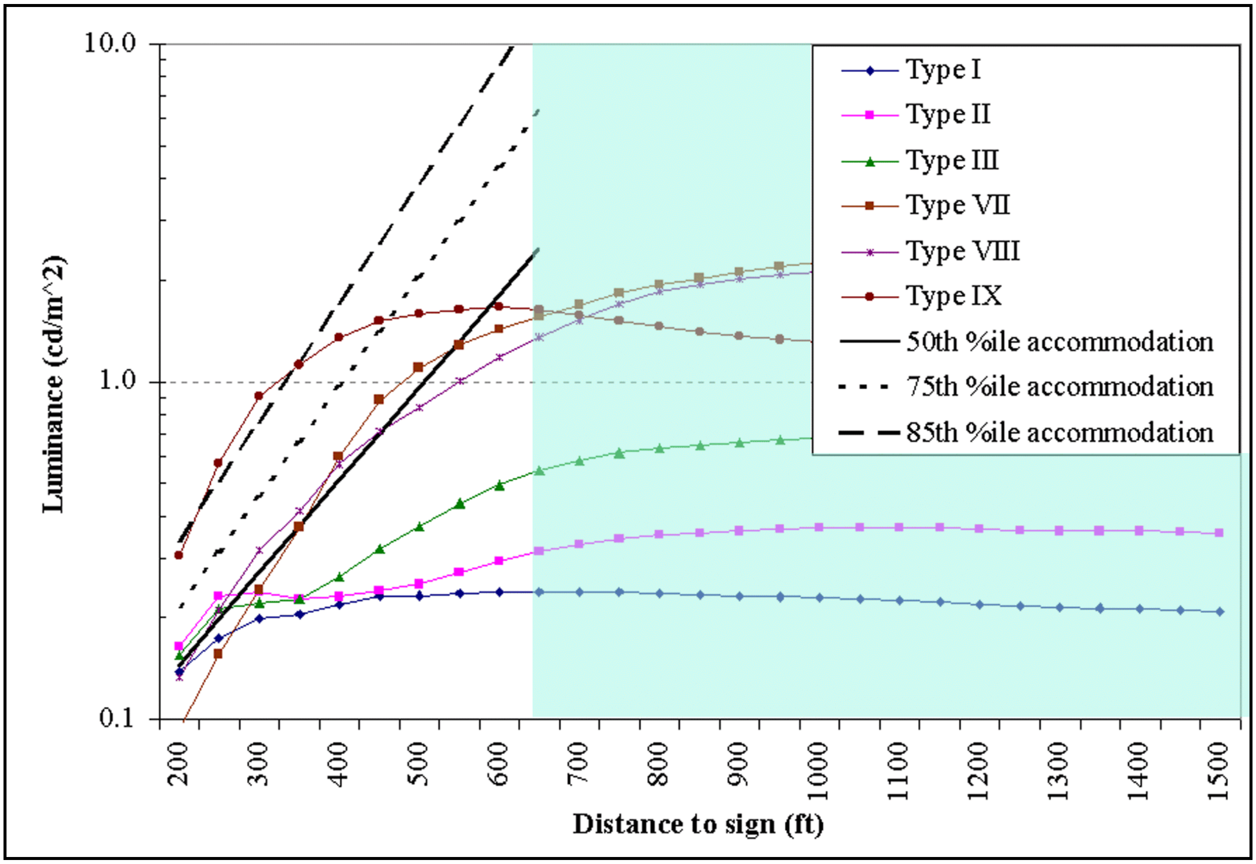


Figure 12. Eighteen-Wheeler Luminance Curves.

Table 7. Overhead Signs Retroreflective Sheeting Performance for Pickup Trucks and SUVs. [A]

Sheeting Type	Accommodation Level (percent)		
	50	**75**	**85**
Type I	400 ft	300 ft	inadequate
Type II	475 ft	350 ft	250 ft
Type III	560 ft	460 ft	360 ft
Type VII	≥ 640 ft [B]	610 ft	530 ft
Type VIII	≥ 640 ft [B]	590 ft	510 ft
Type IX	640 ft [B]	540 ft	460 ft

A Point at which an overhead sign first becomes legible for elderly drivers in a **pickup truck or large SUV**
B For these conditions, the retroreflective sheeting meets the MUTCD criterion

Table 8. Overhead Signs Retroreflective Sheeting Performance for 18-Wheelers. [A]

Sheeting Type	Accommodation Level (percent)		
	50	**75**	**85**
Type I	inadequate	inadequate	inadequate
Type II	275	inadequate	inadequate
Type III	250	inadequate	inadequate
Type VII	350	inadequate	inadequate
Type VIII	450	inadequate	inadequate
Type IX	580	460 ft	350 ft

A Point at which an overhead sign first becomes legible for elderly drivers in an **18-wheeler**
B For these conditions, the retroreflective sheeting meets the MUTCD criterion

To help compare the performance data for the three vehicle types, researchers developed a graph showing each type of retroreflective sheeting and how well it provides adequate overhead sign luminance to elderly drivers. Figure 13 illustrates the results.

This example shows the expected performance of different sheeting types viewed from different vehicles. It is important to note that these results are theoretical and based on modeling efforts of overhead guide signs. The measure of effectiveness is the ability to provide enough luminance to ensure legibility at 640 ft.

Caveats

At first glance, it appears that a possible solution exists for the much debated argument about the most appropriate retroreflective sheeting for a given situation. However, as mentioned in the beginning of this discussion, there are many factors that impact the performance of retroreflective traffic control devices. For instance, the headlamp profile used appears to be reasonable; however, the headlamp technologies and specifications are changing rapidly. For instance, the headlamp profile used does not include the newer high-intensity discharge (HID) headlamps currently found on the more expensive vehicles. Furthermore, it does not include VOA style headlamps. Even if it did, it would take some time for the vehicle fleet to be impacted drastically. There is currently no good source of data that indicates what the 50th or 85th percentile illumination level on an overhead guide sign is. If this data were collected on the road as it should be, rather than in a photometric tunnel under ideal conditions, one would know the impact of headlamp cleanliness and misalignment.

Another caveat of the example is related to the minimum luminance data used to ultimately derive the performance of the different types of retroreflective sheeting. As mentioned, the minimum luminance data were collected in a dark, rural environment with little ambient lighting. This in not the condition where one typically finds overhead signs. Rather, they are usually found on urban freeways and highways with complex backgrounds, increased ambient lighting, and commercial signs competing for the driver's attention.

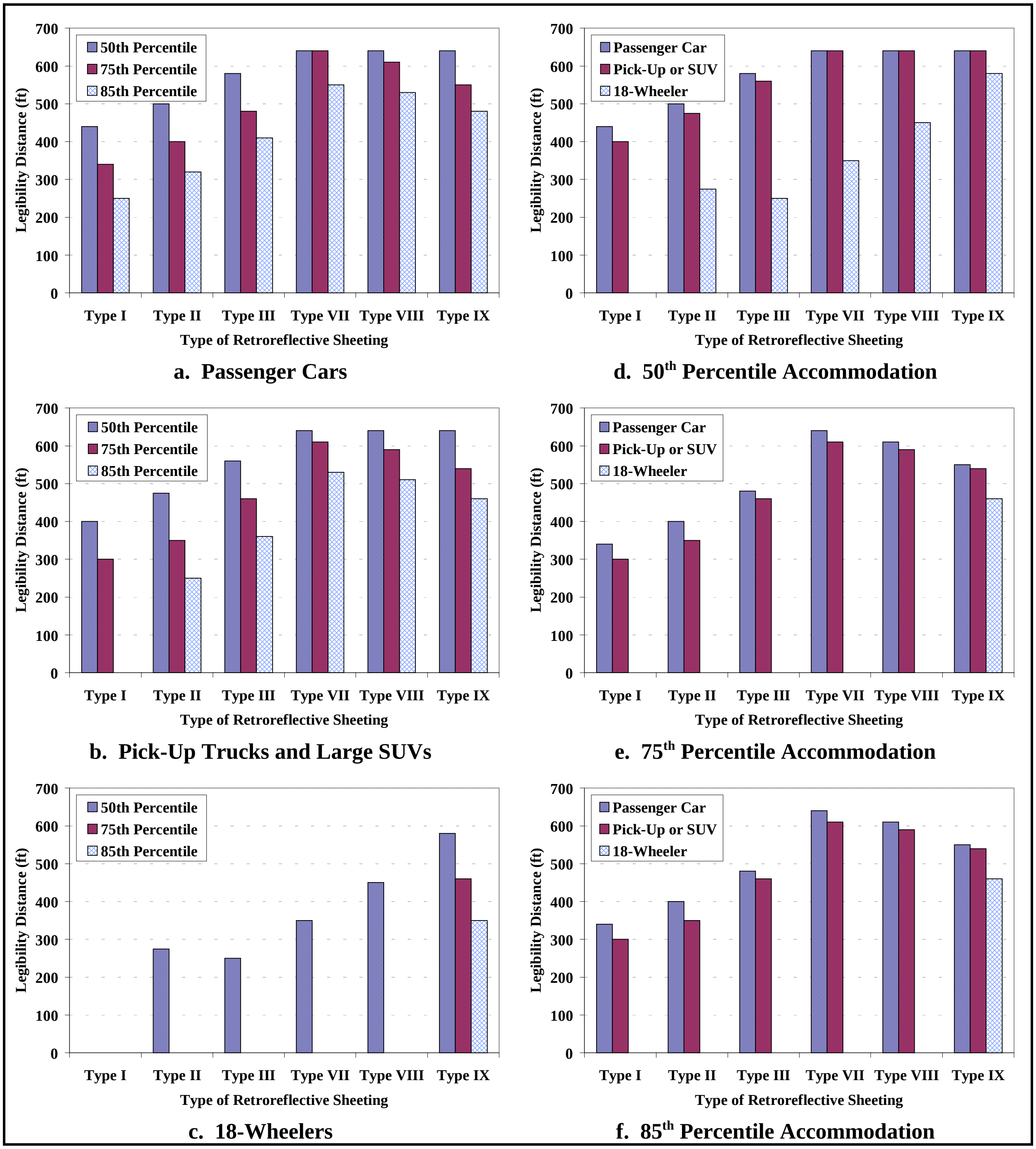


Figure 13. Overhead Sign Sheeting Performance Summary.

It is also important to mention that the numbers and results discussed in this example are for overhead guide signs only. Shoulder-mounted guide signs on the left shoulder would produce substantially different luminance curves (because the headlamp illuminations are different, the geometry is different, and, therefore, the performance of the retroreflective sheetings is different). Furthermore, results from shoulder-mounted guide signs on the right would be different from shoulder-mounted guide sign on the left.

Consequently, it is important to perform research to determine the impacts of such factors. Well-designed research plans can be formulated to answer a number of questions, although rarely all of the questions. Such is the case in this study. For instance, the research has been designed to not only look at the impact of a new alphabet, but also to collect data on the difference between different retroreflective sheeting, with different aged drivers, and in two different vehicles chosen to help resolve some of the issues related to increased observation angles and the newer headlamp designs.

CHAPTER 4
FIELD EVALUATION

The objective of the field evaluation was to determine the legibility distances of overhead and shoulder-mounted guide signs fabricated with Types VIII and IX retroreflective sheetings with Clearview and Series E(Modified) legends. This evaluation also included two different vehicles and subjects of three different age groups. This chapter describes the selection of the study variables, test equipment, research stimuli, study procedure, and data collection and processing.

SELECTION OF VARIABLES

Dependent Variable

The measure of effectiveness used in this study was legibility distance. Previous research has used two measures of effectiveness when studying the visibility of different alphabets. The most common is the legibility distance, the distance at which a subject can read an unknown word. Less frequently used is the recognition distance, the distance at which a subject can identify a word that has been specified beforehand (a known word). The legibility distance provides the truest measure of the readability and performance of a given alphabet. On the other hand, the recognition distance most closely relates to the driving task of finding a desired destination in a guide sign.

The Clearview alphabet has been developed to accommodate microprismatic retroreflective sheeting with its relatively high performance compared to earlier versions of retroreflective sheetings made with glass beads. Naturally, the changes made do not substantially change the footprint of a word. Rather, the changes are meant to reduce the irradiation impacts and therefore, the stroke width of the letters have been shaved, mostly on the internal section of closed loops. Therefore, the recognition of the words should not be impacted significantly. Research summarized in the previous chapter provides validation. However, the legibility, and particularly the nighttime legibility, of the words has the potential to be impacted the most. Consequently, this study exclusively used nighttime legibility as the measure of effectiveness. Furthermore, this approach allowed the researchers to expand the study design to include vehicle type. This approach also allows easy comparisons to be made to earlier research.

Independent Variables

To keep the scope of the study within the resources of the project, researchers identified and tested the following independent factors.

- **Alphabet** - Two alphabets were tested in this project. The control alphabet was Series E(Modified) as defined in the *Standard Alphabets for Highway Signs* publication (14,15). The experimental alphabet was the Clearview Regular Express typeface (shown in Table 1). This earlier typeface of the Clearview alphabet was used for two reasons. First, TxDOT has licensed copies of this version of Clearview. Second, by using the same version of Clearview as used in the earlier TTI-Clearview project (2), direct comparisons can be made easier. Besides, there is little difference in the Clearview Regular Express typeface and the newer ClearviewOne BD-55 typeface.

- **Sign Position** - Originally, this project was intended to include a balance of overhead and shoulder-mounted guide signs. However, after the project started, the focus was changed to right shoulder-mounted guide signs. Therefore, while both types of guide signs are included, most of the data are associated with right shoulder-mounted guide signs. However, because the Clearview alphabet has been designed to perform better than Series E(Modified) under relatively high luminance levels, and right shoulder-mounted signs naturally produce higher luminance levels than overhead mounted signs (because they receive more headlamp illumination), the switch in focus to shoulder-mounted signs was not deemed detrimental to the study's overall objective.
- **Retroreflective Sheeting** - A similar project had evaluated the Clearview Regular Express typeface using Type III sheeting for both the legend and background (2). In this project, Type VIII and Type IX microprismatic retroreflective sheetings were used. There was no mixing of the sheeting. Some trials were also conducted with Type III sheeting in order to make comparisons between this study and the previous TTI-Clearview project (2).
- **Vehicle/Headlamp Type** - Two vehicles were used in this project. One was a 2001 Chevy Suburban four-wheel drive. This vehicle had the tungsten-halogen replacement bulb headlamps. The second vehicle was a 1989 Ford Crown Victoria LTD. This vehicle had sealed-beam headlamps. The Ford was chosen so that comparisons could be made to the previous TTI-Clearview project which used a 1991 Ford Crown Victoria (Ford had made no significant changes to the Crown Victoria between 1989 and 1991). The suburban was used to determine the legibility impact of increased observation angles and newer headlamp technology and specifications.
- **Subject Age** - Three subject age categories were selected for this project. The young group was classified as 18 to 34, the middle-aged group was classified as 35 to 54, and the elderly group was classified as 55 and older. There were a total of 20 subjects in each age category with an equal gender split.

Fixed Factors

The factors that were held constant throughout the experiment include:

- **Alphabet Size** - All alphabets used a 16 in uppercase letter with appropriate lowercase letter heights. For the Series E(Modified) alphabet, the loop height of the lowercase letter was 12 inch. For Clearview, the lowercase height varied between letters.
- **Seat Position** - Each subject performed the study from the driver's seat of each vehicle.
- **Vehicle Speed** - Each trial was performed at approximately 35 mph.
- **Environmental Conditions** - All data were collected under dry, nighttime conditions (i.e., no rain or dew on the signs).
- **External Sign Illumination** - No external lighting was used to light the signs.
- **Ambient Lighting** - The study was performed at Texas A&M University's Riverside Campus. This campus is an old Air Force Base that was donated to the University. It is approximately 12 miles from the main campus and located in a dark, rural environment. There is little lighting from buildings or nearby communities.

- **Inter-letter Spacing** - Spacing between letters remained the same for all words in both alphabets. For Series E(Modified), the standard spacing was used (14). For Clearview, the spacing used in the earlier TTI-Clearview project was used.
- **Sign Size** - All words were presented on a sign background that was 12 ft wide by 9 ft tall. Each word was contained on an 8 ft wide by 2 ft tall panel made with the same type of retroreflective sheeting as the sign background.

Measured Factors

Besides the independent variables and fixed factors, there were also factors that were measured each night. These factors are listed and described below.

- **Visual Acuity** - Each of the 60 test subjects were required to have a valid drivers license. The researchers measured the visual acuity of each subject using the Snellen visual acuity chart.
- **Retroreflectivity** - Before the project began, the retroreflectivity of the signs and backgrounds was measured. Table 9 lists the average values.

Table 9. Retroreflectivity Measurements (cd/lx/m^2).

ASTM Type	Color	Individual Measurements						Average
		1	2	3	4	5	6	
III	Green	51	48	53	57	59	59	55
	White	308	312	310	314	320	313	313
VIII	Green	127	128	110	139	140	149	132
	White	833	682	832	830	790	826	799
IX	Green	101	80	89	88	85	83	88
	White	471	478	468	500	535	528	497
* All readings taken with a Retrosign at 0 degree rotation								

- **Sign Luminance** - Every 100 ft, from 1000 ft to 200 ft, luminance from the driver's point-of-view was recorded for each sign position, each retroreflective sheeting, and each vehicle. The luminance data were measured with the headlamps switch on low-beams, just as the nighttime legibility data were collected. The data are shown in Table 10.

Table 10. Measured Sign Luminance (cd/m^2).

Distance (feet)	2001 Suburban				1989 Crown Victoria LTD			
	Shoulder-Mounted		Overhead		Shoulder-Mounted		Overhead	
	IX	VIII	IX	III	IX	VIII	IX	III
200	8.1	3.1	4.7	0.6	18.6	8.0	15.8	2.1
300	10.7	8.4	7.1	1.7	32.7	40.0	29.1	4.7
400	10.0	16.1	6.4	2.2	33.1	62.0	27.0	6.2
500	8.0	14.6	5.6	2.5	31.9	61.0	21.1	11.8
600	7.2	12.7	5.0	2.3	26.2	58.0	20.2	8.3
700	5.4	10.8	4.3	2.1	22.1	54.0	16.9	8.0
800	4.5	9.5	3.3	1.8	18.2	46.0	13.3	6.8
900	4.0	9.5	3.0	1.6	19.2	53.0	14.0	5.5
1000	3.3	7.3	2.2	1.4	16.2	46.0	9.1	4.9

- **Vehicle Dimensions** - The headlamp and driver eye height for each vehicle were also recorded.
- **Cloud Coverage** - Each night the cloud coverage was recorded.
- **Moon Cycle** - Each night the moon cycle was recorded.

TEST EQUIPMENT

Test Vehicles

As mentioned, two vehicles were used throughout the study. One was a 2001 Chevy Suburban with four-wheel drive. The second was a 1989 Ford Crown Victoria LTD. Both of these vehicles were equipped with a distance measuring device (DMI). The DMIs were calibrated and produced nearly identical results when compared. The DMIs were used to measure and record the legibility distances. Figure 14 shows each test vehicle with their lowbeam lights on.

2001 Chevy Suburban | **1989 Ford Crown Victoria LTD**

Figure 14. Test Vehicles.

Sign Structures

The infrastructure used two sign structures fabricated for the earlier TTI-Clearview project. Each of the signs was 12 ft by 9 ft and covered with the appropriate type of green retroreflective sheeting.

The sign structures were located on one of the runways at the Texas A&M University Riverside Campus. This facility is a decommissioned Air Force Base that was donated to Texas A&M University circa 1950. Figure 15 illustrates the arrangement of runways and taxiways at the Riverside Campus and indicates where the sign structures used in this experiment were located. The overhead structure had about 2000 ft of sight distance in each direction. The runway was level with no sight distance obstructions.

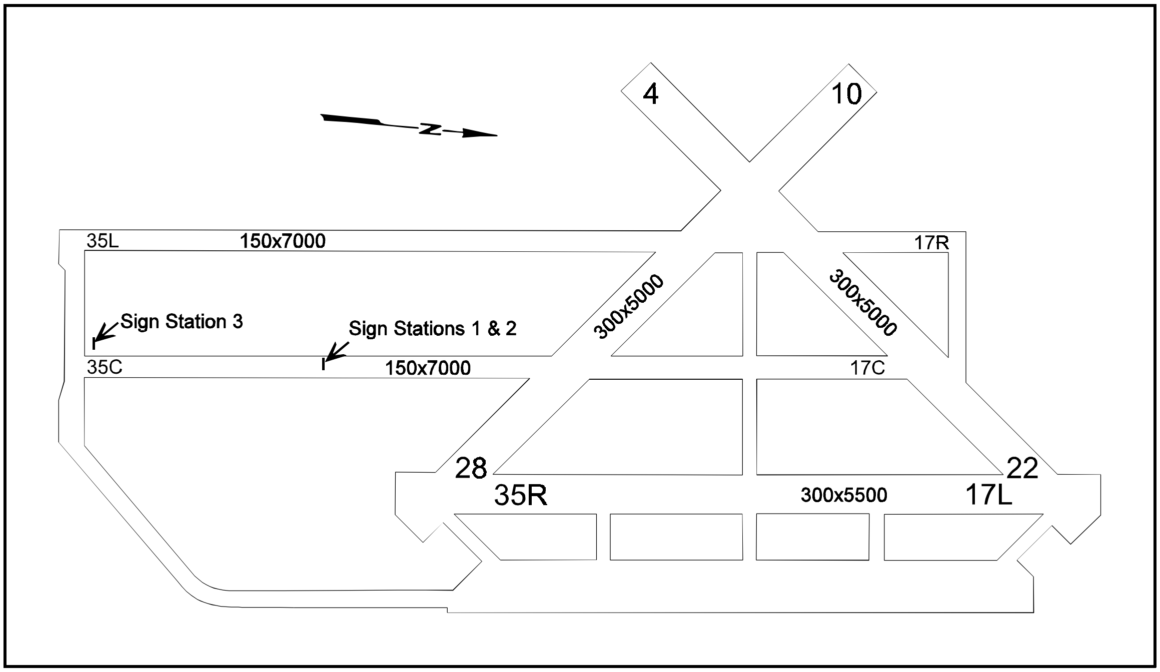


Figure 15. Layout of Runways at Riverside Campus.

Sign stations one and two include variable-height signs powered by mechanical winches. Sign station one was fabricated with Type IX sheeting and used as both a shoulder-mounted sign and an overhead sign. Sign station two was fabricated with Type III sheeting and was used as an overhead sign. Sign station three, at the south end of Runway 35C, was a fixed-height, shoulder-mounted sign fabricated with Type VIII sheeting. Figure 16 contains pictures of these structures.

Sign Stations 1 and 2 **Sign Station 3**

Figure 16. Sign Panels.

RESEARCH STIMULI

Test Words

A total of 21 test words of each alphabet and type of retroreflective sheeting were used for this project. These words were the same words used in the earlier TTI-Clearview project to allow an easier comparison between study results. In order to avoid potential learning/remembering effects among the test subjects, those subjects who had participated in the earlier TTI-Clearview project were excluded from participating in this project. Table 11 lists the words used in the experiment.

Table 11. Test Words.

Neutral Words			Ascender/Descender Words		
Houses	Oceans	Senior	Barley	Felony	Plunge
Honors	Ounces	Sensor	Bishop	Flange	Shapes
Nerves	Senior	Series	Dearly	Forget	Target
Nurses			Eatery	Player	

The test words were fabricated using 16/12 inch uppercase/lowercase letters. Each test word was made from two 4 ft by 2 ft by 0.80 inch aluminum substrate covered with the appropriate type of green retroreflective sheeting. The words were stored in specially designed weatherproof boxes that were kept near each sign station.

Sign Positioning

Based on current signing practices, the following sign positions were used to represent typical sign locations. The bottom of the overhead signs were positioned 18 ft above the road surface. The test vehicle approached the overhead signs straight on. The bottom of the shoulder-mounted signs were positioned 9 ft above the road surface. The test vehicle approached the shoulder-mounted signs with an offset of 24 ft from the edge of the right travel lane to the left of the sign background. Figure 17 shows the dimensions and exact test word location of each sign panel. Only the test word was changed between runs, and each of the three sign panels looked the same (except they were fabricated with different retroreflective sheeting; one with Type III, one with Type VIII, and one with Type IX).

STUDY PROCEDURE

The project was designed so that both vehicles were used together. While the first vehicle began its run past the test signs, the second vehicle would wait. The runway included a length of almost 5000 ft and three sign stations. When the first vehicle passed sign station one, (approximately 2500 ft from the starting point) the second vehicle would begin its run. The course was designed so that headlamp glare from each vehicle was essentially eliminated. This approach allowed the researchers to double their efficiency. This also allowed subjects to be tested as couples or pairs, which proved to be very beneficial from a recruitment standpoint.

Two courses were laid out using raised retroreflective pavement markers (RRPMs). Each course used a different color RRPM so that driving directions provided to the test subjects could be made easily. The RRPMs also delineated a smooth and conspicuous path. A diagram of both courses is illustrated in Figure 18.

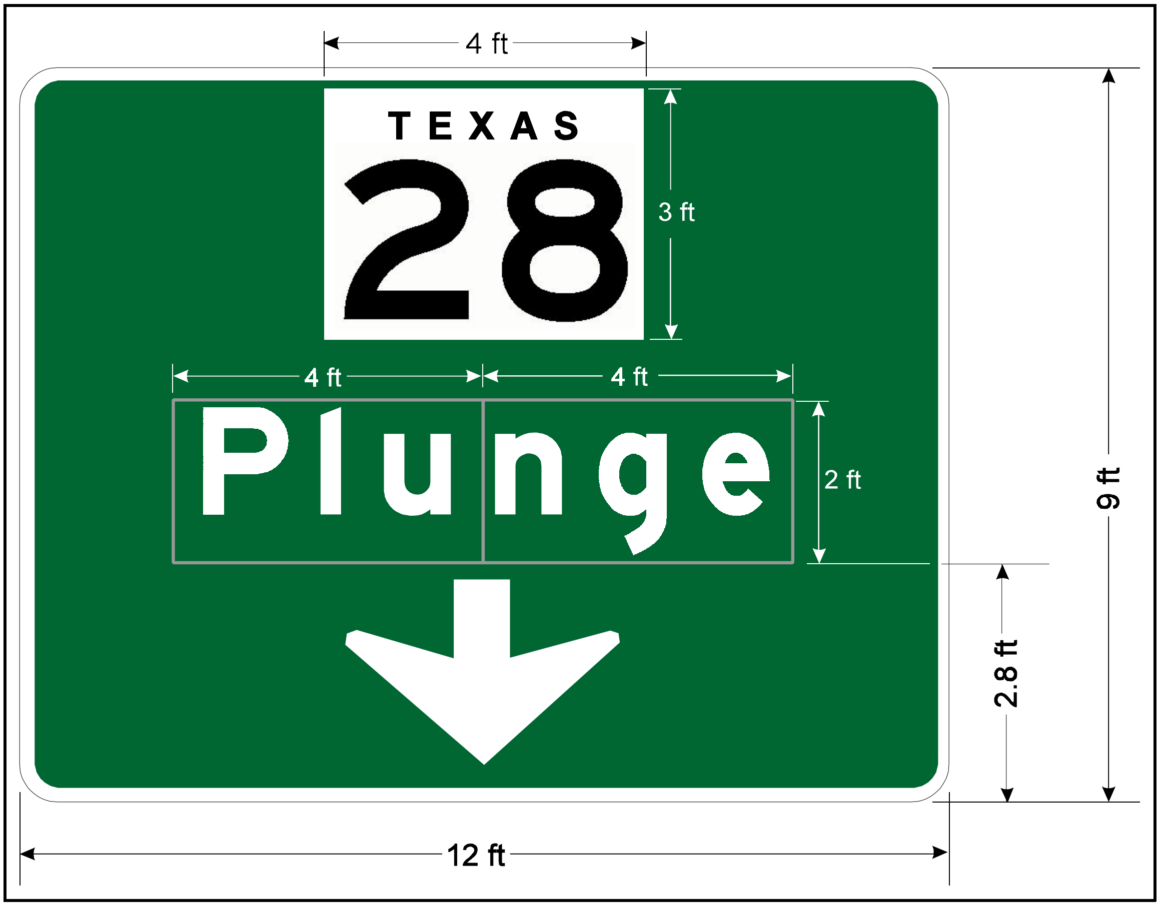


Figure 17. Layout of Sign Panel and Legend.

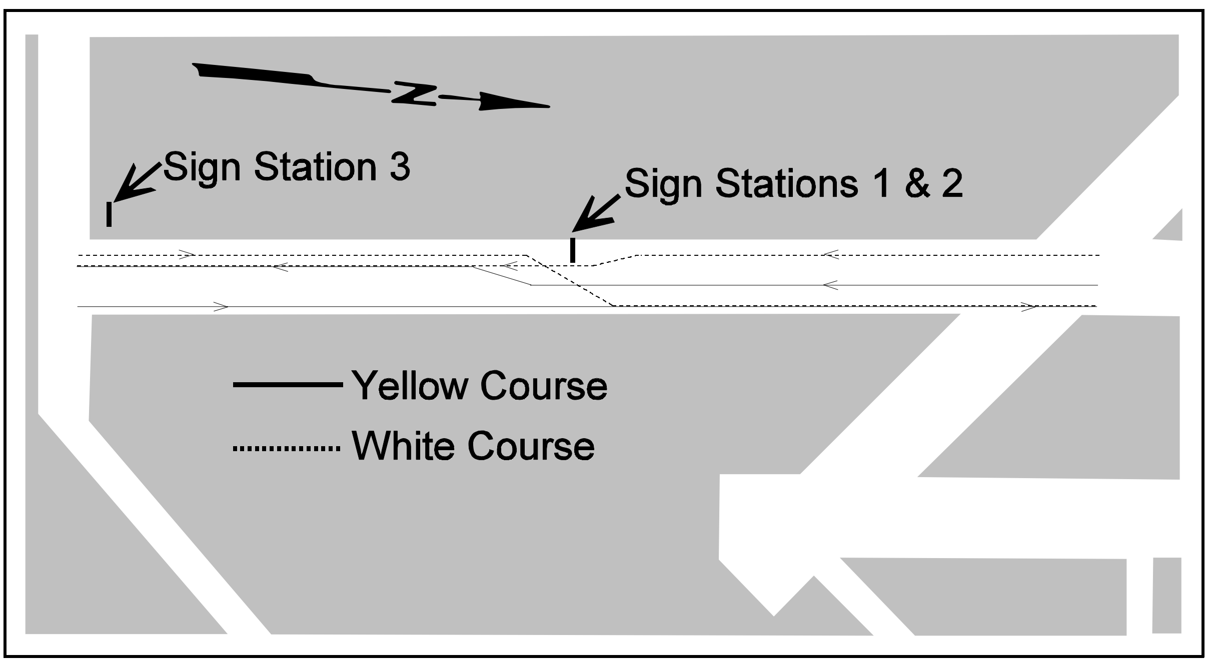


Figure 18. Course Layout.

For each course, the starting point was the north end of the runway. The yellow course was basically a big loop. Two shoulder-mounted guide signs were evaluated when the subjects ran the yellow course (at sign stations one and three). The white course was more a figure-eight shape. For each white course run, the subjects evaluated an overhead sign (at sign station one), then a shoulder-mounted sign (at sign station three), and then, on the way back to the starting point, another overhead sign (at sign station two).

Each subject ran four yellow courses, four white courses, and then four yellow courses. Subjects would then switch vehicles and repeat the process. This procedure took about 90 minutes to complete. With the initial paperwork and visual acuity testing, the entire process took slightly more than 120 minutes. Subjects received $50 for their participation.

For each pair of subjects, the word order was randomized with a few exceptions. For instance, the randomization was designed so that there were an equal number of Clearview and Series E(Modified) words for each sign position and retroreflective sheeting type (except the Type III overhead sign, which included only Series E(Modified) words). The design also included an equal balance between neutral words and ascender/descender words. Finally, the randomization design also included a feature that prohibited a word to be repeated consecutively (regardless of the alphabet).

In an effort to obtain the best experimental control possible, the test vehicles were dedicated exclusively to this project throughout the duration of the data collection activities. The low-beam headlamps were aimed before the study (the study was conducted exclusively with the headlamps in the low-beam position). No other individual was permitted to use the vehicles. The vehicles' windshields and headlamp lens were cleaned each night. Furthermore, the test vehicles did not leave the Riverside Campus. These precautions were implemented to avoid the possibility of anything happening that may cause headlamp misalignment. In addition, every test subject who participated in the study received the same set of instructions, including directions not to guess at the legibility of word. Rather, subjects were informed only to respond when they were reasonably confident with their answer.

DATA COLLECTION AND PROCESSING

This section of the report describes the preparation activities that were completed before executing the data collection plan. The data collection activities are also described.

Preparation

Before the data collection started, the researchers purchased and installed two mechanical winches to raise and lower the overhead signs. Prior to these winches being installed, the signs were raised and lowered with hand cranks.

The researchers also purchased the aluminum substrate needed for the sign panels and test words. The retroreflective sheeting was also purchased at this time. The researchers also acquired the needed RRPMs for the project as well as other equipment including radios and flashlights.

To cut the letters from the prismatic sheeting, the researchers relied on help from others since TxDOT does not currently have sheeting cutters that can handle microprismatic sheeting (although there is a version of Type VIII sheeting that can be cut with a traditional drum-roller cutter). The researchers cut half of the letters at the sign shop in the city of Houston. The second half of the letters were cut at Interstate Signs, Inc. in Little Rock, Arkansas. Both shops used a flatbed cutter, the same cutting software, and the same font-file (supplied by the researchers).

Some microprismatic retroreflective sheetings can be sensitive to the orientation in which the material is presented. This detail can be especially important when cutting letters from microprismatic sheetings because most of the cutting software includes features that allow the letters to be nested (or twisted and turned) to minimize the waste. Figure 19 contains pictures of the three types of microprismatic sheeting currently available.

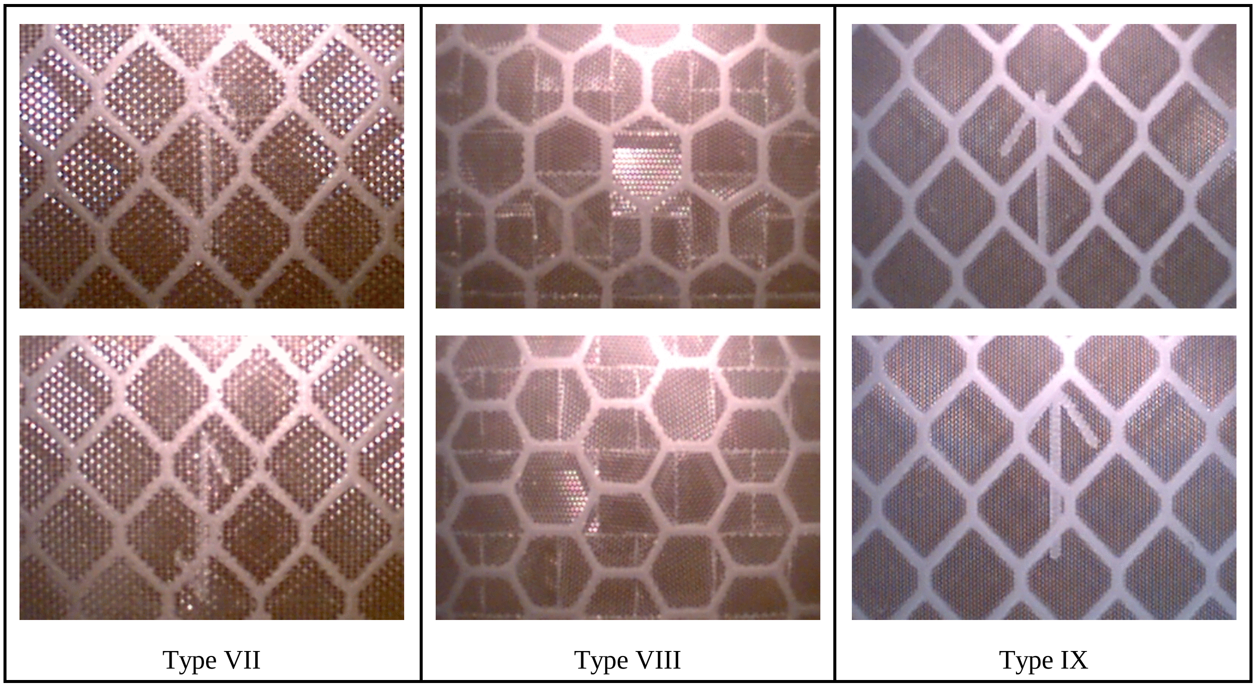


Figure 19. Three Types of Microprismatic Retroreflective Sheetings.

One of the most evident details from the pictures in Figure 19 are the arrows on the Types VII and IX sheetings. These arrows are intended to be used to orient the sheeting when testing the retroreflectivity. For some handheld retroreflectometers such as the Retrosign, considerably different retroreflectivity values can be measured at the exact same spot on the sheeting by simply rotating the retroreflectometer between measurements. This orientational impact can also be seen on the road, but at unusually extreme viewing conditions.

Special care was taken while cutting the letters for this project to keep the arrow on the Type IX sheeting pointing up or down. While Type VIII sheeting has features built in that minimize its orientational sensitivity, all the letters were cut the same as was they were cut with the Type IX sheeting.

After the letters were cut, they were applied to the substrate. Each word was applied to two 4 ft wide by 2 ft tall aluminum panels. All total, there were 99 words (15 Type III Series E(Modified) words, 21 Type VIII Series E(Modified) words, 21 Type VIII Clearview words, 21 Type IX Series E(Modified) words, and 21 Type IX Clearview words). Table 12 show the spacing of the letters for both alphabets.

Table 12. Letter Spacing for Test Words.

Word	Initial Letter	Follow Letter	E(Mod) (inch)	Clvw (inch)		Word	Initial Letter	Follow Letter	E(Mod) (inch)	Clvw (inch)
Barley	B	a	4 - 4/8	3 - 7/8		Oceans	O	c	4 - 1/8	3 - 7/8
Barley	a	r	6 - 1/8	4 - 4/8		Oceans	c	e	3 - 6/8	4 - 3/8
Barley	r	l	3 - 6/8	4 - 6/8		Oceans	e	a	3 - 6/8	4 - 3/8
Barley	l	e	4 - 7/8	3 - 6/8		Oceans	a	n	6 - 1/8	4 - 4/8
Barley	e	y	3 - 3/8	2 - 6/8		Oceans	n	s	4 - 4/8	4 - 3/8
Bishop	B	i	5 - 6/8	4 - 3/8		Ounces	O	u	5 - 3/8	4 - 2/8
Bishop	i	s	4 - 4/8	4 - 4/8		Ounces	u	n	6 - 1/8	5 - 3/8
Bishop	s	h	4 - 7/8	4 - 5/8		Ounces	n	c	4 - 7/8	4 - 4/8
Bishop	h	o	4 - 7/8	4 - 5/8		Ounces	c	e	3 - 6/8	4 - 3/8
Bishop	o	p	4 - 7/8	4 - 4/8		Ounces	e	s	3 - 3/8	4 - 1/8
Dearly	D	e	4 - 1/8	4 - 5/8		Overly	O	v	3 - 6/8	3 - 3/8
Dearly	e	a	3 - 6/8	4 - 3/8		Overly	v	e	3 - 1/8	3 - 1/8
Dearly	a	r	6 - 1/8	4 - 4/8		Overly	e	r	5	4 - 5/8
Dearly	r	l	3 - 6/8	4 - 6/8		Overly	r	l	3 - 6/8	4 - 6/8
Dearly	l	y	4 - 4/8	2 - 6/8		Overly	l	y	4 - 4/8	3 - 1/8
Eatery	E	a	4 - 2/8	4		Player	P	l	4 - 4/8	4 - 3/8
Eatery	a	t	4 - 4/8	3 - 4/8		Player	l	a	4 - 7/8	3 - 5/8
Eatery	t	e	3 - 5/8	4 - 3/8		Player	a	y	4 - 4/8	2 - 4/8
Eatery	e	r	5	4 - 5/8		Player	y	e	3 - 1/8	2 - 5/8
Eatery	r	y	2	3 - 1/8		Player	e	r	5	4 - 5/8
Felony	F	e	2	3 - 3/8		Plunge	P	l	4 - 4/8	4 - 3/8
Felony	e	l	5	4 - 5/8		Plunge	l	u	6 - 1/8	4 - 3/8
Felony	l	o	4 - 7/8	3 - 7/8		Plunge	u	n	6 - 1/8	5 - 3/8
Felony	o	n	4 - 7/8	4 - 4/8		Plunge	n	g	4 - 7/8	4 - 4/8
Felony	n	y	4 - 4/8	3 - 3/8		Plunge	g	e	4 - 7/8	4 - 5/8
Flange	F	l	4	4 - 6/8		Season	S	e	3 - 6/8	4 - 5/8
Flange	l	a	4 - 7/8	3 - 6/8		Season	e	a	3 - 6/8	4 - 3/8
Flange	a	n	6 - 1/8	4 - 4/8		Season	a	s	4 - 4/8	3 - 4/8
Flange	n	g	4 - 7/8	4 - 4/8		Season	s	o	3 - 4/8	4 - 1/8
Flange	g	e	4 - 7/8	4 - 5/8		Season	o	n	4 - 7/8	4 - 4/8
Forget	F	o	2	3 - 3/8		Senior	S	e	3 - 6/8	4 - 5/8
Forget	o	r	4 - 7/8	4		Senior	e	n	5	4 - 5/8
Forget	r	g	2 - 3/8	3 - 7/8		Senior	n	i	6 - 1/8	5
Forget	g	e	4 - 7/8	4 - 5/8		Senior	i	o	4 - 7/8	4 - 5/8
Forget	e	t	3 - 3/8	4		Senior	o	r	4 - 7/8	4 - 4/8
Honors	H	o	5 - 4/8	4 - 5/8		Sensor	S	e	3 - 6/8	4 - 5/8
Honors	o	n	4 - 7/8	4 - 4/8		Sensor	e	n	5	4 - 5/8
Honors	n	o	4 - 7/8	4 - 4/8		Sensor	n	s	4 - 4/8	4 - 3/8
Honors	o	r	4 - 7/8	4 - 4/8		Sensor	s	o	3 - 4/8	4 - 2/8
Honors	r	s	3 - 3/8	3 - 6/8		Sensor	o	r	4 - 7/8	4 - 4/8
Houses	H	o	5 - 4/8	4 - 5/8		Series	S	e	3 - 6/8	4 - 5/8
Houses	o	u	4 - 7/8	4 - 5/8		Series	e	r	5	4 - 5/8
Houses	u	s	4 - 4/8	4 - 3/8		Series	r	i	3 - 6/8	4 - 6/8
Houses	s	e	3 - 4/8	4 - 2/8		Series	i	e	4 - 7/8	4 - 4/8
Houses	e	s	3 - 3/8	4 - 1/8		Series	e	s	3 - 3/8	4 - 1/8
Nerves	N	e	5 - 4/8	4 - 6/8		Shapes	S	h	5 - 1/8	4 - 6/8
Nerves	e	r	5	4 - 5/8		Shapes	h	a	4 - 7/8	4 - 4/8
Nerves	r	v	2	3 - 3/8		Shapes	a	p	6 - 1/8	4 - 5/8
Nerves	v	e	3 - 1/8	3 - 1/8		Shapes	p	e	3 - 4/8	4 - 1/8
Nerves	e	s	3 - 3/8	4		Shapes	e	s	3 - 3/8	4 - 1/8
Nurses	N	u	6 - 4/8	5 - 1/8		Target	T	a	3	2 - 3/8
Nurses	u	r	6 - 1/8	5 - 3/8		Target	a	r	6 - 1/8	4 - 4/8
Nurses	r	s	3 - 3/8	3 - 6/8		Target	r	g	2 - 3/8	3 - 7/8
Nurses	s	e	3 - 4/8	4 - 2/8		Target	g	e	4 - 7/8	4 - 5/8
Nurses	e	s	3 - 3/8	4 - 1/8		Target	e	t	3 - 3/8	4

Execution

During the early part of May, the researchers made several pilot runs. During these pilot runs, they refined the data collection procedure to expedite the nightly activities. The pilot runs also provided a great opportunity to train all those involved, including the coordination between the researchers in the test vehicles and technicians responsible for changing the test words between runs.

During the second half of May 2011 and continuing through the end of June, researchers collected the nighttime legibility data. Over 60 subjects were recruited and run through the two-hour evaluation. Accounting for equipment failure, rain, and sometimes high winds, a total of 60 subjects completed the study.

The design of the study included a balance between number of repetitions and time needed to complete each nightly run (especially since the data were collected in the summertime when nighttime runs could not start until approximately 9:15 PM). Tables 13 and 14 illustrate the goals that were established for the project.

Table 13. Test Subjects.

Statistics	Young	Middle	Old
Age (years)	18-34	35-54	55+
Sample Size	Male: 10 Female: 10	Male: 10 Female: 10	Male: 10 Female: 10

Table 14. Data Collection Goal.

Sign Position	Alphabet	Retroreflective Sheeting	Repetitions	
			per Subject	Total
Shoulder-Mounted	Clearview	Type VIII	12	720
		Type IX	8	480
	Series E(Modified)	Type VIII	12	720
		Type IX	8	480
Overhead	Clearview	Type IX	4	240
	Series E(Modified)	Type IX	4	240
		Type III	8	480

The runs with Type III sheeting on the overhead sign were completed in order to obtain data that could be used to compare to the earlier TTI-Clearview project which included only Type III sheeting. This was done because the data collection procedure used in this project was not exactly the same as the procedure used in the earlier TTI-Clearview projecy.

Data Reduction

The raw data from the DMIs represented the distance from the run starting points to the point where the subject correctly identified the word. In order to calculate the legibility distance, the course lengths were measured (from the starting points to the sign positions). The raw DMI data were then subtracted from the appropriate course length. This calculation results in the distance between the sign and the vehicle, when the subject correctly identified the word. These are the legibility distances. In all, 3316 legibility distances were recorded throughout the project. These data represent the legibility distances of two alphabets, two sign positions, two vehicles, and three types of sheeting. Theoretically, 3360 legibility distances should have been recorded but researchers elected to discard certain data because of periodic subject inattentiveness while approaching the test signs (i.e., the test subject either forgot to read the word or read it at an unreasonably short legibility distance). This occurred because of conversations between the researcher and the test subjects while collecting the data.

CHAPTER 5
ANALYSIS AND RESULTS

In all, 3360 trials were completed. This included 2400 shoulder-mounted sign trials and 960 overhead sign trials. Missing data reduced the number of observations to 2365 for the shoulder-mounted signs and 951 for the overhead signs.

SUBJECT DATA

A total of 60 subjects participated in the data collection effort. The test subjects were categorized into three groupings: young (18 to 34 years old), middle-aged (36 to 54 years old), and old (55 or more years old).

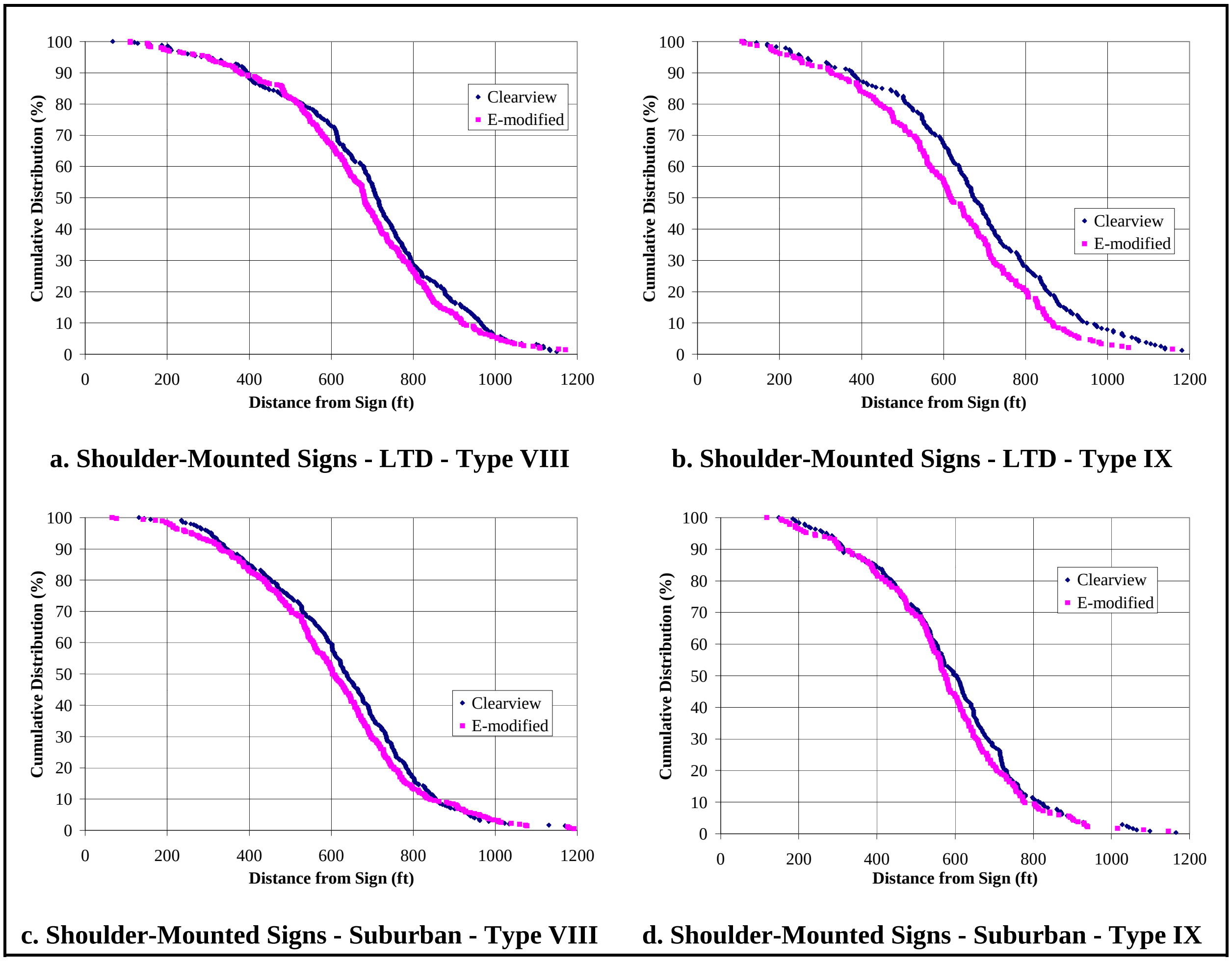
The visual acuity of the drivers ranged from 20/10 to 20/50. Although the minimum visual acuity requirement in Texas for a driver's license is typically 20/40, the subjects with acuity levels worse than 20/40 were included in the sample because they had valid Texas driver's licenses. Test subjects were grouped into three visual acuity groups for analysis: sharp (20/15 to 20/20), fair (20/25 to 20/40), and marginal (greater than 20/40). Table 15 summarizes the number of subjects in each age and visual acuity group.

Table 15. Number of Subjects by Age and Visual Acuity.

Age Group	Visual Acuity			*Totals*
	Sharp (≤ 20/20)	**Fair (20/25 to 20/40)**	**Marginal (> 20/40)**	
Young (18-34)	13	7	0	*20*
Young-Old (35-54)	13	7	0	*20*
Old-Old (≥55)	7	9	4	*20*
Totals	*33*	*23*	*4*	*60*

LEGIBILITY ANALYSIS FOR SHOULDER-MOUNTED SIGNS

Using cumulative distribution plots for the different scenarios (and collapsing the age groups), the legibility data for the shoulder-mounted signs are shown in Figure 20. An initial visual inspection of these cumulative distribution plots shows that the Clearview alphabet repeatably provided legibility distances no worse than Series E(Modified), and, for most cases, provided legibility distances greater than Series E(Modified).



a. Shoulder-Mounted Signs - LTD - Type VIII

b. Shoulder-Mounted Signs - LTD - Type IX

c. Shoulder-Mounted Signs - Suburban - Type VIII

d. Shoulder-Mounted Signs - Suburban - Type IX

Figure 20. Shoulder-Mounted Guide Sign Legibility Distances.

The overall mean legibility distance associated with Clearview was 32 ft (5.2 percent) greater than Series E(Modified). For the mean legibility distances by vehicle type and sheeting type, the improvements ranged from 18 to 58 ft with the largest difference occurring with the LTD Type IX sign (see Table 16). In terms of percentages, these improvements ranged from 3.1 to 9.4 percent. The encouraging finding was that, for all cases, the Clearview alphabet outperformed the Series E(Modified) alphabet.

Assuming a 70 mph roadway, these kinds of improvements would result in added time to read a sign of 0.2 to 0.6 second. For a 55 mph roadway, the improvements would be 0.2 to 0.7 second.

Table 16. Descriptive Statistics for Shoulder-Mounted Signs.

Vehicle	Sheeting	Alphabet	N	Average	Std. Dev.	Differences	
						Magnitude	Percent
LTD	VIII	Clvw	351	693	216	21	3.1
		E(M)	356	672	214		
	IX	Clvw	240	675	224	58	9.4
		E(M)	235	617	217		
Suburban	VIII	Clvw	351	628	201	26	4.3
		E(M)	356	602	202		
	IX	Clvw	244	588	188	18	3.2
		E(M)	232	570	187		

Statistical Analysis

Because of missing observations and the need to keep a balanced data set, researchers used a subset of the data to run statistical analyses. The test was a mixed-factor repeated measures analysis of variance (ANOVA). More specifically, a three-way within-subjects repeated measures ANOVA with a between-subjects effect was used. The dependent factor was legibility distance. The independent factors were alphabet, vehicle, sheeting, and subject age. The independent variables, alphabet, vehicle, and sheeting, were within-subjects factors because all levels of all factors were presented to all subjects. Subject age was a between-subjects factor because each subject has one and only one age. Three replications were used resulting in 24 legibility distances per subject for all 60 subjects. Preliminary analyses by replication showed no statistical differences among replications (i.e., there was no nightly learning or fatigue effect among the subjects). Therefore, the data were collapsed into one data set. The PROC GLM command with the REPEATED option was used in the SAS software package to produce the ANOVA table shown in Table 17.

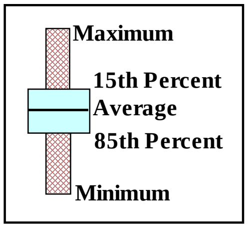
From the ANOVA table, it can be seen that the difference in legibility distances by alphabet were statistically significant ($F_{1,177}$=48.10, p=0.0001). In other words, the increased legibility distances associated with the Clearview alphabet are statistically significant. However, the practical gain, 18 to 58 feet, is somewhat less impressive.

Figure 21 shows box plots of each main effect variable, which were all significant. Although it is hard to tell because of the scale, the most significant impact in terms of age was for older drivers (a 9.3 percent increase with Clearview versus Series E(Modified)). This difference equates to an additional 0.45 second of reading time for older drivers, assuming a 70 mph highway.

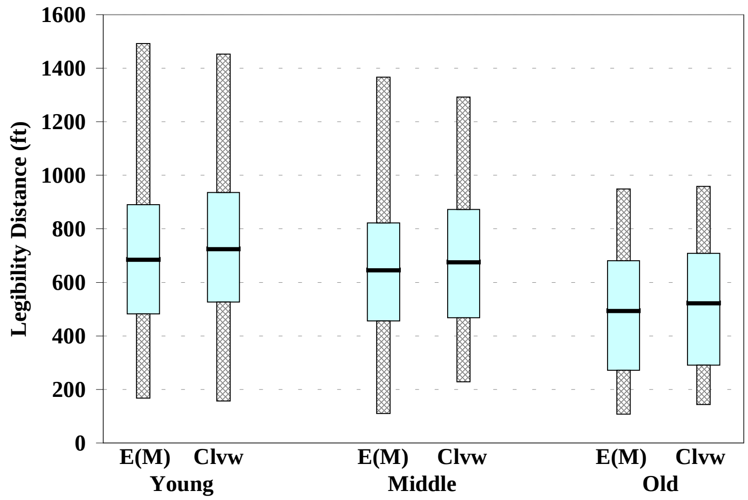
The lack of a significant interaction between alphabet and sheeting or vehicle was surprising since Clearview is touted as having the capability to accommodate higher luminance levels. In other words, Clearview was expected to generate larger legibility distance differences for the higher limits of the luminance-dependent factors such as sheeting type (Type VIII is generally brighter than Type IX) and vehicle type (the LTD produced brighter signs than the Suburban). Relaxing the significance criteria to a 10 percent alpha level, one would conclude that the interaction between alphabet and sheeting was significant. However, the ANOVA results show little doubt that the strength of the main-effect variables greatly outweighs this potential interaction effect. This topic is addressed in a subsequent section of the analysis.

Table 17. ANOVA for Shoulder-Mounted Signs.

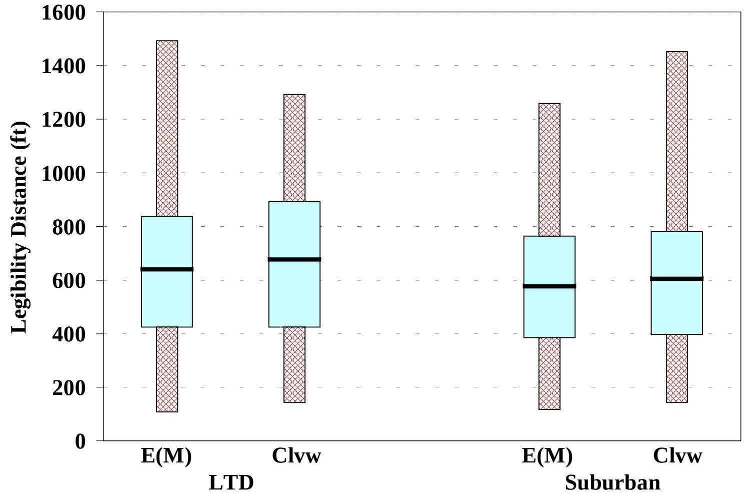
Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	2	10,200,907	5,100,453	24.30	0.0001
	177	37,143,955	209,852		
Vehicle	1	1,643,424	1,643,424	60.37	0.0001
Vehicle×Age	2	35,465	17,732	0.65	0.5226
	177	4,818,583	27,223		
Alphabet	1	390,490	390,490	48.10	0.0001
Alphabet×Age	2	8353	4176	0.51	0.5987
	177	1,436,926	8118		
Sheeting	1	402,303	102,303	46.08	0.0001
Sheeting×Age	2	3937	1968	0.23	0.7983
	177	1,545,319	8730		
Vehicle×Alphabet	1	7742	7742	1.13	0.2901
Vehicle×Alphabet×Age	2	22,874	11,437	1.66	0.1924
	177	1,217,051	6875		
Vehicle×Sheeting	1	5884	5884	0.80	0.3713
Vehicle×Sheeting×Age	2	14,609	7304	1.00	0.3710
	177	1,296,660	7325		
Alphabet×Sheeting	1	27,992	27,992	3.30	0.0708
Alphabet×Sheeting×Age	2	3552	1776	0.21	0.8110
	177	1,499,389	8471		
Vehicle×Alpha×Sheeting	1	22,633	22,663	2.62	0.1072
Vehicle×Alpha×Sheeting×Age	2	1242	621	0.07	0.9306
	177	1,528,114	8633		



NOTE: The percent differences for the mean legibility distances are 5.8, 4.6, and 6.0 for young, middle, and old, respectively.



NOTE: The percent differences for the mean legibility distances are 5.4 and 3.9 for the LTD and Suburban, respectively.



NOTE: The percent differences for the mean legibility distances are 3.8 and 6.3 for Type VIII and Type IX sheeting, respectively.

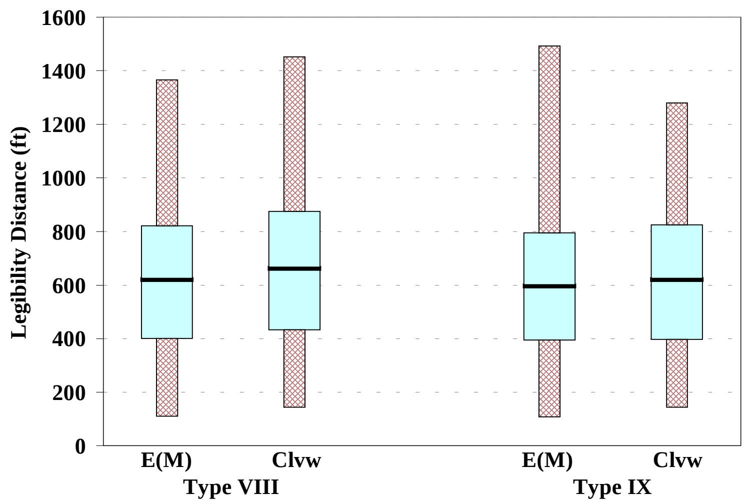


Figure 21. Statistically Significant Relations for Shoulder-Mounted Signs.

LEGIBILITY ANALYSIS FOR OVERHEAD SIGNS

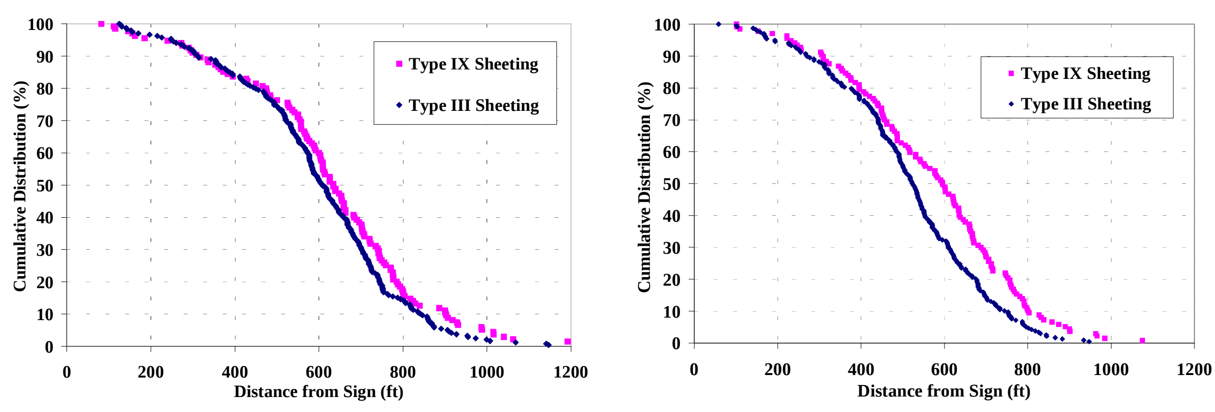
As mentioned, the focus of this project was on shoulder-mounted guide signs. However, researchers still recorded observations for overhead signs. In all, 960 of the 3360 trials were made using overhead signs. Half of the overhead trials (480) were made to evaluate the legibility differences between Type III and Type IX sheeting when using Series E(Modified). A subset of these data (240) were collected in order to make comparisons to the earlier TTI-Clearview project that included Type III sheeting. The second half of the overhead runs (480) were performed in order to compare the legibility distance differences between Clearview and Series E(Modified) when using Type IX sheeting.

Consequently, this part of the report is divided into three sections. The first section addresses the results of the Type III versus Type IX legibility distances (using Series E(Modified) only). The second section presents comparisons of the legibility data collected for this project and the legibility data collected during the earlier TTI-Clearview project. Finally, the last section contains the findings related to the legibility differences of Clearview and Series E(Modified) with Type IX sheeting.

It is important to remind the reader that there were three signs in this study: however, only two signs were capable of being raised to an overhead position. These two signs had Type III and Type IX sheeting. The fixed-height sign was fabricated with Type VIII sheeting. Therefore, no overhead trials were conducted with Type VIII sheeting.

Type III versus Type IX Sheeting

This analysis included 480 trials. In order to keep the comparisons between sheeting types as equal as possible, this analysis only included the Series E(Modified) alphabet (as this was the only alphabet tested on Type III sheeting). The first analysis of the data included cumulative distribution plots comparing the sheeting types (see Figure 22). Visual inspection of the cumulative distribution plots shows that legibility distances associated with Type IX sheeting were greater than legibility distances associated with Type III sheeting. The differences were more pronounced for the Suburban than the LTD.



a. Overhead Signs - LTD - E(M) **b. Overhead Signs - Suburban - E(M)**

Figure 22. Overhead Guide Sign Legibility Distances with Series E(Modified).

The overall mean legibility distance associated with Type IX sheeting was 53 ft (or 9.5 percent) more than Type III sheeting. Table 18 shows the breakdown by vehicle type. For both cases, Type IX legibility distances were longer than Type III legibility distances.

Table 18. Descriptive Statistics for Overhead Signs with Series E(Modified).

Vehicle	Sheeting	Alphabet	N	Average	Std. Dev.	Differences	
						Magnitude	Percent
LTD	III	E(M)	119	606	193	28	4.6
	IX		119	634	209		
Suburban	III		119	504	169	78	15.5
	IX		119	582	191		

If one assumes a similar relationship between the shoulder-mounted sign results and overhead sign results, then Type VIII sheeting could be expected to provide slightly longer legibility distances than Type IX sheeting (at least from a passenger car or SUV). However, as mentioned, Type VIII sheeting was not tested in an overhead sign position. Since the observation angles associated with legibility distances of shoulder-mounted guide signs and overhead guide signs are not substantially different (ranging from 0.21 to 0.33 degrees), it is safe to expect that all microprismatic sheetings will provide longer overhead guide sign legibility distances than Type III sheeting (at least when viewed from a passenger car or SUV). Further analyses of microprismatic sheeting in an overhead position are presented later in this chapter.

Statistical Analysis

Again, the statistical test used was a mixed-factor repeated measures ANOVA. The dependent factor was legibility distance. The independent factors were vehicle type, sheeting type, and subject age. The independent variables, vehicle type and sheeting type, were within-subjects factors because all levels of all factors were presented to all subjects. Subject age was a between-subjects factor because each subject has one and only one age. Two replications were used resulting in eight legibility distances per subject for all 60 subjects. Preliminary analyses by replication showed no statistical differences among replications (i.e., there was no nightly learning or fatigue effect among the subjects). Therefore, the data were collapsed into one database. The ANOVA results are shown in Table 19.

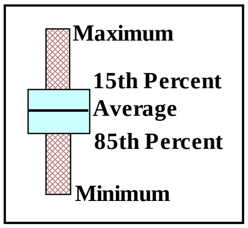
The ANOVA table shows that sheeting type is statistically significant ($F_{1,116}$=34.69, p<0.0001). In other words, the legibility distances associated with Type IX sheeting are statistically greater than the legibility distances associated with Type III sheeting.

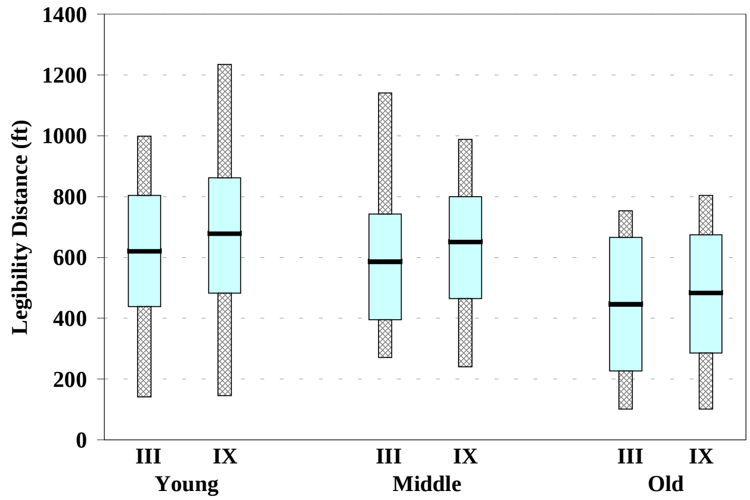
Figure 23 shows the significant relations from the ANOVA. Besides sheeting type, vehicle type and subject age were also found to be statistically significant. Interestingly, the interaction between sheeting type and vehicle type was statistically significant too. This interaction, shown as the bottom graph in Figure 23, may be explained by the irradiation phenomena of Series E(Modified) with relatively bright signs. As will be shown later, the LTD produced luminance values substantially higher than the Suburban. For the overhead signs, the luminance values from the LTD were as much as 4.67 times higher than the Suburban. As can be seen, the higher luminance values produced higher legibility distances. However, the difference between the sheeting types, which also impacts luminance, is less for the LTD than for the Suburban. The reason is that when the subjects were in the LTD, the signs appeared almost five times brighter, and at these higher luminance levels, the Series E(Modified) legend showed some irradiation that reduced the difference in legibility distances. If the signs were even brighter, then one could expect the benefit of sheeting to be even less. This interaction provides substantial evidence for the need to update the 50 year old Series E(Modified) alphabet.

In terms of driver age, the legibility distances associated with Type IX sheeting ranged from 8.4 percent to 11.1 percent. However, unlike with the Clearview alphabet, the older group was not the group associated with the largest differences.

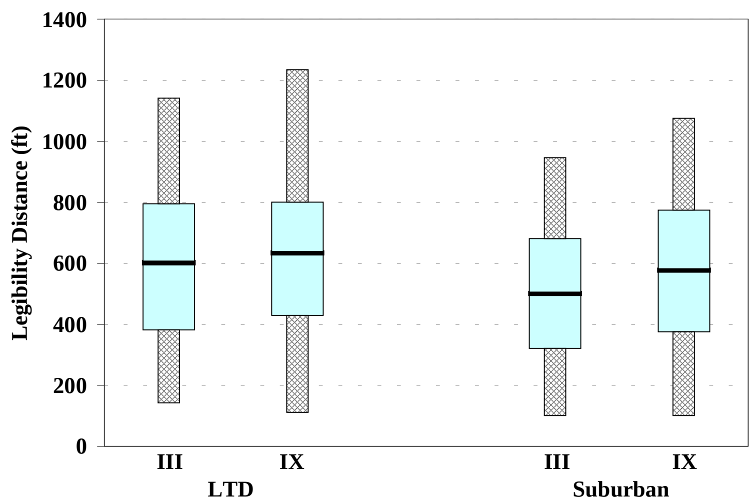
Table 19. ANOVA Results for Overhead Signs with Series E(Modified).

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	2	2,988,681	1,494,340	15.91	<0.0001
	116	10,896,340	93,934		
Vehicle	1	717,705	717,705	62.13	<0.0001
Vehicle×Age	2	6061	3031	0.26	0.7697
	116	1,340,019	11,552		
Sheeting	1	325,652	325,652	34.69	<0.0001
Sheeting×Age	2	22,519	11,260	1.20	0.3051
	116	1,088,916	9387		
Vehicle×Sheeting	1	72,299	72,299	9.64	0.0024
Vehicle×Sheeting×Age	2	25,142	12,571	1.68	0.1916
	116	870,136	7501		

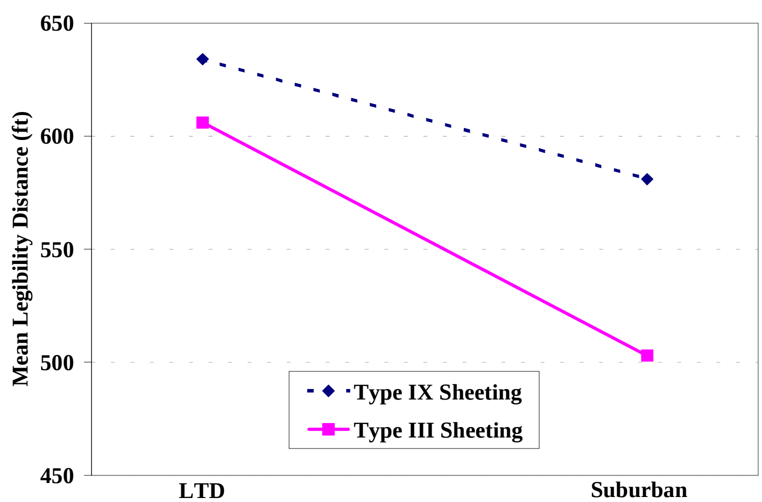




NOTE: The percent differences for the mean legibility distances are 9.3, 11.1, and 8.4 for young, middle, and old, respectively.



NOTE: The percent differences for the mean legibility distances are 5.3 and 15.2 for the LTD and Suburban, respectively.



NOTE: Interaction between vehicle type and alphabet for overhead signs

Figure 23. Statistically Significant Relations for Overhead Signs with Series E(Modified).

Comparison to First TTI-Clearview Project

The data collected for this project included a sample of legibility distances with Type III sheeting (referred to as the control sample). This effort was designed in order to provide a data set to make comparisons with the earlier TTI-Clearview project (2). The earlier project, described in the literature review in Chapter 3, was conducted in 1997 and included Type III sheeting, exclusively. Since the current project was designed to focus on signs made with microprismatic sheeting, a control sample was needed in order to compare the current project to the earlier TTI-Clearview project. The goal was to be able to match the control sample results (collected as part of this project) with the earlier TTI-Clearview project results. If the data matched, then broader comparisons could be made that would provide results related to the benefits of microprismatic sheeting versus Type III sheeting.

The control sample included 240 trials (or one-fourth of the overhead data collected in this project). The control sample was meant to be as identical as possible to the earlier TTI-Clearview project. However, differences existed. Table 20 provides a comparison of the control sample and the earlier TTI-Clearview project.

Table 20. Comparison of TTI-Clearview Projects.

Description	Control Sample	Earlier TTI-Clearview Project (2)
Vehicle*	1989 Ford Crown Victoria LTD	1991 Ford Crown Victoria
Retroreflective Sheeting	Type III	Type III
Alphabet	Series E(Modified)	Series E(Modified)
Sign Position	Overhead	Overhead
Sign Height	18 ft to bottom of sign	20 ft to bottom of sign
Vehicle Approach Path	Head-On	Head-On
Stimuli	Fifteen of the words shown in Table 11	All of the words shown in Table 11
Seat Position	Driver's	All but driver's
Subject Task per Trial	One legibility task	One recognition task and Two legibility tasks
Speed	35 mph	20 mph
NOTE: Ford made no significant changes to the Crown Victoria between 1989 and 1991.		

The first analysis included the development of cumulative distribution plots (shown in Figure 24). The first of these plots shows some promise in terms of matching the two data sets. However, the data from the earlier TTI-Clearview project included two legibility tasks per sign, and the curve shown in the first plot includes both of these distances. In an effort to make the data more comparable, the two legibility tasks were split and shown in the second plot of Figure 24 (with the control sample). From this plot one can see that there was about 100 ft between the first legibility task and the second. More specifically, at the 50^{th} percentile level, the first legibility task was completed 99 ft before the second legibility task (685 ft versus 586 ft). Since the control sample included just one legibility task, the most comparable data from the earlier

TTI-Clearview project should be the first legibility data. However, the second cumulative distribution plot of Figure 24 clearly indicates that the second legibility data were more comparable. Using the 50th percentile level again, the results of the first legibility task of the earlier TTI-Clearview project were 76 ft further than the control sample (685 ft versus 609 ft). For the second legibility task, the results were reversed. The control sample data resulted in legibility distances 23 ft further than the second legibility task of the earlier TTI-Clearview project (609 ft versus 586 ft). Possible explanations of these differences are discussed below.

1276 = First TTI-Clearview Project
4049 = Current Project

The 1276 data shown in this graph includes both legibility tasks.

The 1276 project included two legibility tasks per sign. The 4049 project included one legibility task per sign.

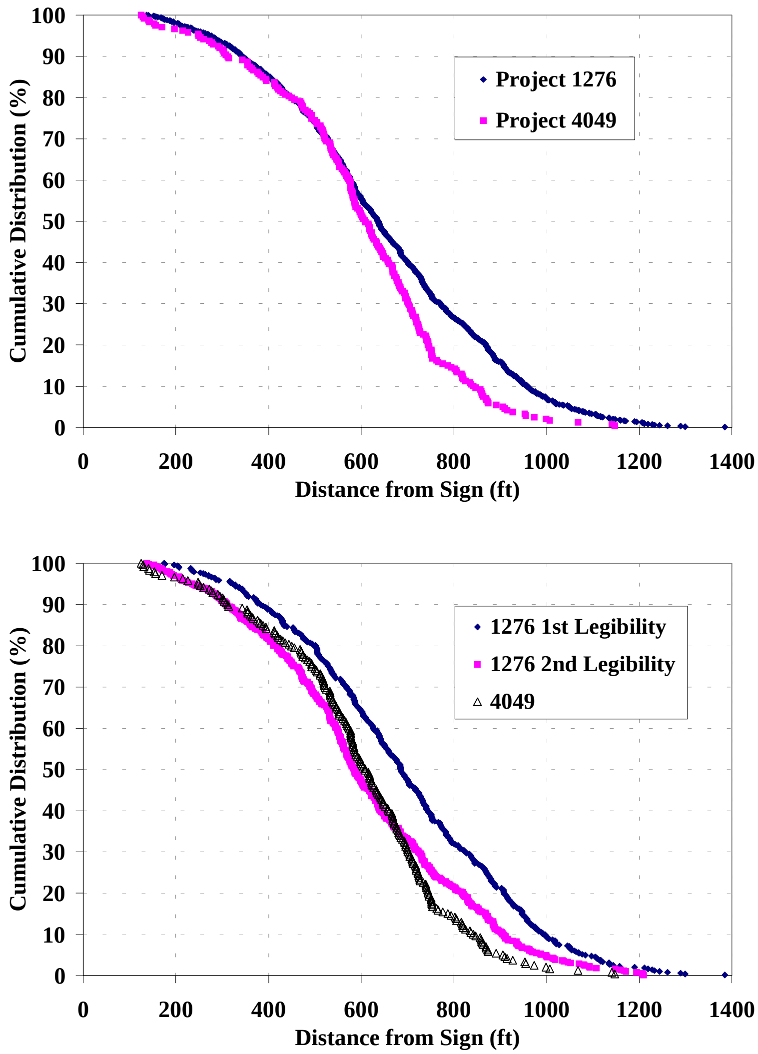
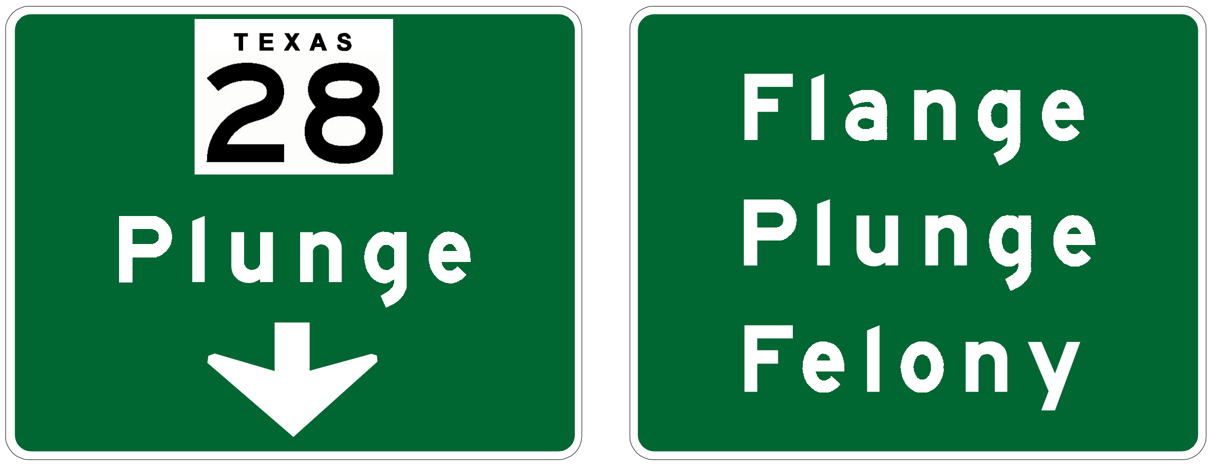


Figure 24. TTI-Clearview Project Comparisons.

One of the main differences was that the subjects were driving when the control sample was obtained, and in the earlier TTI-Clearview project, the subjects were riding in the car while a researcher drove. The driving task for the control sample involved accelerating to 35 mph and setting the cruise control while following a travel lane delineated with raised retroreflective pavement markers. Therefore, the combined driving and legibility tasks of the control sample may have resulted in shorter legibility distances. The subjects of the earlier TTI-Clearview project could focus all of their attention to the sign.

Another reason for the differences could have been the design of the signs. Since the earlier TTI-Clearview project had three tasks (one recognition and two legibility tasks), there were three words on the sign. For the control sample, the sign included only one word. However, the control sample signs also included a State Highway route marker and a Type C arrow. Figure 25 shows the sign designs from both projects. It is possible, although difficult to measure, that the larger white spaces of the control sample signs (the State Highway route marker and Type C arrow) acted as bright sources of light, thereby reducing the legibility of the word.



a. Control Sample **b. Earlier TTI-Clearview Project**

Figure 25. Sign Designs.

Another reason may have been the vehicles' headlamps. As mentioned, the control sample used a 1989 Ford Crown Victoria and the earlier TTI-Clearview project used a 1991 Ford Crown Victoria. While Ford made no substantial changes between the 1989 and 1991 versions of the Crown Victoria, and both vehicles' headlamps were properly aimed before the study, there still exists a potential for different headlamp illumination. For the control sample, the 1989 Crown Victoria's headlamp illumination was measured. However, no measurements were made of the 1991 Crown Victoria's headlamps used in the earlier TTI-Clearview project. Therefore, it is impossible to be 100 percent sure that the illumination levels were the same, or even similar. Furthermore, an analysis discussed later in this chapter clearly demonstrates that brighter signs are more legible and sign brightness is heavily dependent on headlamp illumination, regardless of the type of retroreflective sheeting.

Finally, another possible explanation of the differences is the experimental design and the resulting learning effects. For the sample control, 15 of the 21 words shown in Table 11 were used. However, those same words were used throughout the rest of the project (along with the remaining six words from Table 11). Each subject saw one word per sign, resulting in a total of 56 words per subject. Therefore, assuming an equal distribution of words (they were actually randomized for each subject), each word was shown an average of 2.66 times. For the earlier TTI-Clearview project, the same set of 21 words were used. Each sign had three words, two signs were used per run, and 27 runs were made per subject per time of day (the subjects first participated in a daytime study and then the same set of subjects participated in a nighttime study). Therefore, each subject saw 324 words. Again, assuming an equal distribution of words, each word was shown an average of 15.43 times. Therefore, there is a good chance that the learning effect associated with the earlier TTI-Clearview project resulted in longer legibility distances since the subjects *learned* the set of 21 words and were able to use their recognition abilities to improve their legibility scores. This is especially true for their nighttime data since they were collected after the daytime data were collected.

Despite these experimental design differences, the data sets were compared using legibility distances associated with age groups. The first set of comparisons used the age grouping used throughout this project. However, the earlier TTI-Clearview project did not include subjects that fell into the middle-aged grouping. Therefore, a second set of comparisons were made with revised age groupings.

Table 21. Project Comparisons.

Analysis 1	Project	First Legibility				Second Legibility			
		Age							
		Total	<35	35 - 54	≥ 55	Total	<35	35 - 54	≥ 55
Mean	1276	694	869	n/a	667	607	776	n/a	581
	4049	598	664	642	488	598	664	642	488
85th	1276	433	629	n/a	424	363	535	n/a	339
	4049	387	514	447	252	387	514	447	252

NOTE: 1276 = data from earlier TTI-Clearview project. 4049 = data from current project.

Table 22. Project Comparisons with Revised Age Groups.

Analysis 2	Project	First Legibility				Second Legibility			
		Age							
		Total	<40	40 - 64	≥ 65	Total	<40	40 - 64	≥ 65
Mean	1276	694	869	727	629	607	776	644	542
	4049	598	656	564	510	598	656	564	510
85th	1276	433	629	516	398	363	535	450	330
	4049	387	494	334	321	387	494	334	321

NOTE: 1276 = data from earlier TTI-Clearview project. 4049 = data from current project.

In terms of comparisons, there is little correlation among the data sets. For the control sample versus the first legibility data of the earlier TTI-Clearview project, the differences range from 95 ft to 213 ft. While the second legibility data of the earlier TTI-Clearview project match the control sample better (with differences of 9 ft to 112 ft), there is no practical justification for using these data for comparisons.

With the results of both the cumulative distribution plots (Figure 24) and tabular comparisons (Tables 21 and 22), the researchers do not feel that the studies produced comparable data. Therefore, they did not make further investigations involving the comparisons of the two projects. It may be possible to reanalyze the earlier TTI-Clearview project's data using the same statistical techniques used herein. This may result in more comparable results. However, additional analyses are provided later in this chapter that compare the legibility performance of Type III sheeting and microprismatic sheetings.

Clearview versus Series E(Modified) with Type IX Sheeting

This analysis included 480 trials. The first analysis included the development of cumulative distribution plots for the different scenarios (and collapsing the age groups). These plots are shown in Figure 26. An initial visual inspection shows that the Clearview alphabet repeatably provides legibility distances no worse than Series E(Modified), and, for most cases, provides legibility distances greater than Series E(Modified). Interestingly, as the distance decreases, the difference between the alphabets generally increases. This can be explained by the legibility data from the older drivers, which were consistently shorter than for the young and middle-aged groups. For the age groups, as will be shown later, a statistically significant interaction with alphabet type exists. As a result, older drivers are shown to receive the greatest benefit from Clearview.

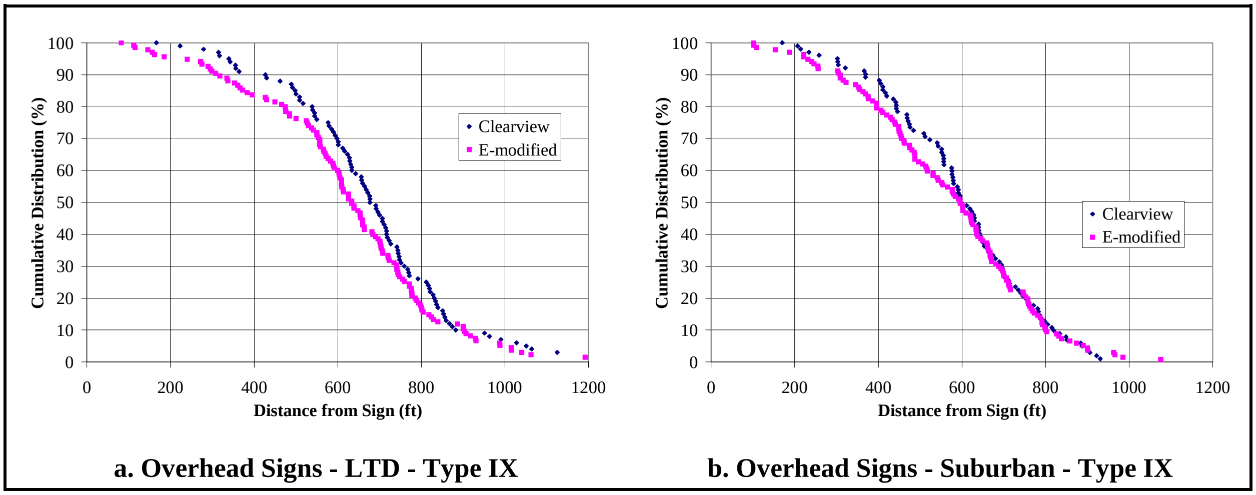


Figure 26. Overhead Guide Sign Legibility Distances.

The overall mean legibility distance for the Clearview alphabet was 40 ft, or 6.7 percent, higher than for the Series E(Modified) alphabet. Split by vehicle type, the Clearview improvements ranged from 26 to 54 ft (see Table 23). Again, these findings were encouraging since Clearview outperformed Series E(Modified) for both vehicles.

Table 23. Descriptive Statistics for Overhead Signs.

Vehicle	Sheeting	Alphabet	N	Average	Std. Dev.	Differences	
						Magnitude	Percent
LTD	IX	Clvw	100	678	190	54	8.6
		E(M)	135	624	204		
Suburban		Clvw	102	595	172	26	4.6
		E(M)	137	569	170		

Statistical Analysis

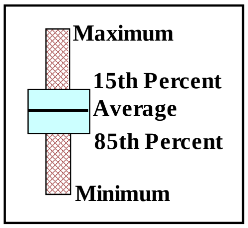
For the overhead signs, a similar statistical test was performed using a subset of the overhead legibility data. The only differences between the shoulder-mounted statistical test and the overhead statistical test were that there was only one type of sheeting (Type IX) and there were two replications instead of three. Therefore, there were only three independent variables (alphabet, vehicle, and subject age). Again, preliminary analyses by replication showed that there were no statistical differences among replications. The ANOVA results are shown in Table 24.

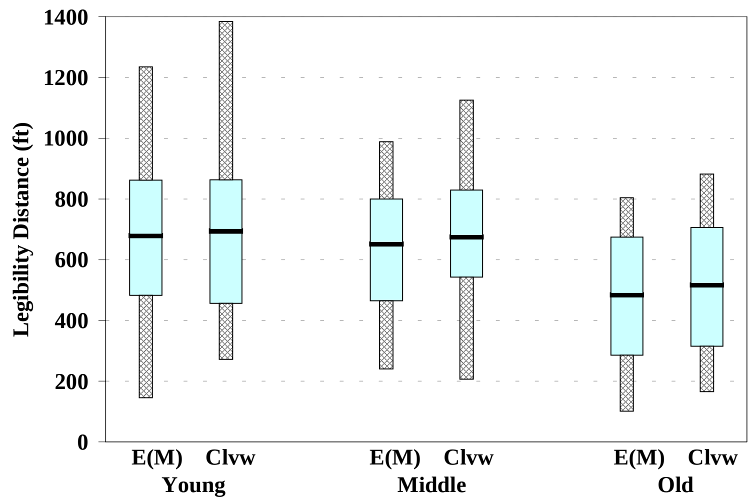
Again, the difference between the alphabets was significant ($F_{1,96}$ = 10.37, p=0.0018) but like the shoulder-mounted guide signs, the practical difference is modest (26 and 54 ft).

Figure 27 shows the significant relationships from the ANOVA shown in Table 24. All main effect variables were significant but, unlike the shoulder-mounted sign analysis, an interaction between alphabet and age was found to be significant ($F_{2,96}$ = 3.70, p=0.0284). As age increases, the benefits of Clearview become more pronounced. For the older group, Clearview provided an increase in legibility distance of 6.8 percent. This increased legibility distance results in an additional 0.33 second of reading time, assuming a 70 mph highway.

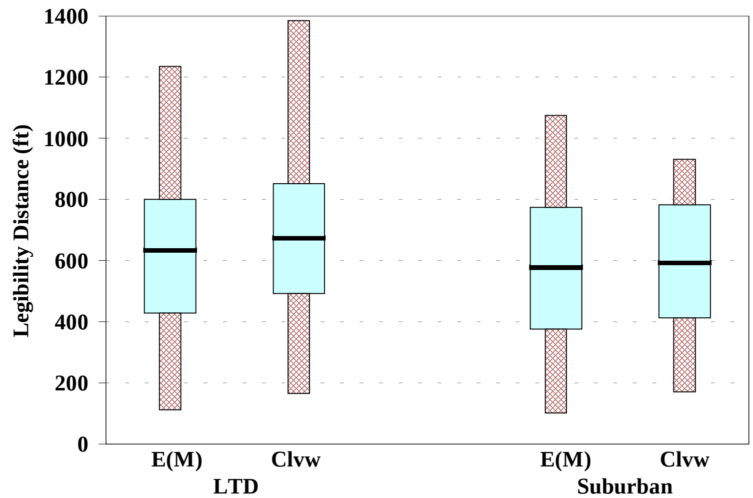
Table 24. ANOVA Results for Overhead Signs.

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	2	1,779,801	889,901	9.34	0.0002
	96	9,151,407	95,327		
Vehicle	1	466,324	466,324	44.61	<0.0001
Vehicle×Age	2	251,011	12,505	1.20	0.3068
	96	1,003,483	10,453		
Alphabet	1	68,800	68,800	10.37	0.0018
Alphabet×Age	2	49,059	24,530	3.70	0.0284
	96	637,051	6636		
Vehicle×Alphabet	1	15,838	15,838	2.21	0.1404
Vehicle×Alphabet×Age	2	20,858	10,429	1.45	0.2385
	96	688,134	7168		

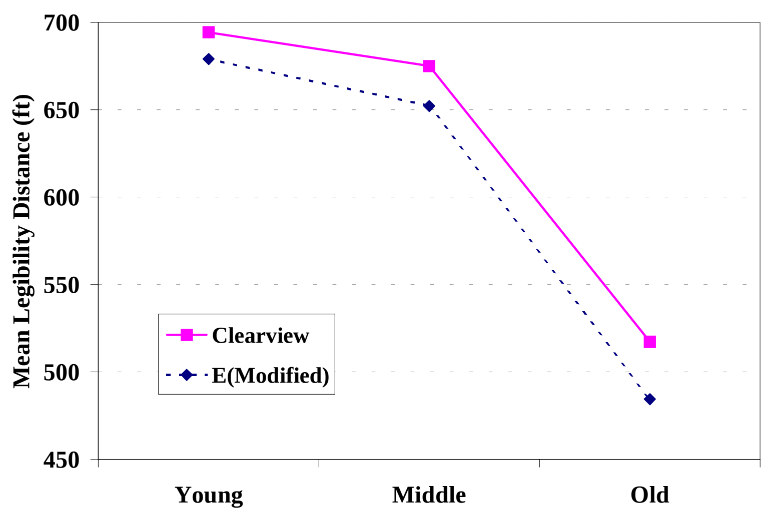




NOTE: The percent differences for the mean legibility distances are 2.3, 3.5, and 6.8 for young, middle, and old, respectively.



NOTE: The percent differences for the mean legibility distances are 6.3 and 2.7 for the LTD and Suburban, respectively.



NOTE: Interaction between age and alphabet for overhead signs.

Note how the performance difference increases as age increases.

Figure 27. Statistically Significant Relations for Overhead Signs.

LEGIBILITY AS A FUNCTION OF LUMINANCE

In order to get another perspective of the results, the researchers used photometric measurements to consolidate the luminance-dependent independent factors (i.e., sign position, vehicle type, and sheeting type). Every 100 ft, from 1000 ft to 200 ft, luminance measurements were made of the signs (from the driver's point-of-view). These data were recorded with the low-beams and are shown in Figure 28.

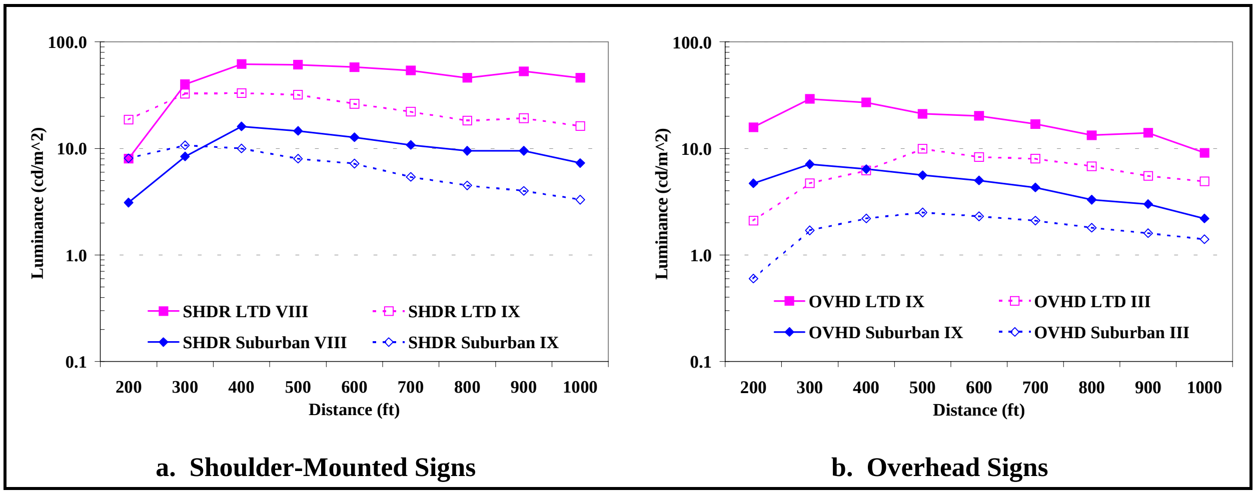


Figure 28. Measured Luminance Readings.

Photometric Measurements

For each case, the LTD produced luminance values at least twice as bright as the Suburban and, in some cases, as much as six times as bright. The reasons for luminance differences can be attributed to the slightly smaller observation angle associated with the LTD and the headlamps of each vehicle. Table 25 shows the pertinent dimensions of the test vehicles. Recalling from Chapter 2, smaller vertical distances between the headlamp height and driver eye height equate to smaller observation angles. Smaller observation angles equate to better performance of any type of retroreflective sheeting. As can be seen from Table 25, the vertical difference between the headlamp and driver eye is less in the LTD than in the Suburban. Therefore, the same sign at the same distance will appear brighter from the LTD than the Suburban.

Table 25. Vehicle Dimensions.

Description	1989 Ford Crown Victoria LTD	2001 Chevy Suburban
Headlamp Height (in)	28.5	38
Driver Eye Height (in)	49	61.5
Difference (in)	20.5	23.5

The second reason that different luminance values were measured can be explained by the headlamp performance of each vehicle. The LTD had the older style sealed-beam lamps that are generally known to produce light in a tunneling method. The Suburban had the newest style of tungsten-halogen replacement bulbs meeting the revised FMVSS108 specification (described in Chapter 2) (7). These newer headlamps are known to produce less light above the horizontal, but more light to the left and right (8). The measured illuminance values are shown in Figure 29 for the centroid of the shoulder-mounted sign.

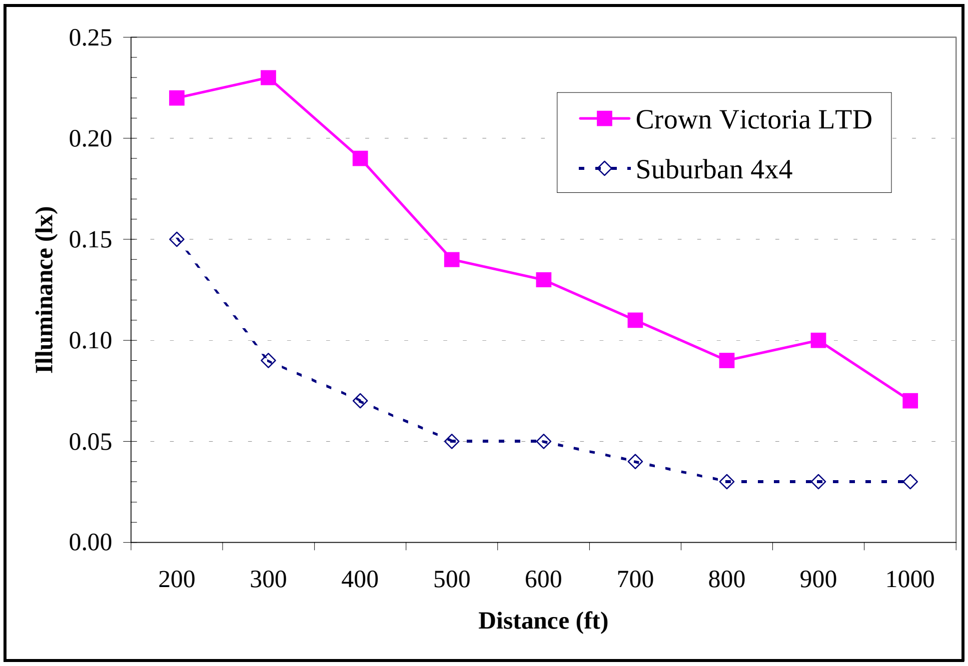


Figure 29. Measured Illuminance.

Legibility as a Function of Luminance

Using the legibility results combined with the measurements of luminance, it is possible to determine the luminance of the sign when the test subjects were able to read them. In essence, this process consolidates the three factors of sign position, vehicle type, and sheeting type into one factor – luminance. Figure 30 shows the results for the average legibility distances of both Clearview and Series E(Modified).

The most significant finding associated with Figure 30 is that, regardless of the luminance of the sign, Clearview consistently performs better than Series E(Modified). Although hardly noticeable, there is a slight trend that shows as luminance increases, the improvements from Clearview increases (as expected because of the irradiation phenomena described earlier).

Another obvious finding is that the brighter the sign, the more legible it is, regardless of the alphabet. However, this trend can be expected to discontinue as luminance approaches a threshold where the irradiation phenomena becomes overpowering. However, the highest luminance level associated with a 50^{th} percentile legibility distance was 54.4 cd/m^2, and this can be considered near the maximum when low-beams illuminate a sign, especially with the current trends in headlamp design which generally decrease the amount of light directed to freeway guide signs, especially overhead signs (16).

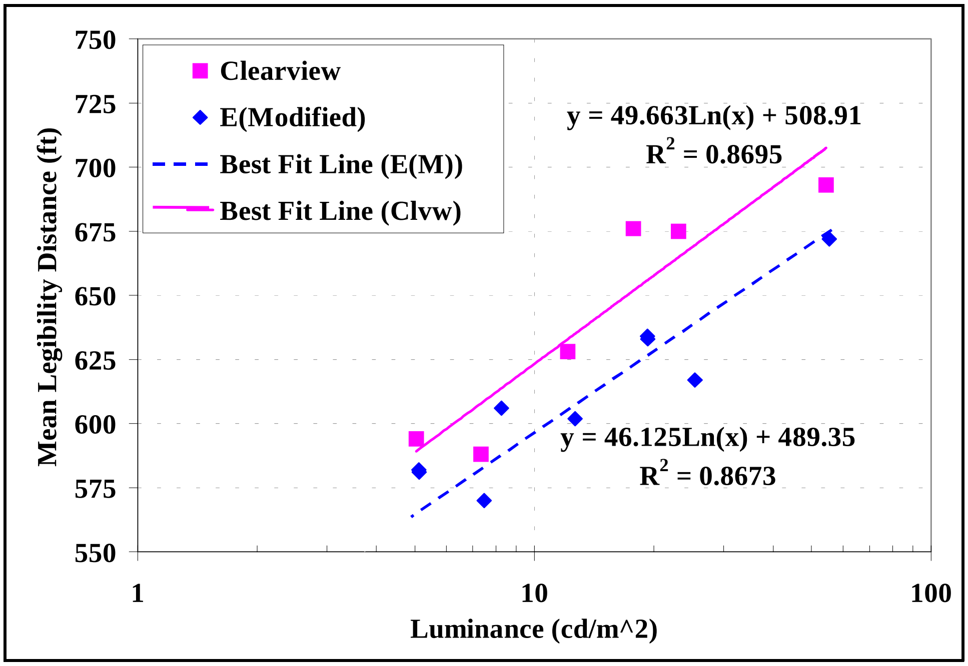


Figure 30. Legibility as a Function of Sign Luminance.

The final finding from Figure 30 is that as the luminance increases, the relative benefits in term of legibility distance decrease. For example, for the shoulder-mounted signs in this study (and using the Clearview 50th percentile legibility distances), the lowest luminance level was 7.3 cd/m^2 while the highest was 54.4 cd/m^2. Despite the fact that there was a 645 percent increase in luminance, the legibility distance only increased 105 ft, or 17.8 percent.

SUMMARY

In order to provide an example of how the research results can be used by TxDOT officials to make decisions about guide signing policies, the findings were integrated together. Two examples are included: one for overhead signs and one for shoulder-mounted signs. The legibility data used in this example are from the subjects in the LTD.

Overhead Guide Signs

The most efficient way to show the data is in a cumulative distribution plot, shown in Figure 31. This plot includes three sets of data. The first set represents the legibility performance of Type III sheeting with a Series E(Modified) legend (TxDOT's current guide signing policy). The second set of data represents the legibility performance of Type IX sheeting with a Series E(Modified) legend (a decision that will be imminently implemented). The final set of data represents the legibility performance of Type IX sheeting with a Clearview legend (a possible improvement to TxDOT's guide signing policy).

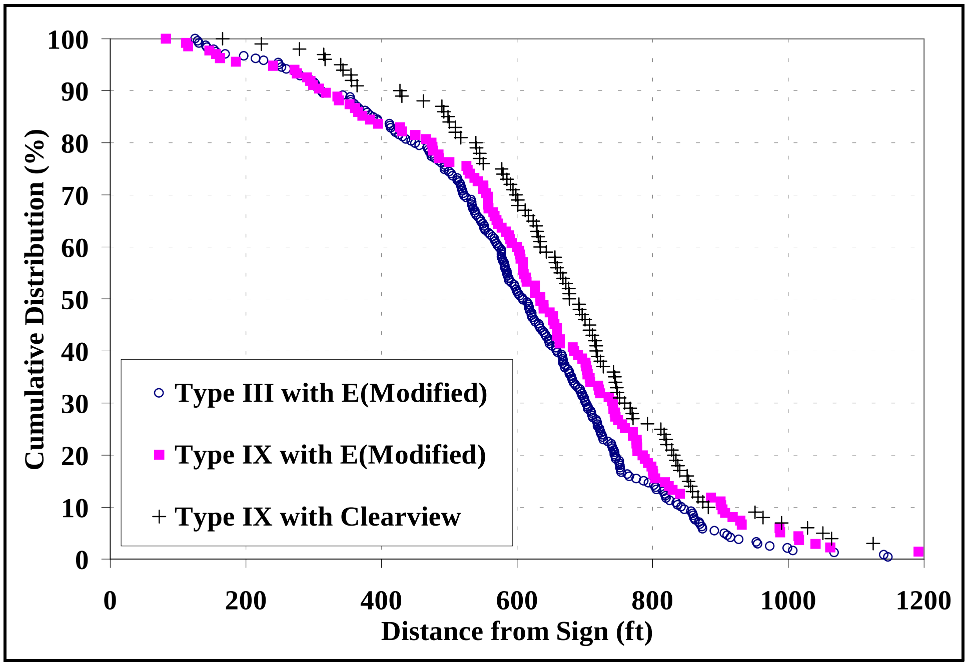


Figure 31. Overall Legibility Improvements.

The data show the sequential and overall legibility improvements that can be achieved with changes to guide sign policy including retroreflective sheeting and alphabet. Individually, the improvements are modest. Using the 50th percentile legibility level, the legibility improvement between Type III with Series E(Modified) and Type IX with Series E(Modified) sheeting is 25 ft or 4.1 percent. The legibility improvement between Type IX with Series E(Modified) and Type IX with Clearview is 43 ft or 6.8 percent. However, the overall improvements are more noteworthy. Again, using the 50th percentile legibility level, the legibility improvement between Type III with Series E(Modified) and Type IX with Clearview is 68 ft or 11.1 percent.

Assuming a 70 mph highway, the overall legibility improvement provides drivers an extra 0.66 second to read an overhead guide sign. For a 55 mph highway, drivers would be provided an extra 0.84 second. Assuming a last look distance equivalent to 3 seconds before passing the signs (17), these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.66 second would equate to a 22.6 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 18.5 percent.

The data included in this example are for Type III and Type IX sheeting. However, it is important to note that Type VIII sheeting can be expected to perform similarly to Type IX (at least for passenger cars and SUVs). The analysis of the shoulder-mounted sign data (see Table 16) shows that Type VIII sheeting performed similarly in terms of the benefits of Clearview versus Series E(Modified). Furthermore, the results of the luminance analysis can be used to further demonstrate that the results of Type VIII sheeting can be expected to provide similar results.

Using a program called Exact Roadway Geometry Output (ERGO), one can easily calculate the luminance of various signing scenarios. Researchers used this program with some minor additions. The dimensions of the LTD were entered in ERGO. Furthermore, a headlamp profile called CARTS50 was entered into ERGO. The CARTS50 headlamp profile was developed as part of a National Highway Traffic Safety Administration (NHTSA) study and includes a sample of 26 headlamps (18). It represents the 50th percentile of the bulbs' photometric tables. Most of the vehicles used to develop CARTS50 were manufactured in the late 1980s with one vehicle from 1990.

In order to compare the results of the ERGO program with the measured luminance values for Type VIII sheeting, the shoulder-mounted sign position was used. The centroid of the sign was offset to the right 30 ft of the right edge of the travel lane with a height of 12.8 ft (the centroid of the test word). The ERGO modeled luminance curve is shown with the measured luminance curve in Figure 32. The curves are very similar, which means that the modeled vehicle and headlamp do a good job of replicating the actual test conditions.

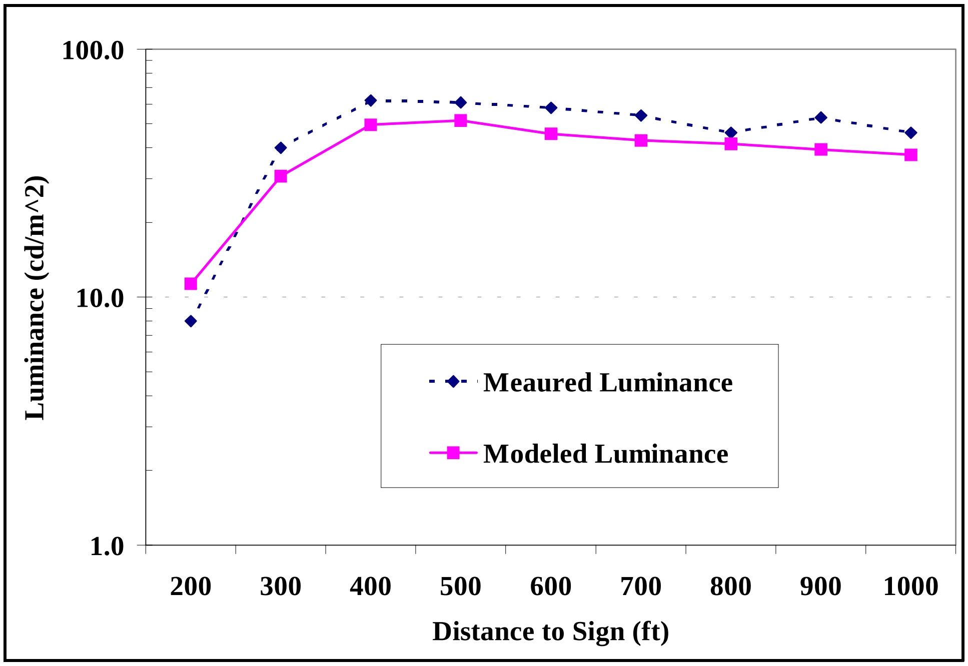


Figure 32. Comparison of Shoulder-Mounted Sign Luminance Values.

Next, using ERGO and the same vehicle and headlamp, the overhead sign was positioned exactly as the overhead signs used in the legibility study were positioned. More specifically, the sign was centered in the travel lane with a height of 21.8 ft (the height to the middle of the test words). Figure 33 shows the resulting luminance curve from ERGO for Type VIII sheeting with the measured luminance curves for Type III and Type IX sheeting.

From Figure 33 it is evident that for distances of 400 ft and greater, Type VIII sheeting produces slightly higher luminance values than Type IX sheeting. At distances less than 400 ft, the trend is reversed. However, the mean legibility distances for overhead signs with microprismatic sheeting ranged from 569 to 678 ft. Using the median value of 623.5 ft, Type VIII sheeting produces a luminance of 26.7 cd/m^2, and Type IX sheeting produces a luminance of 19.6 cd/m^2. Using the same process for the legibility of overhead signs fabricated with Type III sheeting, a luminance value of 8.9 cd/m^2 can be determined.

Now, using the equations of the best fit lines shown in Figure 30, it is possible to estimate the legibility performance associated with Clearview and Series E(Modified) for all three sheeting types. The results are shown in Table 26.

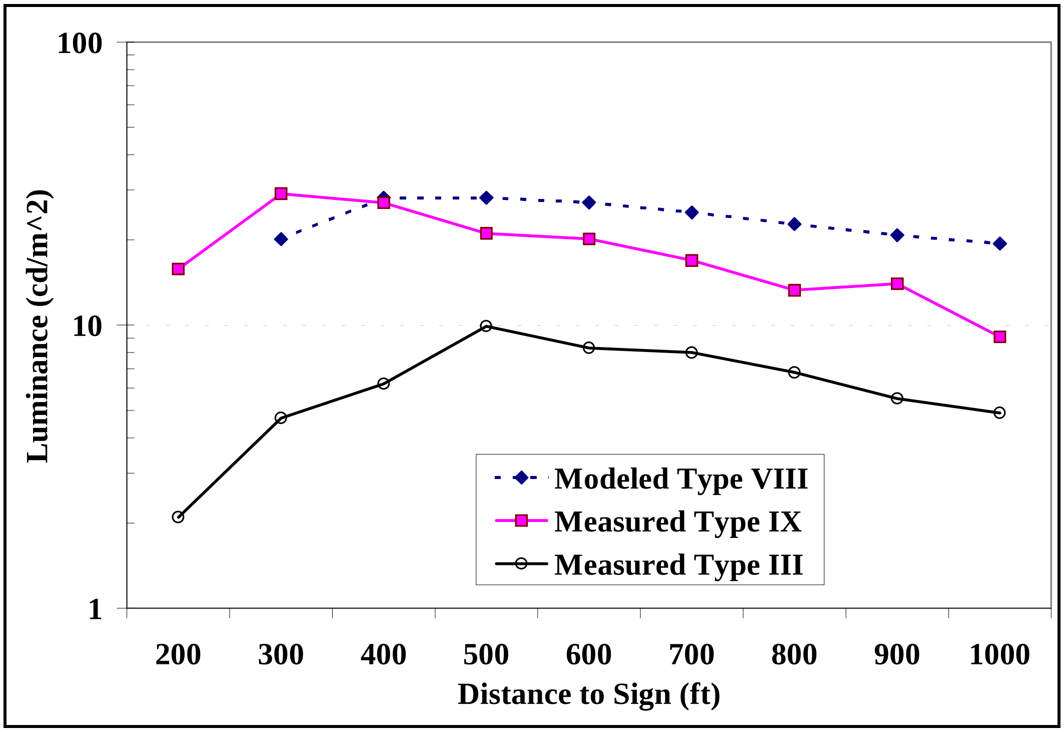


Figure 33. Overhead Sign Luminance Values.

Table 26. Estimated Overhead Sign Legibility Distances.

Sheeting	Luminance (cd/m^2)	Legibility Distance (ft)	
		Series E(Modified)	Clearview
Type III	26.7	590	617
Type VIII	19.6	641	672
Type IX	8.9	627	657

The estimated legibility distances shown in Table 26 (which represent estimated mean legibility distances) provide a more general picture of the expected performance of the Clearview and Series E(Modified) alphabets on overhead freeway guide signs. More specifically, the data show that microprismatic sheeting provides longer legibility distances than TxDOT's current specification of Type III sheeting. The data also show that an increase in legibility can be achieved with the Clearview alphabet instead of the Series E(Modified) alphabet, even with Type III sheeting. Interestingly, these results compare well with the theoretical example provided in Chapter 3 (specifically, Table 6).

Comparing the Type III results with the averaged microprismatic results (Types VIII and IX), it becomes evident that benefits can be achieved by making subtle changes in guide sign policy. For instance, a switch from Type III sheeting with Series E(Modified) to microprismatic sheeting with Series E(Modified) results in an increased mean legibility distance of 44 ft. Switching from microprismatic sheeting with Series E(Modified) to microprismatic sheeting with Clearview adds another 30 ft. Therefore, the estimated overall mean legibility improvement by switching from Type III signs with Series E(Modified) to microprismatic signs with Clearview would be 70 ft, or 11.9 percent.

Assuming a 70 mph highway, the overall legibility improvement provides drivers an extra 0.68 second to read an overhead guide sign. For a 55 mph highway, drivers would be provided an extra 0.86 second. Assuming a last look distance equivalent to 3 seconds before passing the signs, these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.68 second would equate to a 26.4 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 21.2 percent.

Shoulder-Mounted Guide Signs

Researchers used the same approach to determine the impacts of sheeting types and alphabets on shoulder-mounted guide signs. However, the measured luminance curves were available for Types VIII and IX sheeting but not for Type III sheeting. Therefore, ERGO was used to generate the luminance curve for a shoulder-mounted sign with Type III sheeting.

Using ERGO with the same vehicle and headlamp as used in the overhead analysis, the shoulder-mounted sign was positioned exactly as the shoulder-mounted signs used in the legibility study were positioned. More specifically, the sign centroid was offset 30 ft to the right of the right edge of the 12 ft travel lane. The sign centroid was positioned 12.8 ft above the pavement surface. The resulting luminance curve from ERGO for Type III sheeting is shown in Figure 34 with the measured luminance curves for Types VIII and IX sheeting.

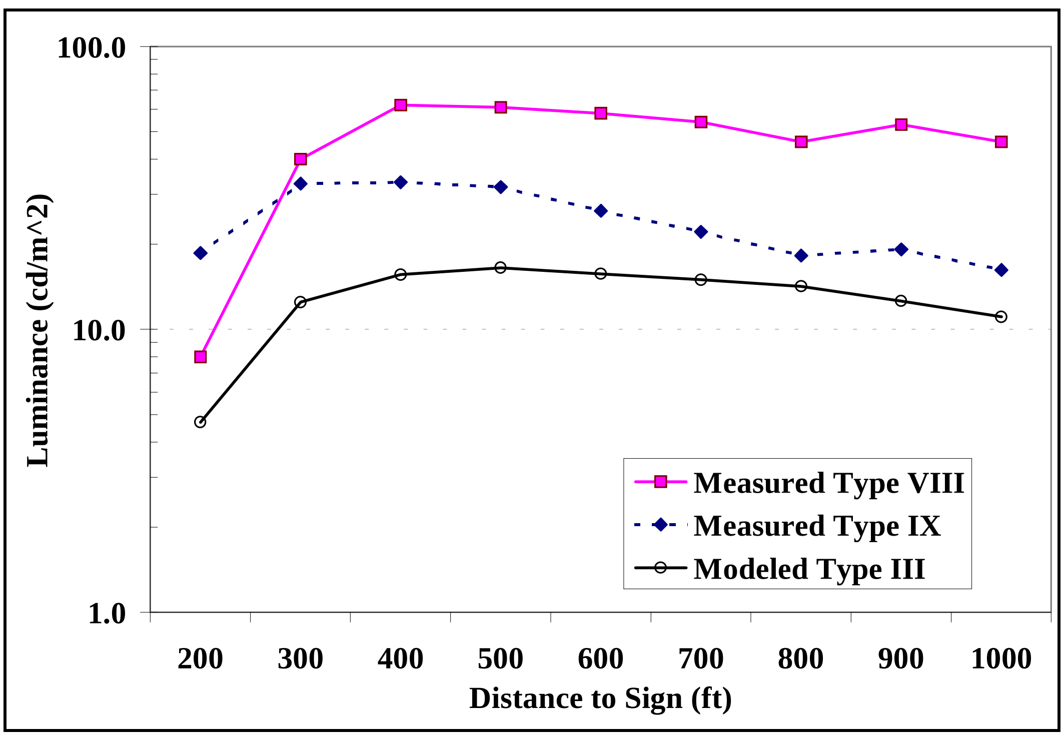


Figure 34. Shoulder-Mounted Sign Luminance Values.

The luminance curves in Figure 34 show that for distances of 300 ft and greater, Type VIII sheeting produces slightly higher luminance values than Type IX sheeting. At distances less than 300 ft, the trend is reversed. Both microprismatic sheetings produce higher luminance values than Type III sheeting.

The mean legibility distances for shoulder-mounted signs with microprismatic sheeting ranged from 570 to 675 ft. Using the median value of 622.5 ft, Type VIII sheeting produces a luminance of 57.2 cd/m^2, and Type IX sheeting produces a luminance of 25.2 cd/m^2. Since no legibility distances were obtained with Type III sheeting, the distance used to determine a luminance value was based on the legibility reduction of Type III sheeting when compared to the average of Type VIII and Type IX for overhead signs. Therefore, researchers assumed a shoulder-mounted sign with Type III sheeting to have a mean legibility distance of 568 ft. The associated luminance was determined to be 16.0 cd/m^2.

Now, using the equations of the best fit lines shown in Figure 30, it is possible to estimate the legibility distance associated with shoulder-mounted signs with Clearview and Series E(Modified) legends, for all three sheeting types. The results are shown in Table 27.

Table 27. Estimated Shoulder-Mounted Sign Legibility Distances.

Sheeting	Luminance (cd/m^2)	Legibility Distance (ft)	
		Series E(Modified)	Clearview
Type III	15.5	616	645
Type VIII	57.2	676	710
Type IX	25.2	638	669

The estimated legibility distances shown in Table 27 (which represent estimated mean legibility distances) provide a more general picture of the expected performance of the Clearview and Series E(Modified) alphabets on shoulder-mounted freeway guide signs. More specifically, the data show that microprismatic sheeting provides longer legibility distances than TxDOT's current specification of Type III sheeting. The data also show that an increase in legibility can be achieved with the Clearview alphabet instead of the Series E(Modified) alphabet, even with Type III sheeting.

Comparing the Type III results with the averaged microprismatic results (Type VIII and Type IX), it becomes evident that benefits can be achieved by making subtle changes in guide sign policy. For instance, a switch from Type III sheeting with Series E(Modified) to microprismatic sheeting with Series E(Modified) results in an increased mean legibility distance of 41 ft. Switching from microprismatic sheeting with Series E(Modified) to microprismatic sheeting with Clearview adds another 33 ft. Therefore, the estimated overall mean legibility improvement by switching from Type III signs with Series E(Modified) to microprismatic signs with Clearview would be 74 ft, or 12.0 percent.

Assuming a 70 mph highway, the overall legibility improvement provides drivers an extra 0.72 second to read a shoulder-mounted guide sign. For a 55 mph highway, drivers would be provided an extra 0.92 second. Assuming a last look distance equivalent to 3 seconds before passing the signs, these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.72 second would equate to a 24.1 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 19.8 percent.

At this point, it is important to recall that these examples have several assumptions associated with them. The most critical assumptions are that the data were generated from legibility measurements from a passenger car and a SUV. The modeled luminance included a fairly dated headlamp profile. Newer headlamps do not produce as much illumination toward overhead signs. However, even with decreased illumination levels, the trends across sheeting type and alphabet should be consistent.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The basic objective of this research project was to compare the nighttime legibility of microprismatic guide signs fabricated in two different alphabets: Clearview and Series E(Modified). This research focused on shoulder-mounted guide signs but also included a smaller sample of overhead guide signs. The design included 60 subjects categorized into three age groups: young (18-34), middle-aged (35-54), and old (55 and older). All 60 subjects conducted the study while driving two different vehicles: a 1989 Ford Crown Victoria LTD and a 2001 Chevy Suburban four-wheel drive (4×4).

The project also included a sample of nighttime legibility performance with Type III sheeting. This effort was designed in order to make comparisons between the legibility performance of guide signs fabricated with Type III sheeting and guide sign fabricated with microprismatic sheetings. This effort was also initiated in order to make direct comparisons to an earlier TTI-Clearview project, which included recognition and legibility of daytime and nighttime guide signs with three different alphabets (including Clearview and Series E(Modified)).

CONCLUSIONS

Comparison with Earlier TTI-Clearview Project

Unfortunately, the results of the comparison between this project and the earlier TTI-Clearview project do not correlate well. Chapter 5 details the hypothesized differences and relates them to the differences in the experimental designs and TTI's current arsenal of photometric measuring equipment, which were not available when the earlier TTI-Clearview project was conducted.

Type III Sheeting versus Microprismatic Sheetings

The results of the analysis show that statistically significant longer legibility distances can be achieved with microprismatic sheetings (when compared to Type III sheeting) for overhead signs. No data were collected for shoulder-mounted signs fabricated with Type III sheeting and, as mentioned, the comparisons between the earlier TTI-Clearview project (which included shoulder-mounted signs fabricated with Type III sheeting) do not correlate strongly enough to make comparisons.

However, an analysis was included that used modeling of Type III shoulder-mounted signs and Type VIII overhead signs (two conditions that were not studied). Combining the legibility results and the modeling efforts, it was shown the microprismatic sheetings produced longer legibility distances than Type III sheeting, for both shoulder-mounted guide signs and overhead guide signs. The results show legibility improvements of 44 and 41 ft for overhead and shoulder-mounted guide signs, respectively.

Clearview on Shoulder-Mounted Guide Signs

For shoulder-mounted guide signs fabricated with microprismatic sheeting, the results show that Clearview provides statistically longer legibility distances than Series E(Modified). The overall mean legibility distances were 32 ft greater with Clearview.

The largest difference between the Clearview and Series E(Modified) alphabets were associated with older drivers. For older drivers the Clearview produced legibility distances 6.0 percent longer than Series E(Modified).

Clearview on Overhead Guide Signs

The research results show that overhead guide signs fabricated with microprismatic sheeting provide statistically significant longer legibility distances with a Clearview legend compared to a Series E(Modified) legend. The overall mean legibility distances were 40 ft greater with Clearview.

Like shoulder-mounted signs, the largest difference between the Clearview and Series E(Modified) alphabets were associated with older drivers. For older drivers, Clearview produced legibility distances 6.8 percent longer than Series E(Modified).

Luminance

An analysis that consolidated the three luminance-dependent factors (sign position, sheeting type, and vehicle type) into luminance was also conducted. The most significant finding is that Clearview produces longer legibility distances, regardless of the amount of sign luminance. The results also show that as luminance increases, the sign becomes more legible, although the benefits of increased luminance decrease as luminance increases. In terms of the alphabets, the results show a slight but noticeable trend indicating that as luminance increases, the benefits (i.e., longer legibility distances) of Clearview increase.

Summary

Two examples are included that use the results of the legibility analyses to show the sequential and overall benefits (i.e., in terms of legibility distance) that TxDOT can expect by switching from Type III sheeting to microprismatic sheeting and by switching from the Series E(Modified) alphabet to the Clearview alphabet.

Sequentially, for overhead signs, the legibility distance improvements are modest. A switch from Type III sheeting with Series E(Modified) to microprismatic sheeting with Series E(Modified) results in an increased mean legibility distance of 44 ft. Switching from microprismatic sheeting with Series E(Modified) to microprismatic sheeting with Clearview adds another 30 ft. The estimated overall mean legibility improvement by switching from Type III overhead signs with Series E(Modified) to microprismatic overhead signs with Clearview would be 70 ft, or 11.9 percent.

Assuming a 70 mph highway, the overall legibility improvement provides drivers an extra 0.68 second to read an overhead guide sign. For a 55 mph highway, drivers would be provided an extra 0.86 second. Assuming a last look distance equivalent to 3 seconds before passing the signs, these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.68 second would equate to a 26.4 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 21.2 percent.

Like overhead guide signs, the sequential benefits for shoulder-mounted guide signs are modest. Switching from Type III sheeting with Series E(Modified) to microprismatic sheeting with Series E(Modified) would result in an increased mean legibility distance of 41 ft. Switching from microprismatic sheeting with Series E(Modified) to microprismatic sheeting with Clearview adds another 33 ft. The estimated overall mean legibility improvement by switching from Type III signs with Series E(Modified) to microprismatic signs with Clearview would be 74 ft, or 12.0 percent.

Again, assuming a 70 mph highway, the overall legibility improvement provides drivers an extra 0.72 second to read a shoulder-mounted guide sign. For a 55 mph highway, drivers would be provided an extra 0.92 second. Assuming a last look distance equivalent to 3 seconds before passing the signs, these time improvements are even more significant. For instance, on a 70 mph highway, an extra 0.72 second would equate to a 24.1 percent increase in time to read an overhead guide sign. For a 55 mph highway, the increase would be 19.8 percent.

RECOMMENDATIONS

For all conditions studied (including Type III sheeting and microprismatic sheetings), the Clearview alphabet significantly outperformed the Series E(Modified) alphabet (the measure of effectiveness was nighttime legibility distance). In terms of sheeting type, the microprismatic sheetings provided statistically longer legibility distances than Type III sheeting. The combined benefits of microprismatic sheeting and Clearview in terms of added legibility distance were nearly 75 ft, and were greatest for drivers over 55 years old.

Furthermore, the previous Clearview research studies show that daytime Clearview legibility performance is not significantly different than Series E(Modified) (1,2). These studies also show that both daytime and nighttime Clearview recognition performance is not significantly different than Series E(Modified).

Therefore, based on the results discovered and presented herein, the researchers recommend that TxDOT begin using microprismatic retroreflective sheeting and Clearview on all new and refurbished guide signs.

TxDOT has already installed a small sample of guide signs with Clearview for evaluation. Anecdotal comments have been favorable. Besides, TxDOT already owns approximately 100 licensed versions of Clearview (although not the most current version, it was the version that was used to make the signs for this study). Additionally, TxDOT has provided a sign manufacturer one licensed version of Clearview (to be used for TxDOT signs, exclusively). Using this licensed copy of Clearview, the sign manufacturer fabricated the small sample of Clearview guide signs already installed in Texas. The fabrication costs were not any different than if TxDOT had specified Series E(Modified).

CHAPTER 7
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