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16. Abstract Project

In Texas, commercial vehicle safety is increasing in priority due to the rising volume of truck traffic and the disproportionate percentage of crashes and fatalities involving large trucks. One particular safety issue is the visibility of signing and pavement markings at night from a commercial vehicle driver's perspective.

Through a nighttime controlled field study, the relationship between vehicle type (passenger car versus commercial vehicle) and sign/pavement marking material was evaluated in terms of the legibility distance of signs and the end detection distance of pavement markings. Additional research issues included investigations among sign type (guide, destination, and speed limit) and age (young, middle-aged, and old).

The findings indicate that the commercial vehicle provided statistically longer legibility distances than the passenger car. However, an examination of headlamp illuminance suggests that the headlamp illuminance of the commercial vehicle used in the nighttime controlled field study was higher than the average headlamp illuminance of on-road commercial vehicles.

In addition, the type of retroreflective material was found to be a significant factor for the speed limit signs and the pavement markings, but not for the guide signs or destination signs. The relationship between vehicle type and material type was found to be statistically significant only for the speed limit signs. However, the practical difference was small and the legibility distance did not clearly depend on any particular combination of vehicle type and material type.

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SIGN AND PAVEMENT MARKING VISIBILITY FROM THE PERSPECTIVE OF COMMERCIAL VEHICLE DRIVERS

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DISCLAIMER

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 Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report is not intended to 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. (TX-85402).

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1. INTRODUCTION

In Texas, commercial vehicle safety is increasing in priority due to the rising volume of truck traffic and the disproportionate percentage of crashes and fatalities involving large trucks. One particular safety issue is the visibility of signs and pavement markings at night from a commercial vehicle driver's perspective. In theory, commercial vehicle drivers are at a disadvantage when it comes to the amount of light returned from retroreflective devices such as signs because the eye/headlamp separation in large trucks is substantially greater than in other types of vehicles, and the performance of retroreflective materials generally decreases as the eye/headlamp separation increases. Currently, the combination of these issues is not considered in the design of signs and pavement markings. Research was needed to determine to what extent, if any, this theoretical disadvantage actually affects the visibility of retroreflective signs and pavement markings at night.

PROJECT OVERVIEW AND REPORT ORGANIZATION

The overall objective of this project was to determine whether vehicle type should be considered in the selection of retroreflective materials. More specifically, the purpose was to determine whether the legibility distance of signs and the end detection distance of pavement markings depends on the relationship between vehicle type (passenger car versus commercial vehicle) and sign/pavement marking material. Additional research issues included investigations among sign type (speed limit, guide, and destination) and driver age (young, middle-aged, and old). A secondary purpose was to measure the headlamp illuminance (i.e., amount of light reaching an object) of various types of commercial vehicles and their respective headlamps.

The Texas Transportation Institute (TTI) conducted the research project described herein from September 1, 2001 to August 31, 2002. The activities that were completed, as well as the report organization, are described below.

- *Literature Review* – The research team reviewed previous research concerning the visibility of signs and pavement markings, vehicle trends, the Texas-based commercial vehicle fleet, vehicle headlamp and driver's eye positions, and geometrical viewing conditions of signs and pavement markings. Chapter 2 summarizes the research reviewed.
- *Commercial Vehicle Driver Survey* – In November and December 2001, the research team conducted truck driver surveys at three truck stops to solicit and evaluate opinions of current signage and pavement markings in Texas. In total, researchers administered 121 surveys (approximately 40 surveys at each location). Chapter 3 describes the design and results of the survey.
- *Nighttime Controlled Field Study* – In April 2002, the research team conducted a nighttime controlled field study to determine the legibility distance of signs and the end detection distance of pavement markings for various types of retroreflective materials. In total, 28 truck drivers viewed 33 sign treatments and six pavement marking treatments in a passenger vehicle and in a commercial vehicle. Chapters 4 and 5 present the experimental design and results from the controlled field study, respectively.

- *Commercial Vehicle Headlamp Study* – In June 2002, the research team performed a headlamp study to determine the headlamp illuminance of on-road commercial vehicles. The illuminance of 10 commercial vehicles' headlamps was measured at four typical sign locations (including the average location of the signs in the controlled field study). Chapters 6 and 7 document the experimental design and results from the headlamp study, respectively.
- *Recommendations* – Based on the results from the research conducted, the research team developed recommendations regarding the design of retroreflective signs and pavement markings. Chapter 8 documents the recommendations.

2. LITERATURE REVIEW

The nighttime visibility of traffic signs and pavement markings is enhanced through the use of retroreflective materials that return light from a vehicle's headlamps back to a driver. However, the ability to see a sign or pavement marking at night is dependent upon several factors:

- the amount and pattern of light produced by a vehicle's headlamps (luminous intensity),
- the amount of light reaching the sign or pavement marking (illumination),
- the retroreflective characteristics of the sign or pavement marking material, and
- the visual characteristics of the driver.

Three terms are commonly used in describing the nighttime performance of retroreflective materials. The luminous intensity is the amount of light produced by the headlamps in a particular direction. The illuminance is the amount of light falling upon the sign or pavement marking. The luminance is the amount of light produced by the sign or pavement marking and represents what the driver sees. Luminance is a function of the illuminance and the retroreflective properties of the material. A device can be highly retroreflective but have low luminance values (and hence low visibility) if it does not receive sufficient illuminance (light) from the headlamps. Likewise, a device can receive high levels of illumination (light) but not be visible if it does not have sufficient retroreflectivity.

The main thrust of this research effort is to determine the impacts of commercial vehicles on the design of retroreflective traffic signs and pavement markings. This is important because of the relationship between the observation angle and the efficiency of retroreflective materials (as the observation angle increases, the efficiency of retroreflective materials decreases). The observation angle is the angle subtended between a vector protruding from one headlamp to a target (such as a traffic sign) and then back to the driver's eyes. Because there are two headlamps, there are two observation angles (the driver's eyes are generally considered as a single point in space since they are relatively close).

One of the key parameters that controls the relative size of the observation angle is the vehicle design, which dictates the placement of the headlamps and the position of the driver's eyes (disregarding the variation caused by human body differences). For instance, in a small sports car such a Corvette, a driver's eyes are not much higher than the headlamps. However, in a typical pickup truck such as an F-150, the driver's eyes are much higher than the driver of the Corvette, but the headlamps are also higher than the Corvette. Despite these similar trends, the difference between the driver's eye height and the headlamps' height is much greater in the F-150 than the Corvette, and therefore the observation angle associated with the F-150 is larger than the Corvette. For larger trucks such as commercial vehicles, the observation angle is even larger. Figure 1 shows how important the observation angle is in terms of retroreflective sheeting performance.

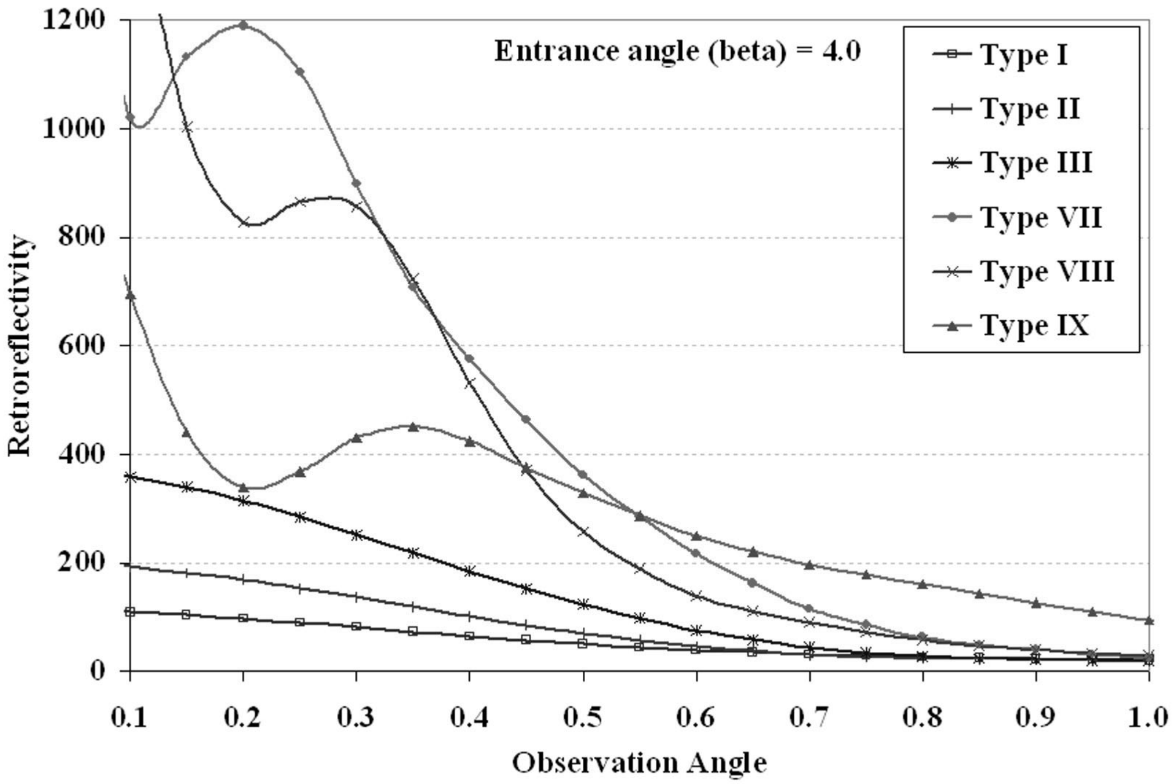


Figure 1. Observation Angle Curves for Retroreflective Sheeting.

RESEARCH FINDINGS

Recently, using visibility models, researchers have noted that at a viewing distance of 500 ft, the amount of light reflected back to the eye of a driver in a light or heavy truck could be reduced by as much as 75 percent compared to the amount of light reflected back to a driver of a passenger car (*1*). This same impact is noted in a 1991 study. The 1991 study also reports that at a viewing distance of 1000 ft the amount of light reaching a commercial vehicle driver is as low as 68 percent. The 1991 report concludes that the amount of light reflected to a commercial vehicle driver's eyes from retroreflective signs is less than the light reflected to a passenger vehicle driver's eyes at any given distance (*2*). These results imply that increased eye height can have a major effect on the legibility of retroreflective signs.

Other research shows, at least theoretically, that certain types of retroreflective sign sheeting accommodate vehicles associated with larger observation angles better than other sheeting types. The same research also includes empirical research findings related to vehicle types and legibility distances. The researchers, using a passenger car and sports utility vehicle (SUV), showed that legibility distances associated with the SUV were less than those associated with the passenger car. However, an important note that detracts from the significance of this comparison is that the vehicles had vastly different headlamp systems (*3*). Nonetheless, the research reviewed herein shows similar trends that indicate that special considerations or changes to the current processes may be needed to accommodate larger vehicles, much in the same way practitioners are trying to accommodate the reduced visibility phenomenon associated with aging.

In 1980, Lundkvist and Sørensen reported on specific luminance measurements taken on a sample of nine different pavement marking materials. The measurements were made at various geometries. The illumination source was fixed at 2 ft. The observation point was in the same vertical plane as the illumination source and was fixed at three points: 3 ft, 4 ft, and 5 ft. At each of these observation points, measurements of the specific luminance of the pavement marking materials were made at six distances: 33 ft, 49 ft, 98 ft, 164 ft, 246 ft, and 328 ft (*4*).

One universal feature of the measurements was that the higher observation points were associated with lower specific luminance measurements. This finding is very similar to that of retroreflective sheeting as discussed earlier. The indication is that commercial vehicle drivers, because of the size of their vehicles, may not be able to see pavement marking materials as well as drivers of smaller vehicles such as passenger cars (*4*).

In 1999, a research study on pavement markings found that increasing the headlamp mounting height from 2 to 4 ft over a range of driver eye heights (4 to 8 ft) resulted in a 19 percent increase in detection distance. This result is not surprising since the observation and entrance angles decrease (increasing the retroreflectivity) as the eye/headlamp separation decreases (*5*). However, higher headlamp mounting heights lead to more glare; thus, other options, such as material, need to be explored.

VEHICLE TRENDS

Vehicle Sales

Motor vehicle sales were examined in an effort to understand the current trends in vehicle preference. A study completed by the Oak Ridge National Laboratory investigated the sales of new automobiles and light trucks. This report shows that while automobile sales have decreased by 15 percent from 1976 to 1997, light truck sales increased by over 170 percent (*6*). Table 1 shows the 10 best selling vehicles sold in the U.S. during 2000 and reveals that half were either light trucks, vans, or SUVs (*7*).

Vehicle Registration

In order to understand how the recent trends in vehicle sales have impacted the vehicle fleet, vehicle registration data were grouped by vehicle type and compared on a national basis as well as a state level (*8*). Figures 2 and 3 show the results, which indicate that there is a larger portion of trucks on Texas roadways than on the nation’s roadways as a whole.

Table 1. Ten Best Selling Vehicles Sold in the U.S. in 2000 (*7*).

Make and Model	Number Sold in 2000
Ford F-Series	876,716
Chevrolet Silverado	645,150
Ford Explorer	445,157
Toyota Camry	422,961
Honda Accord	404,515
Ford Taurus	382,035
Honda Civic	324,528
Ford Focus	286,166
Dodge Caravan/Grand Caravan	285,739
Jeep Grand Cherokee	271,723

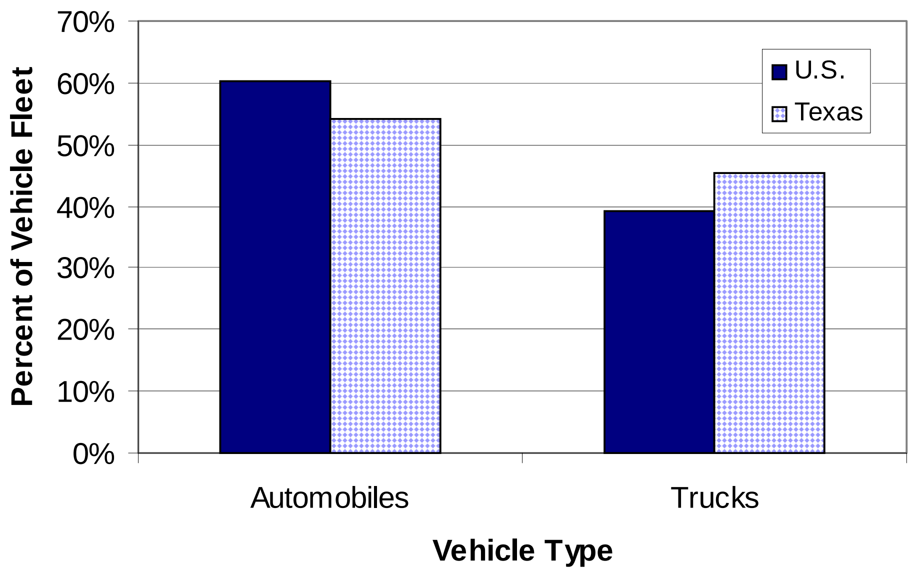


Figure 2. Vehicle Distribution (*8*).

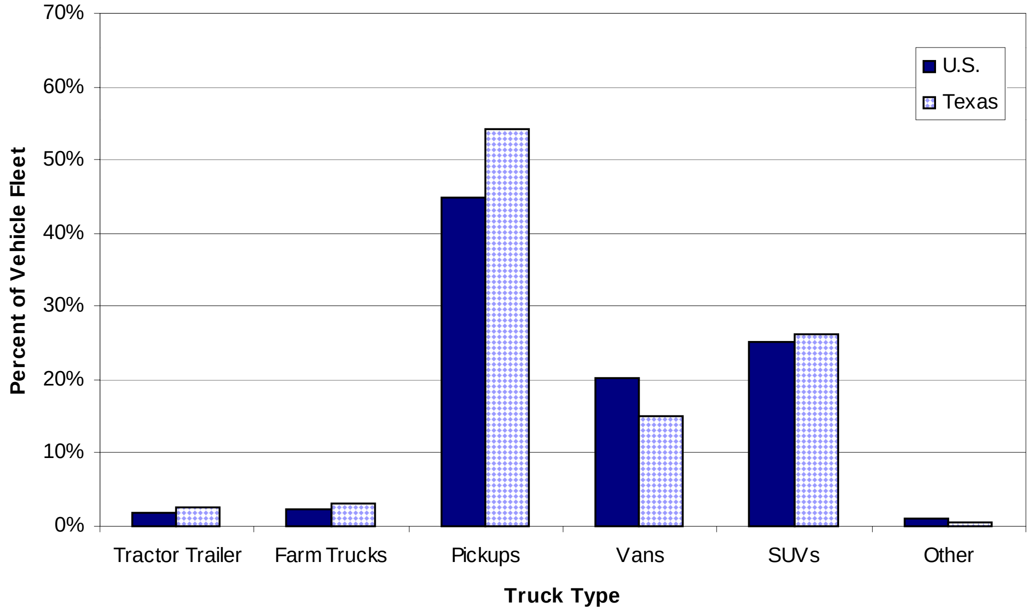


Figure 3. Truck Distribution (*8*).

Texas Commercial Vehicle Fleet

Based on figures from the Vehicle Inventory and Use Survey (VIUS), in 1997, there were approximately 260,000 commercial vehicles registered in Texas. Single unit trucks accounted for about 60 percent of the Texas commercial vehicle fleet, while tractor-trailer combinations accounted for approximately 40 percent (*9*).

Typical trip lengths for the Texas-based commercial vehicle fleet were as follows: 43 percent of the trucking occurred within 50 miles from home; 33 percent of the trucking occurred between 51 and 200 miles from home; and trips that are longer than 201 miles accounted for 16 percent. In 1997, the average annual miles traveled by the Texas fleet were more than 20,000 miles. However, 87 percent of Texas-based commercial vehicle fleet traveled less than 25 percent of their miles outside of Texas (*9*). Thus, most trucking (by the Texas-based fleet) occurred within the state.

In 1997, 45 percent of the Texas-based commercial vehicle fleet was comprised of pre-1988 year models. Thus, almost half of the fleet was more than 10 years old. In contrast, approximately 20 percent of the trucks were 1995 year models or later (two years old or less) (*9*).

In 1993, trucking handled approximately one-half of the Texas originating tonnage. Almost 20 percent of the tonnage was handled by pipeline, 15 percent was handled by rail, and the remaining 15 percent was handled by other modes of transportation (*10*). According to the VIUS, the principal commodities that were moved by Texas commercial vehicles include building materials, processed foods, farm products, mixed cargoes, craftsman's equipment, and machinery. Truck usage by those commodity groups combined accounted for 51 percent of total movements by Texas-registered commercial vehicles (*9*).

Based on truck flow data obtained from the Texas Department of Transportation (TxDOT), the highest commercial vehicle volumes occur on Interstate highways along the following links (*11*):

- Dallas to San Antonio on I-35 – approximately 7500 commercial vehicles per day;
- East of Houston on I-10 – approximately 7500 commercial vehicles per day;
- Dallas to Houston on I-45 – approximately 4500 commercial vehicles per day;
- East of Dallas on I-20 and I-30 – approximately 4500 commercial vehicles per day;
- North of Dallas on I-35 – approximately 4500 commercial vehicles per day; and
- West of Dallas on I-20 to I-10, to El Paso – approximately 3500 commercial vehicles per day.

There are other U.S. highways that also show relatively high commercial vehicle volumes ranging from 1800 to approximately 2000 trucks per day. Some of these highways include: U.S. 77 from Houston to Brownsville; U.S. 59 from Houston to Longview-Marshall; U.S. 281 from Three Rivers to McAllen; and U.S. 84 from Lubbock to I-20 (*11*).

HEADLAMPS AND DRIVER'S EYE POSITIONS

As noted, the vehicle fleet in Texas and the U.S. is changing – the percentage of light trucks and SUVs is increasing. Associated with this change is the placement of headlamps and the driver's eye position within these vehicles. It is important to understand these changes because the location of the headlamps and the driver's eye position are critical in estimating the efficiency of retroreflective products.

Table 2 contains the typical vehicle dimensions that describe the location of the headlamps and driver's eyes in the 10 best selling vehicles sold in the U.S. during 2000. The headlamp and driver eye heights for light trucks/SUVs/vans are approximately 20 percent higher than for passenger cars. This difference in height equates to a 3 ft increase in the distance between the driver's eyes and the headlamps in a light truck.

Table 2. Typical Vehicle Dimensions.

Dimensions (in)	Passenger Cars (N=5)	Light Trucks/SUVs/Vans (N=5)
Headlamp Height above Ground	26	34
Headlamp Separation	45	53
Driver Eye Height	47	58
Driver Eye Offset from Vehicle Centerline	13	16
Driver Eye Setback from Headlamps	83	86
Distance between Driver Eye and Headlamp	21	24

Headlamp Trends

As a result of two events during the last decade (Texas House Bill 916, which practically eliminated overhead lighting from newly installed or refurbished roadway signs, and TxDOT's 1993 guideline, which provides an option to use sign lighting with high-intensity sheeting) newly installed 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 highway vehicles sold in the U.S. (*12*). Prior to 1997, FMVSS 108 included specifications that allowed a reasonable amount of light to be emitted above the horizontal plane. This light 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 GROUPE DE TRAVAIL – BRUXELLES's (an international group of lighting experts working on worldwide harmonization) 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. 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 VOR headlamp reduces overhead illumination by 18 percent, the VOL by 28 percent, and the harmonized headlamp by 33 percent (*13*). According to a recent survey, VOR and mechanical-aim low beams are at least 55 percent predominant in the model year 2000 U.S. on-road fleet (*14*).

The National Highway Traffic Safety Administration (NHTSA) is responsible for FMVSS 108. They have recently solicited public comments regarding numerous consumer complaints about nighttime glare from headlamps and auxiliary lights (*15*). NHTSA's three main concerns are high-intensity discharge lights that appear blue, auxiliary lights such as fog lamps, and headlights mounted on various light trucks (including SUVs, pickups, and vans). It appears that NHTSA is headed toward another revision to the FMVSS 108. One of the possible outcomes is that maximum headlamp heights on commercial vehicles be reduced to eliminate glare. Another feasible outcome is that NHTSA requires headlamps of U.S. vehicles to be more like headlamps currently found in Europe which, as explained above, will decrease the light available to illuminate signs. This is especially important to commercial vehicles, which will be at a distinct disadvantage because of the reduced light and the inherently larger observation angles.

Impacts

The recent trend in vehicle headlamp specifications and the current trends in vehicle sales, especially in Texas, point toward a developing dilemma involving the ability of the traffic engineer to provide adequate nighttime traffic control. The bottom line, however, is how the detection and legibility of traffic control devices are impacted. The most critical nighttime component related to the detection and legibility of traffic control devices is the brightness or luminance of the device. Using modeling efforts, one can easily generate theoretical luminance curves for a variety of situations. A common signing scenario is a right shoulder-mounted sign. The following example depicts a passenger car with weighted 50 percentile headlamps from model year 2000, a Freightliner commercial vehicle with commonly used sealed beam headlamps, and a Peterbilt commercial vehicle with VOA headlamps. The sign was positioned with an offset of 30 ft and a height of 6.5 ft.

Figure 4 shows that, for the conditions modeled, drivers of commercial vehicles will receive about the same amount of light from right shoulder-mounted traffic signs as drivers of passenger cars at distances of about 500 ft and more. At these distances, detection has typically occurred but more importantly, 500 ft is about the threshold of legibility (depending, of course, on many factors such as letter size). At distances less than 400 ft, the drivers of commercial vehicles begin to receive considerably less returned light than drivers of passenger cars. As the distance to the sign decreases, the differences between the commercial vehicles and passenger cars increase. Of course what is not known is how this difference impacts the actual legibility of traffic signs and what activities are needed, if any, to accommodate drivers of commercial vehicles.

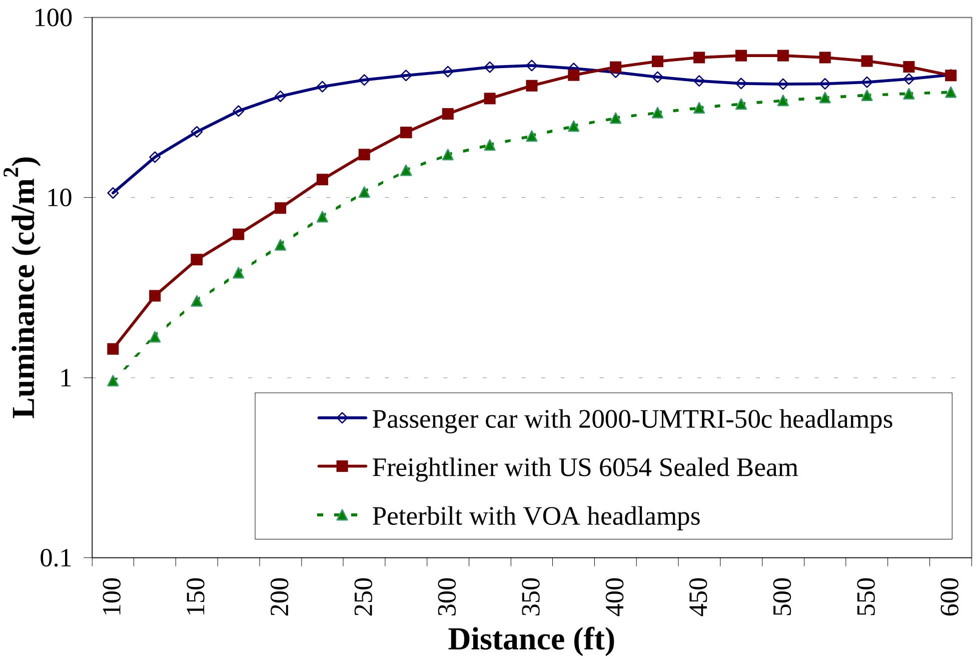


Figure 4. Luminance Comparison for Various Vehicles.

SPECIFICATIONS

Specifications are used to expedite the process of selecting and purchasing retroreflective products. The most common specification related to retroreflective sheeting is ASTM D4956 (*16*). This specification includes a list of nine types of retroreflective sheeting approved for signs, delineators, barricades, and other devices. Each type of sheeting is described with minimum performance characteristics that manufacturers must satisfy in order to be approved within a certain classification. The criteria for the performance characteristics in ASTM D4956 are defined in two-dimensional matrices made up of an array of observation and entrance angles. Currently, the observation angles include 0.2 and 0.5 degrees for all sheeting types with a 0.1 degree criterion listed as optional for some types of sheeting and a 1.0 degree criterion listed for Type IX sheeting only. The current entrance angles include -4.0 and 30.0 degrees for all sheeting types. TxDOT's current and proposed sheeting specifications reference the ASTM specification, as do most other state department of transportation (DOT) specifications (*17*).

In 1993, the Connecticut DOT published the results of a study that examined the validity of the 30 degree entrance angle specification (*18*). The study notes that the current specification of -4.0 degrees is intended for signs that are close to a straight road but turned slightly away from traffic (to avoid the specular glare) as recommended by several publications such as the *Traffic Control Devices Handbook* and the Institute of Transportation Engineer's (ITE) *Traffic Signing Handbook* (*19*, *20*). The 30 degree entrance angle has traditionally been considered to be the widest angle at which signs would be commonly seen on curved roadways and at intersections.

The authors used empirical data from a customized computer software program developed for the DOT's photo log laser videodisc retrieval system that allowed for the measurement of entrance angles from a large sample of in-service signs. The angles were measured at distances of 100 and 200 ft (based roughly on last look distances). In order to complete the study, the researchers made several assumptions such as assuming that the photo van was always positioned in the center of the travel lane, the photo log camera was always in the center of the van, the placement of the sign was always at a right angle to a point on the roadway shoulder line, and the vertical component of the entrance angle was insignificant (*18*).

The researchers took special care to capture both right- and left-mounted shoulder signs. In all, researchers captured entrance angles for 1142 signs and reported that no entrance angles exceeded 30 degrees. Researchers also reported that only 10 signs had entrance angles greater than 25 degrees. For freeway roads, the 99th percentile was found to be 20 degrees, and for non-freeway roads, the 99th percentile was 27 degrees. The authors concluded that the current specification of 30 degrees was adequate but could indeed be dropped to 20 degrees on freeway facilities without adverse impacts (*18*).

Only one other study examining the adequacy of the ASTM's specification angles has been completed (*21*). In January 2002, Brich presented the results of a study in which he investigated the appropriateness of the Virginia DOT's sheeting specification, which included entrance angles out to 50 degrees for work zone signing.

The researchers inventoried 1865 signs in 232 work zones throughout the state of Virginia in the summer of 1999. The majority of these signs (87 percent) were right shoulder-mounted signs with the remainder being left shoulder-mounted signs. Almost all of the signs were attached to wooden posts (91 percent) (*21*).

The research concluded that not every motorist will be exposed to or even experience work zone signage that exhibits large entrance angles such as 40 degrees. However, every motorist on the approach to a sign will experience a 0.2, 0.5, 1.0, 1.5, and a 2.0 degree observation angle depending on the vehicle type. If the vehicle is a commercial vehicle, then one could even experience a 3.0 degree observation angle. The research also concluded that due to the asymmetrical nature of microprismatic retroreflective sheeting materials, orientation and rotation angles are important components of a sheeting's performance, in addition to observation and entrance angles (*21*).

In particular, the research recommended that the maximum entrance angle specification for the Virginia DOT's work zone sheeting specification should be 40 degrees, and the observation angle should be 1.0 degree, but preferably 1.5 degrees. The author suggests that these criteria will still provide a factor of safety for poorly placed or misaligned signs. The recommendations also suggest that the orientation and rotation angles be included in the work zone sign sheeting specifications (*21*).

3. COMMERCIAL VEHICLE DRIVER SURVEY

Over the past 10 years, several commercial vehicle driver surveys have been conducted in order to determine truck drivers' opinions and concerns with such items as work zones and intelligent transportation systems (ITS) (*22*, *23*). In addition, in 2001, TxDOT conducted a survey of their districts and divisions regarding specific countermeasures and/or actions being taken in response to increasing truck traffic volumes (*24*). Similarly, a current National Cooperative Research Program (NCHRP) project (Synthesis of Highway Practice 32-02) has been charged with the task of surveying the state DOTs and a limited number of metropolitan planning organizations (MPOs) in order to identify strategies that are in use or being proposed for managing increased truck traffic. Even though some of these surveys have inadvertently addressed issues concerning signs and pavement markings, none of these surveys have directly solicited the opinions of commercial vehicle drivers with respect to the visibility of traffic signs and pavement markings. Thus, TTI researchers developed a survey to identify the issues and/or concerns commercial vehicle drivers have with the signs and pavement markings currently used on TxDOT roadways. This survey targeted commercial vehicle drivers with varying levels of experience, age, and miles traveled per year.

SURVEY DEVELOPMENT

The survey was divided into two sections. The first section contained 15 questions regarding information about the commercial vehicle drivers and their commercial vehicle driving experience. The second section contained seven questions that focused on the commercial vehicle driver's opinion of Texas roadways. In this section, the survey began with general questions about Texas roadways and progressed to questions that were aimed more specifically at the visibility of signs and pavement markings.

Pilot Study

On October 25, 2001, researchers conducted a small pilot study in the Bryan/College Station area. The purpose of the pilot study was to assess the administration procedure, format of the survey, time needed for an individual to complete the survey, and identify any question deficiencies. Based on this effort and comments from the project director, minor changes were made to the survey. On November 12, 2001, researchers completed the initial data collection effort on I-35 in Buda. After reviewing the results of these surveys, researchers decided to make additional changes to the survey (i.e., one question was added and one question was combined with another similar question). Researchers used the revised survey on I-45 in Huntsville and on I-10 in Brookshire. Appendix A contains both surveys.

Survey Protocol

Researchers selected three study locations in Texas based on geographic location and commercial vehicle volumes: I-35 in Buda, I-45 in Huntsville, and I-10 in Brookshire. Before beginning the survey, the survey administrator obtained permission from the study location property owner to conduct the survey. A total of 121 individuals participated in the one-on-one survey (approximately 40 at each location). The only requirements to participate in the survey were that the individual be 21 years of age or older and have a current Class A or B commercial vehicle driver's license. The survey consisted of both open-ended and multiple-choice questions and took approximately 10 minutes per individual. Participants did not receive compensation for completing the survey.

SURVEY PARTICIPANT CHARACTERISTICS

As shown in Table 3, the average participant was 49 years old with 22 years of commercial driving experience. As expected, the majority of the drivers were males (96 percent), with only 4 percent being women. The participants were mostly from another state (66 percent), with 34 percent being from Texas. All survey participants had a Type A license.

On average, the commercial vehicle drivers drove 49 percent of the time at night. They traveled an average of 44,000 miles per year in Texas compared to 85,000 miles per year in other states. The most traveled type of roadway was the interstate (45 percent of the time); however, 36 percent stated that they drove on all types of roadways. U.S./State Highways were only traveled on 3 percent of the time. The majority of the participants (74 percent) stated that they drove long haul (≥ 250 miles) versus short haul (< 250 miles). Half of the participants stated that they drove different routes, while only 18 percent drove specific routes. The type of motor carrier operations consisted of 46 percent owner-operator, 32 percent for hire (company owns vehicle and contracts hauling service), and 22 percent private (vehicles owned by the company for which the hauling service is provided). The majority of the participants (88 percent) primarily drove a five-axle tractor semi-trailer. Ten percent drove a three-or-four-axle tractor semi-trailer, while only 2 percent drove a straight truck.

SURVEY RESULTS

The data obtained from each study location was combined to provide an overall total of responses. This overall total was used for the analysis of the survey. More detailed information per location can be found in Appendix B.

Commercial Vehicle Driver's Criticisms of Texas Roadways

Table 4 contains the responses of the survey participants when asked "what is your primary criticism of the current roadways in Texas?" There were 98 of the 121 participants surveyed (81 percent) that gave one or more criticisms about Texas roadways. In total, those 98 participants made 138 comments.

Table 3. Characteristics of the Commercial Vehicle Drivers Surveyed.

Driver Characteristic	Survey Locations			Overall
	I-35	I-45	I-10	
Average Age	48	48	51	49
Average Experience	21 years	22 years	22 years	22 years
Percent of Males Surveyed Percent of Females Surveyed	93% 7%	98% 2%	98% 2%	96% 4%
Percent of Participants from Texas	42%	37%	22%	34%
Percent of Participants from Another State	58%	63%	78%	66%
Average Miles Traveled: - In Texas per Year - In U.S. per Year (Excluding Texas)	 39,000 miles 84,000 miles	 52,000 miles 75,000 miles	 41,000 miles 95,000 miles	 44,000 miles 85,000 miles
Average Percent of the Time Participants Drive at Night	53%	43%	48%	49%
Percent of Participants That Drive Primarily on: - Interstates - U.S./State Highways - Interstates and U.S./State Highways - All Types (Includes FM Roads)	 53% 7% 10% 30%	 40% 2% 23% 35%	 41% 0% 15% 44%	 45% 3% 16% 36%
Percent of Participants That Drive: - Short Haul - Long Haul - Both	 5% 73% 22%	 3% 65% 32%	 3% 85% 12%	 4% 74% 22%
Percent of Participants That Drive: - Specific Route - Different Routes - Both	 33% 17% 50%	 15% 65% 20%	 6% 70% 24%	 18% 50% 32%
Type of Motor Carrier Operation: - For Hire - Private - Owner-Operator	 35% 10% 55%	 33% 27% 40%	 29% 27% 44%	 32% 22% 46%
Percent of Participants That Drive: - Straight Truck - Double Trailer Combination - Five-axle Tractor Semi-Trailer 3S2) - Three- or Four-axle Tractor Semi-Trailer	 4% 0% 73% 23%	 0% 0% 93% 7%	 0% 0% 100% 0%	 2% 0% 88% 10%

Table 4. Criticisms of Texas Roadways.

Category	Percent of Comments by Survey Location			Overall (n=138)[d]
	I-35 (n=53)[a]	I-45 (n=40)[b]	I-10 (n=45)[c]	
Construction	25%	10%	20%	19%
Rough Roads/ Maintenance	23%	38%	22%	27%
Entrance and Exit Ramps	17%	7%	18%	14%
Striping and Signs	5%	10%	13%	9%
Lane Width	5%	2%	2%	4%
Other	25%	33%	25%	27%

[a] 53 comments from 31 participants
[b] 40 comments from 33 participants
[c] 45 comments from 34 participants
[d] Total of 138 comments from 98 participants

With the continuous roadwork on the interstates near the study locations, it was not surprising that 46 percent of the overall comments were focused on construction and rough roads/maintenance. Typical examples in these categories were as follows:

- lane width too narrow;
- poor traffic control devices;
- patch road and do not come back and stripe it;
- construction takes too long;
- construction at night is better than during the day;
- too many flashing lights;
- concrete barrier does not have enough reflectors;
- need to provide more directional signing;
- always under construction;
- close off too much of the road at a time (length of zone);
- police officers need to be located before the construction zone, not in the zone;
- barriers make lanes too narrow for trucks;
- rough pavement;
- roads need to be repaired (rutting and pot holes);
- uneven lanes;
- country roads need maintenance; and
- need to improve secondary roads.

Other criticisms focused on entrance and exit ramps (14 percent), striping and signs (9 percent), and lane width (4 percent).

Problems with Signs and/or Pavement Markings on Texas Roadways

Table 5 presents the results obtained when the survey participants were asked if they had any problems with the signs and/or pavement markings currently being used on Texas roadways. The results indicated that 58 percent of the participants did not have any problems with the signs and/or pavement markings on Texas roadways.

Table 5. Responses to the Question "Do You Have Any Problems with the Signs and/or Pavement Markings Currently Being Used on Texas Roadways?"

Response	Percent of Participants by Survey Locations			Overall (n=121)
	I-35 (n=40)	I-45 (n=40)	I-10 (n=41)	
Yes	38%	50%	39%	42%
No	62%	50%	61%	58%

The 51 participants (42 percent) that indicated a problem with signs and/or pavement markings on Texas roadways made 61 comments that generally fell into three categories. Table 6 shows the percent of comments by survey location and overall. The majority of the comments (64 percent) pertained to either sign placement or sign design. The remaining 36 percent of the comments regarded pavement markings.

Table 6. Problems with Signs and/or Pavement Markings on Texas Roadways.

Category	Percent of Comments by Survey Location			Overall (n=61)[d]
	I-35 (n=18)[a]	I-45 (n=24)[b]	I-10 (n=19)[c]	
Sign Placement	28%	54%	26%	38%
Sign Design	22%	21%	37%	26%
Pavement Markings	50%	25%	37%	36%

[a] 18 comments from 15 participants
[b] 24 comments from 20 participants
[c] 19 comments from 16 participants
[d] Total of 61 comments from 51 participants

The comments received by the survey participants are presented by category in Table 7. The results show that the most frequent problem area with signs is the need for more advance warnings at exits and turns. With respect to sign design, several of the participants mentioned that signs are hard to read at night or that signs could be brighter. Specifically, green signs were targeted as being not reflective or faded. For pavement markings, the most frequent problem is the fading and/or brightness (especially in the rain) of the markings. Specifically mentioned were white or edge-line markings.

Location of Texas Roadway Signs

Table 8 shows that approximately 75 percent of the participants stated that they preferred signs to be located either on the right side of the road (43 percent) or overhead (30 percent). Twenty-two percent of the drivers responded that they had no preference for sign location.

Table 7. Participant Comments Concerning Problems with Signs and/or Pavement Markings.

Category	Participant Comments[a]
Signs	*Placement:* - Need more advance warning (especially at exits and turns) (*13 comments*). - Signs need to be raised or lowered so truckers can see around them (*2 comments*). - Not enough signs (speed limit signs too far apart). - Need more advance warning, especially in construction zones. - Signs need to be further off the road. - Need to make sure signs are not obstructed by advertisements or growth. - The placement of flashing arrow signs is sometimes distracting or blinding. - Bridge height signs need to be placed further in advance. - No signs marking routes for oversize loads. *Design:* - Need to make signs bigger (*4 comments*). - Green signs are not reflective, so cannot read at night (*2 comments*). - Green signs that are faded out are really hard to see (*2 comments*). - Not enough visibility to read entire sign (*2 comments*). - Signs could be brighter (*2 comments*). - Can't read because of dual alternating flashing lights on sign. - Don't like the signs in Spanish. - Signs are not big enough and there is not enough information on them. - Remove white letters and replace with FYG letters. - Signs need to be in both English and Spanish.
Pavement Markings	- Pavement markings are faded or are not bright enough so hard to see in the rain (especially white markings on concrete) (*13 comments*). - Pavement markings (center and edge lines) are faded (*2 comments*). - Patch road and do not come back and stripe it. - Pavement markings on secondary roads (SH and FM) need to be upgraded. - Sometimes pavement markings in construction areas are not adequately marked or visible. - Roads need to be re-striped. - Need clearer pavement markings. - Can't see pavement markings on dark pavement. - Need to make pavement markings more reflective.

FYG – Fluorescent Yellow-Green; SH – State Highway; FM – Farm-to-Market
[a] Total of 61 comments from 51 participants

Table 8. Responses to the Question "While Driving at Night in Texas, Where Do You Prefer Roadway Signs To Be Located?"

Responses	Percent of Participants by Survey Location			Overall (n=121)
	I-35 (n=40)	I-45 (n=40)	I-10 (n=41)	
Right Side of the Road	40%	35%	54%	43%
Left Side of the Road	0%	5%	0%	2%
Overhead	38%	33%	20%	30%
No Preference	22%	20%	24%	22%
Chose More Than One	0%	7%	2%	3%

Visibility of Texas Roadway Signs at Night

In order to determine the commercial vehicle driver's opinion on which roadway signs were considered the easiest and the most difficult to see at night, the survey participants were asked three questions:

- Which color of roadway signs are the easiest to see at night in Texas?
- Which color of roadway signs are the hardest to see at night in Texas?
- Overall, do you feel that most Texas roadway signs are ________ (select one of the following: easy, average, or difficult) to see at night?

Easiest Roadway Signs To See at Night in Texas

Table 9 shows that half of the participants felt that green signs were the easiest sign color to see at night. In addition, 22 percent selected white and 12 percent chose yellow.

Table 9. Responses to the Question "Which Color of Roadway Signs Are the Easiest To See at Night in Texas?"

Background Color	Percent of Participants by Survey Location			Overall (n=121)
	I-35 (n=40)	I-45 (n=40)	I-10 (n=41)	
Green	48%	50%	54%	50%
White	20%	25%	20%	22%
Black	10%	5%	1%	6%
Yellow	8%	13%	15%	12%
Blue	5%	0%	0%	2%
Orange	2%	7%	0%	3%
Red	0%	0%	0%	0%
Brown	0%	0%	0%	0%
FYG	2%	0%	5%	2%
Did Not Answer	5%	0%	5%	3%

FYG – Fluorescent Yellow-Green

Hardest Roadway Signs To See at Night in Texas

There was no consensus from the participants as to which color of roadway signs was the hardest to see at night in Texas (Table 10). In fact, the largest percentage of any category was from the individuals that did not answer (28 percent). Black was selected by 22 percent of the participants, with white (15 percent) and green (12 percent) following. It should be noted that this question was added after the I-35 survey was conducted.

Table 10. Responses to the Question "Which Color of Roadway Signs Are the Hardest To See at Night in Texas?"

Background Color	Percent of Participants by Survey Location			Overall (n=81)
	I-35	I-45 (n=40)	I-10 (n=41)	
Green	--	13%	12%	12%
White	--	23%	8%	15%
Black	--	15%	29%	22%
Yellow	--	5%	17%	11%
Blue	--	2%	2%	3%
Orange	--	7%	5%	6%
Red	--	0%	0%	0%
Brown	--	5%	0%	3%
FYG	--	0%	0%	0%
Did Not Answer	--	30%	27%	28%

FYG – Fluorescent Yellow-Green
-- Did not ask this question on I-35 survey

Commercial Vehicle Driver's Opinion of Texas Roadway Signs at Night

As shown in Table 11, 44 percent of the Texas commercial vehicle drivers and 38 percent of the non-Texas drivers felt that most Texas roadway signs were easy to see at night. In addition, 49 percent of Texas and 57 percent of non-Texas participants stated most Texas roadway signs were average to see at night. Thus, over 90 percent of the total commercial vehicle drivers surveyed felt that Texas roadway signs were either easy or average to see at night. Only 5 percent of the total commercial vehicle drivers surveyed indicated that the roadway signs were difficult to see at night.

Brightness of Signs and/or Pavement Markings in Texas

As shown in Table 12, 62 percent of the participants had a comment or concern about the brightness of the signs and/or pavement markings on Texas roadways at night. The 75 participants that indicated concerns about the brightness of the signs and/or pavement markings had a total of 103 comments. As shown in Table 13, 53 percent of the comments dealt with signs, while the remaining 47 percent focused on pavement markings.

Table 11. Responses to the Question "Do You Feel That Most Texas Roadway Signs Are ______ To See at Night?"

Responses	Percent of Participants by Survey Location						Overall	
	I-35		I-45		I-10			
	Texas[a] (n=17)	Non-Texas[b] (n=23)	Texas (n=15)	Non-Texas (n=25)	Texas (n=9)	Non-Texas (n=32)	Texas (n=41)	Non-Texas (n=80)
Easy	59%	40%	33%	28%	33%	44%	44%	38%
Difficult	12%	4%	7%	4%	0%	3%	7%	4%
Average	29%	52%	60%	68%	67%	53%	49%	57%
Did Not Answer	0%	4%	0%	0%	0%	0%	0%	1%

[a] Texas Residents

[b] Non-Texas Residents

Table 12. Responses to the Question "Do You Have Any General Comments or Concerns about the Brightness of Signs and/or Pavement Markings at Night on Texas Roadways?"

Response	Percent of Participants by Survey Location			Overall (n=121)
	I-35 (n=40)	I-45 (n=40)	I-10 (n=41)	
Yes	70%	55%	61%	62%
No	30%	45%	39%	38%

Table 13. Brightness of Signs and/or Pavement Markings on Texas Roadways.

Category	Percent of Comments by Survey Location			Overall (n=103)[d]
	I-35 (n=41)[a]	I-45 (n=24)[b]	I-10 (n=38)[c]	
Signs	54%	54%	53%	53%
Pavement Markings	46%	46%	47%	47%

[a] 41 comments from 28 participants

[b] 24 comments from 22 participants

[c] 38 comments from 25 participants

[d] Total of 103 comments from 75 participants

The comments and/or concerns on the brightness of signs and/or pavement markings are shown in Table 14. Most of the 55 comments on signs focused on the driver's ability to see the signs. There were 31 comments that addressed the signs not being bright, visible, or reflective; that the signs were faded and hard to read; and the difficulty to read signs in the rain. Specifically, problems with green signs, black signs, and orange signs were mentioned. The comments on pavement markings were similar with 26 out of the 48 comments indicating that the markings need to be brighter, the markings are faded, and the markings (especially white ones) are hard to see in the rain.

Table 14. Participant Comments Concerning the Brightness of Signs and/or Pavement Markings.

Category	Participant Comments[a]
Signs	- Need to be brighter, visible, and/or reflective (*17 comments*). - Can't see/read signs because they are old and faded (*5 comments*). - Signs need to be fluorescent *(5 comments*). - Green signs with town and mileage are not reflective, faded out and hard to see (*3 comments*). - Hard to see especially in the rain (*2 comments*). - Have to get really close to signs to see them (*2 comments*). - Miscellaneous lighting near signs makes them hard to read (*2 comments*). - Signs are set up for cars. Trucks are higher, making it hard to see them. - Need to have bigger letters. - Overhead signs need to be lit up. - Don't use orange signs at night or make them brighter. - Need to maintain reflectivity, especially construction signs. - Sign placement sometimes makes signs not visible especially in construction. - In construction, too many lights. Flashing arrow too bright *(5 comments).* - Signs are getting brighter. - Night speed limit signs don't show up as well. - Signs are dirty. - Signs are not big enough or well enough marked. - Signs at night hard to read w/glaring headlights. You have to be right on them to read them. - Signs telling trucks to use particular lane in construction zone are too near the zone and you cannot read them until you are right on top of them. - Need blue lettering on construction signs. - Stop signs angled so that you cannot see them when you are off angle. You can only see them when you are straight on.
Pavement Markings	- Need to be brighter (*10 comments*). - Pavement markings are faded (*10 comments*). - Need to be painted more often (*6 comments*). - Hard to see especially in the rain (*6 comments*). - Add reflectors, helps when raining (*5 comments*). - Markings are hard to see on asphalt (especially white markings in the rain) (*2 comments*). - Stripes are hard to see on concrete (especially white markings in the rain) (*2 comments*). - Reflectors are hard to see especially in the rain. - Need to do markings immediately after they finish a road. - On new surfaces, pavement markings are hard to see because too much glare. - Need clearer markings. - New roads without markings, you can't see where you are going. - At locations that are not striped but have markers, the markers get dirty and you can't see them. - Road markings could be newer on rural roads.

[a] Total of 103 comments from 75 participants

In order to determine whether commercial vehicle drivers notice a difference in the apparent brightness of signs and/or pavement markings when driving another vehicle (i.e., non-commercial), the participants were asked if they felt the signs and/or pavement markings in Texas usually appear brighter, less bright, or the same as when they are driving a passenger vehicle. Using only the commercial vehicle drivers that drove a passenger vehicle in Texas, Table 15 shows that 60 percent of the participants felt that when driving a commercial vehicle the signs and/or pavement markings appear the same as while driving in a passenger vehicle. In addition, only 20 percent of the Texas resident commercial vehicle drivers surveyed felt that signs and/or pavement markings appear brighter in a passenger vehicle.

Table 15. Responses to the Question "At Night When Driving a Commercial Vehicle in Texas, Do Signs and/or Pavement Markings Usually Appear _________ as When You're Driving a Passenger Vehicle?"[a]

Response	Percent of Participants by Survey Location			Overall (n=45)
	I-35 (n=16)	I-45 (n=17)	I-10 (n=12)	
Brighter	19%	35%	0%	20%
Less Bright	25%	12%	25%	20%
Same	56%	53%	75%	60%

[a] Based only on participants that drove a passenger vehicle in Texas

Other Comments

At the conclusion of the survey the participants were asked if they had any general comments or suggestions. A summary of the comments is located in Appendix B. Interestingly, the most frequent comment addressed the need for the drivers of passenger vehicles to be educated about the physical driving limitations of commercial vehicles.

SUMMARY

Researchers conducted the commercial vehicle driver survey in order to identify the issues and/or concerns commercial vehicle drivers have with the signs and pavement markings currently used on TxDOT roadways. Below is a summary of the information gathered through this survey.

- For the commercial vehicle drivers surveyed, approximately half (49 percent) of their travel occurs at night.

- Forty-six percent of the commercial vehicle drivers surveyed are primarily concerned with the construction or maintenance of Texas roadways versus 9 percent who are primarily concerned with signs and pavement markings.

- Over half (58 percent) of the study participants did not identify any problems with the signs and/or pavement markings currently being used in Texas. Those individuals surveyed who indicated a problem (42 percent) primarily focused on signs. The need for more advance warning was the most frequent problem mentioned for signs. In addition, several participants commented that green signs were not reflective and/or faded. The most frequent problem identified for pavement markings was that they were faded and/or not bright enough (especially white or edge-line markings).

- Most commercial vehicle drivers (73 percent) prefer signs to be located either on the right side of the road or overhead.

- Half of the participants selected green as the easiest sign background color to see at night.

- There was no consensus on the most difficult sign background color to see at night. However, 22 percent of the participants stated black was the hardest to see at night, with white (15 percent) and green (12 percent) following.

- Only 5 percent of the participants felt that Texas roadway signs were difficult to see at night.

- Only after being specifically asked about the "brightness" of signs and pavement markings did 62 percent of the participants state that they had a concern. Most of these concerns focused on the driver's ability to see the signs and/or pavement markings at night. Specifically, problems with green signs, black signs, orange signs, and white pavement markings were mentioned.

- Over half (60 percent) of the Texas resident commercial vehicle drivers surveyed felt that there was no difference in the brightness of signs and/or pavement markings when driving a commercial vehicle versus a passenger vehicle. In addition, only 20 percent of the Texas resident commercial vehicle drivers surveyed felt that signs and/or pavement markings appear brighter in a passenger vehicle.

4. NIGHTTIME CONTROLLED FIELD STUDY EXPERIMENTAL DESIGN

This chapter documents the experimental design of the nighttime controlled field study that was conducted in April 2002. The objective of this study was to determine whether the legibility distance of signs and the end detection distance of pavement markings depends on the relationship between vehicle type (passenger car versus commercial vehicle) and sign/pavement marking material. Additional research issues included investigations among sign type (speed limit, guide, and destination) and driver age (young, middle-aged, and old).

LOCATION

Researchers conducted the controlled field study at the TTI proving ground facility, which is a 2000-acre complex of research and training facilities located at the Texas A&M University Riverside Campus (approximately 12 miles northwest of the University's main campus). The proving ground is a former military aircraft base comprised of four major runways and associated taxiways. These concrete runways and taxiways are ideally suited for experimental research and testing in the area of signing and pavement markings.

TREATMENTS

Based on the results of the commercial vehicle driver survey (documented in Chapter 3), researchers decided to focus the nighttime controlled field study on the following four types of signs and one type of pavement marking:

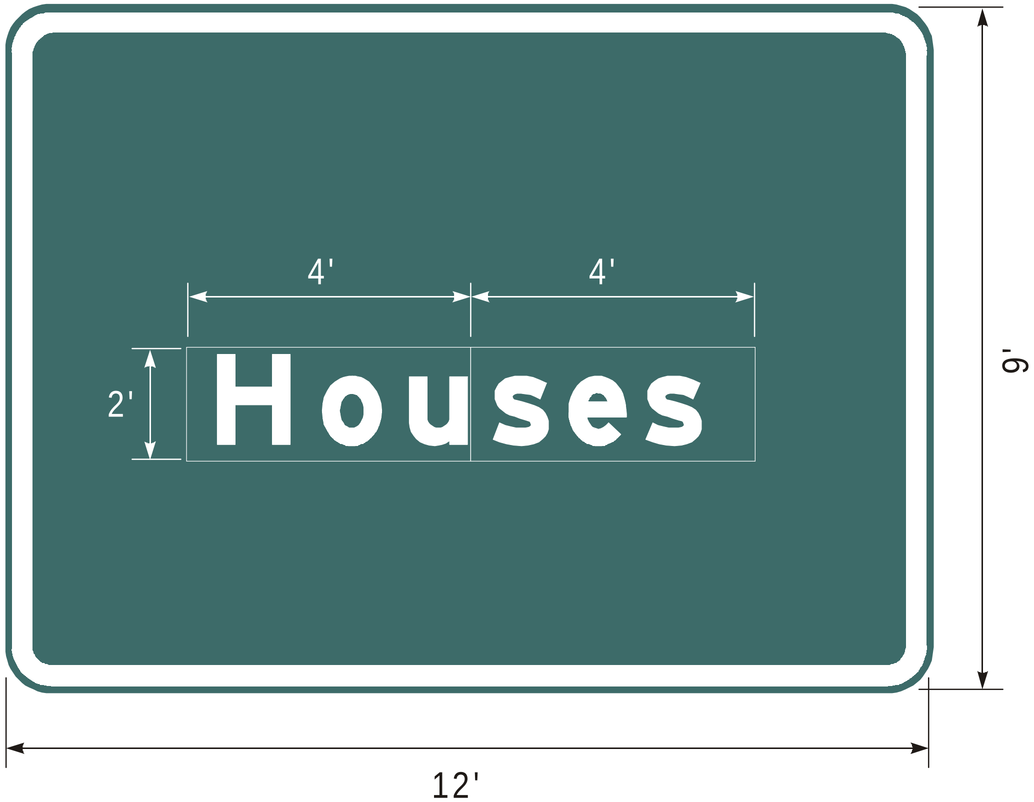
- guide signs (freeway),
- destination signs (D2-1),
- daytime speed limit signs (R2-1),
- nighttime speed limit signs (R2-3), and
- 4-inch white edge-line pavement markings.

For each sign category (e.g., daytime speed limit), three sheeting materials were evaluated: ASTM Type III, Type VIII, and Type IX. The only exception was for the guide sign category in which only Type VIII and Type IX were assessed. Table 16 describes in more detail the sign treatments, while Figures 5 through 8 show the design of the signs. Note that the Type III material used was a non-prismatic material.

Table 16. Sign Treatments.

Sign Category	Sign Height (ft)	Sign Width (ft)	Background Color	Background Material Type [a]	Legend Color	Legend Material Type [a]	Legends
Guide	9	12	Green	VIII	White	VIII	Honors Target Series
Guide	9	12	Green	IX	White	IX	Houses Forget Senior
D2-1	1	3.5	Green	III	White	III	AUSTIN CONROE ALPINE
D2-1	1	3.5	Green	VIII	White	VIII	TEMPLE SPRING DENTON
D2-1	1	3.5	Green	IX	White	IX	LAREDO ROGERS LUFKIN
R2-1	2.5	2	White	III	Black	III	96 48 73
R2-1	2.5	2	White	VIII	Black	VIII	78 93 46
R2-1	2.5	2	White	IX	Black	IX	42 76 92
R2-3	2	2	Black	III	White	III	96 48 73
R2-3	2	2	Black	VIII	White	VIII	78 93 46
R2-3	2	2	Black	IX	White	IX	42 76 92

[a] As defined by ASTM



* Series E(Modified) alphabet with 16/12 inch uppercase/lowercase letters

Figure 5. Guide Sign Structure.

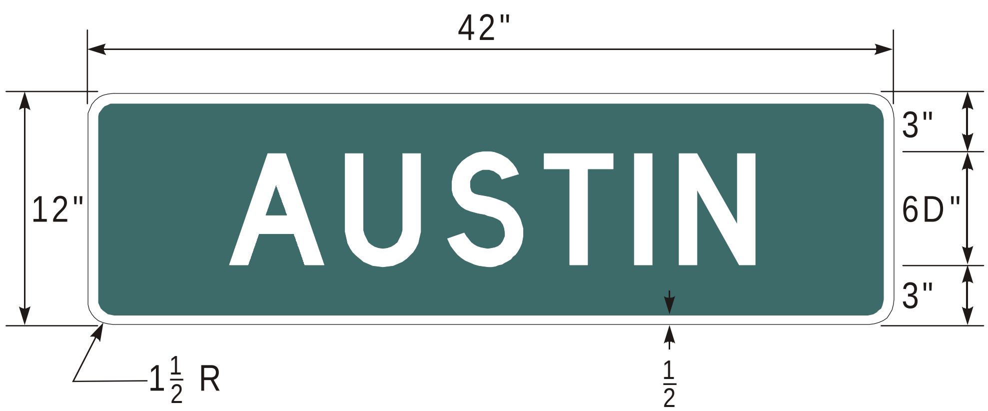


Figure 6. Design of Destination (D2-1) Signs.

Figure 7. Design of Daytime Speed Limit (R2-1) Signs.

Figure 8. Design of Nighttime Speed Limit (R2-3) Signs.

Researchers utilized the existing sign demonstration course shown in Figure 9. There were 29 sign installations on the course. The sign installations were a minimum of 500 ft apart, with several distinct road sections such that no more than eight sign installations were in the field-of-view at any one time. All signs were ground-mounted. Based on current TxDOT signing practices, the bottom of the signs were positioned 7 ft above the road surface. The left edge of the signs was located 18 ft from the right edge of the travel path.

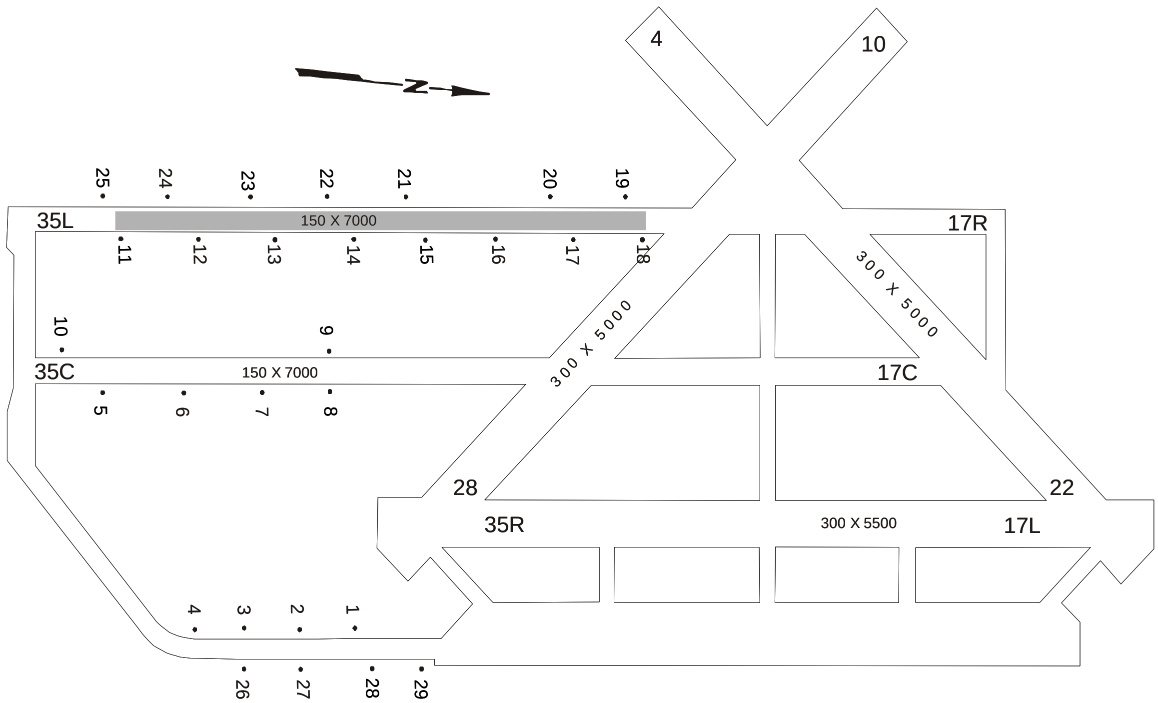


Figure 9. Proving Ground Course.

The shaded region in Figure 9 denotes the location of the three pavement marking treatments. All pavement marking treatments were located to the right of the study vehicle and consisted of a 4 inch solid white edge-line. Table 17 contains a description of the treatment evaluated at each location, while Figure 10 shows examples of the sign treatments used.

All of the sign and pavement marking treatments were seen on an individual basis (e.g., one sign per location), except for the treatments that contained nighttime speed limit signs. In Texas nighttime speed limits signs are seen only in conjunction with daytime speed limit signs; therefore, the researchers simulated this dual signing layout in the study. In other words, a “70 mph” daytime speed limit sign was shown in conjunction with every nighttime speed limit sign treatment (Figure 10d). Based on TxDOT’s current practice, these daytime speed limit signs were made of a non-prismatic Type III sheeting.

Overall, researchers evaluated a total of 33 sign treatments and six pavement marking treatments. Note that no external lighting was used to light the treatments. Also, there was very little ambient lighting present on the course.

Table 17. Treatment Locations.

Location	Treatment Number [a]	Treatment Description	Legend	Material [b]
1	16A	R2-1	96	Type III
2	19B	R2-1	78	Type VIII
3	22C	R2-1	42	Type IX
4	20B	R2-1	93	Type VIII
5	30B	R2-3 [c]	46	Type VIII
6	27A	R2-3 [c]	73	Type III
7	33C	R2-3 [c]	92	Type IX
8	26A	R2-3 [c]	48	Type III
9	1C 2C 3C	Guide	Houses Forget Senior	Type IX
10	4B 5B 6B	Guide	Honors Target Series	Type VIII
11	32C	R2-3 [c]	76	Type IX
12	29B	R2-3 [c]	93	Type VIII
13	31C	R2-3 [c]	42	Type IX
14	28B	R2-3 [c]	78	Type VIII
15	25A	R2-3 [c]	96	Type III
16	7A	D2-1	AUSTIN	Type III
17	10B	D2-1	TEMPLE	Type VIII
18	13C	D2-1	LAREDO	Type IX
19	14C	D2-1	ROGERS	Type IX
20	11B	D2-1	SPRING	Type VIII
21	24C	R2-1	92	Type IX
22	21B	R2-1	46	Type VIII
23	18A	R2-1	73	Type III
24	17A	R2-1	48	Type III
25	23C	R2-1	76	Type IX
26	8A	D2-1	CONROE	Type III
27	15C	D2-1	LUFKIN	Type IX
28	9A	D2-1	ALPINE	Type III
29	12B	D2-1	DENTON	Type VIII
Location	**Treatment Number**	**Treatment Description**	**Length of Edge-Line (ft)**	
Shaded Area	34 35	Low Retroreflectivity	640	
Shaded Area	36 37	Medium Retroreflectivity	860	
Shaded Area	38 39	High Retroreflectivity	1000	

[a] A – ASTM Type III; B – ASTM Type VIII; C – ASTM Type IX
[b] As defined by ASTM
[c] The R2-3 signs will be seen in conjunction with a Type III "70 mph" R2-1 sign

a) Guide Sign

b) Destination (D2-1) Sign

c) Daytime Speed Limit (R2-1) Sign

d) Nighttime Speed Limit (R2-3) Sign

Figure 10. Examples of Sign Treatments.

Prior to conducting the study, the retroreflectivity of the installed signs (background and legend) and pavement markings was measured. Tables 18 through 21 show the average retroreflectivity for each sign treatment, as well as the average retroreflectivity for each material type (by sign category). As discussed previously, each nighttime speed limit sign was seen in conjunction with a daytime speed limit sign. The average retroreflectivity of the nine Type III "70 mph" daytime speed limit signs was 274 cd/lux/m^2. The three pavement marking materials evaluated had average retroreflectivity values of approximately 100, 300, and 800 mcd/m^2/lux (as measured with the Advanced Retro Technology MX-30).

Table 18. Guide Sign Retroreflectivity.

ASTM Type	Legends	Color		Retroreflectivity (cd/lux/m^2)[a]	
		Background	Legend	Background	Legend
VIII	Honors	Green	White	126	799
	Target			120	806
	Series			126	810
			Average	124	805
IX	Houses	Green	White	100	519
	Forget			98	502
	Senior			94	514
			Average	97	512

[a] As measured with a Delta RetroSign® 4500 at 0 degree rotation

Table 19. Destination (D2-1) Sign Retroreflectivity.

ASTM Type	Legends	Color		Retroreflectivity (cd/lux/m^2)[a]	
		Background	Legend	Background	Legend
III	AUSTIN	Green	White	46	263
	CONROE			45	244
	ALPINE			48	271
			Average	46	259
VIII	TEMPLE	Green	White	142	814
	SPRING			153	762
	DENTON			152	812
			Average	149	796
IX	LAREDO	Green	White	70	416
	ROGERS			69	403
	LUFKIN			71	396
			Average	70	405

[a] As measured with a Delta RetroSign® 4500 at 0 degree rotation

Table 20. Daytime Speed Limit (R2-1) Sign Retroreflectivity.

ASTM Type	Legends	Color		Retroreflectivity (cd/lux/m^2)[a]
		Background	Legend	Background
III	96	White	Black	288
	48			285
	73			289
			Average	287
VIII	78	White	Black	852
	93			877
	46			899
			Average	876
IX	42	White	Black	434
	76			391
	92			381
			Average	402

[a] As measured with a Delta RetroSign® 4500 at 0 degree rotation

Table 21. Nighttime Speed Limit (R2-3) Sign Retroreflectivity.

ASTM Type	Legends	Color		Retroreflectivity (cd/lux/m^2)[a]
		Background	Legend	Legend
III	96	Black	White	268
	48			286
	73			279
			Average	278
VIII	78	Black	White	807
	93			811
	46			798
			Average	805
IX	42	Black	White	355
	76			406
	92			402
			Average	388

[a] As measured with a Delta RetroSign® 4500 at 0 degree rotation

VEHICLES

As mentioned previously, two vehicles were utilized in the controlled field study. One was a state-owned 1998 Chevy Lumina with HB4 headlamps. The second vehicle was a state-owned 1986 Freightliner Model C12064ST (tractor only) with 2A1 halogen sealed-beam headlamps. Figure 11 shows the two study vehicles, while Table 22 contains the vehicle dimensions relevant to this research. The Chevy Lumina's dimensions are similar to the dimensions of the five best selling passenger cars in the U.S. during 2000 (Table 2).

a) 1998 Chevy Lumina

b) 1986 Freightliner

Figure 11. Study Vehicles.

Table 22. Study Vehicle Dimensions.

Dimension	1998 Chevy Lumina	1986 Freightliner
Headlamp Height above Ground	26 in	46 in
Driver Eye Height Above Ground	43 in	94 in
Distance between Driver Eye and Headlamp	17 in	48 in
Driver Eye Offset from Vehicle Centerline	13 in	21.5 in
Driver Eye Setback from Headlamps	90 in	80 in
Headlamp Separation	44 in	76 in

The low-beam headlamps of both vehicles were aimed before the data collection started. Also, each vehicle was equipped with a distance measuring instrument (DMI). The DMIs were used to measure the legibility distances.

Both study vehicles were dedicated exclusively to this research; thus, no other individual was allowed to use the vehicles. In addition, the vehicles remained at the Riverside Campus for the duration of the study. These precautions were implemented to prevent anything from happening that may cause injury to the vehicles or misalign the headlamps.

PARTICIPANTS

Researchers recruited a total of 28 individuals from the Bryan-College Station area to participate in the controlled field study. Participants had to be 21 years of age or older and possess a valid Texas commercial driver's license (Class A or B). Both males and females were recruited; however, only one female actually participated in the study. A standard static visual acuity (Snellen) eye test was performed on each participant. In addition, the following information was recorded for each participant:

- age,
- gender,
- number of years driving a commercial vehicle, and
- number of miles driven in Texas per year.

Table 23 contains the average participant's characteristics. Compared to the commercial vehicle driver survey participants (Table 3), on average the controlled field study participants were younger, had less experience, and drove fewer miles in Texas per year. This is possibly a limitation of the relatively small recruiting area.

Table 23. Participant Characteristics.

Characteristic	Average
Age	43
Visual Acuity	20/22
Number of Years Driving a Commercial Vehicle	18
Number of Miles Driven Per Year in Texas	19,000

STUDY PROCEDURE

The controlled field study was conducted at night on a closed-course test track at the Texas A&M University Riverside Campus in April 2002. Participant check-in and briefing took place at the TTI facility. Upon arrival, researchers provided the participants with an explanation of the study, including their driving task, and asked them to read and sign the informed consent document. At this point, a standard static visual acuity (Snellen) eye test was performed on each participant.

Participants were then told that they would be driving on a closed-course simulating a roadway typically encountered in Texas. They were instructed to drive 30 mph (maximum speed) and to only use the low-beam headlamps. Participants were accompanied at all times by a researcher in the passenger side of the front seat. The researcher provided verbal directions to the participant about where to drive and the maximum speed allowed on the course segment. The instructions utilized throughout the study are located in Appendix C.

As the participants drove through the predetermined course, they were instructed to notify the researcher when (1) he/she could read the word or number on the sign or (2) he/she could clearly see the end of the pavement marking. The researcher recorded the verbal response and distance of the vehicle at that point, as well as any comments made by the participant. At the end of the course, the researcher asked the participant a series of follow-up questions. The data collection forms are also located in Appendix C.

Each participant completed the study twice, once driving the 1998 Chevy Lumina and once driving the 1986 Freightliner. In order to balance the study, half of the participants completed the study in the commercial vehicle first and half of the participants completed the study in the passenger vehicle first. Also, two courses were developed so that each participant did not have the same travel path (i.e., see the signs and pavement markings in the same order). These courses were laid out using retroreflective raised pavement markers (RRPMs). The two study courses were also balanced within vehicle type.

The participants were compensated $25.00 per hour, and the study took approximately two hours to complete. Payment was made upon completion of an individual's participation.

DATA REDUCTION

For the signs, the DMI distance recorded by the researcher represented the distance from the starting points to the point where the participant correctly identified the word or number on the sign. However, the desired legibility distance is the distance from the sign position to the location where the participant correctly identifies the legend. In order to compute the legibility distance, the researchers measured the course length from the starting points to the sign positions. The DMI distances were then subtracted from the appropriate course length. The end detection distances for the pavement marking treatments were computed in a similar fashion. In all, 1821 legibility distances and 334 end detection distances were computed. Theoretically, 1848 legibility distances and 336 end detection distances should have been calculated; however, occasionally a participant would forget to verbally respond, or the researcher would inadvertently push the wrong button on the DMI. In addition to the distance data, the remarks made by the participants during the study, as well as the follow-up survey comments were reviewed and summarized.

5. NIGHTTIME CONTROLLED FIELD STUDY RESULTS

The data were first categorized into five subsets, defined by the type of traffic control device under study. These five categories included guide signs, destination signs, daytime speed limit signs, nighttime speed limit signs, and pavement markings. Statistical testing of each category of data was completed using a three-way mixed-effect analysis of variance (ANOVA) statistical test. More specifically, a two-way within-subjects repeated measures ANOVA with a between-subjects effect was used. The dependent factors were legibility distance for the sign evaluation and end detection distance for the pavement marking evaluation. The independent factors were sign type, vehicle, material, and age.

Based on a preliminary analysis of the data, researchers decided to divide the age of the participants into categories (originally age was treated as a continuous variable). Table 24 shows the assigned age group categories and their associated data.

Table 24. Age Group Characteristics.

Characteristic	Age Group		
	< 35	35 to 50	> 50
Number of Participants	10	9	9
Average Age	29	41	60
Average Visual Acuity	20/16	20/25	20/26
Average Number of Years Driving a Commercial Vehicle	4	18	32
Average Number of Miles Driven Per Year in Texas	19,000	23,000	14,500

Note that the effect of additional factors, such as course and replication, were also investigated in order to test the effectiveness of the experimental design in terms of eliminating systematic biases that may have been caused by such factors as the ordering of the devices or the vehicle the participants first used. These exploratory analyses showed that these factors had no consistent effect on the dependent factors.

GUIDE SIGNS

Table 25 shows the ANOVA for the guide sign data. It can be seen that the differences in the legibility distances by age group and by vehicle type were statistically significant. The fact that material type did not significantly affect the legibility distance is not surprising, since both types of sheeting used were microprismatic materials (i.e., Type III sheeting was not evaluated for the guide sign category). Figure 12 shows the box plots for each variable found to be significant.

As expected, the younger participants (< 35 years old) had the longest average legibility distance (835 ft). The average legibility distance for the older participants (> 50 years old) was 609 ft, which is 27 percent lower than that of the younger participants. The middle-aged participants (35 to 50 years old) had an average legibility distance of 745 ft.

Surprisingly, the average legibility distance for the Freightliner (777 ft) was 12 percent greater than the average legibility distance for the Chevy Lumina (694 ft).

Table 25. ANOVA for Guide Signs.

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F-Value	p-value [a]
Age Group	2	2,403,164	1,201,582	20.49	0.0001
Error	70	4,105,429	58,649		
Vehicle	1	407,180	407,180	11.69	0.0011
Vehicle × Age Group	2	110,990	55,495	1.59	0.2106
Error	70	2,438,250	34,832		
Material	1	21,926	21,926	1.62	0.2076
Material × Age Group	2	4908	2454	0.18	0.8348
Error	70	948,805	13,554		
Vehicle × Material	1	6052	6052	0.41	0.5263
Vehicle × Material × Age Group	2	20,136	10,068	0.67	0.5126
Error	70	1,044,656	14,924		

[a] Shaded values are significant ($\alpha = 0.05$)

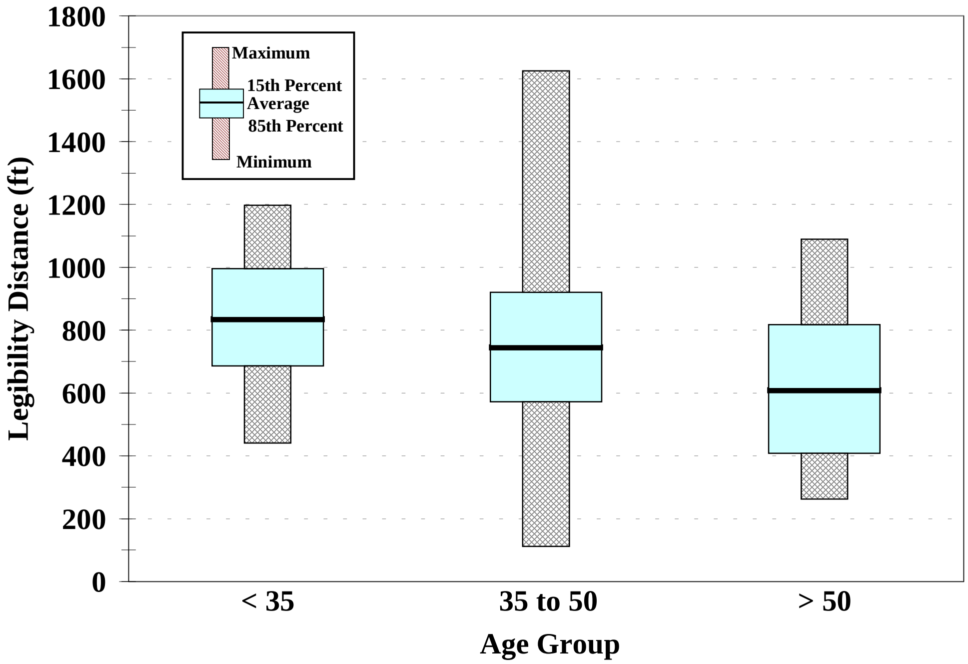
DESTINATION SIGNS

As with the guide signs, the differences in the legibility distances for the destination signs were statistically significant by age group and by vehicle type (Table 26). Figure 13 shows the box plots for each significant variable.

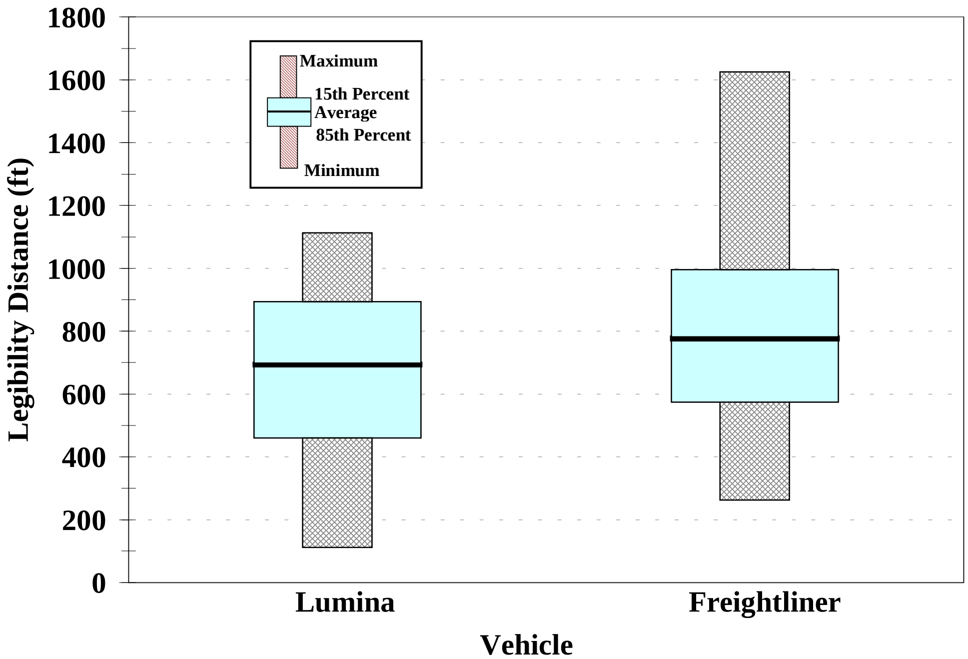
Similar to the guide sign data, the average legibility distance for the older participants (237 ft) was 25 percent lower than that of the younger participants (316 ft). The middle-aged participants had an average legibility distance of 279 ft.

Yet again, the average legibility distance for the Freightliner (294 ft) was 12 percent greater than the average legibility distance for the Chevy Lumina (263 ft).

Even though a non-microprismatic sheeting was included, material type was not a significant factor. However, several participants commented that the Type VIII and Type IX materials produced a glare, which may have inhibited them from reading the sign at longer distances.



a) Legibility Distance by Age Group



b) Legibility Distance by Vehicle

Figure 12. Statistically Significant Factors for Guide Signs.

Table 26. ANOVA for Destination (D2-1) Signs.

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F-Value	p-value [a]
Age Group	2	217,801	108,900	4.24	0.0180
Error	77	1,979,654	25,710		
Vehicle	1	114,251	114,251	12.40	0.0007
Vehicle × Age Group	2	441	220	0.02	0.9764
Error	77	709,316	9212		
Material	2	610	305	0.24	0.7842
Material × Age Group	4	4773	1193	0.95	0.4355
Error	154	192,918	1253		
Vehicle × Material	2	5220	2610	1.91	0.1543
Vehicle × Material × Age Group	4	5932	1483	1.08	0.3672
Error	154	210,945	1370		

[a] Shaded values are significant ($\alpha = 0.05$)

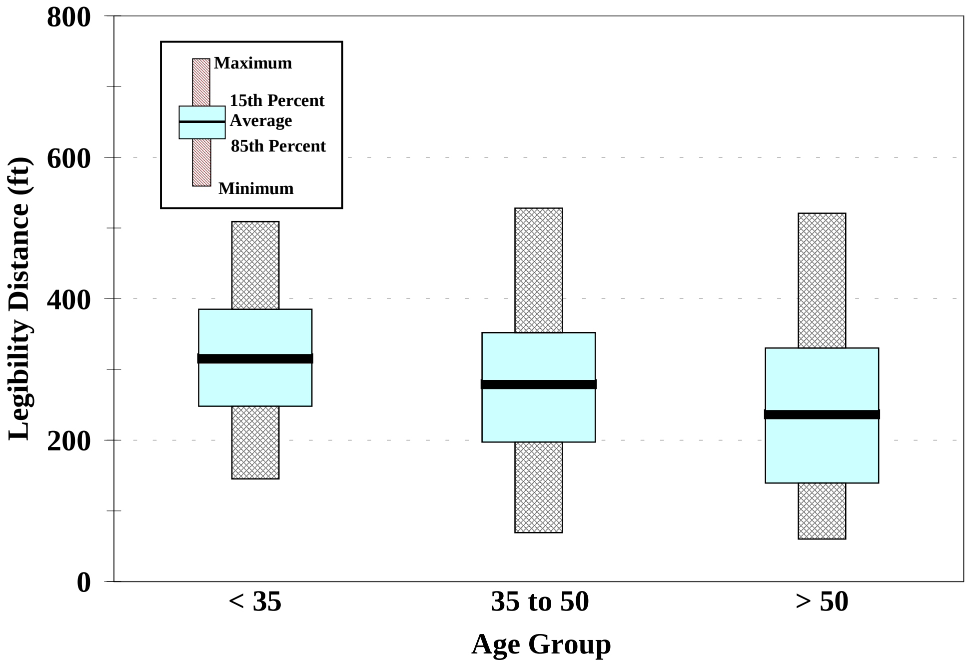
DAYTIME SPEED LIMIT SIGNS

As shown in Table 27, age group, vehicle type, and material type were found to significantly affect the legibility distance of the daytime speed limit signs. In addition, researchers determined that the interaction between vehicle type and material type was statistically significant. Figure 14 shows the box plots for each significant variable, while Figure 15 illustrates the interaction between the vehicle type and material type variables.

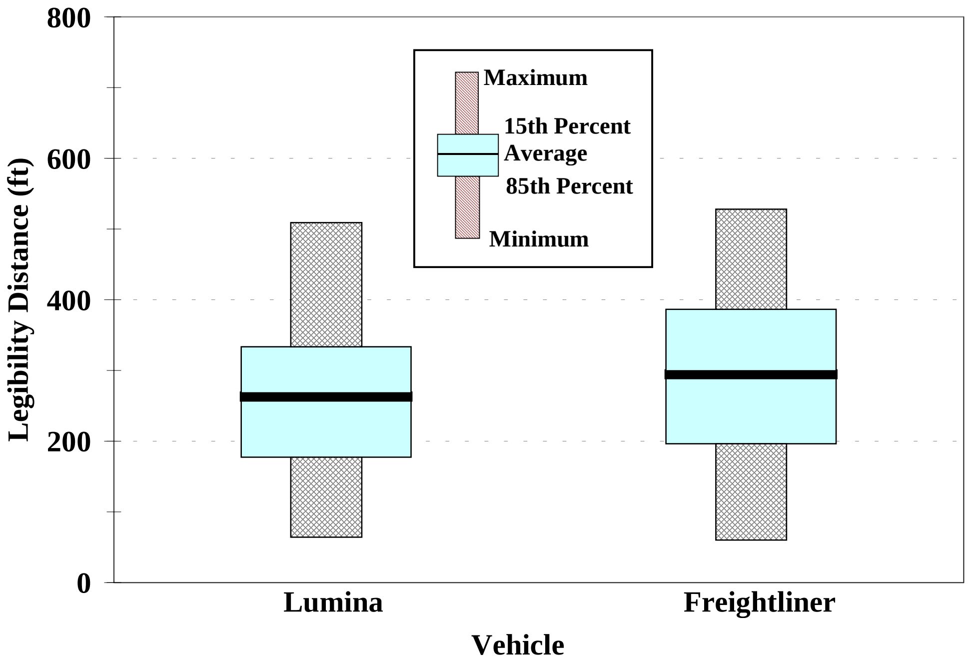
Following the previous trends, the average legibility distance decreased (465 ft, 445 ft, and 362 ft) as age increased (young, middle-aged, and old, respectively). Thus, the average legibility distance for the older participants was 22 percent lower than that of the younger participants.

The average legibility distance for the Freightliner was again greater than that of the Chevy Lumina (446 ft and 404 ft, respectively). With respect to material, the Type IX sheeting had the longest average legibility distance (437 ft) compared to the Type VIII and Type III sheeting (426 ft and 413 ft, respectively).

However, more importantly, are the results shown in Figure 15. This figure shows the significant relationship between vehicle type and material. For both vehicles, Type IX sheeting had the longest average legibility distance, followed by Type VIII and Type III, respectively. However, the increase in the average legibility distance for the Chevy Lumina across the material types was only 8 ft. In contrast, the increase in the average legibility distance for the Freightliner across the material types was approximately 40 ft.



a) Legibility Distance by Age Group



b) Legibility Distance by Vehicle

Figure 13. Statistically Significant Factors for Destination (D2-1) Signs.

Table 27. ANOVA for Daytime Speed Limit (R2-1) Signs.

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F-Value	p-value [a]
Age Group	2	541,895	270,948	6.07	0.0036
Error	77	3,437,312	44,640		
Vehicle	1	180,231	180,231	33.16	0.0001
Vehicle × Age Group	2	9957	4978	0.92	0.4045
Error	77	418,561	5436		
Material	2	36,748	18,374	11.57	0.0001
Material × Age Group	4	4586	1147	0.72	0.5782
Error	154	244,586	1588		
Vehicle × Material	2	16,137	8,068	4.42	0.0136
Vehicle × Material × Age Group	4	2042	510	0.28	0.8907
Error	154	280,954	1824		

[a] Shaded values are significant ($\alpha = 0.05$)

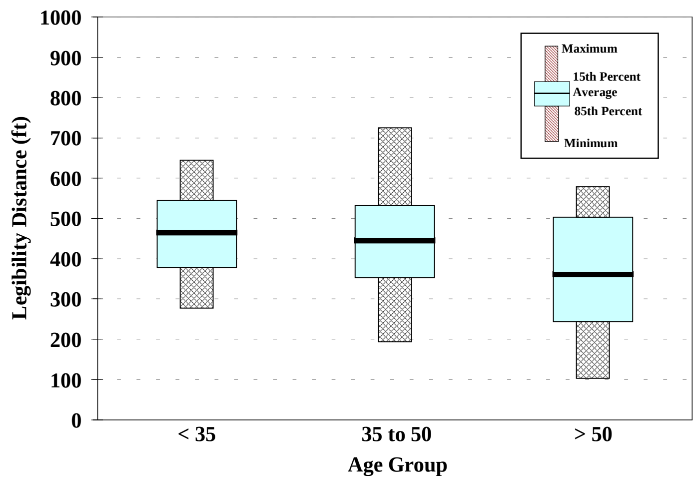
NIGHTTIME SPEED LIMIT SIGNS

Table 28 shows the ANOVA table for the nighttime speed limit sign data. It can be seen that the differences in the legibility distances by age group, vehicle type, and material type were statistically significant. Figure 16 shows the box plots for each significant variable. In addition, researchers determined that the interaction between vehicle type and age group, as well as the interaction between vehicle type and material type were statistically significant. Figure 17 illustrates both of these interactions.

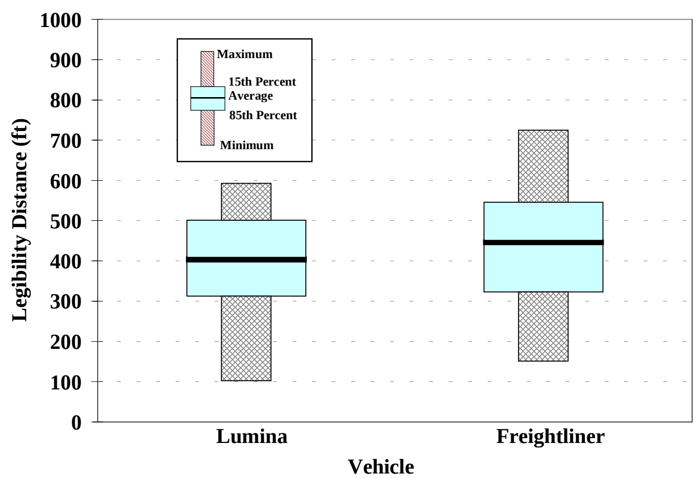
The average legibility distance decreased (490 ft, 470 ft, and 406 ft) as age increased (young, middle-aged, and old, respectively). The average legibility distance for the older participants was 17 percent lower than that of the younger participants.

Following the previous trends, the average legibility distance for the Freightliner (466 ft) was greater than the average legibility distance for the Chevy Lumina (448 ft). As shown in Figure 17, as the age of the participant increases the average legibility distance associated with each vehicle type decreases.

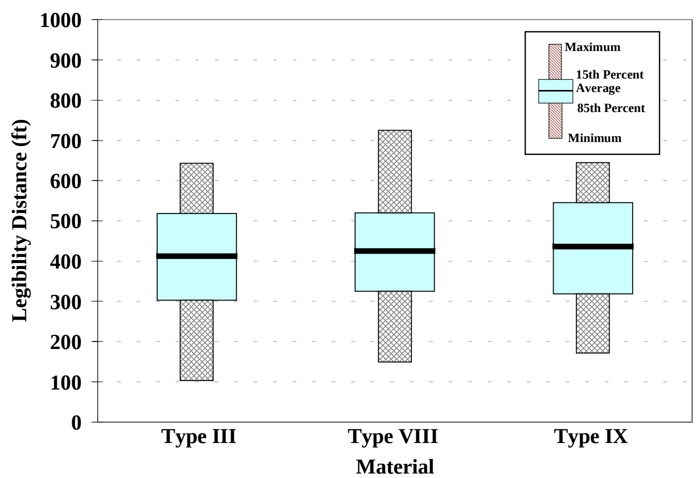
Again, the Type IX sheeting had the longest average legibility distance (466 ft). However, unlike the legibility distance of the daytime speed limit signs, the Type III sheeting had a legibility distance of 462 ft, and the Type VIII sheeting had a legibility distance of 443 ft. More importantly, Figure 17 shows the significant relationship between vehicle type and material. For both vehicles, the average legibility distance for Type IX sheeting and Type III sheeting were very similar (a difference of approximately 1 percent). Also for both vehicles, the average legibility distance for the Type VIII sheeting was less than that of the Type III or Type IX sheeting (a difference of approximately 5 percent).



a) Legibility Distance by Age Group



b) Legibility Distance by Vehicle



c) Legibility Distance by Material

Figure 14. Statistically Significant Factors for Daytime Speed Limit (R2-1) Signs.

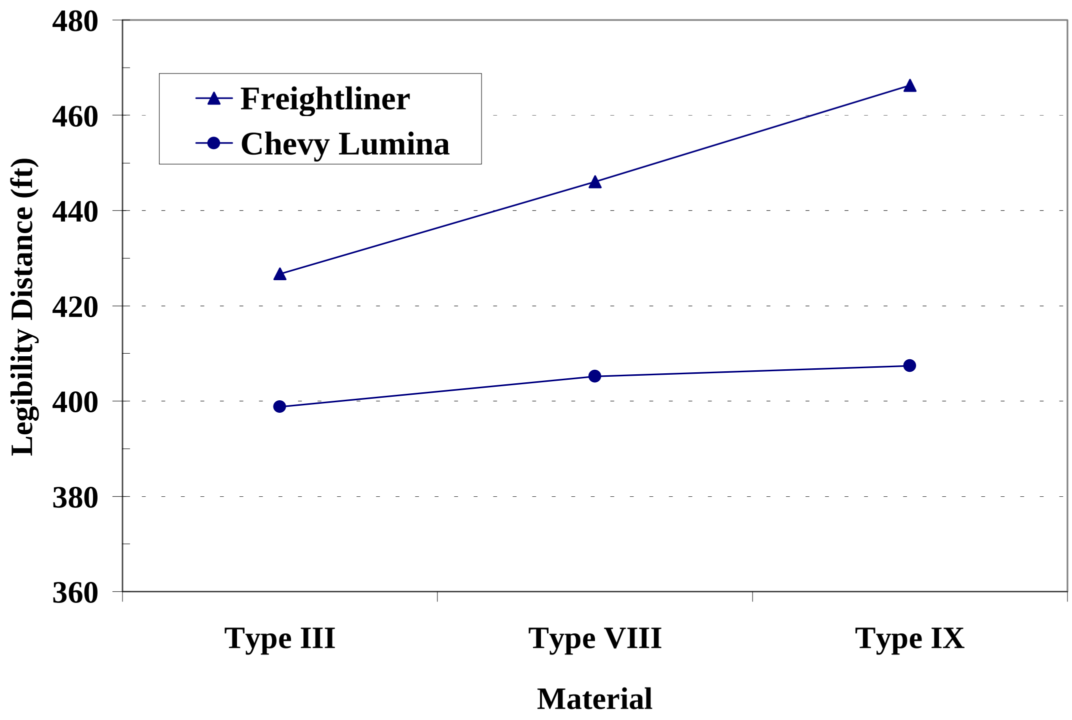
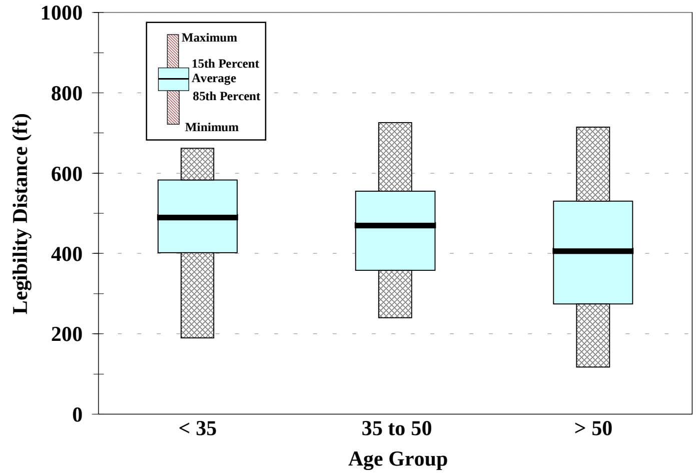


Figure 15. Interaction between Vehicle Type and Material Type for Daytime Speed Limit Signs (R2-1).

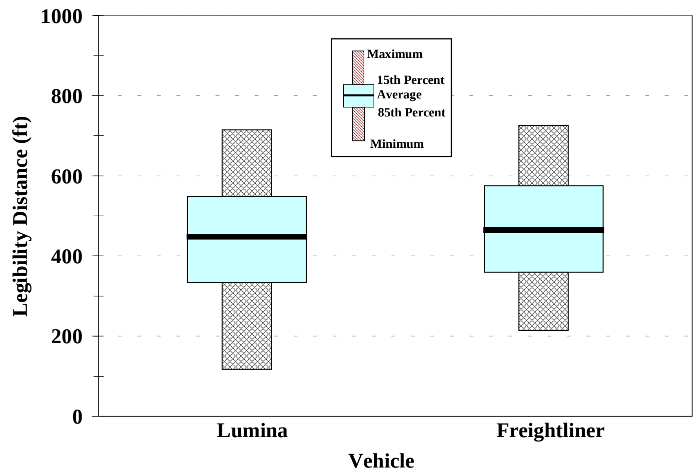
Table 28. ANOVA for Nighttime Speed Limit (R2-3) Signs.

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F-Value	p-value [a]
Age Group	2	597,674	298,837	8.26	0.0006
Error	76	2,750,053	36,185		
Vehicle	1	53,691	53,691	7.76	0.0068
Vehicle × Age Group	2	57,237	28,618	4.13	0.0198
Error	76	526,079	6922		
Material	2	57,804	28,902	9.55	0.0001
Material × Age Group	4	9723	2431	0.80	0.5247
Error	152	459,873	3026		
Vehicle × Material	2	30,623	15,311	3.84	0.0235
Vehicle × Material × Age Group	4	29,033	7258	1.82	0.1274
Error	152	605,494	3984		

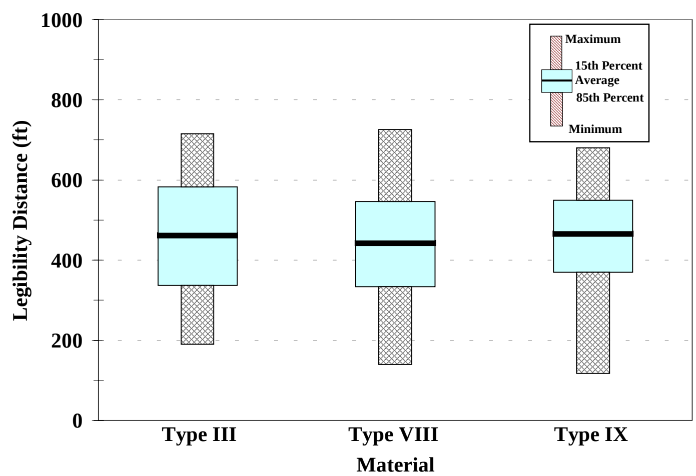
[a] Shaded values are significant ($\alpha = 0.05$)



a) Legibility Distance by Age Group

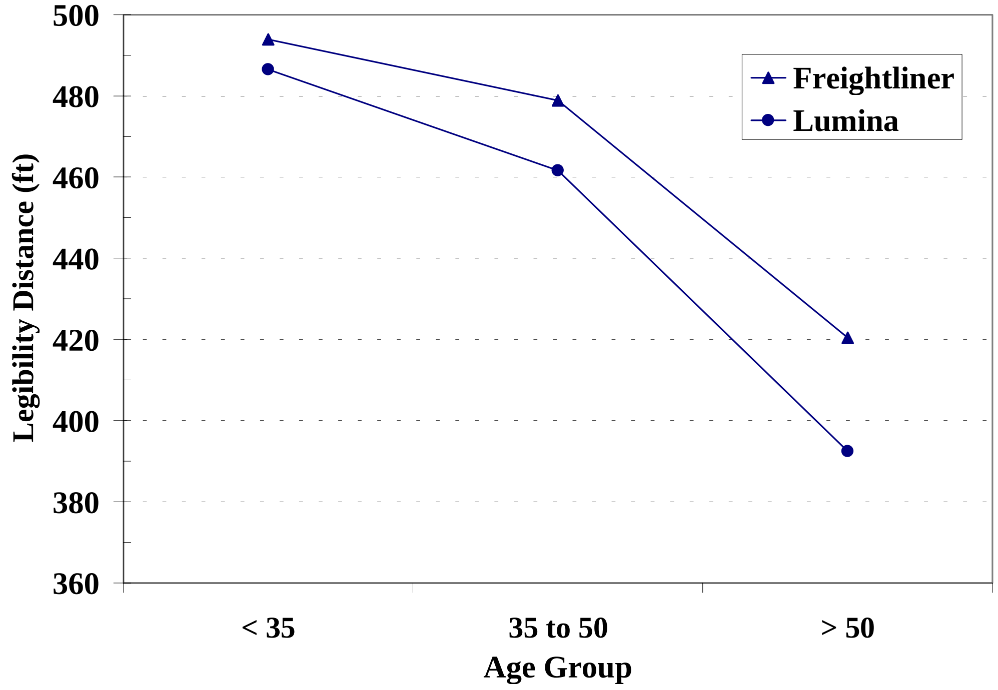


b) Legibility Distance by Vehicle

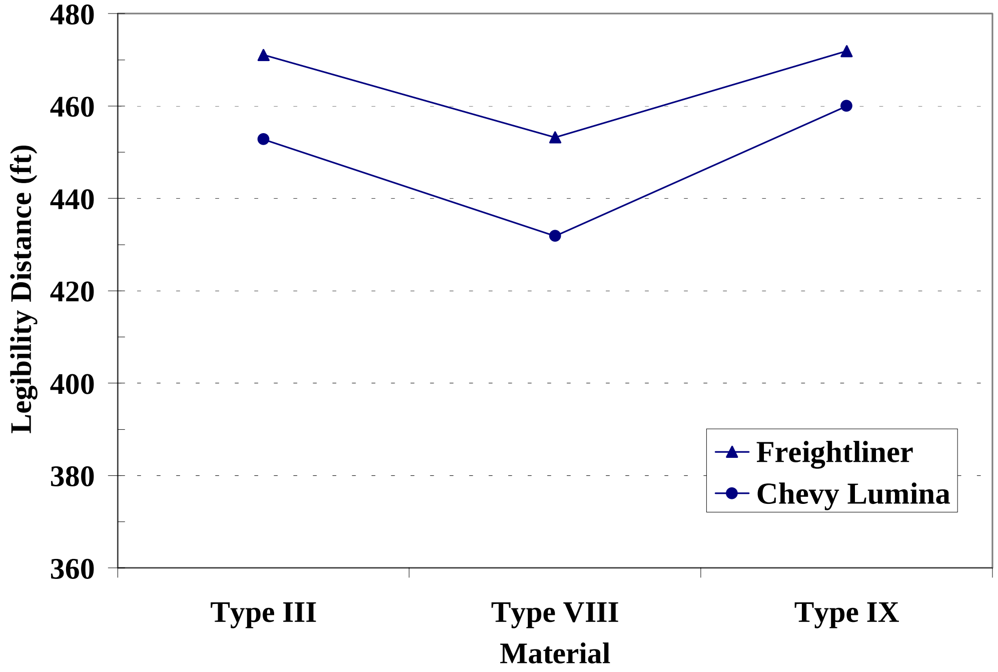


c) Legibility Distance by Material

Figure 16. Statistically Significant Factors for Nighttime Speed Limit (R2-3) Signs.



a) Interaction between Age Group and Vehicle Type



b) Interaction between Material Type and Vehicle Type

Figure 17. Variable Interactions for Nighttime Speed Limit Signs (R2-3).

PAVEMENT MARKINGS

As shown in Table 29, age group and material type were found to significantly affect the end detection distance of 4-inch white edge-line pavement markings. In addition, it was determined that the interaction between age group and material type was statistically significant. Figure 18 shows the box plots for each variable that was found to be significant, while Figure 19 illustrates the interaction between the age group and material type variables.

Table 29. ANOVA for Pavement Markings.

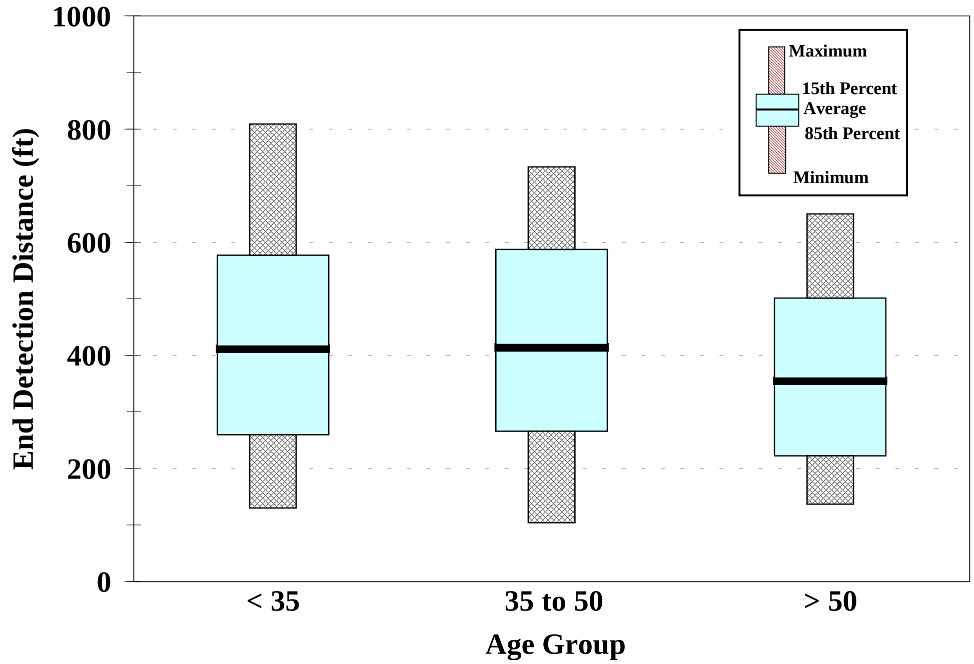
Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F-Value	p-value [a]
Age Group	2	258,878	129,439	5.68	0.0059
Error	52	1,184,458	22,778		
Vehicle	1	1833	1833	0.04	0.8407
Vehicle × Age Group	2	46,827	23,413	0.52	0.5969
Error	52	2,336,061	44,924		
Material	2	2,394,466	1,197,233	478.17	0.0001
Material × Age Group	4	31,702	7925	3.17	0.0201
Error	104	260,394	2504		
Vehicle × Material	2	9487	4744	1.44	0.2409
Vehicle × Material × Age Group	4	7180	1795	0.55	0.7023
Error	104	341,858	3287		

[a] Shaded values are significant ($\alpha = 0.05$)

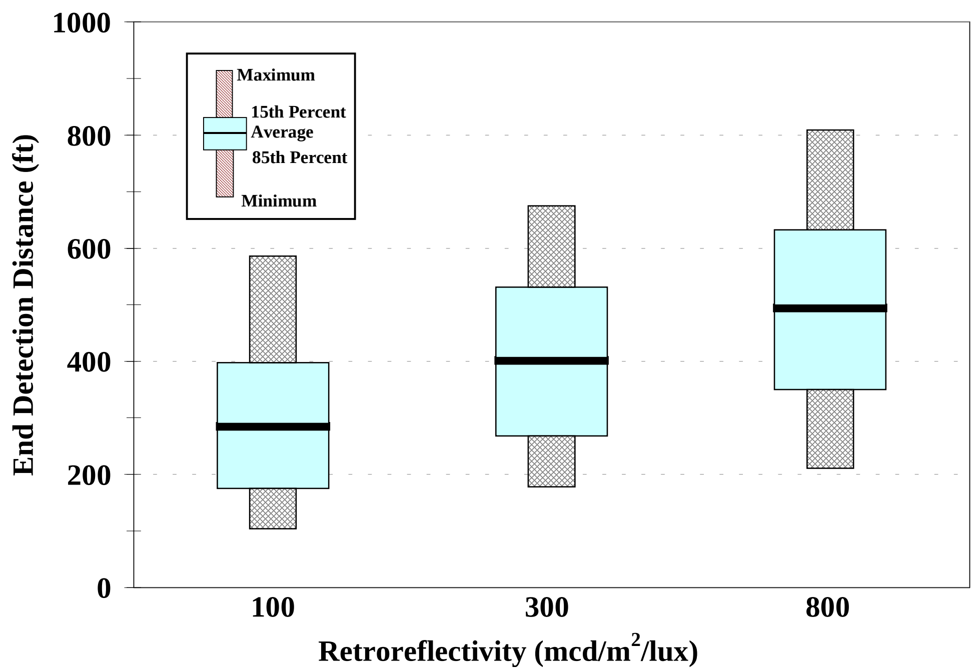
The middle-aged participants had the longest average end detection distance (414 ft), followed closely by the younger participants (411 ft). The average end detection distance for the older participants was 355 ft, which is 14 percent lower than both the middle-aged and younger participants.

With respect to material, the 800 mcd/m^2/lux marking had the longest average end detection distance (494 ft). As the retroreflectivity of the markings decreased (300 to 100 mcd/m^2/lux), the average end detection distance also decreased (401 to 285 ft, respectively). As Figure 20 illustrates, a 200 mcd/m^2/lux increase in retroreflectivity (100 to 300 mcd/m^2/lux) increased the average end detection distance by 41 percent. However, an additional 500 mcd/m^2/lux increase in retroreflectivity (300 to 800 mcd/m^2/lux) only increased the average end detection distance by 23 percent. Thus, as the retroreflectivity of the marking increases, the relative benefits in terms of end detection distance decrease.

In addition, several of the participants commented that the 800 mcd/m^2/lux marking was brighter than the others and thus easier to see. Several participants also commented that the 100 mcd/m^2/lux marking was dim, dull, or dirty thus making it hard to see.



a) End Detection Distance by Age Group



b) End Detection Distance by Material

Figure 18. Statistically Significant Factors for Pavement Markings.

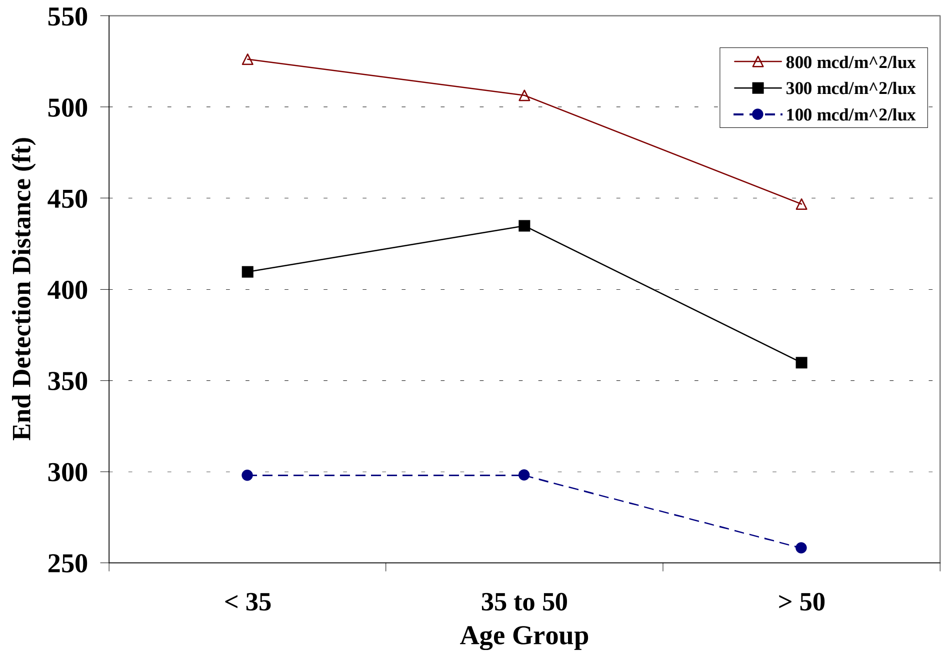


Figure 19. Interaction between Material Type and Age Group for Pavement Markings.

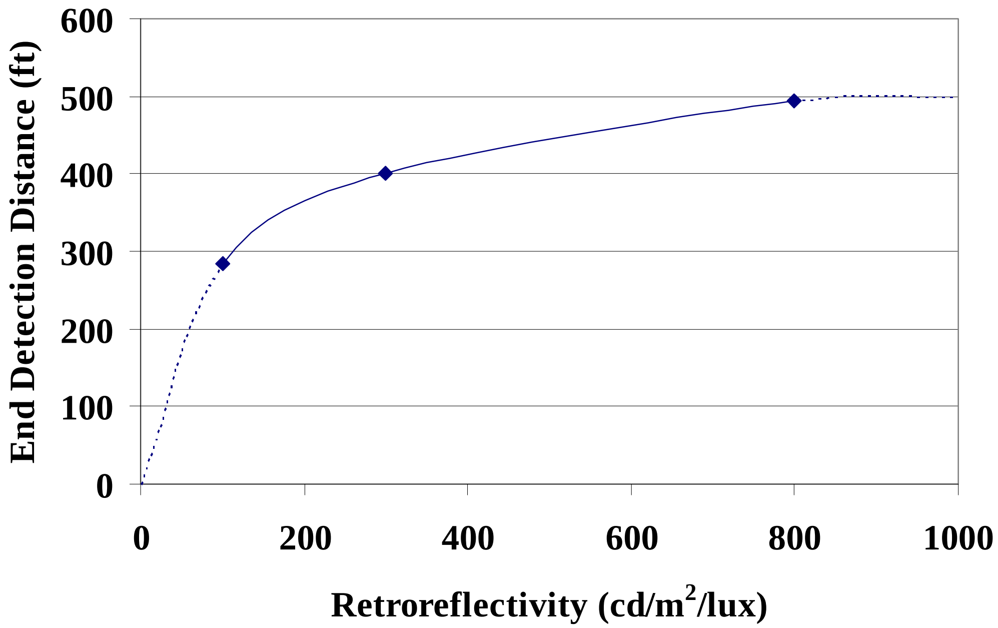


Figure 20. End Detection Distance as a Function of Pavement Marking Retroreflectivity.

As shown in Figure 19, the three pavement marking materials follow a similar trend across the age group. In general, as the age of the participant increases, the average end detection distance associated with each material decreases.

FOLLOW-UP SURVEY

Upon completion of the study, each participant was asked a series of follow-up questions to obtain the driver's perspective on the brightness of the signs and pavement markings viewed. This section is a summary of the responses obtained from these one-on-one surveys. A total of 28 individuals participated in the survey after driving the Chevy Lumina, and 27 participated in the survey after driving the Freightliner.

Pavement Markings

The first part of the survey contained three questions and focused on the visibility of the different pavement marking treatments. The participants were first asked if they noticed any changes in the appearance of the white pavement markings they had encountered. While driving the Chevy Lumina, 19 of the participants (68 percent) noticed a change in the appearance of the markings. Ten of these participants indicated that the 100 mcd/m^2/lux marking was the dimmest and/or the 300 and 800 mcd/m^2/lux markings were the brightest. In addition, four participants stated that the brightest pavement markings were the easiest to see.

While driving the Freightliner, 22 participants (81 percent) noticed a change in the appearance of the markings. Seven of these participants indicated that the 300 and 800 mcd/m^2/lux markings were the brightest.

The participants were then asked if they had encountered any markings that they preferred. While driving the Chevy Lumina, 57 percent of the participants preferred the brighter markings (300 and 800 mcd/m^2/lux). Similarly, 59 percent of the participants while driving the Freightliner preferred the brighter markings (300 and 800 mcd/m^2/lux).

The third question asked the participants if all the pavement markings they had encountered would be bright enough if they were driving on an actual roadway. While driving the Chevy Lumina, 82 percent of the participants felt that all of the pavement markings they encountered would be bright enough for them while driving on an actual roadway. While driving the Freightliner, 78 percent of the participants felt that all of the pavement markings they encountered would be bright enough for them while driving on an actual roadway. Interestingly, three individuals out of each group remarked that the 100 mcd/m^2/lux marking would not be bright enough.

Signs

The second part of the survey contained four questions and focused on the visibility of the different signing treatments. The participants were first asked if they noticed any changes in the appearance of the signing treatments they had encountered.

While driving the Chevy Lumina and the Freightliner, most of the participants (71 percent and 59 percent, respectively) stated that there was no change in the appearance of the guide signs. Of those participants that did notice a change in appearance, they either thought the guide signs were too bright or hard to read.

Over half of the participants while driving either the Chevy Lumina (57 percent) or the Freightliner (59 percent) felt that there was no change in the appearance of the destination signs. However, while driving the Freightliner, 30 percent of the participants thought that some of the destination signs were hard to read.

For the daytime speed limit signs, 57 percent of the participants while driving the Chevy Lumina indicated that they noticed a change in the appearance of the signs. Half of those participants stated that some of the signs were either too bright or too reflective. While driving the Freightliner, 67 percent of the participants noticed a change in the appearance of the daytime speed limit signs, of which, 44 percent responded that the signs were too bright or hard to read.

While driving the Chevy Lumina and the Freightliner, most of the participants (71 percent and 63 percent, respectively) stated that there was no change in the appearance of the nighttime speed limit signs. Of those participants that did notice a change in appearance, they thought some of the signs were easier to read than others.

The participants were then asked if they had encountered any signs that they preferred. The majority of participants (89 percent and 81 percent) for both groups (Chevy Lumina and Freightliner, respectively) indicated a sign preference. The most frequently preferred sign type for both groups was the nighttime speed limit signs followed by the guide signs.

The third question asked the participants if all the signs they had encountered would be bright enough if they were driving on an actual roadway. While driving the Chevy Lumina and the Freightliner, 100 percent and 93 percent of the participants, respectively, felt that all the signs they had encountered would be bright enough while driving on an actual roadway. However, while driving the Freightliner, all of the participants felt that some or all of the signs were too bright. While driving the Chevy Lumina, 43 percent of the participants thought that some of the signs were too bright.

Upon completion of the entire study (i.e., after the participants drove both the Chevy Lumina and Freightliner), the participants were asked which vehicle did they feel they could see the signs better. Forty-eight percent of the participants felt the signs were easier to see in the Chevy Lumina, while 22 percent indicated that the signs were easier to see in the Freightliner. Twenty-six percent of the participants felt that there was no difference between the vehicles.

SUMMARY

Table 30 contains a summary of the statistically significant findings from the nighttime controlled field study. For all categories, the age of the participant significantly affected the results. Typically, the average legibility distance for the older participants (> 50 years old) was

17 to 27 percent lower than that of the younger participants (< 35 years old). The average end detection distance for the older participants was 14 percent lower than both the younger and middle-aged participants.

Table 30. Statistical Significance of the Factors Studied.

Variable or Interaction	Guide Signs	Destination Signs	Daytime Speed Limit Signs	Nighttime Speed Limit Signs	Pavement Markings
Age Group	X	X	X	X	X
Vehicle	X	X	X	X	
Material			X	X	X
Material × Age Group					X
Vehicle × Age Group				X	
Vehicle × Material			X	X	
Vehicle × Material × Age Group					

X – significant

For all of the sign categories, the type of vehicle was a significant factor. In all of these cases, the commercial vehicle had longer average legibility distances than the passenger car. Typically, the average legibility distance for the commercial vehicle was 4 to 12 percent greater than that of the passenger car. This result was unexpected because in theory commercial vehicle drivers are at a disadvantage when it comes to the amount of light returned from retroreflective devices such as signs.

Material was significant for the speed limit signs and the pavement markings. For the daytime speed limit signs, the average legibility distance for the Type IX sheeting was 3 to 6 percent longer than that of the Type VIII and Type III sheeting, respectively. For the nighttime speed limit signs, the difference between the average legibility distance for Type IX sheeting and Type III sheeting was practically negligible (only approximately 1 percent). In contrast, the average legibility distance for Type VIII sheeting was approximately 5 percent less than that of the Type III and Type IX sheeting.

For the pavement markings, the marking with the highest retroreflectivity (800 mcd/m^2/lux) had the longest average end detection distance, while the marking with the lowest retroreflectivity (100 mcd/m^2/lux) had the shortest average end detection distance. Increasing the retroreflectivity by 200 mcd/m^2/lux (from 100 mcd/m^2/lux to 300 mcd/m^2/lux) increased the average end detection distance by 41 percent. Increasing the retroreflectivity by an additional 500 mcd/m^2/lux (from 300 mcd/m^2/lux to 800 mcd/m^2/lux) increased the average end detection distance by 23 percent.

With respect to the research objective, the relationship between vehicle type and material type was of prime concern. This relationship was found to be statistically significant only for the daytime and nighttime speed limit signs; however, the practical difference in the legibility distance between material types as a function of vehicle type was small. For the daytime speed limit signs, the Type IX sheeting produced the largest increase in legibility distance for the commercial vehicle (40 ft) compared to the passenger car (8 ft). This same finding was not replicated for the nighttime speed limit signs. Furthermore, the relationship between vehicle type and material type for the nighttime speed limit signs was less distinctive in terms of performance differences.

6. COMMERCIAL VEHICLE HEADLAMP STUDY EXPERIMENTAL DESIGN

This chapter documents the experimental design of the commercial vehicle headlamp study that was conducted in June 2002. The objective of this study was to determine the headlamp illuminance (i.e., amount of light reaching an object) of actual commercial vehicles as they are driven on the road. This task was performed to help researchers identify the differences between the amount of headlamp illuminance cast by various vehicle types. In total, the illuminance of 10 commercial vehicles' headlamps was measured at four typical sign locations (including the location of the signs in the controlled field study). TTI researchers also measured the illuminance of the headlamps of the two study vehicles used in the controlled field study.

ILLUMINANCE POSITIONS

Researchers measured the headlamp illuminance (right and left headlamps separately) at specific points representing typical sign locations and approach distances. Figure 21 illustrates the sign types (left shoulder, overhead, right shoulder, and right guide signs) and their placement with respect to the travel lanes. Using these sign locations and the commercial vehicle dimensions in Table 22, the software program Exact Road Geometry Output (ERGO™) 2001 was utilized to compute the horizontal and vertical (H/V) angles associated with each headlamp at three viewing distances (200, 500, and 650 ft). Table 31 contains the dimensions of the sign placement simulated and the illumination positions for each headlamp. Note that the right shoulder sign location represents the average location of the signs in the controlled field study.

Due to time constraints, it was not feasible to determine the H/V angles based on each individual vehicle's headlamp dimensions. Thus, the H/V points for the sign placements were based on the 1986 Freightliner (commercial vehicle used in the controlled field study) headlamp mounting height (46 inches).

The H/V angles were then converted to xy coordinates, so the illumination positions could be plotted on the measuring screen. Figures 22 and 23 illustrate the locations of the illumination positions for the left and right headlamps, respectively. Figure 24 shows all of the illumination positions on the measuring screen.

As mentioned previously, it was also desired to measure the headlamp illuminance of the 1998 Chevy Lumina used in the controlled field study. Using the Lumina's dimensions (Table 22) and the same sign locations, the H/V angles were computed and plotted for each headlamp at three viewing distances (200, 500, and 650 ft). Appendix D details the H/V angles and illumination positions for the 1998 Chevy Lumina.

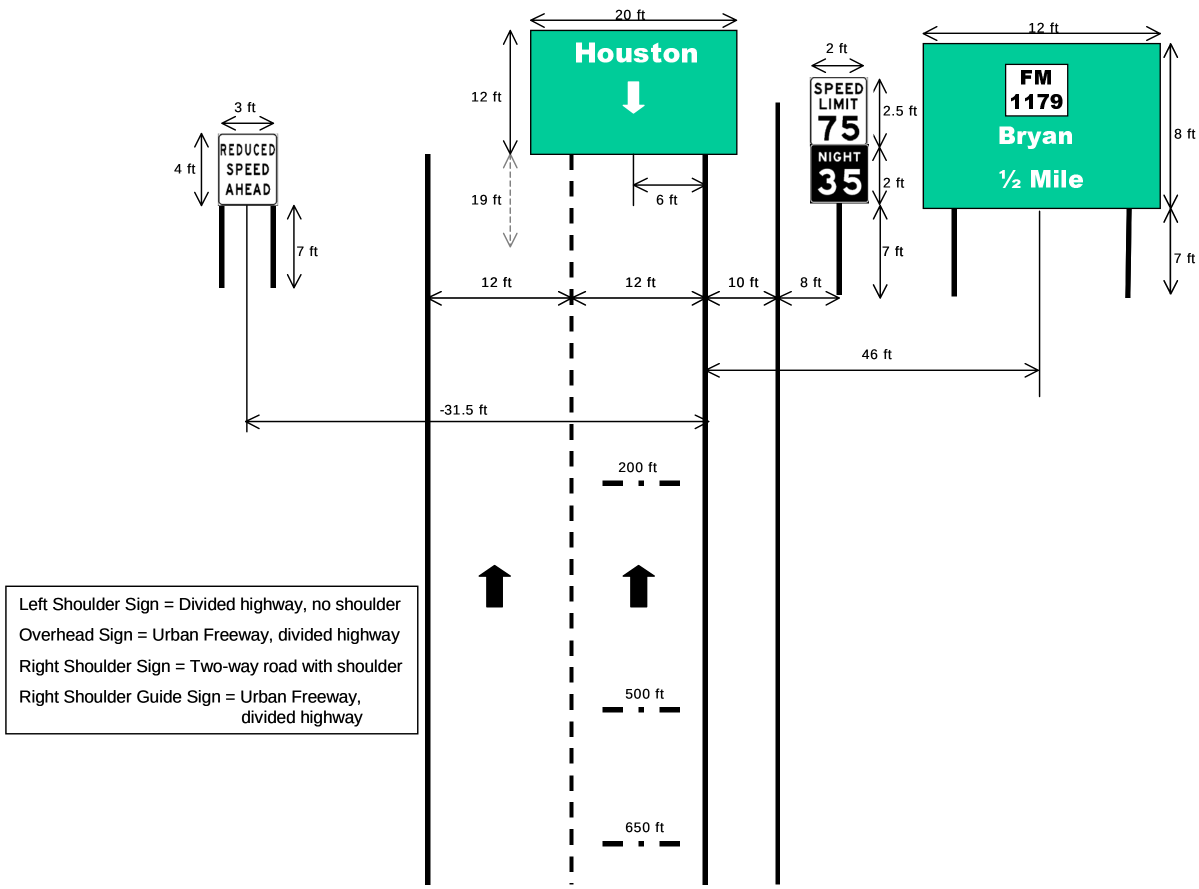


Figure 21. Sign Placement.

LOCATION

As with the controlled field study, the commercial vehicle headlamp study was conducted at the TTI proving ground facility at the Texas A&M Riverside Campus. However, the headlamp measurements were performed inside a large hanger owned by TTI instead of on the runway system in order to minimize the impact of extraneous light.

PARTICIPANTS AND COMMERCIAL VEHICLES MEASURED

Ten individuals were recruited from the Bryan-College Station area to participate in the commercial vehicle headlamp study. Participants had to be 21 years of age or older, possess a valid Texas commercial driver's license (Class A or B), and be able to drive a commercial vehicle to the study site.

In total, the researchers measured the physical dimensions and headlamp illuminance of 10 commercial vehicles: four Freightliner models, three International models, one Ford model, one GMC model, and one Kenworth model. The age of the commercial vehicles ranged from 3 to 16 years old. The average odometer reading of the 10 vehicles was approximately 400,000 miles.

Four of the commercial vehicles had 2A1 sealed-beam headlamps, three had 2B1 sealed-beam headlamps, and two had 2D1 sealed-beam headlamps (the type of headlamp on one vehicle could not be determined).

Table 31. Sign Placement and Illumination Positions.

Sign Type	Viewing Distance (ft)	Sign Centroid Offset [a] (ft)	Sign Centroid Height (ft)	Left Headlamp		Right Headlamp	
				Horizontal Angle (degrees)	Vertical Angle (degrees)	Horizontal Angle (degrees)	Vertical Angle (degrees)
Right Guide	200 500 650	46	11	15.4 6.3 4.9	2.0 0.8 0.6	13.7 5.6 4.3	2.0 0.8 0.6
Right Shoulder	200 500 650	18	9.25	7.7 3.1 2.4	1.5 0.6 0.5	5.9 2.4 1.8	1.5 0.6 0.5
Overhead Guide	200 500 650	0	25	0.9 0.4 0.3	6.0 2.4 1.9	-0.9 -0.4 -0.3	6.0 2.4 1.9
Left Shoulder	200 500 650	-31.5	9	-6.4 -2.6 -2.0	1.5 0.6 0.5	-8.2 -3.3 -2.5	1.5 0.6 0.5

[a] Measured from the right edge of the right travel lane

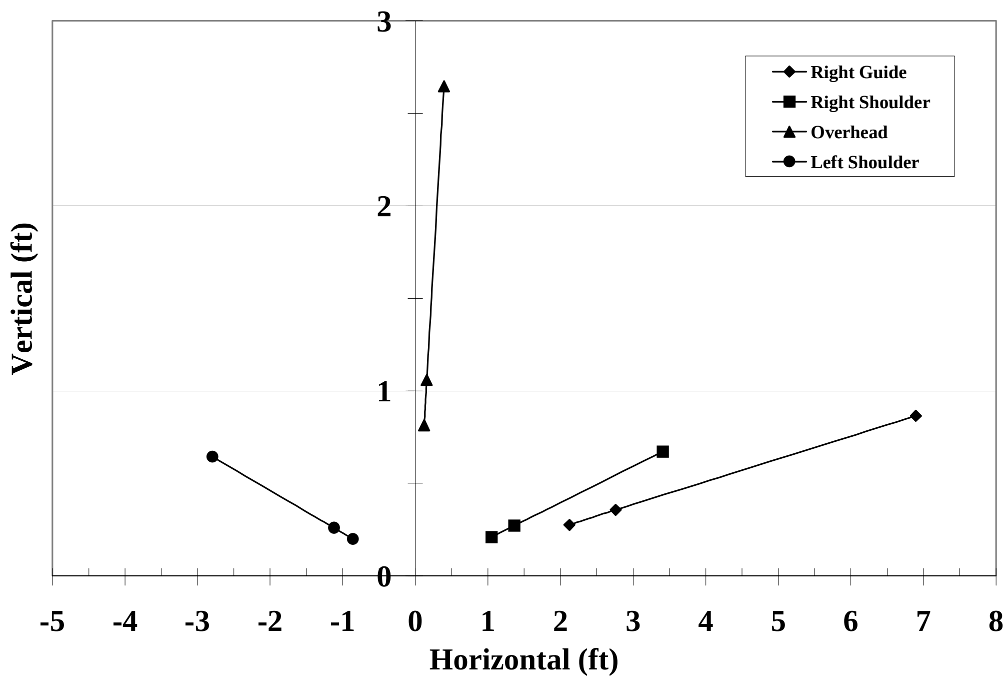


Figure 22. Left Headlamp Illumination Positions.

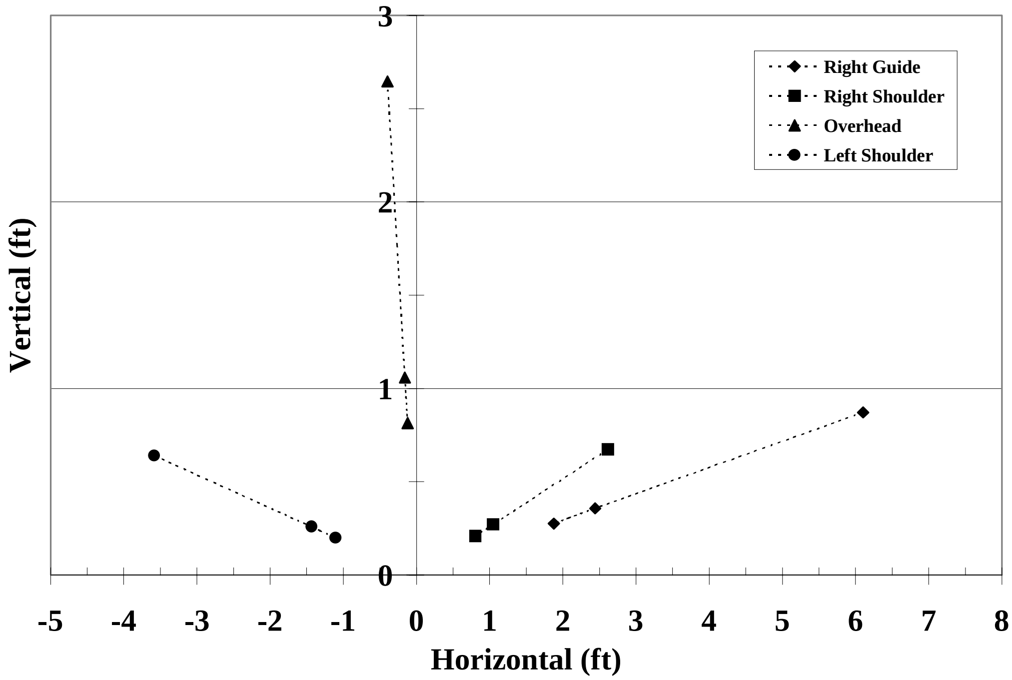
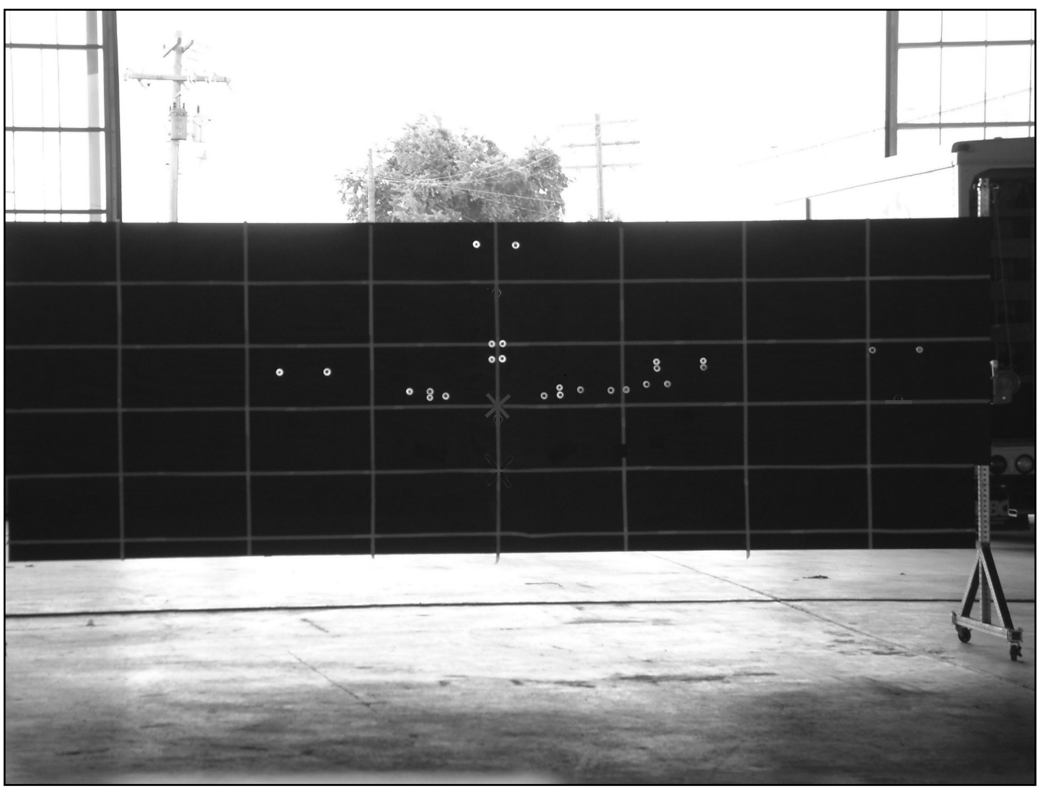


Figure 23. Right Headlamp Illumination Positions.



This picture was taken during the day to better show the screen, but measurements were made at night.

Figure 24. Right and Left Headlamp Illumination Positions on the Measuring Screen.

STUDY PROCEDURE

Researchers conducted the commercial vehicle headlamp study at night at the Texas A&M Riverside campus inside building 7090. Upon arrival, participants were provided an explanation of the study and asked to read and sign the Informed Consent document. The participant then drove their vehicle into the hangar through large doors on the opposite wall from the measuring screen. The vehicle was guided toward the screen by centering over several temporary pavement markings that were placed on the floor. Once the front of the vehicle's headlamps was 25 ft from the measuring screen (location marked on the floor) the vehicle was parked and the engine turned off.

Before taking illuminance measurements, the vehicle's make, model, model year, and odometer reading were recorded on the data form. In addition, the type of low-beam headlamp was recorded. The participant was then asked if the headlamps were original to the vehicle. If not, the researchers noted any changes that had been made.

Next, the following physical dimensions were measured on each vehicle:

- Headlamp height: the distance from the ground to the center of the vehicle's headlamp.
- Lateral separation of headlamps: the distance from the center of the right headlamp to the center of the left headlamp.
- Driver eye height: the distance from the ground to the center of the driver's eye.
- Lateral offset of driver: the distance from the center of the vehicle to the center of the driver's eyes (or nose).
- Longitudinal setback of driver: the distance from the front of the vehicle's headlamp to the driver's eyes.

Note that the "driver" for the measurements previously described was a 6 ft tall TTI researcher. In addition to the measurements previously described, two additional measurements were taken. A permanent line in the floor was located under the temporary pavement markings that were used to initially align the measuring screen and vehicle. The distance from this line to the center of left and right headlamps was measured. Using this left horizontal measurement and the headlamp height, the 0,0 point on the measuring screen (denoted with an "x") was aligned with the center of the left headlamp.

At this point, the vehicle was started and the low-beam headlamps were activated. Next, the right headlamp was covered with a black tarp. Three illuminance meters were then placed on the screen at the three left headlamp H/V points for the right guide sign. The illuminance (lux) values were recorded for each position. The meters were then moved to the next set of points and the process repeated until the illuminance for all 12 left headlamp positions was recorded.

The black tarp was then removed from the right headlamp, and the measuring screen was repositioned. The same measurement process was completed for the 12 right headlamp positions. Appendix E shows the data form used in the commercial vehicle headlamp study.

Photographs of the left and right headlamp distributions on the measuring screen, as well as measurements of the ambient light, were also taken.

The participants were compensated $40.00 per hour, and the study took approximately one hour to complete. Payment was made upon completion of a participant's participation.

In addition to the 10 commercial vehicles, researchers also measured the left and right headlamp illuminance of the 1986 Freightliner and the 1998 Chevy Lumina.

DATA REDUCTION

The raw illuminance data for each commercial vehicle (measured at 25 ft) was converted to the projected illuminance at 200, 500, and 650 ft. The right and left headlamp data for each commercial vehicle were then summed to yield the illuminance of both headlamps for each commercial vehicle. The average illuminance of both headlamps for all 10 vehicles was then computed for each sign location (left shoulder, overhead, right shoulder, and right guide) and distance (200, 500, and 650 ft).

7. COMMERCIAL VEHICLE HEADLAMP STUDY RESULTS

In this chapter, the vehicle dimensions, as well as the headlamp illuminance of the 10 commercial vehicles that participated in the headlamp study are presented. In addition, the vehicle dimensions and headlamp illuminance of the Freightliner truck used in the controlled field study are compared to the results of the 10 commercial vehicles. The headlamp illuminance of the Chevy Lumina is also presented.

VEHICLE DIMENSIONS

Table 32 contains a quantitative description of the dimensions of the 10 commercial vehicles, as well as the dimensions of the 1986 Freightliner used in the controlled field study. Overall, the Freightliner dimensions are comparable to the average dimensions of the 10 commercial vehicles that participated in the headlamp study.

Table 32. Vehicle Dimensions.

Dimension (in)	10 Commercial Vehicles			1986 Freightliner
	Average	Maximum	Minimum	
Headlamp Height above Ground	43	48.5	39	46
Headlamp Separation	74	81	68.5	76
Driver Eye Height	92	99	85	94
Driver Eye Offset from Vehicle Centerline	21	24	17	21.5
Driver Eye Setback from Headlamps	87	96	74	80
Distance between Driver Eye & Headlamp	49	56	40.5	48

As part of an ongoing TxDOT research project being conducted at TTI (0-1796), researchers measured the headlamp illuminance of 42 passenger vehicles (23 passenger cars and 19 light trucks/SUVs/vans). Figure 25 shows the distribution of the headlamp height and driver eye height for the 10 commercial vehicles in this study and the 42 vehicles in the 0-1796 study. In addition, the measurements for the 1986 Freightliner and the 1998 Chevy Lumina are illustrated. It can be seen that the average headlamp height across the vehicle types varies by approximately 20 inches, while the average driver's eye height varies by approximately 40 inches.

The headlamp and driver's eye height are the main vehicle-dependent factors that define observation angle. Figure 26 demonstrates how the observation angle increases for each headlamp as three vehicle types approach a right shoulder-mounted sign.

COMMERCIAL VEHICLE HEADLAMP ILLUMINANCE

As discussed previously, the average illuminance of both headlamps for all 10 commercial vehicles was computed for each sign location (left shoulder, overhead, right shoulder, and right guide) and distance (200, 500, and 650 ft). However as Figure 27 shows, the individual measurements of both headlamps varied across the 10 vehicles measured. This variation was especially true for the headlamp illuminance measured at the right shoulder location (which represents the average location of the signs in the controlled field study).

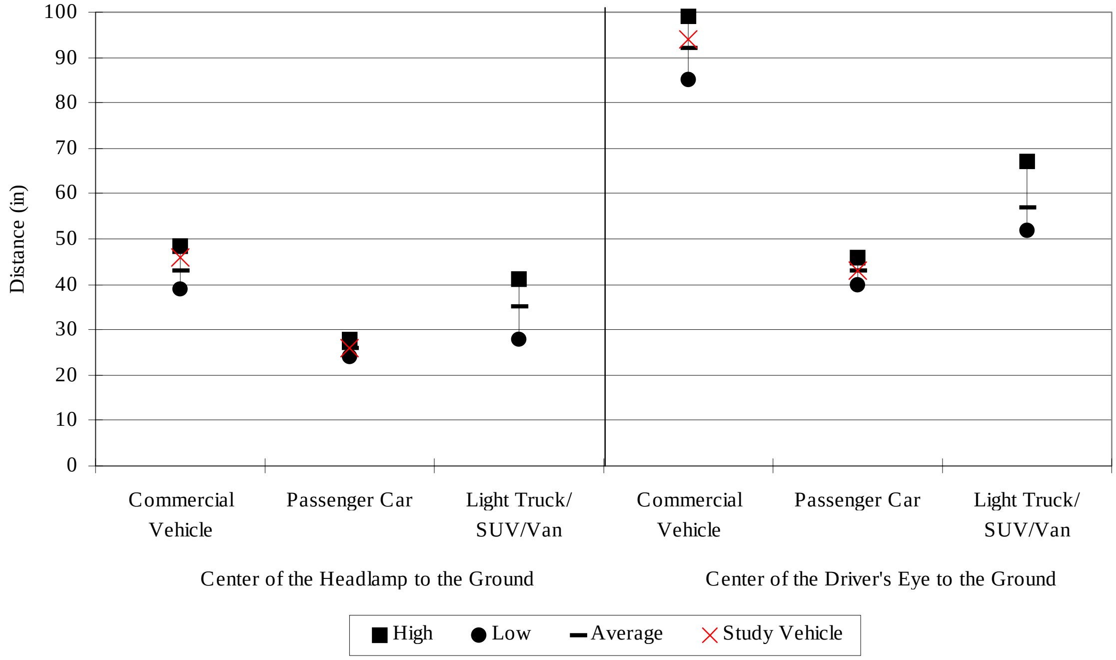
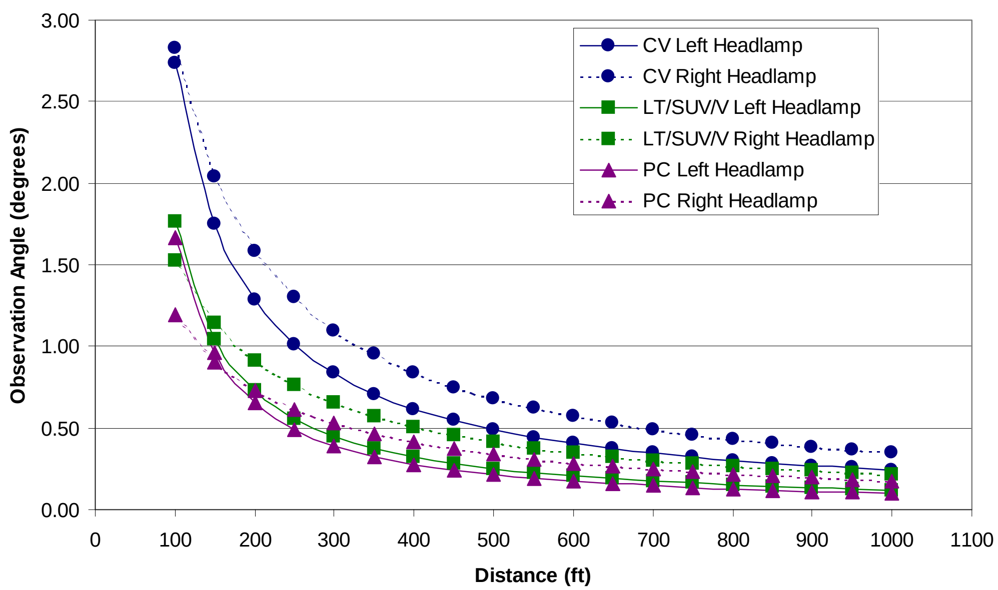


Figure 25. Comparison of Vehicle Dimensions by Vehicle Type.



CV – Commercial Vehicle; LT/SUV/V – Light Truck/SUV/Van; PC – Passenger Car

Figure 26. Observation Angle by Vehicle Type.

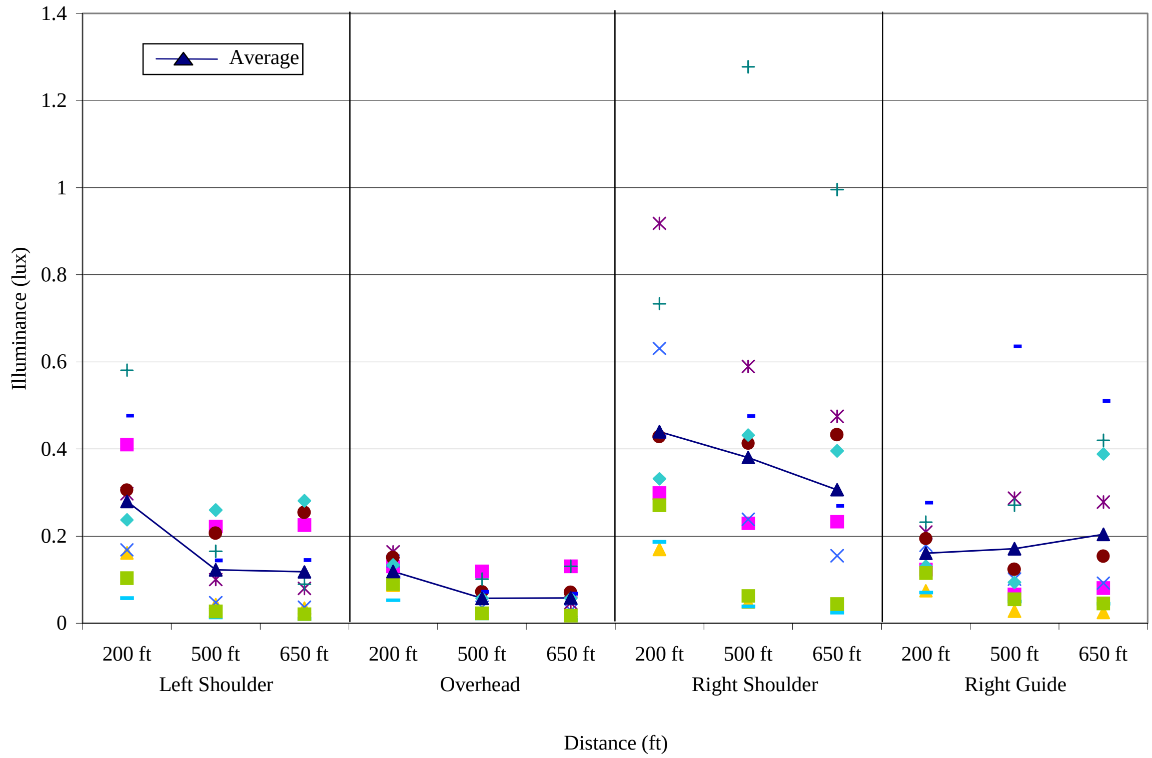


Figure 27. Variation in Commercial Vehicle Illuminance Data (Both Headlamps).

This figure also demonstrates that in general the average illuminance of both headlamps decreases as the distance increases. The average illuminance of both headlamps ranged from 0.06 to 0.44 lux over all of the sign locations. The highest average illuminance values occurred at the right shoulder sign location.

Figure 28 illustrates the average illuminance of both headlamps for all 10 vehicles, as well as the illuminance of both of the Freightliner's headlamps. As shown in this figure, the headlamp illuminance of the Freightliner was typically higher than the average headlamp illuminance of the 10 commercial vehicles. The illuminance of the Freightliner's headlamps ranged from 0.16 to 0.79 lux over all of the sign locations. The largest difference between the two commercial vehicle categories occurred at the right shoulder location. Further examination of the Freightliner's headlamps revealed that the headlamp housings were not stable and thus the headlamps had become misaligned during the study.

PASSENGER CAR HEADLAMP ILLUMINANCE

Figure 29 shows the illuminance of both of the Chevy Lumina's headlamps for each sign location (left shoulder, overhead, right shoulder, and right guide) and distance (200, 500, and 650 ft). Similar to the other illuminance measurements, in general the average illuminance of both headlamps decreases as the distance increases. The illuminance of both headlamps ranged from 0.03 to 0.41 lux over all of the sign locations. Again, the highest average illuminance values occurred at the right shoulder sign location.

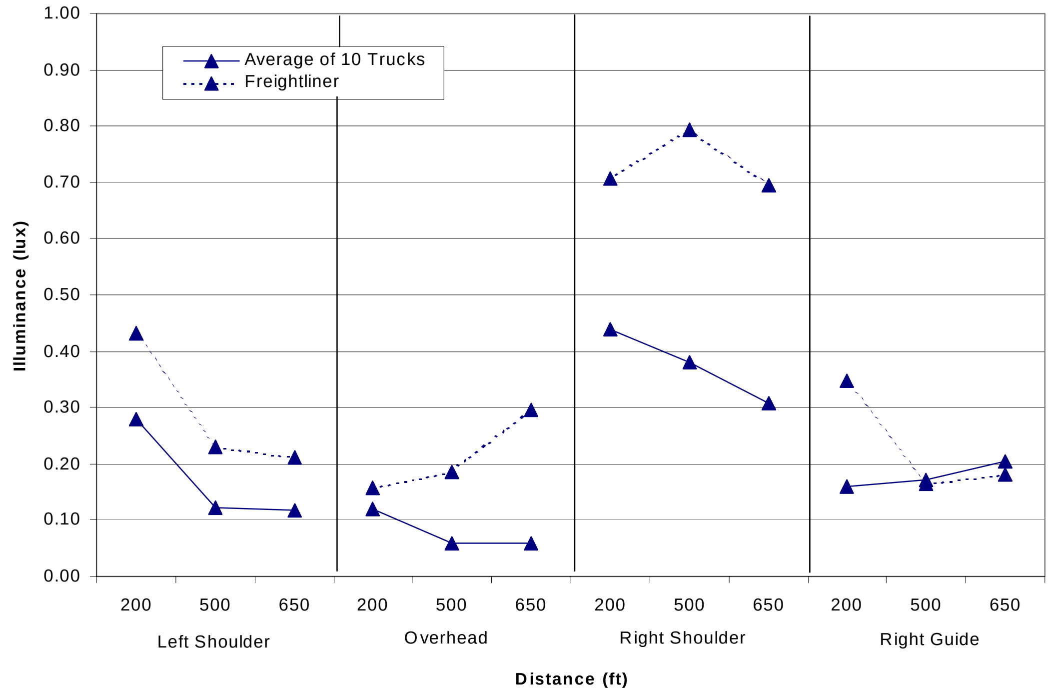


Figure 28. Comparison of Commercial Vehicle Headlamp Illuminance (Both Headlamps).

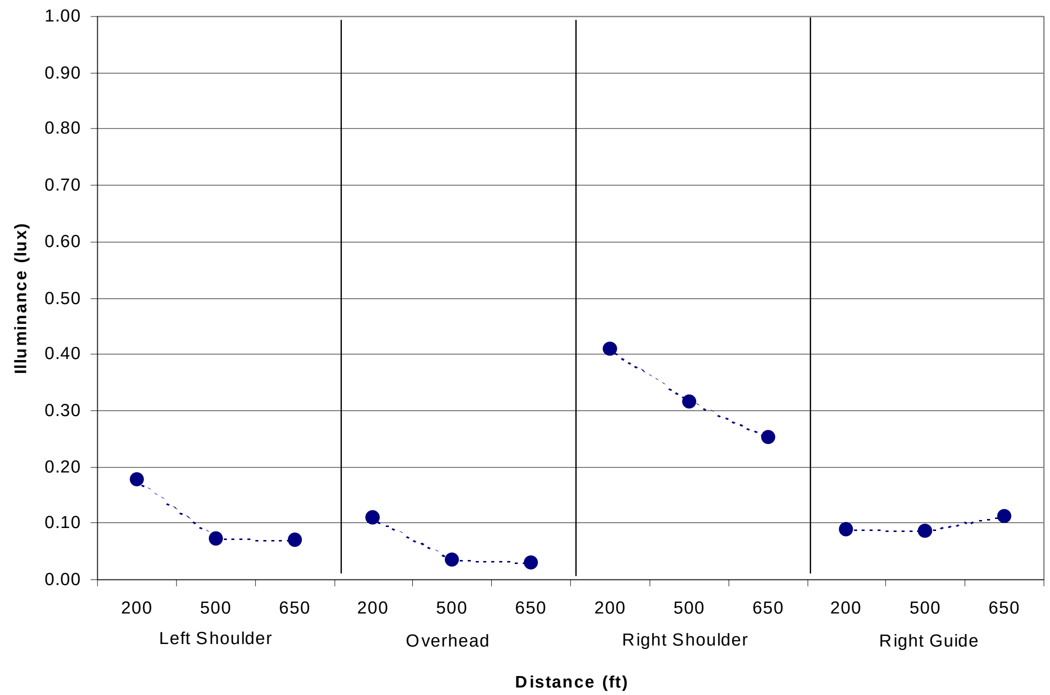


Figure 29. Chevy Lumina Headlamp Illuminance (Both Headlamps).

As previously mentioned, TTI researchers measured the headlamp illuminance of 23 passenger cars as part of another TxDOT research project. Figure 30 compares the average illuminance of 23 passenger cars' headlamps and the illuminance of the Chevy Lumina's headlamps. As shown in this figure, the headlamp illuminance of the Chevy Lumina was quite similar to the average headlamp illuminance of the 23 passenger cars, except at the right shoulder location. It should be noted that for the 23 passenger cars the illuminance of both headlamps was measured simultaneously instead of the left and right headlamps being measured separately and then summed.

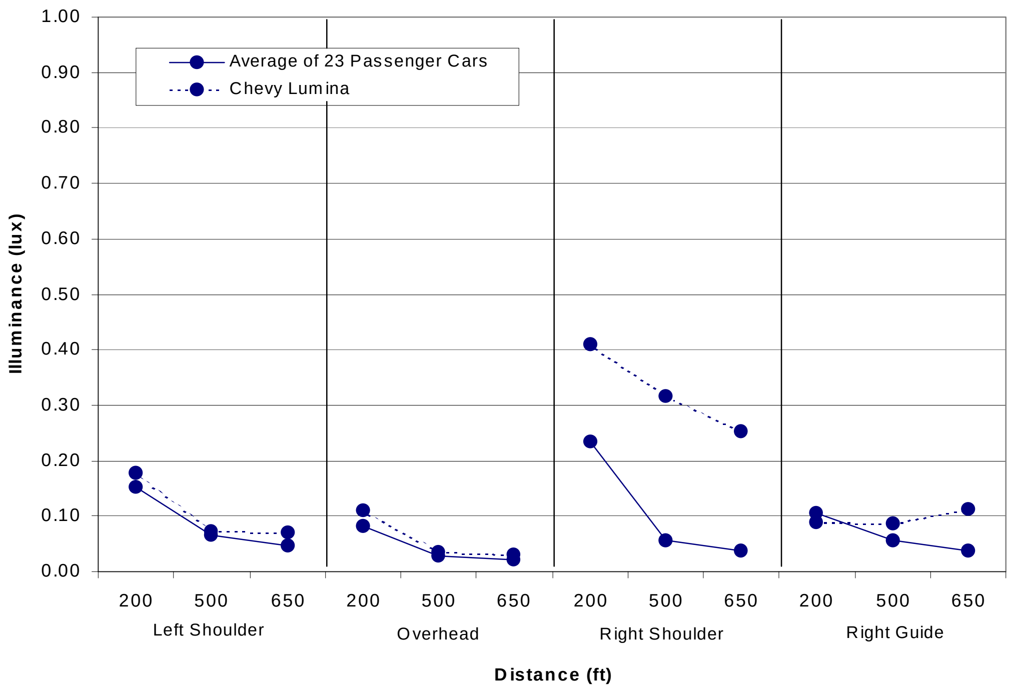


Figure 30. Comparison of Passenger Car Headlamp Illuminance (Both Headlamps).

SUMMARY

The vehicle dimensions of the Freightliner and Chevy Lumina (two vehicles used in the nighttime controlled field study) were comparable to the on-road fleet. However, the headlamp illuminance of the Freightliner was consistently greater than the average headlamp illuminance of the 10 commercial vehicles measured in the commercial vehicle headlamp study. This difference was especially noticeable at the right shoulder location, which represents the average location of the signs in the nighttime controlled field study. The higher illuminance produced by the Freightliner's headlamps occurred because the headlamp housings were not stable and thus the headlamps became misaligned during the study. The headlamp illuminance of the Chevy Lumina was quite similar to the average headlamp illuminance of the 23 passenger cars measured in another TTI research project. But again, the largest difference occurred at the right shoulder location.

8. DISCUSSION OF RESULTS

The results of the nighttime controlled field study showed that the type of vehicle significantly affected the legibility distance of signs. For all of the sign types studied, the average legibility distance for the Freightliner was 4 to 12 percent greater than the average legibility distance of the Chevy Lumina. For the guide signs the 83 ft increase in legibility distance equates to an additional 0.81 seconds of reading time for commercial vehicle drivers, assuming a 70 mph roadway. However, for the destination and speed limit signs the percent difference in legibility distance only represents a practical gain of 18 to 42 ft (0.18 to 0.41 seconds of reading time).

Nevertheless, the effect of vehicle type on the legibility distance of the signs studied was unexpected because in theory commercial vehicle drivers are at a disadvantage when it comes to the amount of light returned from retroreflective devices such as signs. However, as determined in the commercial vehicle headlamp study, the headlamp illuminance of the Freightliner was greater than the average headlamp illuminance of the 10 on-road commercial vehicles. This difference was especially noticeable for right shoulder-mounted signs, which represented the average location of the signs in the nighttime controlled field study. Thus, the amount and pattern of light emitted by the Freightliner's headlamps increased the amount of light falling on the signs (illuminance), which in turn reduced the disadvantage associated with the larger eye/headlamp separation of commercial vehicles and increased the amount of light returned to the driver (luminance). This higher than expected luminance allowed the participants in the Freightliner to read the signs farther in advance than expected. This hypothesis supports the results of the nighttime controlled field study.

In order to get another perspective of the results, researchers calculated the luminance of the right shoulder-mounted signs. The software program ERGO™ 2001 was used to determine the retroreflectivity values for the relevant geometries associated with each headlamp. These retroreflectivity values were then used in conjunction with the measured headlamp illuminance of the study vehicles, as well as the average headlamp illuminance of the 10 on-road commercial vehicles, to calculate the luminance returned to the three vehicles for a right shoulder-mounted sign. As shown in Figure 31, the amount of light returned to the Freightliner and the Chevy Lumina are comparable. In contrast, for all three material types the luminance of the sign for the average on-road commercial vehicle is lower than the luminance of the two vehicles used in the nighttime controlled field study. This is of particular interest when speculating what may have happened if the Freightliner's headlamps would have illuminated the signs similarly to the average on-road commercial vehicle's headlamps.

Based on the luminance values in Figure 31, it appears that the average on-road commercial vehicle would indeed receive less luminance from a right shoulder-mounted sign than a passenger car. Therefore, drivers of commercial vehicles may be at a disadvantage when it comes to the amount of light returned from retroreflective traffic signs. However, additional illuminance measurements of commercial vehicle headlamps are needed in order to better establish the headlamp illuminance of a "typical" on-road commercial vehicle. Also, additional legibility studies should be conducted using a commercial vehicle that illuminates signs similar to the identified "typical" commercial vehicle before any further conclusions can be made.

With respect to the legibility performance results reported earlier in this report, it is important to note that the calculated luminance of the signs do not necessarily correlate on a one-to-one basis with the observed legibility distances. Therefore, direct comparisons between Figure 31 and the reported findings of the legibility studies should be carefully made.

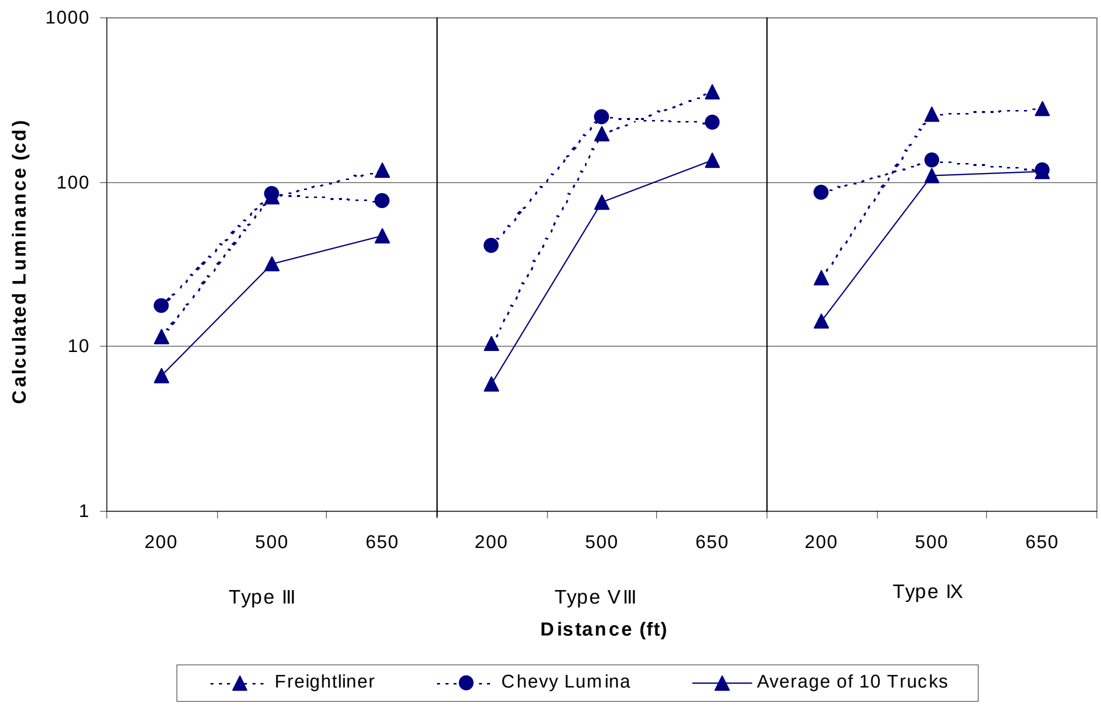


Figure 31. Right Shoulder-Mounted Sign Luminance Values.

9. CONCLUSIONS AND RECOMMENDATIONS

The overall objective of this project was to determine whether vehicle type should be considered in the selection of retroreflective materials. More specifically, the purpose was to identify sign and pavement marking materials that provide adequate levels of luminance from the perspective of commercial vehicle drivers while still meeting the requirements of drivers of passenger vehicles. Through a nighttime controlled field study, the relationship between vehicle type (passenger car versus commercial vehicle) and sign/pavement marking material was evaluated in terms of the legibility distance of signs and the end detection distance of pavement markings. This study included 28 participants that were categorized into three age groups: young (< 35), middle-aged (35 to 50), and old (>50). Additional research issues included investigations among sign type (guide, destination, and speed limit).

The project also included a commercial vehicle driver survey and a commercial vehicle headlamp study. The commercial vehicle driver survey was conducted in order to solicit commercial vehicle drivers' opinions of the current signage and pavement markings in Texas. Researchers conducted the commercial vehicle headlamp study to measure the headlamp illuminance (i.e., amount of light reaching an object) of on-road commercial vehicles.

CONCLUSIONS

Commercial Vehicle Driver Survey

The results of the commercial vehicle driver survey showed that 46 percent of the commercial vehicle drivers surveyed are primarily concerned with the construction or maintenance of Texas roadways versus 9 percent who are primarily concerned with signs and pavement markings. In addition, 58 percent of the commercial vehicle drivers surveyed did not identify any problems with the signs and pavement markings in Texas. Only after being specifically asked about the "brightness" of the signs and pavement markings used in Texas did 62 percent of the participants state that they had a concern. Even though most of these concerns focused on the driver's ability to see the signs and/or pavement markings at night, only 5 percent of those surveyed felt that Texas roadway signs were difficult to see at night. Interestingly, 60 percent of the Texas resident commercial vehicle drivers surveyed felt that there was no difference in the brightness of signs and/or pavement markings when driving a commercial vehicle versus a passenger vehicle. In addition, only 20 percent of the Texas resident commercial vehicle drivers surveyed felt that signs and/or pavement markings appear brighter in a passenger vehicle.

Nighttime Controlled Field Study

For all of the sign types studied, as well as for the pavement markings, the age of the participant significantly affected the results. Typically, the average legibility distance for the older participants (> 50 years old) was 17 to 27 percent lower than that of the younger participants (< 35 years old). The average end detection distance for the older participants was 14 percent lower than that of the younger participants. These results reiterate the importance of the continuing effort to try to accommodate the reduced visibility phenomenon associated with aging in the design of retroreflective traffic control devices.

For all of the sign categories, the type of vehicle was a significant factor. In all of these cases, the commercial vehicle had longer average legibility distances than the passenger car. Typically, the average legibility distance for the commercial vehicle was 4 to 12 percent greater than that of the passenger car. This result was unexpected because in theory commercial vehicle drivers are at a disadvantage when it comes to the amount of light returned from retroreflective devices such as signs.

Material was significant for the speed limit signs and the pavement markings. For the daytime speed limit signs, the average legibility distance for the Type IX sheeting was 3 to 6 percent longer than that of the Type VIII and Type III sheeting, respectively. For the nighttime speed limit signs, the difference between the average legibility distance for Type IX sheeting and Type III sheeting was practically negligible (only approximately 1 percent). In contrast, the average legibility distance for Type VIII sheeting was approximately 5 percent less than that of the Type III and Type IX sheeting.

For the pavement markings, the marking with the highest retroreflectivity (800 mcd/m^2/lux) had the longest average end detection distance, while the marking with the lowest retroreflectivity (100 mcd/m^2/lux) had the shortest average end detection distance. Increasing the retroreflectivity by 200 mcd/m^2/lux (from 100 mcd/m^2/lux to 300 mcd/m^2/lux) increased the average end detection distance by 41 percent. Increasing the retroreflectivity by an additional 500 mcd/m^2/lux (from 300 mcd/m^2/lux to 800 mcd/m^2/lux) increased the average end detection distance by 23 percent.

With respect to the research objective, the relationship between vehicle type and material type was of prime concern. This relationship was found to be statistically significant only for the daytime and nighttime speed limit signs, and even then the practical difference in the legibility distance between material types as a function of vehicle type was small. For the daytime speed limit signs, the Type IX sheeting produced the largest increase in legibility distance for the commercial vehicle (40 ft) compared to the passenger car (8 ft). This same finding was not replicated for the nighttime speed limit signs. Furthermore, the relationship between vehicle type and material type for the nighttime speed limit signs was less distinctive in terms of performance differences.

Headlamp Illuminance

The results of the commercial vehicle headlamp study show that the headlamp illuminance of the Freightliner used in the nighttime controlled field study was consistently greater than the average headlamp illuminance of on-road commercial vehicles. This difference was especially noticeable at the right shoulder location, which represented the average location of the signs in the nighttime controlled field study. Thus, the amount and pattern of light emitted by the Freightliner's headlamps increased the amount of light falling on the signs (illuminance), which in turn reduced the disadvantage associated with the larger eye/headlamp separation of commercial vehicles and increased the amount of light returned to the driver (luminance). This higher than expected luminance allowed the participants in the Freightliner to read the signs farther in advance than expected. This hypothesis supports the results of the nighttime controlled field study. The headlamp illuminance of the passenger car used in the nighttime controlled field study was quite comparable to the average headlamp illuminance of the on-road fleet.

RECOMMENDATIONS

Neither the sign nor pavement marking findings revealed consistent relationships between vehicle type and material type. For the legibility of signs, the relationship between vehicle type and sheeting type was found to be statistically significant only for daytime and nighttime speed limit signs, and even then the practical difference was small. For the end detection of pavement markings, the study revealed no statistical or practical relationship between vehicle type and material type. However, the study clearly showed that brighter pavement marking materials benefit drivers of both vehicle types.

Since no consistent relationship was revealed between vehicle type and either sign sheeting or pavement marking materials (as measured using nighttime driver performance), TxDOT can make decisions about their sign sheeting and pavement marking materials without necessarily being concerned about any specific vehicle type. In other words, for the scenarios studied, no specific considerations with respect to sign sheeting and pavement marking materials are needed for passenger car drivers or commercial vehicle drivers. The researchers also recommend that TxDOT install and maintain pavement marking materials at the highest retroreflectivity level feasible.

Based on the results of the research study documented herein, further research may include:

- additional measurements of the headlamp illuminance of commercial vehicles in order to better establish the headlamp illuminance of a “typical” on-road commercial vehicle;
- additional legibility studies using a commercial vehicle that illuminates signs similar to the identified “typical” commercial vehicle;
- pavement marking end detection studies under wet weather conditions;
- studies to assess the design of sign placement with respect to commercial vehicles; and
- the education of passenger vehicle drivers about the physical driving limitations of commercial vehicles.

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APPENDIX A:
COMMERCIAL VEHICLE DRIVER SURVEY

COMMERCIAL VEHICLE DRIVER SURVEY INTRODUCTION

This research study is being conducted by the Texas Transportation Institute (TTI), which is part of the Texas A&M University System (TAMU). It is sponsored by the Texas Department of Transportation. The study is being conducted to assess truck drivers' opinion of current roadway guidance devices.

We are looking for truck drivers to participate in a traffic survey so that we may obtain travel information from a commercial vehicle driver's point of view. There is no right or wrong answer, only your personal opinion. All information will be confidential and we will not use your name at any time.

The study will take approximately 10 minutes to complete. If you are uncomfortable answering any questions, please let me know. Also, if you choose not to continue to participate in the research for any reason, you are free to quit at any time.

SURVEY USED AT THE I-35 LOCATION

First, for background purposes, I need to ask you a few questions about yourself and your truck driving experience.

Part I – BACKGROUND

Do you currently have a Class A or B Commercial Driver's License? Yes_____ No_____
If yes, what type? ______________________
How many years have you had your commercial A or B license? ____________
Do you drive a commercial vehicle at night? Yes_____ No_____
If yes, what percentage of the time do you drive at night in Texas? __________
When driving your commercial vehicle, what type(s) of roads do you typically travel on (*circle all that apply*)? a) Interstate b) U.S./State Highways c) FM d) Local streets
Gender: ____ DOB: _________ Local Zip Code: _________ Residence State: ____

NOTE: If the subject does not have a current Class A or B Commercial Driver's License, does not drive at night, drives only on local streets, or is not 21 years of age, explain to him/her that they do not qualify to participate in the study, and thank them for their time.

What type of motor carrier operations do you have?

a) For Hire ______ Contract Hauling Service to: ___________________________________
b) Private _______ Company:____
c) Owner-Operator ______ Contract Hauling Service to:_____________________________

What is the type of truck you primarily drive (*circle response*)?

a) Straight b) Five-axle tractor-semi trailers (3S2 3-axle trailer w/2-axle semi)
c) Double trailer combinations d) Three- and four-axle tractor-semi trailers

Do you drive (*circle response*)? Short-haul shipping distance (<250 mi) Yes No
Long-haul shipping distance (≥250 mi) Yes No

What are your average miles traveled per year? Locally: ________ Texas: ________
United States:________

While traveling in Texas, do you usually drive a specific route or are you often in unfamiliar locations?____

What type of passenger vehicle (non-commercial) do you usually drive, if any (*circle response*)?
a) Standard car b) SUV c) Mini-van d) Van e) ≤ ½ Ton Pick-up f) > ½ Ton Pick-up
Where do you normally drive this passenger vehicle? ________________________________

The next part of the survey will focus on your opinion of Texas roadways from a commercial driver's point of view.

PART II – OPINION OF ROADWAY GUIDANCE DEVICES

1. Based on your truck driving experience, what is your primary criticism of current roadways in Texas? *If signs and/or pavement markings are mentioned go to Question 2b, if not continue with Question 2a.* ____
____
____
____

2a. Do you have any problems with the signs and/or pavement markings currently being used on Texas roadways? Yes ____ No____ If NO, go to Question 3a. If YES, briefly explain. *If the response deals with visibility or brightness, clarify what type of sign/pavement marking, what color, placement of device, what the specific problem is, and what their suggestions are regarding that specific problem.* ____
____
____
____

2b. Can you recall specific location(s) within Texas where you have experienced the problem(s) you just identified? Yes____ No_____ If YES, where and briefly explain. __________________
____
____
____

3a. While driving at <u>night in Texas</u>, where do you prefer roadway signs to be located (*circle response*)? a) Right side of roadway; b) Left side of roadway; c) Overhead; or d) no preference Briefly explain why. ____

____

____

____

3b. In your opinion, which color or colors of roadway signs are the easiest to see at <u>night in Texas</u>? *If the subject states more than one color, please mark all responses in the order of the easiest to the hardest, with 1 being the easiest and 8 being the hardest. DO NOT READ THE COLORS TO THE SUBJECT!*
a)___red b)___black c)___white d)___orange e)___yellow f)___brown
g)___green h)___blue

3c. From a commercial vehicle driver's perspective, do you feel that most <u>Texas</u> roadway signs are a) very easy; b) easy; c) neither easy nor hard; d) difficult; or e) very difficult to see at <u>night</u> (*circle response*)?

4a. Do you have any general comments or concerns about the brightness of signs and/or pavement markings at <u>night in Texas</u>? Yes____ No_____ If NO, go to Question 5a. If YES, briefly explain. *Include what <u>type</u> of sign/pavement marking, what color, <u>placement</u> of device, what the specific problem is, and what their suggestions are regarding that specific problem.*

____

____

____

____

4b. Can you recall specific locations within <u>Texas</u> where you have experienced the problem(s) you just identified? Yes____ No_____ If YES, where and briefly explain. __________________

____

____

____

If the subject DOES NOT drive a passenger vehicle in Texas go to Question 6.

5a. In <u>Texas</u>, do you notice a difference at <u>night</u> in the brightness of signs and/or pavement markings when you are driving a commercial vehicle versus a passenger vehicle? Yes____ No_____ If NO, go to Question 5b. If YES, briefly explain *(if the subject answers Question 5b here, proceed to Question 6).* ____

____

____

____

5b. At night when driving a commercial vehicle in Texas, do signs and/or pavement markings usually appear a) brighter; b) less bright; or c) the same as when you are driving a passenger vehicle (*circle response*)?

6. General comments or suggestions:____
____
____
____

That completes the survey – Thank you!

SURVEY USED AT THE I-45 and I-10 LOCATIONS

First, for background purposes, I need to ask you a few questions about yourself and your truck driving experience.

Part I – BACKGROUND

Do you currently have a Class A or B Commercial Driver's License? Yes_____ No_____
If yes, what type? _____________________
How many years have you had your commercial A or B license? ____________
Do you drive a commercial vehicle at night? Yes_____ No_____
If yes, what percentage of the time do you drive at night in Texas? __________
When driving your commercial vehicle, what type(s) of roads do you typically travel on (*circle all that apply*)? a) Interstate b) U.S./State Highways c) FM d) Local streets
Gender: ____ DOB: _________ Local Zip Code: _________ Residence State: ____

NOTE: If the subject does not have a current Class A or B Commercial Driver's License, does not drive at night, drives only on local streets, or is not 21 years of age, explain to him/her that they do not qualify to participate in the study, and thank them for their time.

What type of motor carrier operations do you have (*check one*)?
a) For Hire ______ b) Private _______ c) Owner-Operator ______

What is the type of truck you primarily drive (*circle one response*)?
a) Straight b) Five-axle tractor-semi trailers (3S2 3-axle trailer w/2-axle semi)
c) Double trailer combinations d) Three- and four-axle tractor-semi trailers

Do you drive (*circle response*)?	Short-haul shipping distance (<250 mi)	Yes	No
	Long-haul shipping distance (≥250 mi)	Yes	No

What are your average miles traveled per year? United States:________ Texas: ________

While traveling in Texas, do you usually drive a) specific routes; b) different routes; or c) both (*circle one response*)?

What type of passenger vehicle (non-commercial) do you usually drive, if any (*circle one response*)? a) Standard car b) SUV c) Mini-van d) Van e) ≤ ½ Ton Pick-up f) > ½ Ton Pick-up g) Motorcycle
Where do you normally drive this passenger vehicle? ___________________________________

The next part of the survey will focus on your opinion of Texas roadways from a commercial driver's point of view.

PART II – OPINION OF ROADWAY GUIDANCE DEVICES

1. Based on your truck driving experience, what is your primary criticism of current roadways in Texas? *If signs and/or pavement markings are mentioned go to Question 2b, if not continue with Question 2a*. ____
____
____
____

2a. Do you have any problems with the signs and/or pavement markings currently being used on Texas roadways? Yes ____ No____ If NO, go to Question 3a. If YES, briefly explain. *If the response deals with visibility or brightness, clarify what type of sign/pavement marking, what color, placement of device, what the specific problem is, and what their suggestions are regarding that specific problem.* ____
____
____
____

2b. Can you recall specific location(s) within Texas where you have experienced the problem(s) you just identified? Yes____ No_____ If YES, where and briefly explain. _________________
____
____
____

3a. While driving at night in Texas, where do you prefer roadway signs to be located (*circle one response*)? a) Right side of roadway; b) Left side of roadway; c) Overhead; or d) no preference
Briefly explain why. ____
____
____
____

3b. In your opinion, which color or colors of roadway signs are the easiest to see at night in Texas? Which color or colors of roadway signs are the hardest to see at night in Texas? *Please mark all responses in the order of the easiest to the hardest, with 1 being the easiest and 8 being the hardest. DO NOT READ THE COLORS TO THE SUBJECT!*
a)___red b)___black c)___white d)___orange e)___yellow f)___brown
g)___green h)___blue

3c. From a commercial vehicle driver's perspective, do you feel that most Texas roadway signs are a) easy; b) average; or c) difficult to see at night (*circle one response*)?

4a. Do you have any general comments or concerns about the brightness of signs and/or pavement markings at night in Texas? Yes____ No_____ If NO, go to Question 5a. If YES, briefly explain. *Include what type of sign/pavement marking, what color, placement of device, what the specific problem is, and what their suggestions are regarding that specific problem.*

____

____

____

____

4b. Can you recall specific locations within Texas where you have experienced the problem(s) you just identified? Yes____ No_____ If YES, where and briefly explain. __________________

____

____

____

If the subject DOES NOT drive a passenger vehicle in Texas go to Question 6.

5. At night when driving a commercial vehicle in Texas, do signs and/or pavement markings usually appear a) brighter; b) less bright; or c) the same as when you are driving a passenger vehicle (*circle one response*)?

6. General comments or suggestions:____

____

____

____

That completes the survey – Thank you!

APPENDIX B:
ADDITIONAL COMMERCIAL VEHICLE DRIVER SURVEY RESULTS

Table B1. I-35 Survey – Criticisms of Roadways in Texas.[a]

Category	Percent of Participants (n=40)	Example of Criticisms
Construction	33%	- Lane width too narrow. - Poor traffic control devices. - Patch road and do not come back and stripe it.
Rough Roads/ Maintenance	30%	- Rough pavement. - Roads need to be repaired.
Entrance and Exit Ramps	23%	- Ramps are too short. - No acceleration lanes. - Layout of ramp is not marked.
Striping and Signs	8%	- Green signs and are old and do not show up. - White stripes on SH and FM roads are faded. - White lines on new pavement are hard to see when raining.
Lane Width	8%	- Narrow lanes. - Secondary roads are not wide enough.
Miscellaneous	33%	- Inexperienced truck drivers. - Passenger vehicle drivers. - Congestion. - Frontage roads (one-way vs. two-way). - Split speed limits.
Did Not Comment	23%	- None.

SH – State Highway; FM – Farm-to-Market

[a] 52 comments from 31 participants

Table B2. I-45 Survey – Criticisms of Roadways in Texas.[a]

Category	Percent of Participants (n=40)	Example of Criticisms
Construction	10%	- Construction takes too long. - Construction at night is better than during the day. - Too many flashing lights. - Concrete barrier does not have enough reflectors.
Rough Roads/ Maintenance	38%	- Rough pavement. - Roads need to be repaired (rutting and pot holes). - Uneven lanes.
Entrance and Exit Ramps	8%	- Not long enough. - Need more room to weave and merge.
Striping and Signs	10%	- Pavement markings on road faded (center and edge lines). - Need more advance warning – signs too late.
Lane Width	3%	- Roads too narrow.
Miscellaneous	33%	- Passenger vehicle drivers. - Differential speed limits (day vs. night; truck vs. car). - Speed limit too low at night. - Center median barriers are needed. - Need more rest areas.
Did Not Comment	18%	- None.

[a] 40 comments from 33 participants

Table B3. I-10 Survey – Criticisms of Roadways in Texas.[a]

Category	Percent of Participants (n=41)	Example of Criticisms
Construction	22%	- Need to provide more directional signing. - Always under construction. - Close off too much of the road at a time (length of zone). - Police officers need to be located before the construction zone, not in the zone. - Barriers make lanes too narrow for trucks.
Rough Roads/ Maintenance	10%	- Asphalt ruts. - Interstates rutted and need work. - Pretty rough, have to be alert to keep truck on road. - Where bridge and road connects, the road is not level. - Country roads need maintenance. - Need to improve secondary roads.
Entrance and Exit Ramps	20%	- Exit and entrance ramps too short. - Entrance and exit ramp combinations. - Lack of traffic yielding to ramp traffic. - Yield system easily violated.
Striping and Signs	15%	- Green signs that are faded out are really hard to see. - Green signs are not reflective and cannot be read at night. - When it rains it is hard to see pavement markings. - Pavement markings need to be brighter. - Bridge height signs need to be placed further in advance. - Need more advance notice of construction and exits.
Lane Width	2%	- Some roads are too narrow.
Miscellaneous	27%	- Split speed limit. - Too much traffic. - Weight restrictions. - Passenger vehicle drivers. - Truck only lanes.
Did Not Comment	17%	- None.

[a] 45 comments from 34 participants

Table B4. I-35 Survey – Problems with Signs and/or Pavement Markings Currently Being Used in Texas.

Category	Example of Comments[a]
Signs	*Placement:* - Not enough warning for exits or lane ends. - Not enough signs (speed limit signs too far apart). - Signs need to be raised or lowered so truckers can see around them. - Need more advance warning, especially in construction zones. - Need less signs. *Design:* - Green signs are old and do not show up. - Signs are not big enough and there is not enough information on them. - Need to make signs bigger. - Signs need to be in both English and Spanish.
Pavement Markings	- Pavement markings are faded or are not bright enough so hard to see in the rain (especially white markings on concrete) (*7 comments*). - Patch road and do not come back and stripe it. - Pavement markings on secondary roads (SH and FM) need to grade.

SH – State Highway; FM – Farm-to-Market

[a] Total of 18 comments from 15 participants

Table B5. I-45 Survey – Problems with Signs and/or Pavement Markings Currently Being Used in Texas.

Category	Example of Comments[a]
Signs	*Placement:* - Need more advance warning (especially at exits and turns) (*9 comments*). - Signs need to be further off the road. - Need to make sure signs are not obstructed by advertisements or growth. - Some signs block driver’s view at intersections when in cab over truck. - The placement of flashing arrow signs is sometimes distracting or blinding. *Design:* - Not enough visibility to read entire signs (*2 comments*). - On local roads, signs are too small and hard to read. - Signs need to be lighted up so that they are more visible. - Signs could be bigger.
Pavement Markings	- Pavement markings (center and edge lines) are faded (*2 comments*). - Sometimes pavement markings in construction areas are not adequately marked or visible. - Roads need to be re-striped. - Need clearer pavement markings. - Can’t see pavement markings on dark pavement.

[a] Total of 24 comments from 20 participants

Table B6. I-10 Survey – Problems with Signs and/or Pavement Markings Currently Being Used in Texas.

Category	Example of Comments[a]
Signs	*Placement:* - Need more advance signing (especially at exits) (*3 comments*). - Bridge height signs need to be placed further in advance. - No signs marking routes for oversize loads. *Design:* - Green signs are not reflective, so cannot read at night (*2 comments*). - Green signs that are faded out are really hard to see. - Remove white letters and replace with FYG letters. - Signs could be brighter. - Can't read because of dual alternating flashing lights on sign. - Don't like the signs in Spanish.
Pavement Markings	- Pavement markings hard to see when it rains (especially in construction) (*4 comments*). - Pavement markings could be brighter (*2 comments*). - Need to make pavement markings more reflective.

FYG – Fluorescent Yellow-Green
[a] Total of 19 comments from 16 participants

Table B7. I-35 Survey – Concerns about the Brightness of Signs and/or Pavement Markings in Texas at Night.

Category	Example of Comments[a]
Signs	- Need to be brighter (*5 comments*). - Can't see/read signs because they are old and faded (*4 comments*). - Hard to see especially in the rain (*2 comments*). - Have to get really close to signs to see them (*2 comments*). - Miscellaneous lighting near signs makes them hard to read (*2 comments*). - Signs are set up for cars. Trucks are higher, making it hard to see them. - Green signs with town and mileage are not reflective. - Can't read letters on green signs until really close to the sign. - Signs need to be fluorescent and near the road. - Fluorescent signs are better. - Overhead signs need to be lit up. - Don't use orange signs at night or make them brighter.
Pavement Markings	- Need to be brighter (*6 comments*). - Pavement markings are faded (*3 comments*). - Hard to see especially in the rain (*3 comments*). - Markings are hard to see on asphalt (especially white markings in the rain) (*2 comments*). - Stripes are hard to see on concrete (especially white markings in the rain) (*2 comments*). - Pavement markings are not reflective in the rain. - Reflectors are hard to see especially in the rain. - Need to do markings immediately after they finish a road.

[a] Total of 41 comments from 28 participants

Table B8. I-45 Survey – Concerns about the Brightness of Signs and/or Pavement Markings in Texas at Night.

Category	Example of Comments[a]
Signs	- Signs need to be more visible, reflective, or brighter (*5 comments*). - Signs are getting brighter. - Need to have bigger letters. - Need to be lighted. - Night speed limit signs don't show up as well. - Need to maintain reflectivity, especially construction signs. - Sign placement sometimes makes signs not visible especially in construction. - Orange signs with flashing beacons are so distracting you can't see what the sign says. - In construction, too many lights. Flashing arrow too bright.
Pavement Markings	- Pavement markings are faded (*2 comments*). - Hard to see especially when raining (*2 comments*). - Pavement markings are faded, so they are hard to see until you are on top of them instead of beside them. - On new surfaces, pavement markings are hard to see because of too much glare. - Need clearer markings. - New roads without markings, you can't see where you are going. - At locations that are not striped but have markers, the markers get dirty and you can't see them. - Need to be touched up. - Need to be painted more often.

[a] Total of 24 comments from 22 participants

Table B9. I-10 Survey – Concerns about the Brightness of Signs and/or Pavement Markings in Texas at Night.

Category	Example of Comments[a]
Signs	- Signs could be brighter (*4 comments*). - Signs need to be reflective, can't read when not (*2 comments*). - Arrowboards are too bright (*2 comments*). - Green signs faded out and hard to see at night (*2 comments*). - When light hits green signs at night you cannot read. - Signs are dirty. - Signs could be lit up more. - Some signs are faded and need to be replaced. - Older signs do not have reflection. - Signs are not big enough or well enough marked. - Signs at night hard to read with glaring headlights. You have to be right on them to read them. - Signs telling trucks to use particular lane in construction zone are too near the zone and you cannot read them until you are right on top of them. - Need blue lettering on construction signs. - Stop signs angled so that you cannot see them when you are off angle. You can only see them when you are straight on.
Pavement Markings	- Add reflectors, helps when raining (*5 comments*). - Pavement markings faded and hard to see, especially when it rains (*4 comments*). - Pavement markings need to be repainted (*3 comments*). - Pavement markings need to be more reflective (*2 comments*). - Pavement markings could be brighter (*2 comments*). - Pavement marking need to be painted more often. - Road markings could be newer on rural roads.

[a] Total of 38 comments from 25 participants

Table B10. Other Comments Received.

Survey Location	Comments
I-35	- Drivers of passenger vehicles need to be educated about trucks (*6 comments*). - Need to stripe more often (*1 comment*). - Need a truck stop sign (picture of truck used on a sign in other states) (*1 comment*). - New blue lights on new vehicles are bright when behind us (*1 comment*). - Length needs to be extended on entrance and exit ramps (*1 comment*). - Speeds should be equal for cars and trucks. Need designated truck lane (*1 comment*).
I-45	- Can see markings better in a car (*1 comment*). - I like the street signs on FM and local streets (*1 comment*). - Main problem is the dips in the road. Need to smooth out the pavement surface when they re-do the roads (*1 comment*). - Seems some of the red lights go from amber to red too fast, need to adjust timing (*1 comment*). - Frontage roads too narrow (*1 comment*). - Not enough room, roads too narrow in construction areas (*1 comment*). - Need to educate passenger vehicle drivers (*1 comment*). - Need to raise speed limit (*1 comment*).
I-10	- Educate passenger vehicle drivers about trucks (*2 comments*). - Not enough advance notice of exits (*1 comment*). - Fog lights blind you. Need to prohibit them since no one turns them off (*1 comment*). - Get construction done (*1 comment*). - Need more roads around Dallas (*1 comment*). - Passenger cars with high beams (*1 comment*). - Cars and trucks need same speed limit. Also, need same speed limit for day and night.

APPENDIX C:
NIGHTTIME CONTROLLED FIELD STUDY
DATA COLLECTION FORMS

PROJECT 4269 NIGHTTIME CONTROLLED FIELD STUDY DATA FORM
Course 1

Subject No.:_____________ Date:______________
Administrator:___________ Test Vehicle Used:_______________
Time Started:____________ Time Completed:________________

Gender:___ DOB:_______ Age:_____ Snellen Eye Test:_________________ Vistech Eye Test:_________________	Driving Restriction:_____________________ _____________________________________ Own Restriction:________________________ _____________________________________

Location/ Treatment	Word	Distance (ft)	Comments	Location/ Treatment	Word	Distance (ft)	Comments
9/1C	E-Houses			6/27A	BSL-73		
10/6B	E-Series			7/33C	BSL-92		
11/32C	BSL-76			8/26A	BSL-48		
12/29B	BSL-93			19/14C	D-Rogers		
13/31C	BSL-42			20/11B	D-Spring		
14/28B	BSL-78			21/24C	WSL-92		
15/25A	BSL-96			22/21B	WSL/46		
16/7A	D-Austin			23/18A	WSL/73		
17/10B	D-Temple			24/17A	WSL/48		
18/13C	D-Laredo			25/23C	WSL/76		
9/2C	E-Forget			26/8A	D-Conroe		
10/4B	E-Honors			27/15C	D-Lufkin		
38/PM-N	H-Retro			28/9A	D-Alpine		
34/PM-N	L-Retro			29/12B	D-Denton		
36/PM-N	M-Retro			37/PM-S	M-Retro		
1/16A	WSL-96			35/PM-S	L-Retro		
2/19B	WSL-78			39/PM-S	H-Retro		
3/22C	WSL-42			9/3C	E-Senior		
4/20B	WSL-93			10/5B	E-Target		
5/30B	BSL-46						

Comments: ____
____

PROJECT 4269 NIGHTTIME CONTROLLED FIELD STUDY DATA FORM
Course 1 – Follow-up Survey

Subject No.:_____________ Date:________________
Administrator:___________ Test Vehicle Used:_________________

Pavement Marking Rating Survey

1. Were there any noticeable changes in the appearance of the white pavement markings that you encountered during your drive through of the study section? ____ Yes ____ No
If yes, describe the changes. ____
____

2. Was there a section of the white pavement marking that you encountered that you preferred?
____ Yes ____ No If yes, why?____
____

3. If you were driving, would all the pavement markings that you encountered be bright enough for you?
____ Yes ____ No

Sign Rating Survey

1. Were there any noticeable changes in the appearance of the:
White daytime speed limit signs? ____ Yes ____ No
If yes, describe ____
____
Black nighttime speed limit signs? ____ Yes ____ No
If yes, describe ____
____
Expressway guide signs? ____ Yes ____ No
If yes, describe ____
____
City destination signs? ____ Yes ____ No
If yes, describe ____
____

2. Were there any signs that you encountered that you preferred? ____ Yes ____ No
If yes, why?____
____

3. If you were driving, would all the signs that you encountered be bright enough for you?
____ Yes ____ No

4. Were there any signs that you encountered that you felt were too bright? ____ Yes ____ No
If yes, can you recall which ones?____
____

General Comments:____
____

PROJECT 4269 NIGHTTIME CONTROLLED FIELD STUDY DATA FORM
Course 2

Subject No.:_____________ Date:______________
Administrator:___________ Test Vehicle Used:_______________
Time Started:____________ Time Completed:________________

Gender:___ DOB:_______ Age:_____ Snellen Eye Test:_________________ Vistech Eye Test:_________________	Driving Restriction:_____________________ _____________________________________ Own Restriction:_______________________ _____________________________________

Location/ Treatment	Word	Distance (ft)	Comments	Location/ Treatment	Word	Distance (ft)	Comments
19/14C	D-Rogers			11/32C	BSL-76		
20/11B	D-Spring			12/29B	BSL-93		
21/24C	WSL-92			13/31C	BSL-42		
22/21B	WSL/46			14/28B	BSL-78		
23/18A	WSL/73			15/25A	BSL-96		
24/17A	WSL/48			16/7A	D-Austin		
25/23C	WSL/76			17/10B	D-Temple		
5/30B	BSL-46			18/13C	D-Laredo		
6/27A	BSL-73			9/1C	E-Houses		
7/33C	BSL-92			10/5B	E-Target		
8/26A	BSL-48			38/PM-N	H-Retro		
37/PM-S	M-Retro			34/PM-N	L-Retro		
35/PM-S	L-Retro			36/PM-N	M-Retro		
39/PM-S	H-Retro			1/16A	WSL-96		
26/8A	D-Conroe			2/19B	WSL-78		
27/15C	D-Lufkin			3/22C	WSL-42		
28/9A	D-Alpine			4/20B	WSL-93		
29/12B	D-Denton			9/2C	E-Forget		
9/3C	E-Senior			10/6B	E-Series		
10/4B	E-Honors						

Comments: ____
____

PROJECT 4269 NIGHTTIME CONTROLLED FIELD STUDY DATA FORM
Course 2 – Follow-up Survey

Subject No.:_____________ Date:________________
Administrator:___________ Test Vehicle Used:_________________

Pavement Marking Rating Survey

1. Were there any noticeable changes in the appearance of the white pavement markings that you encountered during your drive through of the study section? ____ Yes ____ No
   If yes, describe the changes. ____
   ____

2. Was there a section of the white pavement marking that you encountered that you preferred?
   ____ Yes ____ No If yes, why?____
   ____

3. If you were driving, would all the pavement markings that you encountered be bright enough for you?
   ____ Yes ____ No

Sign Rating Survey

1. Were there any noticeable changes in the appearance of the:
   White daytime speed limit signs? ____ Yes ____ No
   If yes, describe ____
   ____

   Black nighttime speed limit signs? ____ Yes ____ No
   If yes, describe ____
   ____

   Expressway guide signs? ____ Yes ____ No
   If yes, describe ____
   ____

   City destination signs? ____ Yes ____ No
   If yes, describe ____
   ____

2. Were there any signs that you encountered that you preferred? ____ Yes ____ No
   If yes, why?____
   ____

3. If you were driving, would all the signs that you encountered be bright enough for you?
   ____ Yes ____ No

4. Were there any signs that you encountered that you felt were too bright? ____ Yes ____ No
   If yes, can you recall which ones?____
   ____

General Comments:____
____

APPENDIX D:
CHEVY LUMINA H/V ANGLES AND ILLUMINANCE POSITIONS

Table D1. Sign Placement and Chevy Lumina Illumination Positions.

Sign Type	Viewing Distance (ft)	Sign Centroid Offset [a] (ft)	Sign Centroid Height (ft)	Left Headlamp		Right Headlamp	
				Horizontal Angle (degrees)	Vertical Angle (degrees)	Horizontal Angle (degrees)	Vertical Angle (degrees)
Right Guide	200 500 650	46	11	15.1 6.1 4.7	2.4 1.0 0.8	14.1 5.7 4.4	2.5 1.0 0.8
Right Shoulder	200 500 650	18	9.25	7.4 3.0 2.3	1.9 0.8 0.6	6.4 2.5 2.0	1.9 0.8 0.6
Overhead Guide	200 500 650	0	25	0.5 0.2 0.2	6.5 2.6 2.0	-0.5 -0.2 -0.2	6.5 2.6 2.0
Left Shoulder	200 500 650	-31.5	9	-6.7 -2.7 -2.1	1.9 0.8 0.6	-7.8 -3.1 -2.4	1.9 0.8 0.6

[a] Measured from the right edge of the right travel lane

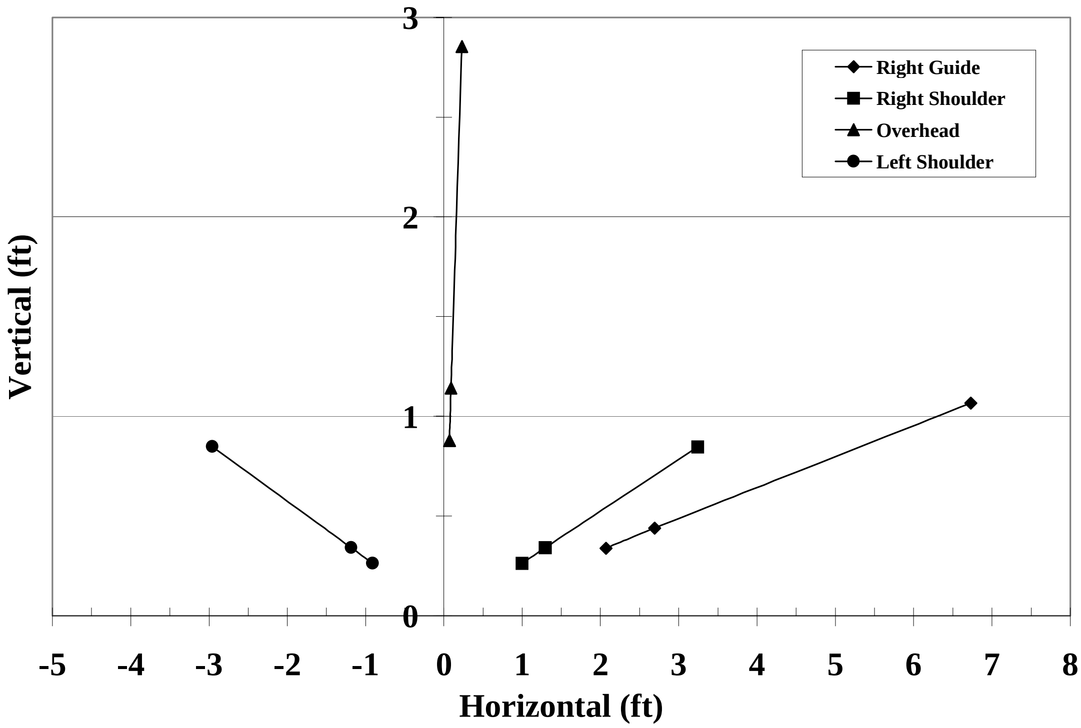

Figure D1. Chevy Lumina Left Headlamp Illuminance Positions.

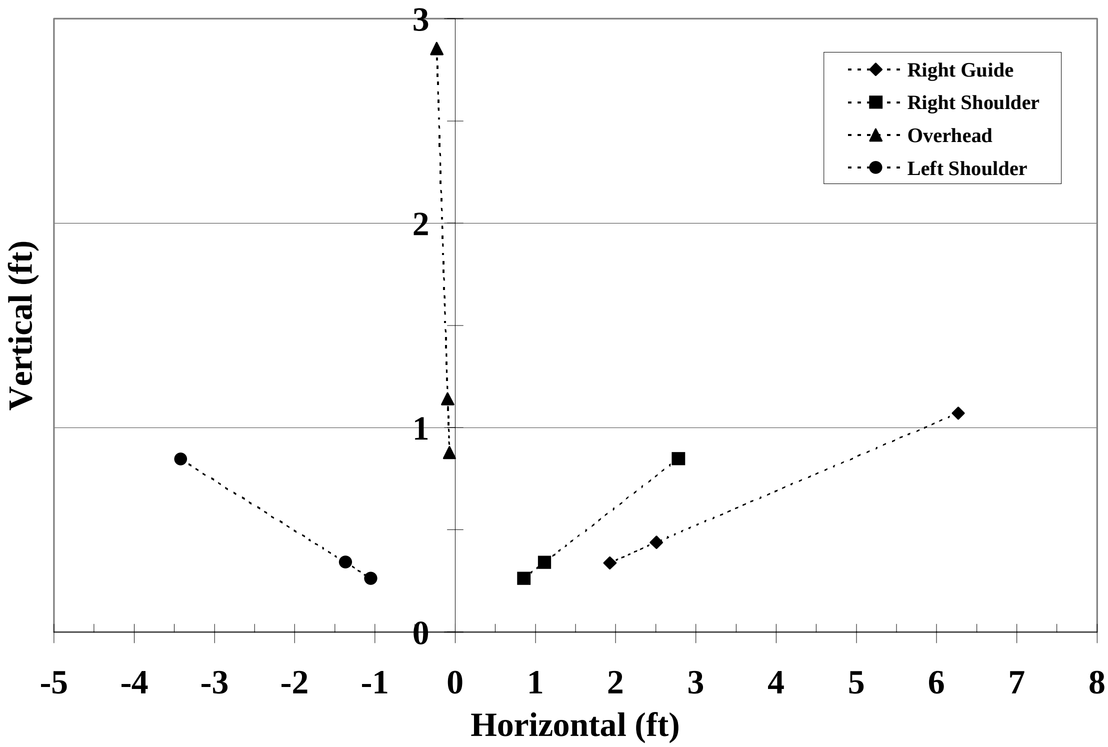

Figure D2. Chevy Lumina Right Headlamp Illuminance Positions.

APPENDIX E:
COMMERCIAL VEHICLE HEADLAMP STUDY
DATA COLLECTION FORM

PROJECT 4269 COMMERCIAL VEHICLE HEADLAMP STUDY DATA FORM

1. Vehicle make, model, year, and mileage ____
2. Type of headlamp ____
3. Does the truck have lights over the cab? Yes No If yes, how many?____ Are they: ON OFF
4. Distance from the center of a headlamp to the ground (in) ____________________________
5. Lateral separation between headlamps (center to center) (in) __________________________
6. Distance from the center of the driver's eye to the ground (in) __________________________
7. Lateral offset of the driver's nose from the center of the vehicle (in) ____________________
8. Longitudinal setback of the driver's eye from the front of the headlamp (in) ______________
9. **LEFT** (driver's side) headlamp measurements

Sign Position	Illuminance at Distance (lux)		
	200 ft (Meter 1)	**500 ft (Meter 2)**	**650 ft (Meter 3)**
1. Fluorescent Green Circles (Right Guide)			
2. Fluorescent Pink Circles (Right Shoulder)			
3. Fluorescent Yellow Circles (Overhead)			
4. Fluorescent Orange Circles (Left Shoulder)			
5. Fluorescent Pink Quarter Circle (4269)			

10. **RIGHT** (passenger's side) headlamp measurements

Sign Position	Illuminance at Distance (lux)		
	200 ft (Meter 1)	**500 ft (Meter 2)**	**650 ft (Meter 3)**
1. Dark Blue Circles (Right Guide)			
2. Red Circles (Right Shoulder)			
3. Green Circles (Overhead)			
4. Light Blue Circles (Left Shoulder)			
5. Red Quarter Circle (4269)			

11. Ambient light measurements

Position	Illuminance (lux)
1. Middle Right	
2. Top Center	
3. Middle Left	