EVALUATION OF RETROREFLECTIVE SHEETINGS FOR USE ON TRAFFIC CONTROL DEVICES AT CONSTRUCTION WORK ZONES

Final Report

by

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16. ABSTRACT

The overall objective of this project was to evaluate the relative adequacy of the engineering grade, super-engineering grade, and high-intensity grade sheetings when used on traffic control devices at construction work zones. Evaluation criteria included driver visibility needs, durability and economics, and other practical considerations. To meet the objectives of this project, a research plan consisting of literature review, controlled field experiments, real-world field experiments, accelerated weathering tests, survey of Oklahoma traffic control contractors, and economic analysis was adopted. The results of these tasks formed the basis for the findings and conclusions of this study.

While the high-intensity grade sheeting has the highest target value of the three sheeting grades, the tradeoff between detection and legibility of traffic control signs was interpreted to favor the use of the super-engineering grade on signs in both urban and rural construction projects. Durability, economics, and other practical issues emphasized by traffic control contractors support this conclusion. Nevertheless, use of the high-intensity grade sheeting in urban construction projects may be warranted at locations with visual clutter and excessive background lights.

The beneficial effects of upgrading the type of sheeting used on barrels, barricades, and vertical panels from engineering grade to high-intensity grade or super-engineering grade were demonstrated by the significant increase in both the detection and recognition distances of these devices. Yet, the benefits of upgrading to the high-intensity grade were found to be offset by the significant increase in cost, the less durability of the sheeting material, and the problems with fabrication and handling. Upgrading to super-engineering grade offers the most cost-effective and balanced solution.

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NOTICE

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EXECUTIVE SUMMARY

It is estimated that as much as 90% of the information essential to the driving task is acquired visually. Retroreflective sheetings are used on traffic control devices to enhance their visibility, particularly at nighttime. Improving the visibility of traffic control devices should be helpful to drivers in all age groups, particularly the elderly drivers.

The overall objective of this project was to evaluate the relative adequacy of the engineering grade, super-engineering grade, and high-intensity grade sheetings when used on traffic control devices at construction work zones. Evaluation criteria included driver visibility needs, durability and economics, and other practical considerations. The basic question addressed in this research was as follows:

> *Based on driver visibility needs, durability and economics, and other practical considerations, which of the three retroreflective sheeting products available in the market is most adequate for use on traffic control devices (signs, drums, barricades, and vertical panels) at construction work zones.*

To meet the objectives of this project, a research plan consisting of literature review, controlled field experiments, real-world field experiments, accelerated weathering tests, survey of Oklahoma traffic control contractors, and economic analysis was adopted. A total of 239 subject drivers participated in the field experiments. The results of these tasks formed the basis for the findings and conclusions of this study.

As it is expected with any research effort involving human factors, some conflicting evidence were noted in the findings. The weakest point in the data obtained during the field experiments was the large amount of variability in the drivers' responses that could not be explained. Another weak point was the small sample size employed during the real-world experiments. Fortunately, larger sample sizes were available during the controlled experiments. The strongest point in the appraisal of drivers visibility needs was the questionnaire response data concerning the adequacy of the different sheetings and other comments provided by the drivers.

In the urban construction project, the high-intensity grade sheeting demonstrated greater target value, in terms of mean array detection distance, than the super-engineering grade sheeting both during daytime and nighttime conditions. At the rural test site, no statistically significant difference was found between the target values of the engineering grade, super-engineering grade, and high-intensity grade sheetings both during daytime and nighttime conditions.

At nighttime, signs with super-engineering grade sheeting were more often legible than signs with high-intensity grade or engineering grade sheetings. During daylight conditions, the mean recognition distances of signs with high-intensity-grade and super engineering grade sheetings were not significantly different, and both were greater than the legibility distance of signs with engineering grade sheeting. Questionnaire ratings concerning the legibility and adequacy of signs favored the super-engineering grade. Some drivers reported glare problems with the high-intensity grade sheeting particularly at nighttime.

In terms of mean recognition distance, there was no significant difference in the conspicuity of barrels and barricades with super-engineering grade and high-intensity grade sheetings both during daytime and nighttime conditions. Barrels and barricades with engineering grade sheeting were less conspicuous than those with high-intensity grade and super-engineering grade sheetings.

Results of the contractors' survey indicate that the expected service life of traffic control devices at construction work zones is less than one year. Typical modes of retroreflective sheeting deterioration include color fading, abrasion, peeling, and impact cracking. Issues of frequent vandalism and device knockdowns by traffic were noted by the contractors. Usually, devices are replaced because they do not meet the "like-new" requirement specified in the contract documents. Issues of sheeting durability and ease of fabrication were emphasized in the contractor's comments. Engineering grade sheeting was characterized as being the most durable and the easiest to work with during device fabrication. Super-engineering grade was praised for its resemblance to the engineering grade in durability and ease of fabrication and handling. High-intensity grade received low ratings from the durability point of view. Problems with the handling, fabrication, and transportation of high-intensity sheetings were reported by one contractor.

Limited data on the performance of the different sheetings under natural exposure conditions were available in the published literature. Based on weatherometer test results, all the three grades of sheeting exceeded the minimum SIA requirements specified by the ASTM after the prescribed number of hours of artificial weathering.

Two measures of economic efficiency were employed in the evaluation of the different sheetings: cost per year of device service life and cost of device per construction project. High-intensity grade was found to be the most costly when used on signs, barrels, barricades, and vertical panels. Differences between the cost per year of engineering grade and super-engineering grade sheetings were insignificant when used on signs, barrels, and vertical panels. Similar findings were obtained for the cost per project. Barricades with super engineering grade demonstrated lower cost per year and cost per project than barricades with engineering grade.

While the high-intensity grade sheeting has the highest target value of the three sheeting grades, the tradeoff between detection and legibility of traffic control signs was interpreted to favor the use of the super-engineering grade on signs in both urban and rural construction projects. Durability, economics, and other practical issues emphasized by traffic control contractors support this conclusion. Nevertheless, use of the high-intensity grade sheeting in urban construction projects may be warranted at locations with visual clutter and excessive background lights.

The beneficial effects of upgrading the type of sheeting used on barrels, barricades, and vertical panels from engineering grade to high-intensity grade or super-engineering grade were demonstrated by the significant increase in both the detection and recognition distances of these devices. Yet, the benefits of upgrading to the high-intensity grade were found to be offset by the significant increase in cost, the less durability of the sheeting material, and the problems with fabrication and handling. Upgrading to super-engineering grade offers the most cost-effective and balanced solution.

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INTRODUCTION

PROBLEM STATEMENT

Highway construction work zones pose unique safety problems to the traveling public because of the unexpected and unusual situations present. Not only is there a disruption to the continuous traffic flow expected by motorists, but safety of construction workers is also at risk. The Manual on Uniform Traffic Control Devices (MUTCD) states that adequate warning, delineation, and channelization by means of proper pavement marking, signing and channelization devices which are effective under varying light and weather conditions should be provided to assure the motorists of positive guidance while approaching and traversing highway construction work zones [5].

It is estimated that as much as 90% of the information essential to the driving task is acquired visually [6]. To be effective, traffic control devices must be visible from a sufficient distance to provide drivers with adequate perception and response time. Visibility of traffic control devices is more critical to nighttime driving than during the day, because driver's reliance on these devices for the necessary warning, regulation, and guidance increases as the ambient light decreases. Improving the visibility of traffic control devices should be helpful to drivers in all age groups, particularly the elderly drivers. Recent studies indicate that, among other age-related diminishing performance capabilities, a significant decline in visual acuity and depth perception begins in the mid-fifties [3, 4]. Older drivers need greater illumination to see objects clearly, but they suffer from excessive glare more than other drivers.

Retroreflective sheetings are used on traffic control devices to enhance their visibility, particularly at nighttime. A retroreflective sheeting is a flexible sheet consisting of large number of retroreflective elements such as microscopic glass beads or prismatic reflectors. Retroreflection takes place when the headlight beam strikes the traffic control device and is reflected directly back to the light source. Three grades of retroreflective sheetings are available in the market: engineering grade, super-engineering grade, and high-intensity grade.

The visibility distance of control devices, particularly signs, cannot be increased simply by increasing the retroreflectivity of the sheeting material. There is an optimum level of luminance above which signs become difficult to read. Although the MUTCD requires that control devices be either reflectorized or illuminated to show approximately the same shape and color day and night, it does not provide specific guidance concerning the adequate level of luminance needed.

The Oklahoma Department of Transportation (ODOT) recognizes that minimum retroreflective requirements for traffic control devices at construction work zones must be determined based on driver visibility needs, durability, and economics. The need for this research is emphasized by the lack of empirical evidence concerning performance limitations and relative adequacy of the three grades of retroreflective sheetings available. Manufacturers recommendations may not be very helpful, and ODOT engineers had to rely solely on engineering judgment and subjective assessment of the retroreflective sheeting products.

OBJECTIVES AND SCOPE

The research presented in this report was carried out under ODOT Project 2177 -- "Evaluation of Retroreflective Sheeting Products for Use on Traffic Control Devices at Construction Work Zones," which was initiated in Spring, 1990. The overall objective of this project was to evaluate the relative adequacy of the engineering grade, super-engineering grade, and high-intensity grade sheetings when used on traffic control devices at construction work zones. Evaluation criteria included driver visibility needs, durability, and economics.

The basic question which was addressed in this research was as follows:

Based on driver visibility needs, durability and economics, and other practical considerations, which of the three retroreflective sheeting products available in the market is most adequate for use on traffic control devices (signs, drums, barricades, and vertical panels) at construction work zones.

RESEARCH APPROACH

To meet the objectives of this project, a research plan consisting of six tasks was adopted. These tasks and the type of work performed are briefly described as follows:

Task 1. Literature Review - Review, evaluate and document existing information on: i) experience with performance of retroreflective sheeting products at construction work zones, and ii) measures of driver visibility needs, and durability and economics of sheeting materials.

Task 2. Controlled Field Experiments - The purpose of this task was to gather driver response measures concerning the relative adequacy of the different sheeting products in a planned lane closure situation. A sample of 165 paid driver subjects participated in the experiments. A test vehicle instrumented with distance measuring equipment was used. Daylight drivers were different from those who drove at night. To permit paired comparisons of driver's responses, some nighttime drivers were utilized in evaluating more than one type of sheeting.

All subject drivers were briefed on the test method, and each driver received specific instructions before entering the vehicle. Additional instructions were given to each subject by an experimenter riding in the vehicle. The experimenter recorded measurements of detection and recognition distances of traffic control devices as they were seen and read by each driver. After completing the test drive, each driver subject completed a questionnaire concerning the adequacy of the different devices which were present during the test.

Task 3. Real-World Field Experiments - The objective of this task was to gather driver response measures regarding the relative adequacy of the different retroreflective sheeting products in real-world field conditions. Two construction sites were selected for the real-world field experiments; one rural and one urban. Deployment of the retroreflective sheeting treatments on traffic control devices was planned in coordination with ODOT. The engineering grade sheeting was not tested at the urban site because ODOT does not specify its use at urban construction sites.

A sample of 74 ODOT personnel served as driver subjects. An effort was made to insure that the drivers had no special knowledge of the design or placement of traffic control devices. Daylight drivers were different from those who drove at night. Similar to task 2, a questionnaire concerning the adequacy of devices was completed by each subject driver following the test drive.

Task 4. Accelerated Weathering Tests - In this task, weatherometer test results were obtained from a number of sources including the ODOT Materials Laboratory and Seibulite International, Inc. Measurements of retroreflectivity of the weathered sheetings were analyzed and compared with the minimum performance requirements prescribed by the ASTM.

Task 5. Survey of Oklahoma Traffic Control Contractors - The purpose of this task was to gather data on service lives, cost items, deterioration modes, and problems with the handling and fabrication of traffic control devices with each type of retroreflective sheeting. A survey consisting of 11 questions was designed and mailed to the three major traffic control contractors in Oklahoma.

Task 6. Economic Analysis - Conduct life-cycle cost analysis for each sheeting type using the data obtained from the contractors' survey. Measures of effectiveness included the cost per year of service life of the control device and the cost per construction project where the device can be used.

OVERVIEW OF THE NEXT CHAPTERS

The results of the above six tasks form the basis for the findings and conclusions presented in the remainder of this report. Chapter 2 presents background material and the results of literature review. In Chapter 3, details of the research methodology are described. Chapter 4 summarizes the results of statistical analyses of device detection and recognition distances obtained during the field experiments. Driver's opinions concerning the adequacy of the different retroreflective sheetings are presented in Chapter 5. The contractor's survey results are summarized in Chapter 6. In chapter 7, the accelerated weathering test results are discussed. Results of the economic analysis are covered in Chapter 8. Finally, Chapter 9 presents an appraisal of the research findings and the conclusions of this study. The material presented in these chapters is supplementd by Appendices A through E.

CHAPTER 2

BACKGROUND

PRINCIPLES OF RETROREFLECTIVITY

Reflection of light occurs when the light illuminating an object is reflected back from the object. The brightness of the reflected light is directly related to the intensity of the light source and the type of material from which the object is made. As depicted in Figure 1, there are three types of reflection: diffuse, mirror, and retroreflection. Diffuse reflection results when light strikes an object that has a microscopically rough surface. The light scatters in all directions, and only a small amount of light is reflected back to the light source. Because only a small amount of light is returned along the path of the incident (incoming) light beam, diffuse reflecting materials have poor nighttime visibility to drivers.

Mirror reflection takes place when light strikes a microscopically smooth surface. The light is reflected from the surface at an equal, but opposite, angle from that of the incident light beam. Light is returned directly to the source only when the light beam is exactly perpendicular to the surface.

Retroreflection occurs when light strikes an object and is reflected directly back to the source of light. Because a relatively large amount of light is returned, retroreflective materials appear brightest to an observer located near the light source. It is the principle of retroreflection that is applied to traffic control devices. As shown in figure 2, there are two basic types of retroreflectors: a spherical lens and a cube corner reflector. A spherical lens reflector uses microscopic glass beads and a reflecting surface placed at the focal point to return light to its source. In cube-corner reflectors , light is reflected successively from the three back faces of the cube and is redirected to the source.

TYPES OF RETROREFLECTIVE SHEETINGS

A retroreflective sheeting is a flexible sheet that consists of very large number of spherical lens or cube-corner retroreflective elements embedded in a weather resistant transparent film. To reflect color, pigment or dye is inserted into the film or onto the reflective surface behind the retroreflective elements. Although there are a number of variations, the three common types of sheetings used on traffic control devices are: 1) *engineering grade*, 2) *super-engineering grade*, and 3) *high-intensity grade* sheetings. Table 1 shows the ASTM and the FP-85 classification schemes of retroreflective sheeting products [1, 9].

Both the engineering and super-engineering grades are of *enclosed lens* type sheeting with the main distinction between the two being a higher quality glass bead in the super-engineering grade sheeting. As shown in Figure 3, an enclosed lens sheeting consists of a layer of transparent plastic of the appropriate color in which microscopic glass beads are embedded. The plastic covering enables the

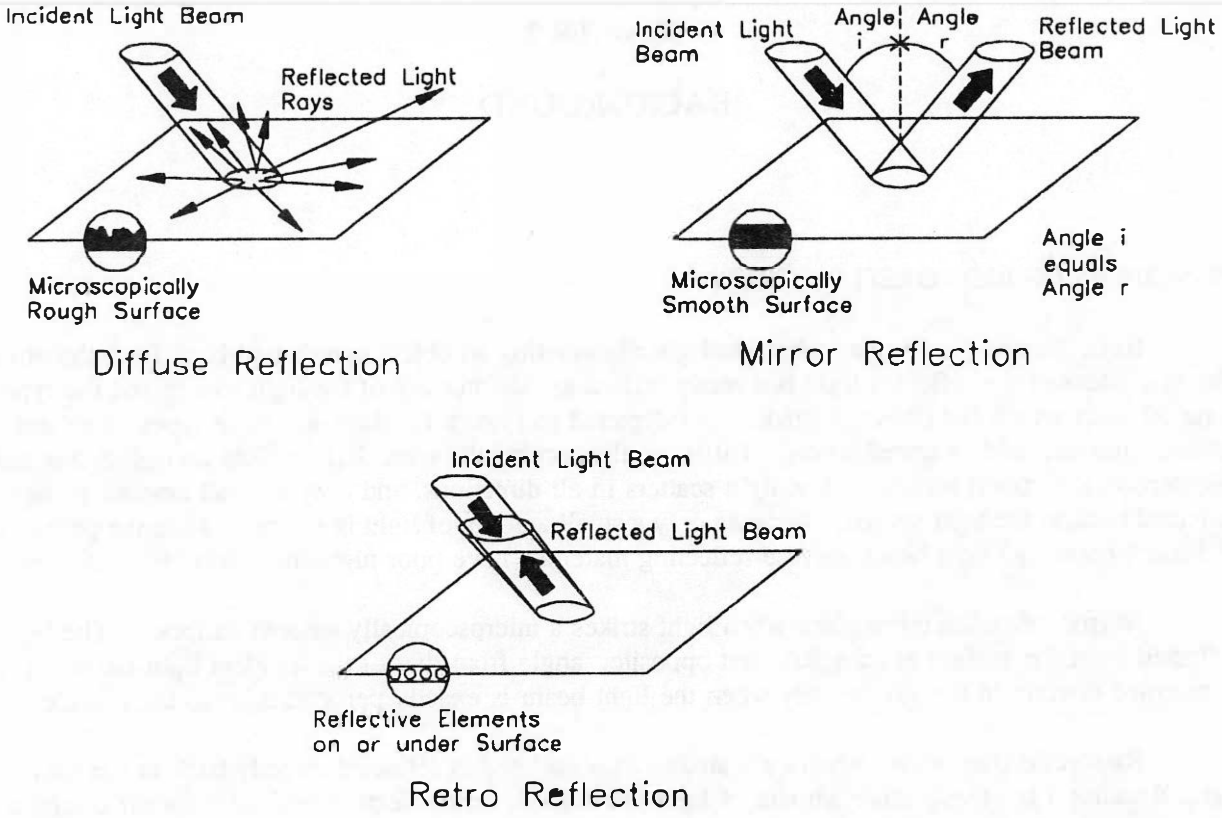


Figure 1. Types of Reflection

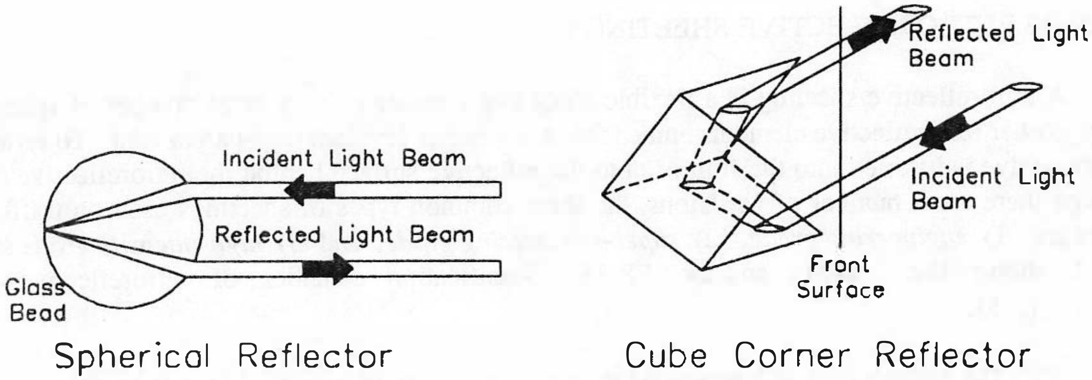
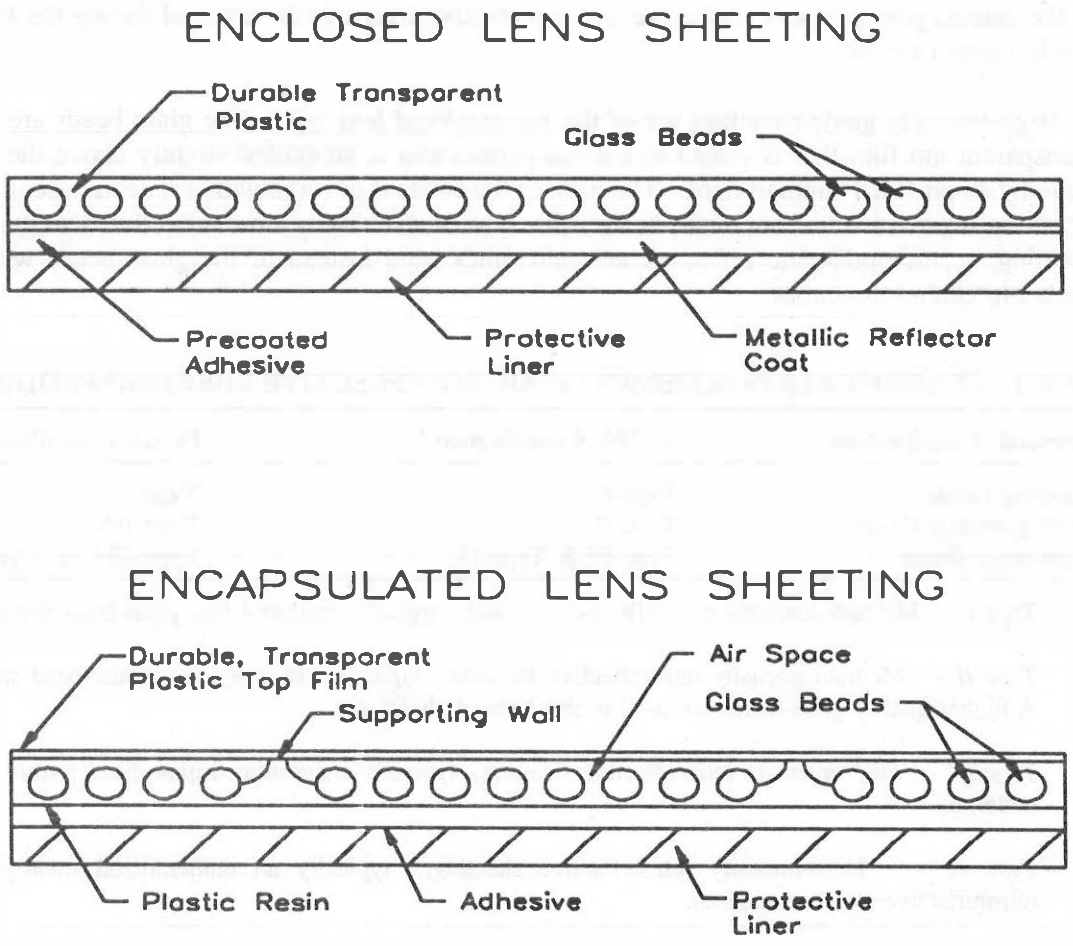
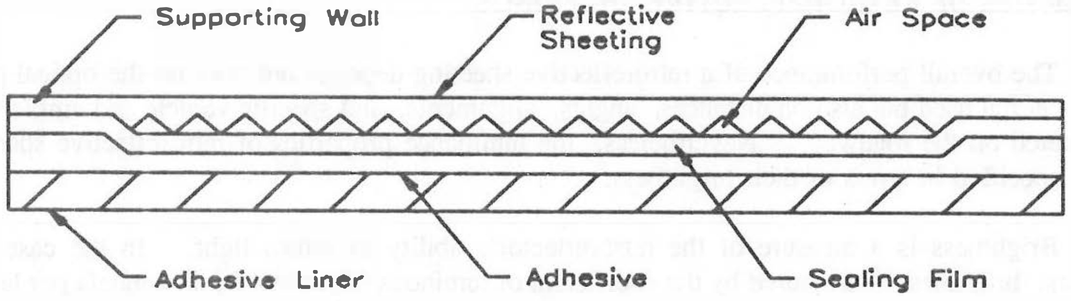


Figure 2. Types of Retroreflectors



A) Spherical Type



B) Cube Corner Type

Figure 3. Schematic of Retroreflective Sheeting Composition

sheeting to be equally bright under dry and wet conditions. A metallic reflector shield is provided behind the plastic, plus a layer of adhesive and a protective liner that is removed during the fabrication of a traffic control device.

High-intensity grade sheetings are of the *encapsulated lens* type. The glass beads are protected by a transparent top film that is sealed in a mesh pattern and is supported slightly above the beads by walls leaving an air filled compartment. The back of the beads is covered with a reflective coat. Because an air cushion is provided in front of the beads, this type of sheeting is more reflective than the enclosed lens sheeting. Microprismatic reflectors are sometimes used instead of the glass beads with the air cushion being behind the cubes.

TABLE 1. CLASSIFICATION SCHEMES OF RETROREFLECTIVE SHEETING PRODUCTS

Commercial Classification	ASTM Classification [a]	FP-85 Classification
Engineering Grade	Type-I	Type-II
Super-Engineering Grade	Type-II	Type-IIA
High-Intensity Grade	Type-III & Type-IV	Type-IIIA & Type-IIIB

[a] *Type I* - Medium-intensity retroreflective sheeting, typically enclosed lens glass-bead sheeting.

Type II - Medium-intensity retroreflective sheeting, typically enclosed lens glass-bead sheeting. A higher quality glass-beads are used in this type of sheeting.

Type III - High-intensity retroreflective sheeting, typically encapsulated glass-bead retroreflective material.

Type IV - High-intensity retroreflective sheeting, typically an unmetallized microprismatic retroreflective element material.

PROPERTIES OF RETROREFLECTIVE SHEETINGS

The overall performance of a retroreflective sheeting depends not only on the optical properties of the material used but also on distances, angles, alignments, and specific vehicle and ambient lighting encountered on the roadway. Nevertheless, the luminance properties of retroreflective sheetings are usually specified in terms of their brightness.

Brightness is a measure of the retroreflector's ability to return light. In the case of small reflectors, brightness is measured by the coefficient of luminous intensity, R, in candela per lux (cd/lx) or candela per footcandle (cd/fc). Because traffic control devices have a relatively large area, the *coefficient of retroreflection*, R', has been adopted as a measure of brightness. It is merely the coefficient of luminous intensity divided by the area of the retroreflector. The units of R' are candela per lux per square meter (cd/lx/m) or candela per footcandle per square foot (cd/fc/ft). Usually, the term R' is referred to as *Specific Intensity Per Unit Area, SIA*. It is important to note that the human subjective perception of brightness is not linear with instrument readings of R or R'. A tenfold increase in brightness, as measured by instruments, may be perceived as only two to three times brighter.

The brightness of sheeting materials is always described in context of another important property, its angularity which is defined by the *entrance angle* of the light and the *observation angle* of the motorist. These two angles change with the viewing distance between the vehicle and the control device. The observation angle depends on the height of the dirver's eye with respect to the vehicle headlights, whereas the entrance angle depends on the location of the vehicle with respect to the device. The term "angularity" refers to the range of angles at which a retroreflective sheeting on a control device will remain retroreflective.

Minimum SIA values for the different sheeting grades and colors have been prescribed by the ASTM [1] and the FP-85 [9], in terms of two observation angles and two entrance angles. The two observation angles are +0.2 and +0.5 degrees corresponding to viewing distances of 500 ft and 200 ft, respectively, assuming that the driver' eye height is 21-inch above the vehicle headlight. The two entrance angles are -4 and +30 degrees. The 30 degrees is considered to be the widest angle between the driver and any sign that would have to be seen. The -4 degrees is intended to be for signs close to the edge of the roadway but oriented away from the perpendicular to avoid the specular reflection that occurs at zero degrees.

EVALUATION OF RETROREFLECTIVE SHEETINGS

Three primary factors must be considered in evaluating the fitness of a retroreflective sheeting material for use on traffic control devices at highway construction work zones. These factors are: 1) driver visibility needs, 2) durability and economics, and 3) practical considerations.

Driver Visibility Needs

The adequacy of a traffic control device at construction work zones is dependent on many factors. Some of these factors are related to the device itself, namely: *conspicuity*, *legibility*, *brightness*, and *luminance contract*.

Conspicuity refers to the likelihood that a device located in the visual periphery of a motorist will be seen at a given distance. It is a function of the device expectancy, external contrast, device size and alignment, and visual complexity of the surrounding area.

Legibility is an index that relates the size of letters and symbols, viewing distance, and recognition acuity of the driver. For a given letter size and design visual acuity, legibility is influenced by the internal contrast of the device (legend against background), brightness of the device background, and the ambient luminance. The interaction among all these factors determines the legibility distance of a given device.

Brightness refers to the amount of light reflected from a retroreflective device that reaches the driver's eye. In general, the brighter the device the more conspicuous it will be. However, high brightness letters or symbols on low brightness background may reduce legibility because of a halo effect of the brighter legend. Excessive brightness of the background can also produce glare discomfort.

Luminance contrast is by far more important to maintaining the detectability and legibility of a control device than the overall brightness of the device. There are two types of luminance contrast:

external and internal. *External contrast* is the ratio of device luminance to the luminance of the surroundings (i.e., the background against which the entire device is seen). *Internal contrast* is the contrast of the letters or symbol against the background of the device. External contrast is critical to conspicuity, while internal contrast is critical to legibility.

Durability and Economics

The economic implications of the relative durability and service life of retroreflective sheeting materials must be considered in evaluating the different sheetings. A life-cycle cost analysis based on the cost of the sheeting, total cost of the control device, service life of the device, and benefits would help identify the relative cost-effectiveness.

Practical Considerations

The modes of deterioration of traffic control devices at construction work zones are different from those at other highway segments. Usually, contractors replace the devices because they do not meet the "like-new" requirement specified in the contract documents. Issues of frequent vandalism, device knockdowns by traffic, and care in the handling, storing, and installation of devices at highway work zones must be considered in the evaluation of different sheeting materials. Input from traffic control contractors should be helpful in identifying performance limitations of the different sheetings.

LITERATURE REVIEW FINDINGS

A considerable body of literature exists regarding the safety problems at construction work zones and the configuration, design, application and performance of traffic control devices in a variety of highway construction situations. Nevertheless, a review of the literature produced very little insight on the adequacy of retroreflective sheetings at construction work zones. Only one published report was found specifically related to this subject.

In 1988, the Wisconsin DOT conducted a limited study to evaluate the engineering grade, super-engineering grade, and high-intensity grade sheetings at a construction project near I-94 [10]. The findings of this study were based on the subjective judgment of a field review panel consisting of six employees of the WDOT and an FHWA representative. Evaluation criteria included nighttime visual appearance of control devices, legibility of sign messages, average speed of vehicles in the work zone, and abrasion resistance using a sand-blaster. The field evaluation team recommended the use of high-intensity grade sheeting on barrels and delineator tubes. Super-engineering grade was judged to be most effective for use on signs. Glare problems associated with high-intensity sheeting on signs were noted by the observers. The engineering grade sheeting was found to be the most damage resistant, super-engineering grade sheeting was second, and high-intensity grade sheeting was the least damage resistant.

A recent telephone survey was carried out by the Kansas DOT to gather information on traffic control devices used at construction work zones. One of the questions asked had to do with the type of retroreflective sheeting used on signs and drums. Only engineering grade and high-intensity grade sheetings were included in the survey. Of the forty four state DOTs involved in the survey, 64%, 30%, and 6% indicated that they use high-intensity, engineering, and combination of high-intensity and engineering grades of sheeting, respectively, on signs. The percentages of state DOTs which use high-intensity grade and engineering grade sheetings on drums were 70% and 30%, respectively.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter summarizes the methods and procedures which were used in this study to evaluate the relative adequacy of the engineering grade, super-engineering grade, and high-intensity grade retroreflective sheetings at construction work zones. The chapter is divided as follows: First, the field experiments required by tasks 2 and 3 are briefly described. Second, the methods used to obtain data required by task 4 on durability and economics are presented.

FIELD EXPERIMENTS

Field experiments were conducted to obtain responses from test drivers as to the overall adequacy of the three sheeting types under daytime and nighttime conditions. The experimental plan included two real-world construction projects and a controlled roadway. To accommodate the inherent differences between rural and urban environments, particularly at nighttime, the real-world experiments were performed at one urban and one rural construction projects. The engineering grade sheeting was evaluated for the rural environment only because the ODOT does not specify its use in urban areas.

Study Sites

The study sites were selected in coordination with the ODOT. They include: 1) urban, real-world highway construction work zone, 2) rural, real-world highway construction work zone, and 3) an existing controlled roadway.

The urban highway construction work zone involved a bridge rehabilitation project at Lake Overholser, in Oklahoma City, Oklahoma. The number of lanes on N.W. 39th Expressway was reduced to one lane in each direction. Eastbound traffic was controlled using the sequence of control devices shown in Figure 4-A, whereas westbound traffic was controlled using the sequence of control devices shown in Figure 4-B. High-intensity grade and super-engineering grade sheetings were used on the westbound and eastbound control devices, respectively.

The rural highway construction work zone involved the widening of 1.5 miles of SH-37 to four lanes from I-44 in the Tri-City area west. Traffic was controlled using the sequence of control devices shown in Figure 5.

The controlled experiments were conducted at a closed road in the Clinton-Sherman Airpark at Burns Flat, Oklahoma. A planned lane-closure was set up using the control and warning devices shown in Figure 6.

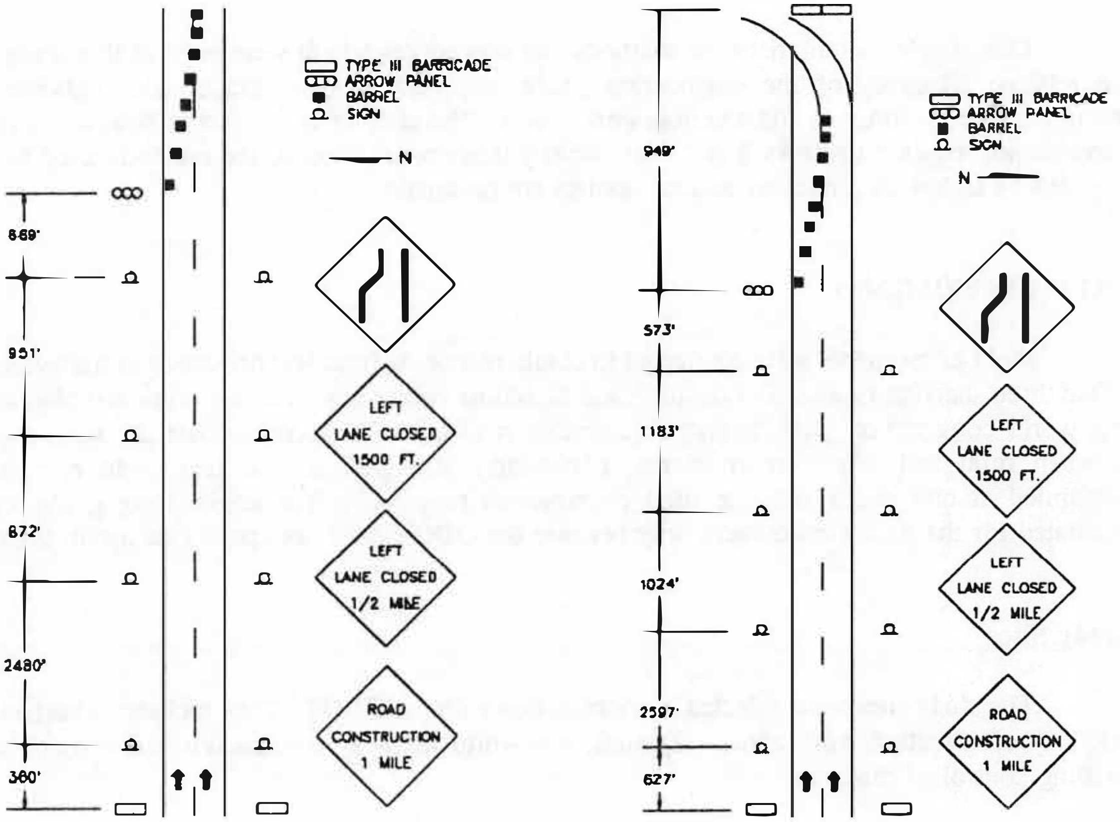


Figure 4. Schematic of Urban Construction Site

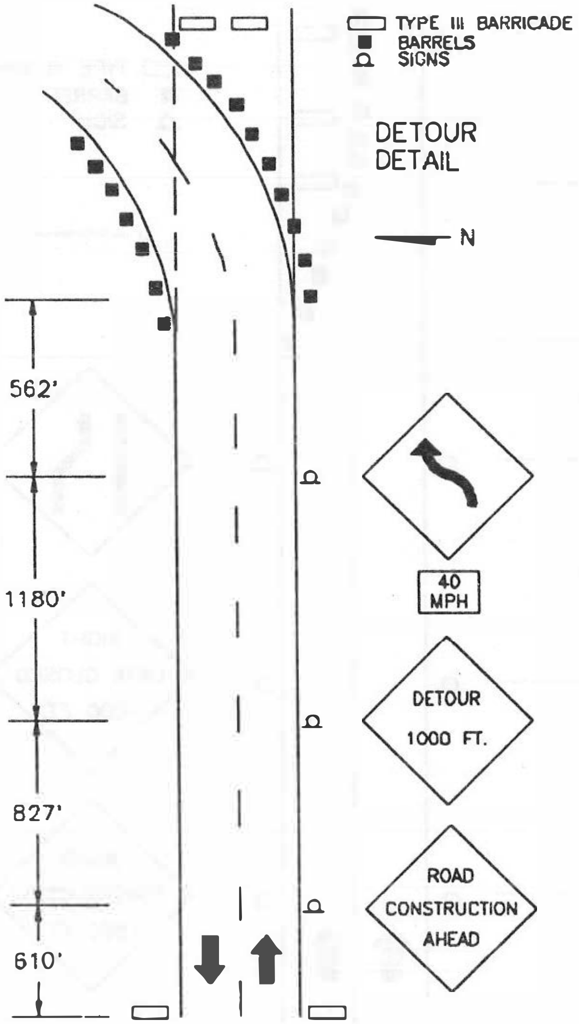


Figure 5. Schematic of Rural Project Site

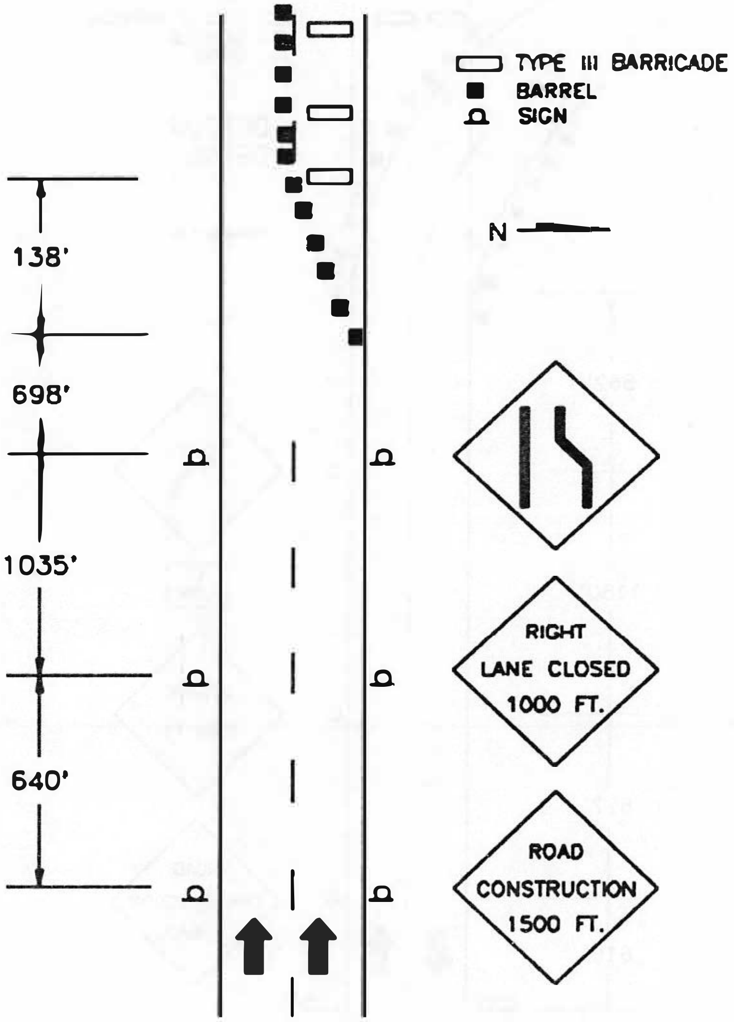


Figure 6. Schematic of Controlled Experiments site.

Test Drivers

Table 2 summarizes the numbers of test drivers involved in the field experiments at each of the three sites. In the urban real-world experiments, a sample of 30 driver subjects was selected from the ODOT Division 9 personnel. An effort was made to ensure that the drivers did not have special knowledge of traffic control devices at construction work zones. For each type of sheeting, five drivers took part in the daytime experiments and 10 drivers in the nighttime experiments. During the nighttime experiments with the super-engineering grade sheeting, one driver's response was deleted from the data because he did not follow the instructions.

TABLE 2. NUMBER OF TEST DRIVERS USED IN FIELD EXPERIMENTS

Test Site	Sheeting Grade					
	Engineering		Super-Engineering		High-Intensity	
	Day	Night	Day	Night	Day	Night
N.W. 39th	--	--	5	10	5	10
SH-37	5	10	5	9	5	10
Burns Flat	27	28	27	29	25	29

In the rural real-world experiments, 44 test drivers were selected from the ODOT Division 9 personnel. Five drivers participated in the experiments during the daytime for each type of sheeting. At nighttime, the number of drivers involved in evaluating the engineering grade, super-engineering grade, and high-intensity grade sheetings were 10, 9, and 10, respectively. Ten responses were discarded because the drivers did not follow the instructions given by the experimenter. They include two responses during the daytime and two responses during the nighttime experiments with the engineering grade sheeting, two responses during nighttime experiments with the high-intensity grade sheeting, and four responses during the nighttime experiments with the super-engineering grade sheeting.

For the controlled field experiments, a sample of 165 paid driver subjects were employed. During daytime, the number of drivers involved in the experiments with the engineering grade, super-engineering grade, and high-intensity grade sheetings were 27, 27, and 25, respectively. For nighttime conditions, 28, 29, and 29 drivers participated in the experiments with the engineering grade sheeting, super-engineering grade sheeting, and high-intensity grade sheetings. One driver did not follow the instructions during the nighttime experiments with the super-engineering grade sheeting, therefore, his response was deleted from the data.

To help isolate the variation between drivers, the controlled experiments were planned so that paired observations could be obtained using the same driver with different sheeting grades. At nighttime, 10 drivers were repeated in evaluating both the engineering grade and super-engineering grade sheetings, 11 drivers were repeated in evaluating both the engineering grade and high-intensity grade sheetings, and 24 drivers were repeated in evaluating both the super-engineering grade and high-intensity grade sheetings.

A driver biographical data sheet was designed to obtain information on drivers characteristics. Appendix A shows a sample driver biographical data sheet.

In selecting the driver subjects, an effort was made to ensure that their age and sex distributions closely match those of the population of drivers on Oklahoma highways. The age and sex distributions of the drivers who participated in the experiments are presented in Tables 3 and 4 in relation to the national distributions [8]. Other characteristics of the test drivers are given in Tables A-1 through A-7 (Appendix A).

TABLE 3. AGE DISTRIBUTION

Test Site	Age					
	< 25	25 - 34	35 - 44	45 - 54	55 - 64	> 65
N.W. 39TH	17.2 / 12.1	55.2 / 25.0	20.7 / 20.1	3.5 / 13.3	3.4 / 11.7	0.0 / 12.5
SH-37	11.8 / 12.1	64.7 / 25.0	14.7 / 20.1	5.9 / 13.3	2.9 / 11.7	0.0 / 12.5
Burns Flat	14.0 / 12.1	33.5 / 25.0	22.0 / 20.1	23.2 / 13.3	6.1 / 11.7	1.2 / 12.5
Average	14.3 / 12.1	51.1 / 25.0	19.1 / 20.1	10.9 / 13.3	4.1 / 11.7	0.4 / 12.5

a/b: a = Percent of drivers used in the study, b = Percent of drivers in the State.

TABLE 4. SEX DISTRIBUTION

Test Site	Male	Female
N.W. 39TH	79.3 / 52.0	20.7 / 48.0
SH-37	85.3 / 52.0	14.7 / 48.0
Burns Flat	52.4 / 52.0	47.6 / 48.0

a/b: a = Percent of drivers used in the study, b = Percent of drivers in the State.

Test Procedure

A four door sedan instrumented with a distance measuring device was used to conduct the field experiments. The vehicle was one of the OSU motorpool Chevy, Celebrity fleet. The distance measuring device was the Roadstar-40 manufactured by Nu-Metric, Inc. It is a microprocessor-based device with programmed instructions. A proximity sensor attached to the front left wheel sends electrical impulse to the microprocessor which in turn converts it to the distance traveled. The device had a "display hold" feature which freezes the display while the device is continuing to compute the distance traveled. This feature enables the experimenter to record the necessary distances.

All drivers were briefed before the field experiments and each driver was given an instruction sheet that summarizes the test procedure. Exhibit 1 illustrates the instruction sheet used. Every subject drove through the test site accompanied by an experimenter. The experimenter, sitting next to the test driver, operated the distance measuring instrument and recorded subjects' responses. After the test drive, each driver was asked to complete a questionnaire concerning the adequacy of the traffic control devices which were present during the test. The questionnaire form is included in Appendix B.

EXHIBIT I

INSTRUCTION TO DRIVERS

I. Welcome to Test Vehicle:

Drive this car as you would any other. Please:

- Show me your driver's license
- Adjust seat, test brake paddle, check mirrors, and buckle seat belt
- Apply the brakes and come to safe stop at a stop sign or traffic signal or if I direct you to stop.

Let us drive a little so you can get used to the car. Practice accelerating and braking around here.

II. Ready to Begin:

Please drive through this course as you normally drive your own vehicle. This means that you will generally stay in your lane and maintain a speed equal to the posted speed limit. As you go along, you will see various ORANGE-COLORED highway construction SIGNS and devices such as BARRICADES, BARRELS, etc. You may be forced to change lanes.

You need to do FIVE things during the drive through:

1. Tell me at once, immediately, whenever you see any ORANGE-COLORED traffic sign ahead of you. This is the first time it appears to you on the horizon, even if you cannot read it. Continue driving and maneuvering as you would normally do on this type of roadway.

2. Tell me at once, immediately, whenever you are able to read any ORANGE-COLORED traffic sign ahead of you. Please READ THE SIGN LOUD. This very important. Continue driving and maneuvering as you would normally do on this type of roadway.

3. Tell me at once, immediately, whenever you see any ORANGE-COLORED BARRICADES OR BARRELS ahead of you. This is the first time they appear to you on the horizon, even if you cannot tell what kind of device it is. Continue driving and maneuvering as you would normally do on this type of roadway.

4. Tell me at once, immediately, whenever you are able to read any ORANGE-COLORED traffic sign posted on the BARRICADES ahead of you. Please READ THE SIGNS LOUD. This very important. Continue driving and maneuvering as you would normally do on this type of roadway.

5. Apply your brakes and come to safe stop without skidding or loosing control when I ask you to stop.

III. After Test Drive:

Please fill out the questionnaire which will be given to you.

Figures 7 through 16 show photographs of the test vehicle, the ODOT mobile research unit which was used as a field office during the real-world experiments, and other photographs taken during the field experiments.

DURABILITY AND ECONOMICS

The data on durability and economics used in this research consisted of: 1) existing weatherometer test results, and 2) data obtained from the three major sign contractors in Oklahoma.

The accelerated weathering test is described in the ASTM G-23 [2]. A weatherometer chamber is used to simulate the effects of years of natural weathering by exposing specimens of the sheeting to artificial weathering effects for prescribed numbers of hours. Typically, the test is conducted for 500, 1000, 2000, 3000, and 4000 hours of exposure. The weatherometer data used in this study were obtained the ODOT Materials Laboratory, Oklahoma City, Oklahoma, Seibulite International, Inc., Rancho Dominguez, California, and Industrial Testing Laboratories, Berkeley, California.

Data on service lives and cost items of the three sheeting products were obtained from: 1) Action Safety Company, Oklahoma City, Oklahoma, 2) Advance Warning, Muskogee, Oklahoma, and 3) Flasher Company, Oklahoma City, Oklahoma. A survey consisting of 11 questions was mailed to each of the three major contractors to gather data on the types of sheetings used, the quantity of sheetings purchased per year, service lives of the sheetings, on how many projects a device can be used, types of deterioration experienced with every sheeting, cost items, and problems related to the fabrication and handling. Details of the contractors' questionnaire are given in Appendix C.

Figure 7. Test Vehicle

Figure 8. ODOT's Research Van

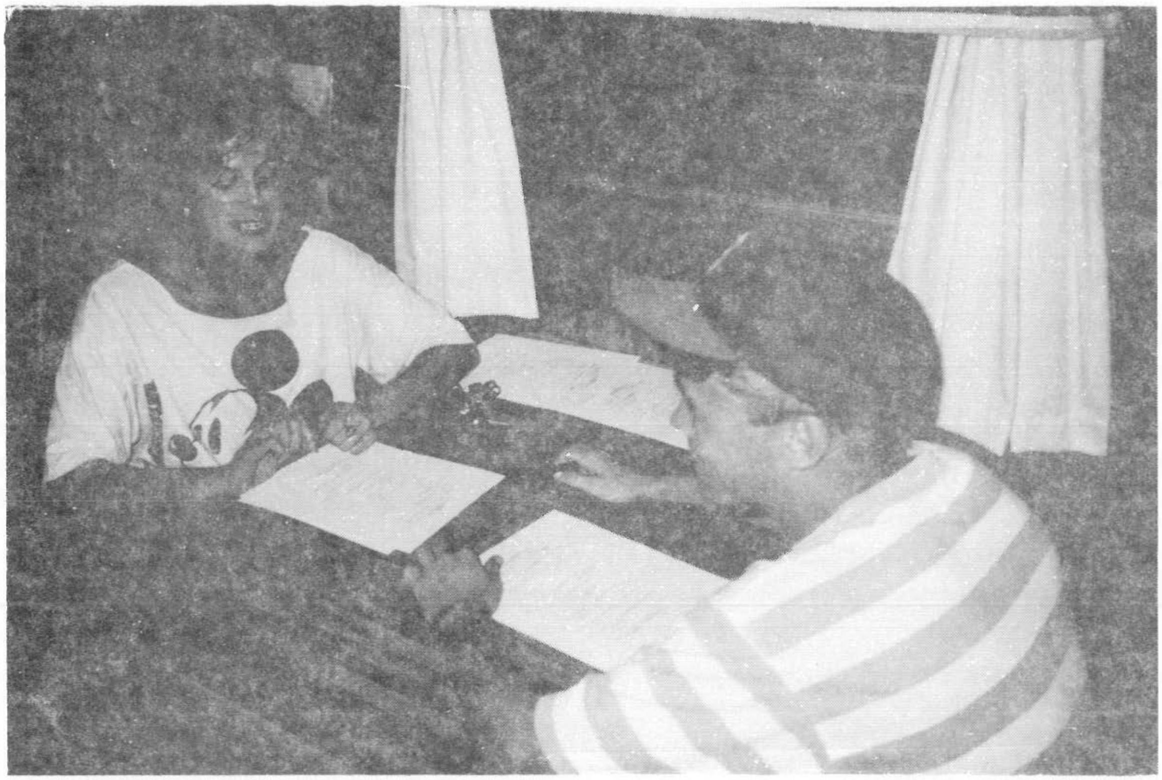


Figure 9. Drivers Completing Biographical Data Questionnaire Before Test Drive

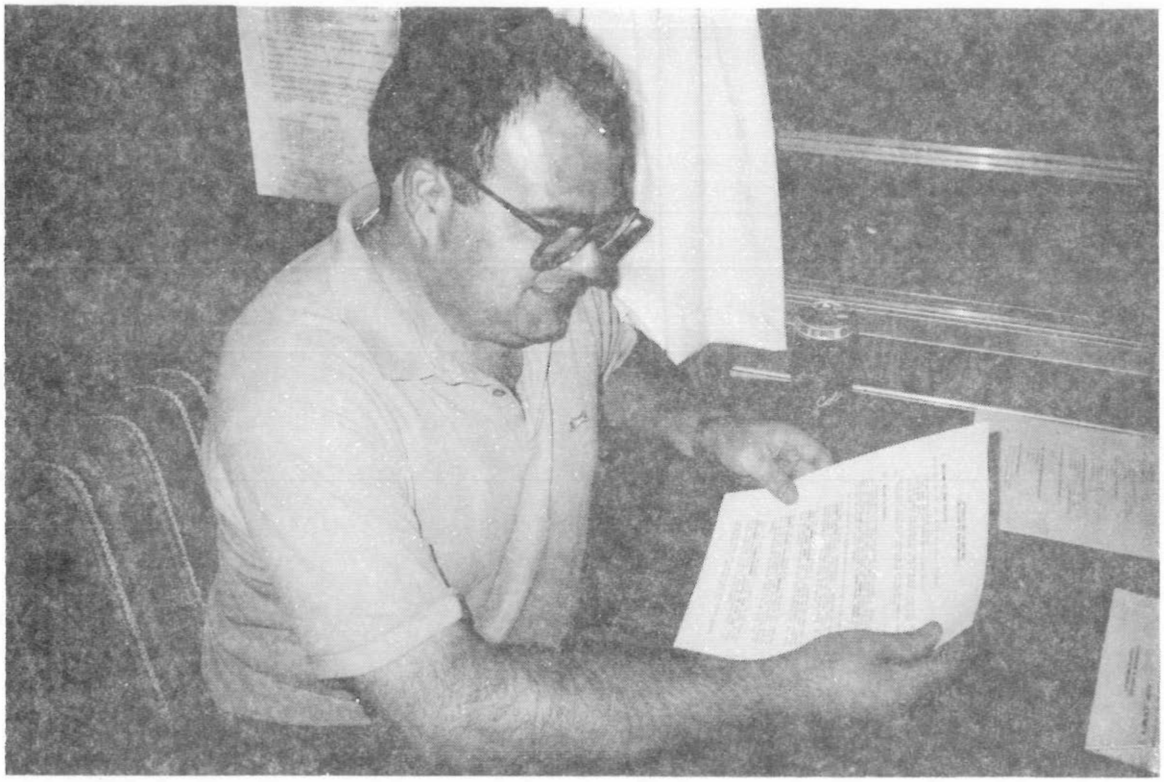


Figure 10. Driver Reading Instructions Sheet Before Test Drive

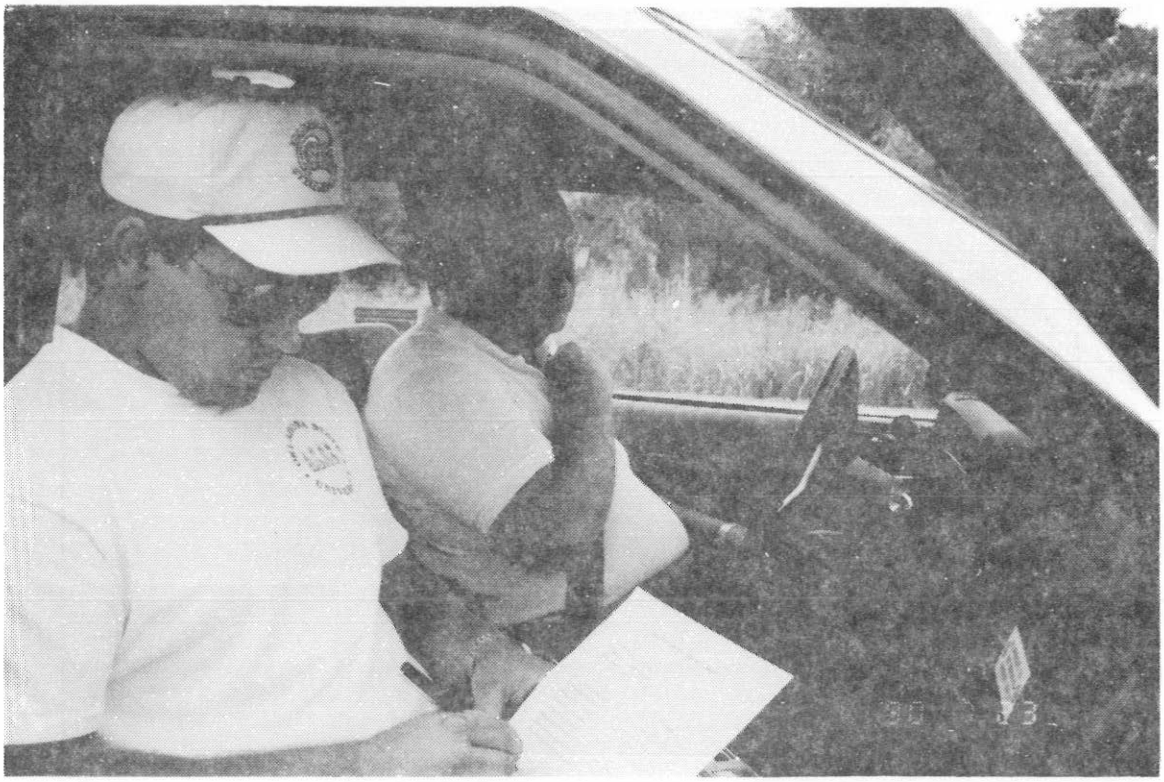


Figure 11. Diver and Experimenter Preparing for Test Drive

Figure 12. Photograph Taken During Test Drive

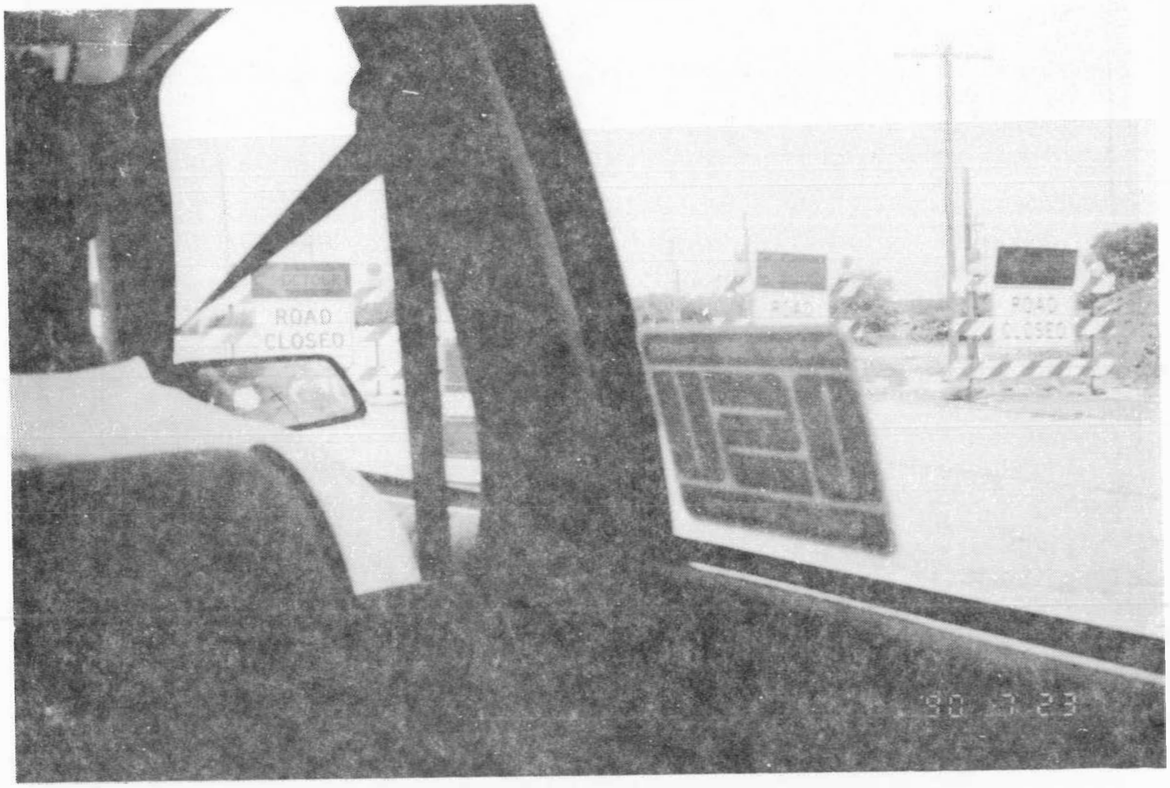


Figure 13. Another Photograph Taken During Test Drive

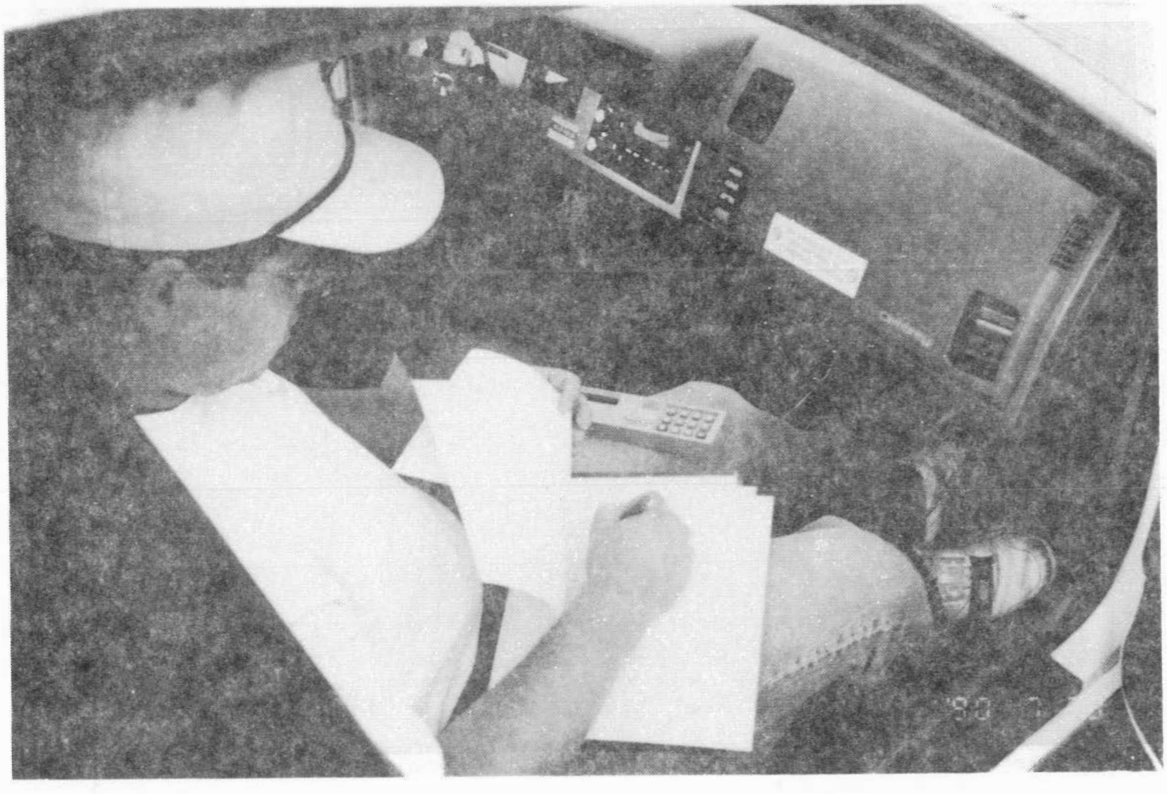


Figure 14. Experimenter Operating the DMI

Figure 15. Driver Completing Questionnaire After Test Drive

Figure 16. Test Driver Waiting For His Turn

CHAPTER 4

STATISTICAL ANALYSIS OF DETECTION AND RECOGNITION DISTANCES

This chapter summarizes the results of the statistical analyses of mean detection distances (MDDs) and mean recognition distances (MRDs) of traffic control devices which were recorded during the field experiments. The chapter is organized as follows. First, the terms detection distance and recognition distance are introduced. Second, a brief background on the theory of the statistical tests performed is presented. Third, the major findings of the statistical analyses of MDDs and MRDs are discussed.

DETECTION AND RECOGNITION DISTANCES

As described in chapter 2, driver visibility needs are central to evaluating the adequacy of a retroreflective sheetings. A major consideration in specifying the minimum grade of sheeting to be used on traffic control devices at construction work zones is the visibility distance of these devices.

Two types of visibility distance were used in this research: *detection distance* and *recognition distance*. *Detection distance* is defined as the distance upstream of an *array* of control devices where the driver first sees the array but not necessarily recognizes the shape of the individual devices or be able to read the message displayed, if there is any. *Recognition distance* is the distance to the point upstream of a *device* where the driver can recognize the shape of the device and, in the case of signs, be able to read the message.

Factors that influence the detection and recognition distances of a particular device may be grouped into two categories: 1) reflective sheeting related factors, and 2) other factors. Examples of factors which are related to the type of sheeting include brightness, external contrast, and internal contrast. Other factors which are not related to the type of sheeting include size of the device, mounting height, and size of letters and symbols. With letter size and mounting height held constant, recognition distance is primarily affected by the type of sheeting and the surrounding luminance. Detection distance of signs cannot be increased by simply increasing the level of retroreflectivity. There is a threshold level beyond which signs become more difficult to read.

In this study, the field experiments were designed to help answer the following two questions:

1. *Is there statistically significant difference between the mean detection distances of the different grades of retroreflective sheeting when used on traffic control devices at construction work zones during daytime conditions? during nighttime conditions?*

2. *Is there statistically significant difference between the mean recognition distances of the different grades of retroreflective sheeting when used on traffic control devices at construction work zones during daytime conditions? during nighttime conditions?*

Tables D-1 through D-5 (Appendix D) list the mean detection distances and mean recognition distances of each grade of sheeting at each test site. In Table D-2, the recognition distance of barricades with super-engineering grade sheeting is not shown because barricades were not used after the barrels on the eastbound direction of N.W. 39th expressway.

As described in Chapter 3, some of the controlled experiments were designed to isolate the source of variation due to drivers. Paired observations were obtained at nighttime by using the same driver with different grades of sheeting. Differences between the paired observations are given in Tables D-6 through D-8 (Appendix D).

BACKGROUND

The t-test was employed to compare the mean detection and recognition distances of the different grades of sheeting. This t-test is appropriate when the population variances are not known but can be estimated from samples of measurements on each grade of sheeting. To help discuss the application of the t-test in comparing two population means, the following terminology will be used:

X_{ij} = detection/recognition distance for sheeting type i and driver j,
$\overline{X}_i$ = sample mean distance of sheeting type i,
s_i^2 = sample variance for sheeting type i,
n = sample size (number of drivers),
μ_i = population mean distance for sheeting type i, and
σ_i^2 = population variance for sheeting type i.

Comparison of Two Population Means Using Independent Samples, and Unknown Variances

To test the hypothesis H_o: $\mu_1 = \mu_2$ against an alternative hypothesis, a t-statistic is computed using the means and variances of two random samples drawn from the two populations.

The formula to calculate t-statistic depends on whether the variances σ_1^2 and σ_2^2 are equal or not. Equality of variances is tested using the following F-statistic:

$$F = \frac{\text{Larger Sample Variance}}{\text{Smaller Sample Variance}} \tag{1}$$

This F-test is a two-tailed test since the null hypothesis H_o: $\sigma_1^2 = \sigma_2^2$ is tested against the alternative hypothesis H_1: $\sigma_1^2 \neq \sigma_2^2$.

If the F-test indicates that the variances are *equal* then the t-statistic is given by:

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \tag{2}$$

where s_p is the pooled standard deviation which is computed as:

$$s_p = \sqrt{\frac{(n_1-1)\,s_1^2+(n_2-1)\,s_2^2}{n_1+n_2-2}} \tag{3}$$

and the corresponding degrees of freedom are:

$$df = n_1 + n_2 - 2 \tag{4}$$

If the F-test indicates that the variances are *not equal*, then an approximate t value is computed as follows:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}} \tag{5}$$

and the associated degrees of freedom are given by:

$$Eff.\ df = \frac{\left(\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}\right)^2}{\frac{(s_1^2/n_1)^2}{n_1-1}+\frac{(s_2^2/n_2)^2}{n_2-1}} \tag{6}$$

Based on the level of significance of the test and the degrees of freedom, the computed t-statistic is compared with a tabulated t-value. If the computed value lies in the acceptance region of the t-distribution curve, then the null hypothesis, H_o, is not rejected. Otherwise H_o is rejected and the alternative hypothesis, H_a, is accepted at the specified level of significance.

In testing the null hypothesis H_o: $\mu_1 = \mu_2$, the rejection regions associated with an alternative hypothesis are as follows:

Alternative Hypothesis, H_a	Rejection Region
H_a: $\mu_1 < \mu_2$	$t < -t_{\alpha,\,df}$
H_a: $\mu_1 > \mu_2$	$t > t_{\alpha,\,df}$

Comparison of Two Population Means Using Paired observations

In testing the equality of the means of two populations of visibility distances of two sheetings, any difference that is present between the averages of the two samples obtained from these populations may be due to drivers rather than sheeting types. Paired comparisons help isolate the source of variation due to drivers so that any observed differences will be attributed to sheeting type only. This method requires that the difference, D, between the distances recorded for the same driver with two types of sheeting be computed.

To test the hypothesis: H_o: $\mu_1 - \mu_2 = 0$ against the alternative hypothesis H_1: $\mu_1 - \mu_2 > 0$, the t-statistic is given by:

$$t = \frac{\overline{D}}{s_D/\sqrt{n}} \qquad (7)$$

where s_D is the standard deviation of the differences between the distances recorded for each driver with two types of sheeting.

As discussed earlier, the computed t-statistic is then compared with the tabulated t-value with the appropriate degrees of freedom and level of significance. Location of the rejection regions are as shown earlier.

RESULTS OF STATISTICAL ANALYSES

The computations required by the F-test and t-test were performed using the Statistical Analysis Systems (SAS) microcomputer program. All tests were conducted using a confidence level of 95%.

Tables E-1 through E-4 (Appendix E) summarize the conclusions of the different hypotheses tested for the urban project, rural project, and the controlled experiments using equations 1 through 6. The following paragraphs summarize the major findings of the statistical analyses.

Mean Detection Distance, MDD

1. *Urban Project, Nighttime Conditions* - The MDD of high-intensity grade sheeting was significantly greater than the MDD of super-engineering grade sheeting.
2. *Urban Project, Daytime Conditions* - The MDD of high-intensity grade sheeting was significantly greater than the MDD of super-engineering grade sheeting.
3. *Rural Project, Nighttime Conditions* - The MDDs of engineering grade, super-engineering grade, and high-intensity grade sheetings were not significantly different.
4. *Rural Project, Daytime Conditions* - The MDDs of engineering grade, super-engineering grade, and high-intensity grade sheetings were not significantly different.
5. *Controlled Experiments* - The MDDs were not considered because the drivers could see the array of devices, irrespective of the sheeting type used, as soon as they entered the gate to the test road.

Mean Recognition Distance, MRD

1. *Urban Project, Nighttime Conditions*

Super-Engineering Grade Versus High-Intensity Grade

Word Signs - The MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting for two of the three word signs analyzed. For the third word sign, the MRDs of both sheetings were not significantly different. When all the word signs were combined, the MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting.

Symbol Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barrels - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of super-engineering grade sheeting and high-intensity grade sheeting were not significantly different for all the traffic control devices analyzed except two of the three word signs. Super-engineering grade sheeting on these two word signs had greater MRD than that of high-intensity grade sheeting.

In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

2. *Urban Project, Daytime Conditions*

Super-Engineering Grade Versus High-Intensity Grade

Word Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRD of high-intensity grade sheeting was significantly greater than that of super-engineering grade sheeting.

Barrels - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different for all the traffic control devices analyzed except symbol signs. High-intensity grade sheeting on symbol signs had greater MRD than that of super-engineering grade sheeting.

In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

3. *Rural Project, Nighttime Conditions*

A. *Engineering Grade Versus Super-Engineering Grade*

Word Signs - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different when every word sign was analyzed individually. The same conclusion was reached, when all word signs were combined.

Symbol Signs - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different.

Barricades - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting when used on symbol signs and barricades. Nevertheless, there was no significant difference between the MRDs of both sheetings on barrels or word signs.

In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

Several drivers indicated that the size of the letters used on word signs was somewhat small, which may have limited their recognition distances of these signs regardless of the type of sheeting used. Therefore, increasing the retroreflectivity of the sign background did not seem to change the MRD of word signs.

B. *Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different for two of the three word signs analyzed. For the third word sign, the MRD of engineering grade sheeting was significantly greater than that of high-intensity grade sheeting. When all word signs were combined and analyzed, the MRDs of both sheetings were not significantly different.

Symbol Signs - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different.

Barrels - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different.

Barricades - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRDs of engineering grade and high-intensity grade sheetings were not significantly different, except for barricades and one of the three word signs. High-intensity grade sheeting on barricades had greater MRD than that of engineering grade sheeting. For one word sign, engineering grade sheeting had grater MRD than high-intensity grade sheeting. In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

C. Super-Engineering Grade Versus High-Intensity Grade

Word Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different for two of the three word signs analyzed. The third word sign indicated that the MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting. When all word signs were combined and analyzed, the MRDs of both sheetings were not significantly different.

Symbol Signs - The MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting.

Barrels - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barricades - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different, except for symbol signs and one of the three word signs. Super-engineering grade sheeting on symbol signs and one word sign had greater MRD than that of high-intensity grade. In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

4. Rural Project, Daytime Conditions

A. Engineering Grade Versus Super-Engineering Grade

Word Signs - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different for two of the three word signs analyzed. For the third word sign, the MRD of engineering grade sheeting was significantly greater than that of super-engineering grade sheeting. When all word signs were combined and analyzed, the MRDs of both sheetings were not significantly different.

Symbol Signs - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different.

Barrels - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different.

Barricades - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of engineering grade and super-engineering grade sheetings were not significantly different, except for one of the three word signs. Engineering grade sheeting on that word sign had greater MRD than that of super-engineering grade sheeting.

Overall, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

B. *Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different for every individual word sign analyzed. The same conclusion was reached when all word signs were combined.

Symbol Signs - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different.

Barrels - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different.

Barricades - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of engineering grade and high-intensity grade sheetings were not significantly different when used on all the traffic control devices analyzed.

In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

C. *Super-Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRD of High-intensity grade sheeting was significantly greater than that of super-engineering grade sheeting for each word sign analyzed. The same conclusion was reached when all word signs were combined.

Symbol Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barrels - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barricades - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

<u>Summary</u> - Based on the test results, the MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different, except for word signs. High-intensity grade sheeting on word signs had significantly greater MRD than that of super-engineering grade sheeting. Overall, symbol signs had significantly greater MRD than word signs regardless of sheeting type.

5. *Controlled Experiments, Nighttime Conditions*

A. *<u>Engineering Grade Versus Super-Engineering Grade</u>*

Word Signs - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

<u>Summary</u> - Based on the test results, the MRD of super-engineering grade sheeting was greater than that of engineering grade sheeting for all the traffic control devices analyzed. The MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

B. *<u>Engineering Grade Versus High-Intensity Grade</u>*

Word Signs - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting when used on one of the two word signs analyzed. Nevertheless, there was no significant difference between the MRDs of both sheetings on the second word sign.

When both word signs were combined and analyzed, the MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Symbol Signs - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

<u>Summary</u> - Based on the test results, the MRD of high-intensity grade sheeting was greater than that of engineering grade sheeting for all the traffic control devices analyzed except one of the two word signs. There was no significant difference between the MRDs of both sheetings on that word sign.

Overall, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

C. Super-Engineering Grade Versus High-Intensity Grade

Word Signs - The MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barrels and Barricades - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of both sheetings were not significantly different, except for word signs. Super-engineering grade sheeting on word signs had greater MRD than that of high-intensity grade sheeting. In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

6. Controlled Experiments, Daytime Conditions

A. Engineering Grade Versus Super-Engineering Grade

Word Signs - The MRDs of engineering grade and super-engineering grade sheetings were not significantly different. The same conclusion was reached when letter signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRD of super-engineering grade sheeting was greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of super-engineering grade sheeting was greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRD of super-engineering grade sheeting was greater than that of engineering grade sheeting when used on symbol signs, barrels and barricades. Nevertheless, there was no significant difference between the MRDs of both sheetings when used on word signs. As mentioned earlier, the insignificant difference between the MRDs of both sheetings may be attributed to the inadequate letter size used on word signs.

In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

B. Engineering Grade Versus High-Intensity Grade

Word Signs - The MRDs of engineering grade and high-intensity grade sheetings were not significantly different. The same conclusion was reached when letter signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRD of high-intensity grade sheeting was greater than that of engineering grade sheeting when used on symbol signs, barrels and barricades. Nevertheless, there was no significant difference between the MRDs of both sheetings when used on word signs.

Overall, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

C. *Super-Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barrels and Barricades - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different when used on all devices analyzed. In general, the MRD of symbol signs was significantly greater than that of word signs for each type of sheeting used.

Paired Comparisons of Mean Recognition Distances, Nighttime Conditions

To help isolate the source of variation due to drivers, the differences between the paired observations given in Tables D-6 through D-8 (Appendix D) were analyzed using the paired t-test method. These observations were recorded during the controlled experiments at nighttime. Table E-5 (Appendix E) lists the results of the paired comparisons using equation 7. The following paragraphs summarize the major findings of the statistical analyses.

A. *Engineering Grade Versus Super-Engineering Grade*

Word Signs - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting for each word sign analyzed. The same conclusion was reached when word signs were combined.

Symbol Signs - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRD of super-engineering grade sheeting was significantly greater than that of engineering grade sheeting when used on all the traffic control devices analyzed.

B. *Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting for one of the two word signs analyzed. Nevertheless, there was no significant difference between the MRDs of both sheetings on the second word sign.
When both word signs were combined and analyzed, the MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Symbol Sign - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Barrels and Barricades - The MRD of high-intensity grade sheeting was significantly greater than that of engineering grade sheeting.

Summary - Based on the test results, the MRD of high-intensity grade sheeting was greater than that of engineering grade sheeting, except for one of the two word signs, where there was no significant difference between the MRDs of both sheetings.

C. *Super-Engineering Grade Versus High-Intensity Grade*

Word Signs - The MRD of super-engineering grade sheeting was significantly greater than that of high-intensity grade sheeting for each word sign. The same conclusion was reached when word signs were combined.

Symbol Signs - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Barrels and Barricades - The MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different.

Summary - Based on the test results, the MRDs of super-engineering grade and high-intensity grade sheetings were not significantly different, except for word signs. Super-engineering grade sheeting on word signs had greater MRD than that of high-intensity grade sheeting.

CHAPTER 5

DRIVERS OPINIONS AND COMMENTS

Information on the adequacy of traffic control devices was collected using a questionnaire which was designed for this purpose. The questionnaire was completed by each driver after the test drive. In addition to the specific questions asked, the questionnaire had space for the drivers to provide any comments that they would like to add. Drivers were not aware of the type of sheeting used.

The questionnaire form is included in Appendix-B along with a summary of the drivers responses. The following paragraphs present the questionnaire findings.

DRIVERS' ASSESSMENT OF SIGNS

The questionnaire included three questions concerning signs. In the first question, drivers were asked about the ease of reading the signs. The overall adequacy of signs in terms of providing the necessary guidance was the subject of the second question. The third question asked drivers if they had any suggestions to improve the signs.

Ease of Reading Signs

Figure 17 depicts the percentages of drivers who rated the signs as adequate to read. In this study, a sign was considered "adequate to read" when the driver's response to question 1 was "easy" or "very easy".

In the urban project, signs with super-engineering grade sheeting were judged as adequate to read by more drivers than signs with high-intensity grade sheeting during both daytime and nighttime conditions. Nevertheless, the percentage of drivers who viewed the signs as adequate to read was less during nighttime than during daytime for both sheetings. This may be attributed to the inadequate size of letters used on word signs.

At the rural site, signs with engineering grade sheeting were regarded by more drivers as adequate to read than signs with super-engineering grade or high-intensity grade sheeting both during daytime and nighttime conditions. The percentages of "adequate" responses obtained for signs with super-engineering grade sheeting and signs with high-intensity grade sheeting were very close both during daytime and nighttime conditions.

In the controlled experiments, during daytime conditions, signs with high-intensity grade sheeting were viewed as adequate to read by more drivers than signs with engineering grade or super-engineering grade sheeting. The percentages of "adequate" responses obtained for signs with engineering grade

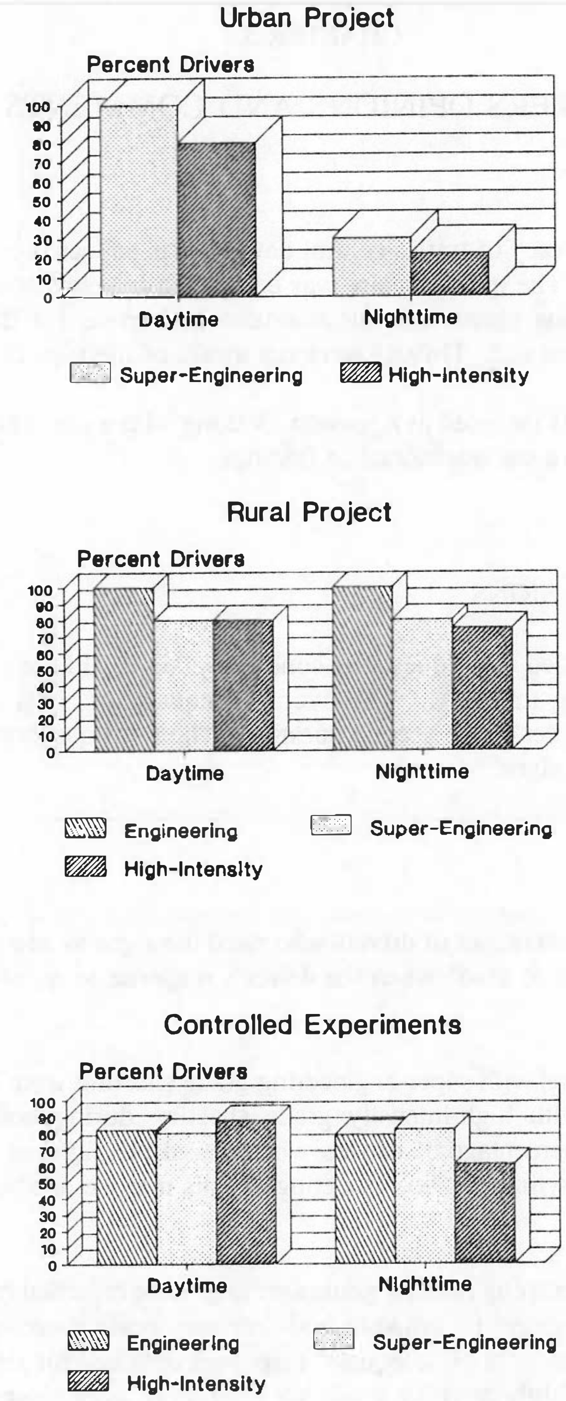


Figure 17. Ease of Reading Signs

sheeting and signs with super-engineering grade sheeting were close during daytime conditions. At nighttime, signs with engineering grade and super-engineering grade sheetings received more favorable responses than signs with high-intensity grade sheeting. The percentages of "adequate" responses during nighttime were 79%, 82%, and 61% for signs with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. Internal contrast and glare problems may have been responsible for the difficulty in reading signs with high-intensity grade sheeting at nighttime conditions.

Overall Adequacy of Signs

Figure 18 illustrates the percentages of drivers who rated the signs as adequate in terms of providing the necessary guidance. In this study, a sign was considered "overall adequate" when the driver's response to question 2 was "good" or "very good".

In the urban project, during daytime conditions, the percentages of "adequate" responses obtained for signs with super-engineering grade sheeting and signs with high-intensity grade sheeting were similar and equal to 100%. At nighttime, signs with super-engineering grade sheeting were regarded by more drivers as adequate in terms of providing the necessary guidance than signs with high-intensity grade sheeting.

At the rural site, during daytime conditions, signs with super-engineering grade sheeting were judged as adequate by 100% of the drivers compared to 80% for signs with high-intensity grade sheeting and 60% for signs with engineering grade sheeting. At nighttime, signs with engineering grade and super-engineering grade sheetings were judged as adequate by more drivers than signs with high-intensity grade sheeting.

In the controlled experiments, the percentages of "adequate" responses obtained for signs with super-engineering grade and high-intensity grade sheetings were very close both during daytime and nighttime conditions. Signs with engineering grade sheeting received less 'adequate' responses, particularly during daytime conditions.

Drivers' Suggestions for Improving Signs

1. *Overall Size of Signs*

Figure 19 illustrates the percentages of drivers who indicated that the dimensions of signs need to be increased. At the urban site, during daytime conditions, 40% of the drivers indicated that signs with super-engineering grade sheeting need to be made larger compared to 20% for signs with high-intensity grade sheeting. At nighttime, the percentages were 30% and 11% for signs with super-engineering grade sheeting and high-intensity grade sheeting, respectively.

In the rural project, more drivers indicated that signs with engineering grade sheeting need to be made larger than signs with super-engineering grade or high-intensity grade sheeting both during daytime and nighttime conditions. Signs with super-engineering grade and high-intensity grade sheetings received similar responses regardless of the time of day.

In the controlled experiments, during daytime conditions, the percentages of drivers recommending an increase in the size of signs with engineering grade, super-engineering grade, and high-intensity grade

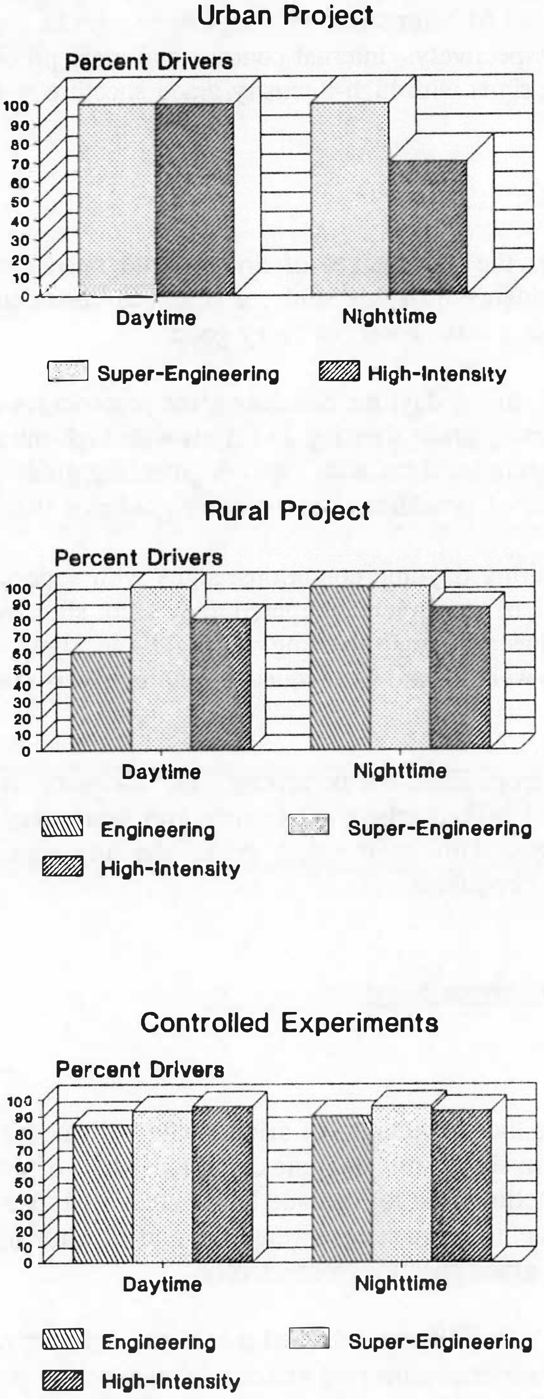


Figure 18. Adequacy of Signs in Providing Guidance

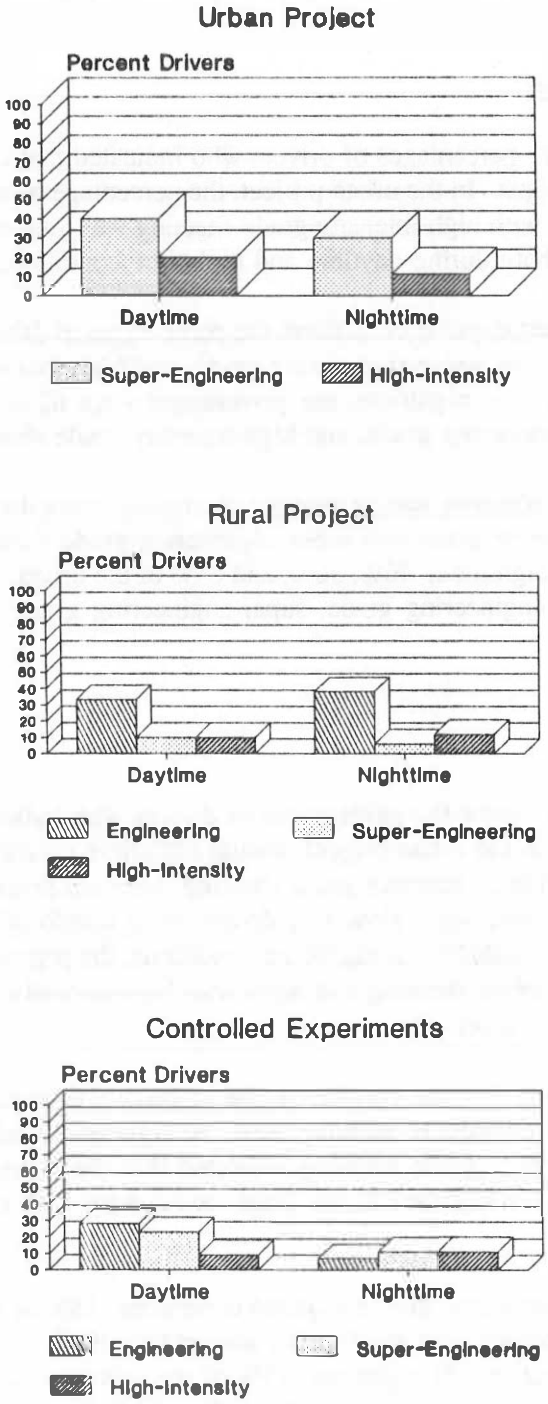


Figure 19. Distribution of Drivers Who Indicated that Larger Signs are Needed

sheetings were 28%, 23%, and 9%, respectively. At nighttime, the percentages were 7%, 11%, and 11% for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

2. Letter Size on Word Signs

Figure 20 depicts the percentages of drivers who indicated that changes were needed in the size of the letters used on word signs. In the urban project, the percentage of drivers who indicated that larger letters were needed on signs with high-intensity grade sheeting was greater than that for signs with super-engineering grade sheeting both during daytime and nighttime conditions.

At the rural site, during daytime conditions, the percentages of drivers recommending larger letters on signs with engineering grade, super-engineering grade, and high-intensity grade sheetings were 67%, 35%, and 40%, respectively. At nighttime, the percentages were 62%, 60%, and 88% for signs with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

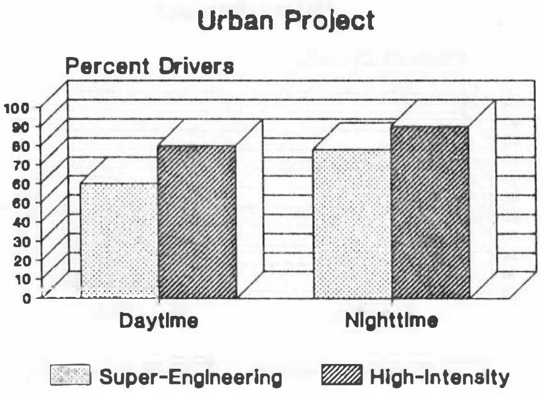
In the controlled experiments, during daytime conditions, more drivers expressed a need for larger letters on signs with engineering grade and super-engineering grade sheetings than for signs with high-intensity grade sheeting. At nighttime, 46%, 36%, and 64% of the drivers indicated that letter size should be increased on signs with engineering grade, super-engineering grade high-intensity grade sheetings, respectively.

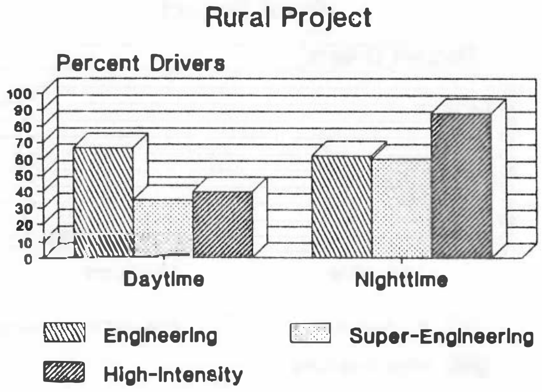
3. Sign Brightness

Figures 21 and 22 show the percentages of drivers who indicated that changes were needed in the brightness of signs. In the urban project, during nighttime conditions, the percentage of drivers who indicated that signs with high-intensity grade sheeting were *too bright* was more than that for signs with super-engineering grade sheeting. However, drivers were comfortable with the brightness of both sheetings during daytime. Nevertheless, at nighttime conditions, the percentages of drivers indicating that signs with super-engineering grade sheeting and signs with high-intensity grade sheeting were *not bright enough* were 20% and 12%, respectively.

At the rural site, during daytime conditions, the brightness of signs was judged "Ok as is" by all the drivers for each of the three grades of sheeting used. At nighttime conditions, 12% of the drivers who saw the signs with high-intensity grade sheeting indicated that the signs were *too bright*. Signs with engineering grade sheeting were regarded as *not bright enough* by 12% of the drivers during nighttime conditions.

In the controlled experiments, during daytime conditions, 13% of the drivers indicated that signs with high-intensity grade sheeting were *too bright* compared to 0% for signs with engineering grade or super-engineering grade sheetings. At nighttime, 15% of the drivers who saw signs with high-intensity grade sheeting judged them as *too bright* compared to 4% and 0% for signs with super-engineering grade sheeting and engineering grade sheeting, respectively. Nevertheless, the percentages of *not bright enough* responses were 12%, 7%, and 4% for signs with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. At nighttime, the percentages were 10%, 4%, and 3% for signs with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.





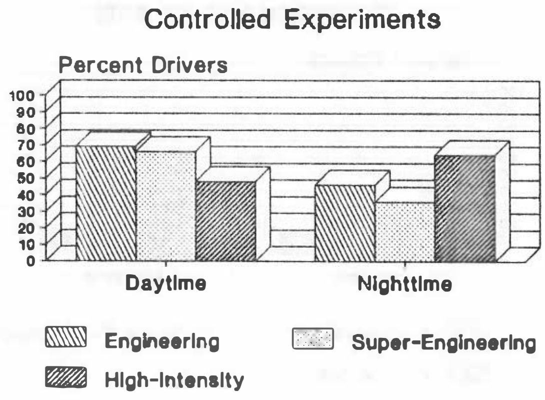


Figure 20. Distribution of Drivers Who Indicated that Larger Letters are Needed on Word Signs

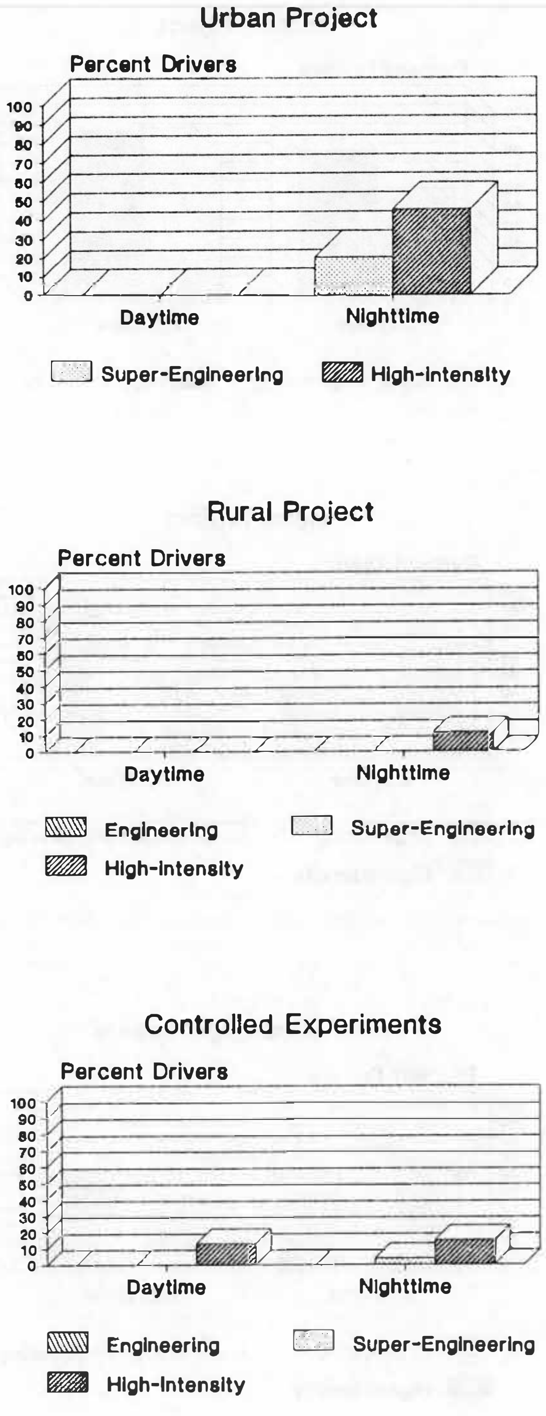
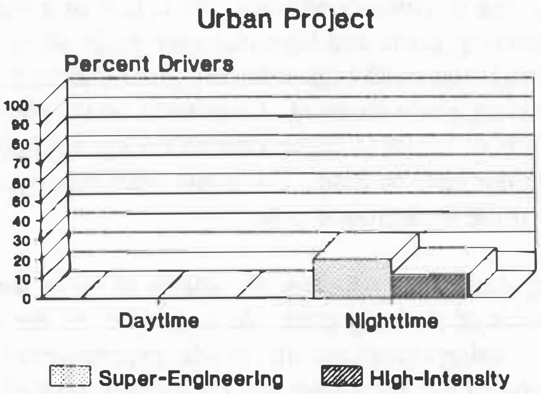
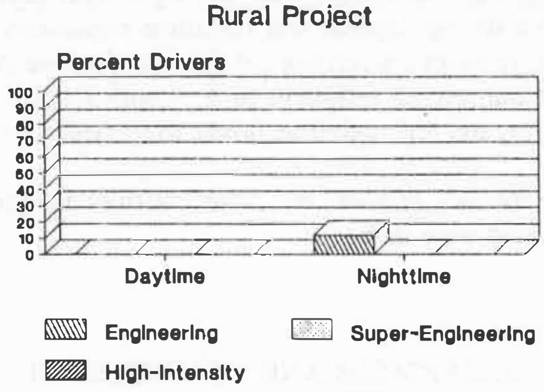


Figure 21. Distribution of Drivers Who Indicated that Signs are Too Bright





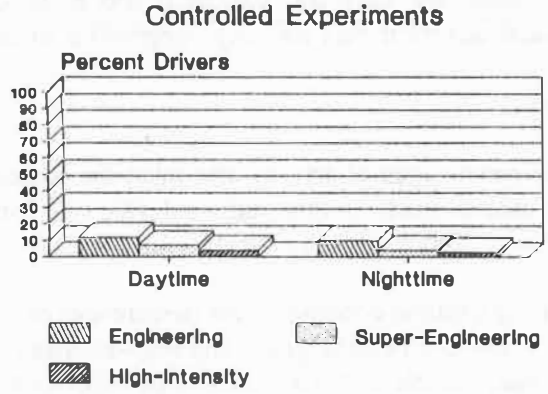


Figure 22. Distribution of Drivers Who Indicated that Signs are not Bright Enough

4. *Sign Colors*

In the urban project, during daytime conditions, the colors of signs were judged as "Ok" by all the drivers for both super-engineering grade and high intensity grade sheetings. At nightime, there were three comments regarding colors of signs with high-intensity grade sheeting, and one comment concerning color of signs with super-engineering grade sheeting. Comments on the colors of signs with high intensity grade sheeting were: change colors of letters to white, change background color to yellow and letter colors to white, and black letters were not easy to read. For signs with super-engineering grade sheeting, the only comment was to tone down the background color.

At the rural site, during daytime conditions, the colors of signs were judged as "Ok" by all the drivers for each of the three grades of sheeting used. At nighttime, all the drivers regarded the colors of signs as "Ok" for each grade of sheeting except one driver who experimented with super-engineering grade sheeting on signs. That particular driver recommended changing colors of the background to yellow or white.

In the controlled experiments, all drivers who saw signs with super-engineering grade sheeting judged their colors as "Ok" both during daytime and nighttime conditions. For signs with engineering grade sheeting, there were three remarks concerning colors: one daytime driver recommended changing the background color to bright fluorescent yellow or pink, another daytime driver noted changing the color of letters to reflective silver, and one nighttime driver suggested changing the background color to yellow.
Signs with high-intensity grade sheeting received one comment from a daytime driver who noted that the black letters on orange background were dark.

DRIVERS' ASSESSMENT OF BARRICADES AND CHANNELIZATION DEVICES

The questionnaire included three questions concerning barrels and barricades. The adequacy of these devices in terms of providing sufficient time to react was the subject of the first question. In the second question, drivers were asked how easy and smooth it was to follow the path provided by the devices. The third question asked drivers if they had any suggestions to improve the devices.

Adequacy of Warning Provided

Figure 23 illustrates the percentages of drivers who rated the barrels and barricades as adequate in terms of providing sufficient time to react. In this study, a device was considered "adequate" when the driver's response to question 4 was "good" or "very good".

In the urban project, during daytime conditions, the percentages of "adequate" responses obtained for barrels and barricades with super-engineering grade and high-intensity grade sheetings were similar and equal to 100%. At nighttime, barrels and barricades with super-engineering grade sheeting were judged as adequate by 100% of the drivers compared to 88% for devices with high-intensity grade sheeting.

At the rural site, during daytime conditions, barrels and barricades with super-engineering grade sheeting were regarded as adequate by 100% of the drivers compared to 80% and 60% for devices with

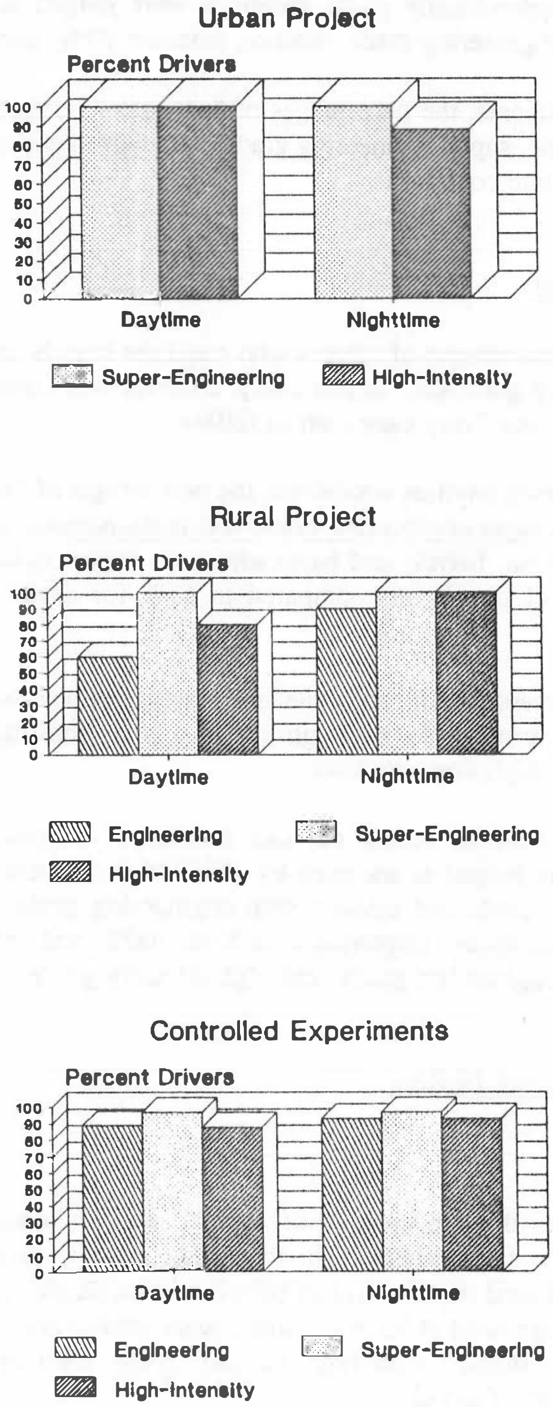


Figure 23. Adequacy of Channelization Devices in Providing Early Warning

high-intensity grade and devices with engineering grade sheetings respectively. At nighttime, devices with super-engineering grade and high-intensity grade sheetings were judged as adequate by 100% of the drivers, whereas devices with engineering grade sheeting received 90% "adequate" responses.

In the controlled experiments, the percentages of "adequate" responses obtained for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings were close both during daytime and nighttime conditions.

Adequacy of Guidance Provided

Figure 24 depicts the percentages of drivers who rated the barrels and barricades as adequate in terms of providing the necessary guidance. In this study, a device was considered "adequate" when the driver's response to question 5 was "very easy path to follow".

In the urban project, during daytime conditions, the percentages of "adequate" responses obtained for barrels and barricades with super-engineering grade and high-intensity grade sheetings were similar and equal to 100%. At nighttime, barrels and barricades with super-engineering grade sheeting were judged as adequate by 100% of the drivers compared to 67% for devices with high-intensity grade sheeting.

At the rural site, the percentages of "adequate" responses obtained for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings were similar and equal to 100% both during daytime and nighttime conditions.

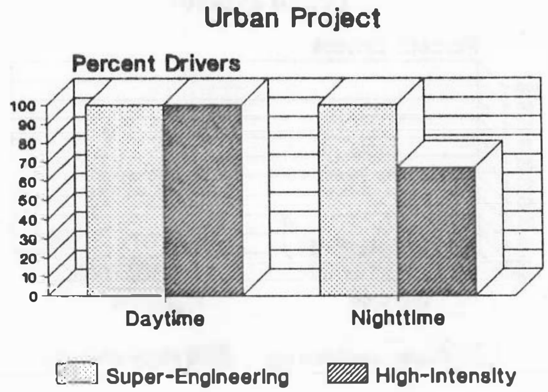
In the controlled experiments, during daytime conditions, barrels and barricades with super engineering grade sheeting were judged as adequate by 100% of the drivers compared to 96% and 88% for devices with high-intensity grade and devices with engineering grade sheetings, respectively. At nighttime, the percentages of "adequate" responses were 82%, 100%, and 96% for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

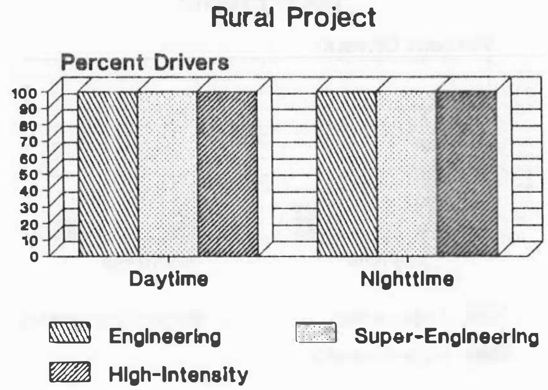
Drivers' Suggestions for Improving Devices

1. *Overall Size of Devices*

Figure 25 illustrates the percentages of drivers who indicated that the overall size of channelization devices needs to be increased. In the urban project, during daytime conditions, the percentages of drivers who indicated that the size of barrels and barricades with super-engineering grade and high-intensity grade sheetings need to be made larger were similar and equal to 20%. At nighttime, 12% of the drivers who experimented with high-intensity grade sheeting on barrels and barricades recommended increasing the size of devices.

At the rural site, during daytime conditions, 60% of the drivers indicated that barrels and barricades with engineering grade sheeting need to be made larger compared to 33% and 20% for devices with super-engineering grade and devices with high-intensity grade sheetings, respectively. At nighttime, the percentages were 25%, 0%, and 12% for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.





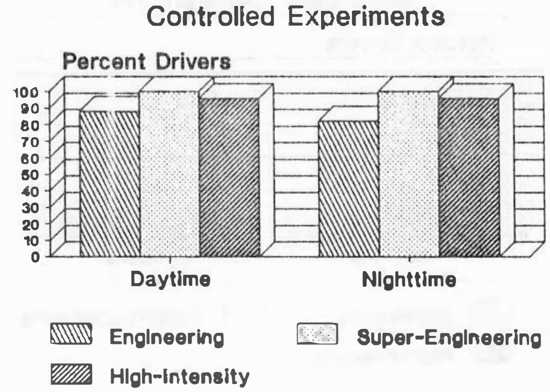


Figure 24. Adequacy of Channelization Devices in Providing Guidance

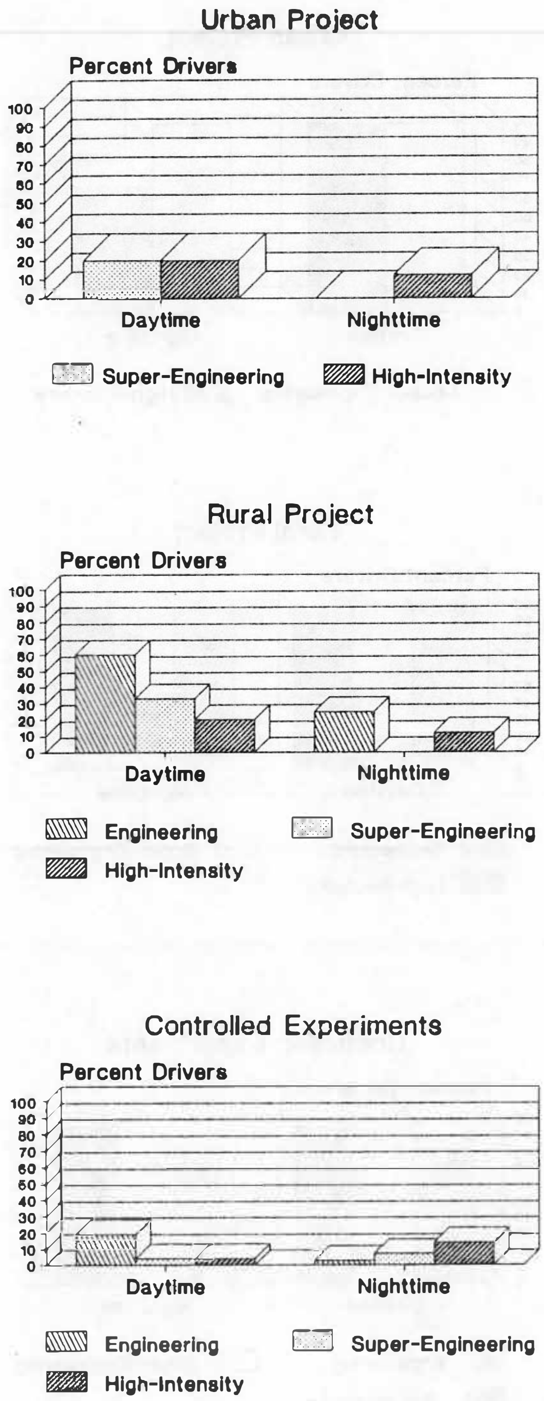


Figure 25. Distribution of Drivers Who Indicated that Larger Channelization Devices are Needed

In the controlled experiments, during daytime conditions, 19% of the drivers indicated that barrels and barricades with engineering grade sheeting need to be made larger, whereas the percentages of similar responses for devices with super-engineering grade and high-intensity grade sheetings were 4% and 4% respectively. At nighttime, 14% of the drivers recommended that the size of barrels and barricades with high-intensity grade sheeting should be increased compared to 7% and 3% for devices with super-engineering grade and devices with engineering grade sheetings, respectively.

2. *Device Brightness*

Figures 26 and 27 depict the percentages of drivers who indicated that changes were needed in the brightness of barrels and barricades. In the urban project, during nighttime conditions, 20% of the drivers who saw barrels and barricades with high-intensity grade sheeting regarded their brightness as *too much.* Nevertheless, the percentages of drivers indicating that devices were *not bright enough* at nighttime were 5% and 2% for super-engineering grade and high-intensity grade sheetings, respectively.

At the rural site, drivers who experimented with high-intensity grade sheeting on barrels and barricades indicated that the devices were *too bright* both during daytime and nighttime conditions. During daytime conditions, however, 23% of the drivers said that barrel and barricades with engineering grade sheeting were *not bright enough* compared to 10% and 0% for devices with super-engineering grade and devices with high-intensity grade sheetings, respectively.

In the controlled experiments, during nighttime conditions, 17% of the drivers indicated that barrels and barricades with high-intensity grade sheeting were *too bright*. Nevertheless, the percentages of *not bright enough* responses during nighttime were 21%, 4%, and 0% for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. During daytime conditions, 11% of the drivers said that barrels and barricades with engineering grade sheeting were *not bright enough* compared to 8% and 7% for devices with super-engineering grade and devices with high-intensity grade sheetings, respectively.

3. *Colors of Devices*

The colors of barrels and barricades were judged as "Ok" by all drivers at all test sites during both daytime and nighttime conditions except one nighttime driver who saw the devices with engineering grade sheeting. That particular driver recommended changing the colors of the orange stripes to yellow.

OVERALL ADEQUACY OF SIGNS, BARRELS AND BARRICADES

Figure 28 illustrates the percentages of drivers who rated all the traffic control devices as adequate in terms of providing the necessary warning and guidance. In this study, the array of devices was considered "overall adequate" when the driver's response to question 7 was "good" or "very good".

In the urban project, during daytime conditions, the percentages of "adequate" responses obtained during the experiments with super-engineering grade and high-intensity grade sheetings were similar and equal to 100%. At nighttime, the array of devices with super-engineering grade sheeting was judged as

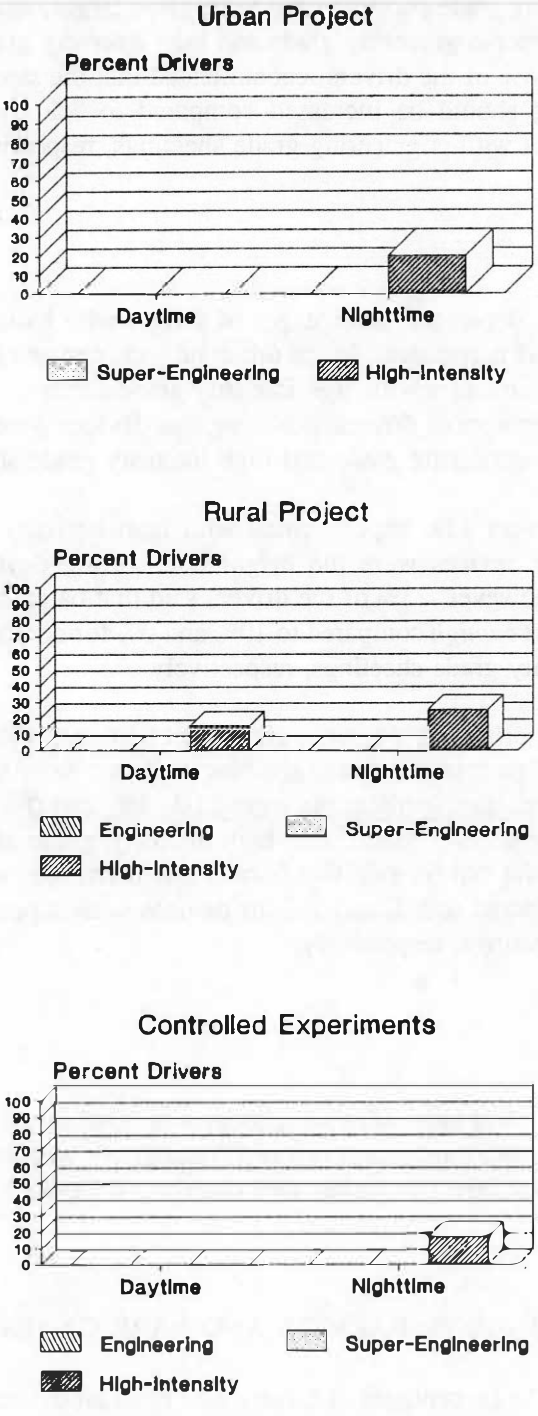


Figure 26. Distribution of Drivers Who Indicated that Channelization Devices are Too Bright

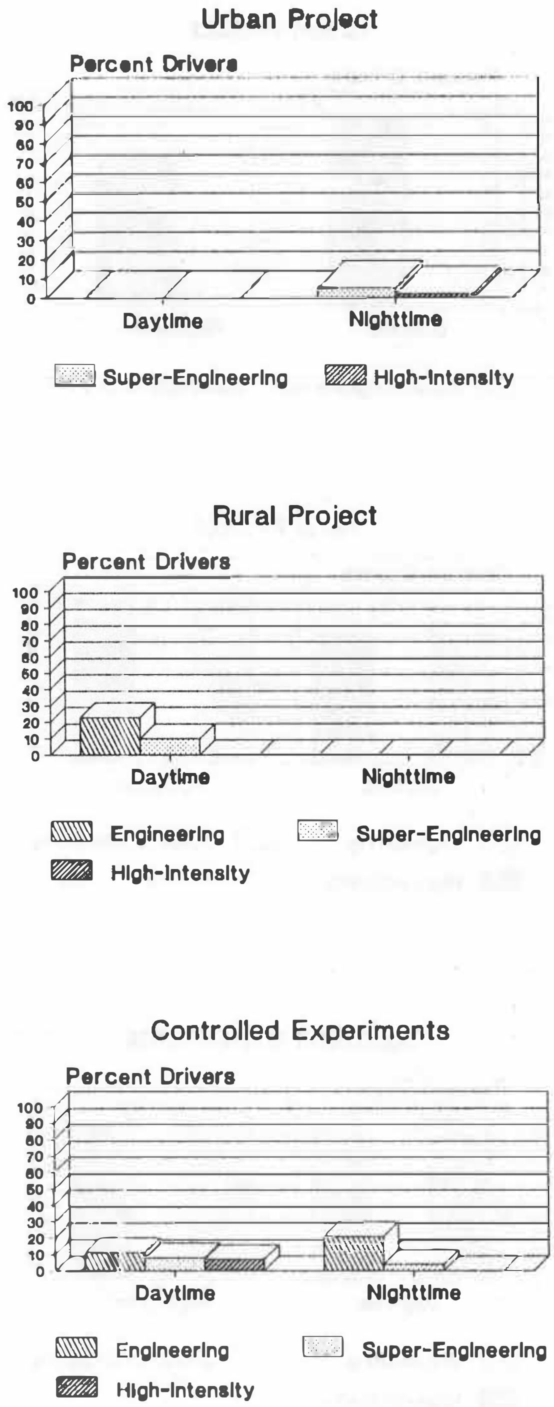


Figure 27. Distribution of Drivers Who Indicated that Channelization Devices are not Bright Enough

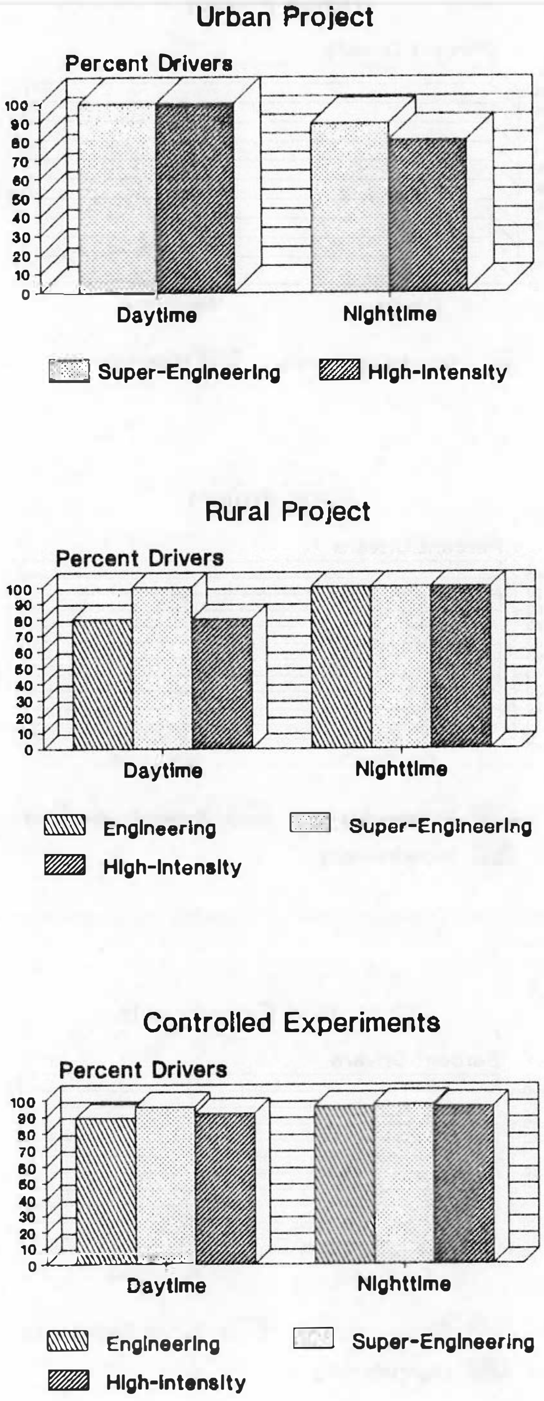


Figure 28. Overall Adequacy of Entire Array of Devices

adequate by 89% of the drivers compared to 80% for the array of devices with high-intensity grade sheeting.

At the rural site, during daytime conditions, the percentages of "adequate" responses were 80%, 100%, and 80% when engineering grade, super-engineering grade and high-intensity grade sheetings were used on the array of devices, respectively. At nighttime, the percentage of "adequate" responses was 100% for each of the three grades of sheeting tested.

In the controlled experiments, the percentages of "adequate" responses obtained for the array of devices with engineering grade, super-engineering grade, and high-intensity grade sheetings were close both during daytime and nighttime conditions.

OTHER COMMENTS

The following are citations of the drivers' remarks which were noted on the questionnaire:

Urban Project, Super-engineering Grade Sheeting, Nighttime

- It seems that the black letters on the signs were washed out by the orange.
- The reflective coating was just right on the signs.
- Signs need larger letters and sign size.
- Letter size should be larger.
- The letters on the "Lane Closed Ahead" signs were small and hard to read at night while watching other vehicles. The barrels seemed to be bright enough to follow.
- Prefer symbols, more raised pavement markers, clearer regulatory signs.

Urban Project, Super-engineering Grade Sheeting, Daytime

- I think that the white stripes on the barricades and barrels would show up better if they were yellow.

Urban Project, High-intensity Grade Sheeting, Nighttime

- White letters on orange background may help reading signs.
- Lettering on first warning sign was too narrow. I was on top of the sign before I could read it. The 'Merge Right' symbol sign should be made larger.
- I feel that signs and barrels gave fair warning, but the signs were hard to read.
- Some of the letters on the signs were very difficult to read. They were kind of faded.
- On the second set of signs, glare seemed to be quite high thereby reducing sight of lettering.
- The signs seemed to glare at a distance.

Urban Project, High-intensity Grade Sheeting, Daytime

- Lettering on signs was blurry until we were almost on top of them.

Rural Project, Engineering Grade Sheeting, Nighttime

- I believe the overall size of signs was a little small.

Rural Project, Engineering Grade Sheeting, Daytime

No comments.

Rural Project, Super-engineering Grade Sheeting, Nighttime

- The orange showed up very well.
- The detour was very smooth and easy to follow. I feel that the barricades and barrels were more important than the signs although the signs were also effective.
- Signs could be brighter and letters made larger.

Rural Project, Super-engineering Grade Sheeting, Daytime

- Roadway alignment made it hard to see and read some devices.
- The white/orange stripes on barricades could be wider with a larger proportion given to the orange. They appear mostly white until you get fairly close. The white blends in with the sky & road during the day while orange stands out. Curve signs are very easy to read.

Rural Project, High-intensity Grade Sheeting, Nighttime

- It was hard for me to read the print on the signs. I had to concentrate and slow down some.
- The signs are very easy to see. However, the letters are not as easy to read.
- I found that symbol signs were more visible from farther away.
- Make letters and symbols somewhat larger.

Rural Project, High-intensity Grade Sheeting, Daytime

- The signs with orange flags were very easy to pick out. The flags should be used with the barricades which were hard to see.

Controlled Experiments, Engineering Grade Sheeting, Nighttime

- Orange background was Ok, but letters were not clear enough to read from a distance.
- If we had a symbol for Road Construction it would be easier to read. I have taught adult courses for G.E.D. What reading level is necessary for reading the word "construction"?
- The signs themselves were Ok as is and the color is very easy to see. But in my opinion, the letters need to be just a little larger to be more legible.
- Everything was fine, I liked the color and brightness.

- The lane closed symbol sign was great, but I would have liked to be able to read the other signs quicker.

Controlled Experiments, Engineering Grade Sheeting, Daytime

- Larger letters on signs.
- All signs and devices were of the same color. I feel the instructional signs should be of a different color to attract attention.
- Overall the signs provided very good warning of the construction ahead.
- Larger signs, larger letters.
- The signs were fine in size and color; it would help if lettering was a bit more bold.
- I have a problem with the black numbers on the orange signs. The black letters were Ok, but the numbers were not.

Controlled Experiments, Super-engineering Grade Sheeting, Nighttime

- Last week, the signs and devices were easier to see. (Note: Last week refers to experiments with high-intensity grade sheeting).
- I saw the signs very well but it took a while to be able to read the words.
- Signs and barricades were easy to see but barrels need to be brighter.
- The background brightness was much better than last week. (Note: Last week refers to experiments with high-intensity grade sheeting).

Controlled Experiments, Super-engineering Grade Sheeting, Daytime

- I had more trouble reading the numbers stating the distances than reading the words. I would like the numbers bigger.
- Letters on signs need to be larger so that people can see them better and have time to make adjustment.
- It was very easy to see and read. It was safe to drive under these conditions.
- Merge sign was not as large as I would have liked. Overall, very good.
- Letters on signs need to be larger. Rest of sign was Ok.
- The signs and coloring were very adequate.
- Signs were adequate as far as size and color. Letters were a little small.

Controlled Experiments, High-intensity Grade Sheeting, Nighttime

- It was easier to see the signs, barricades, and barrels tonight than last week. (Note: Last week refers to experiments with engineering grade sheeting).
- Letters were easier to read than numbers.
- They were easy to read and I could see them fast.
- Warning signs were too bright, could not read them.
- It took longer to read the signs than last week. (Note: Last week refers to experiments with engineering grade sheeting).

- Need to have a little bigger letters.
- The size and color were Ok, but the words were hard to read on the signs.
- Signs were highly visible but hard to read at a distance. Barricades highly visible. Barrels need to be a little brighter.
- The background was very bright which made the words hard to read.

Controlled Experiments, High-intensity Grade Sheeting, Daytime

- The orange seemed too dark for the black lettering. I was able to see them from a great distance but I was unable to read the signs.
- Letters need to be bigger and brighter.

Summary

The drivers' comments indicate that the letters used on word signs were somewhat small in size. In general, the drivers preferred symbol signs to letter signs. At nighttime conditions, some drivers noted glare problem with high-intensity grade sheeting on signs. They indicated that the background of signs was too bright which made it difficult to read the legend.

CHAPTER 6

CONTRACTORS SURVEY RESULTS

Data on service lives and cost items of the three sheeting types were obtained using a questionnaire which was sent to each of the three major contractors in Oklahoma. In addition to service lives and costs, the questionnaire asked about types of sheetings used, the quantity of sheeting purchased per year, modes of deterioration experienced with every sheeting, and problems related to the fabrication and handling of different traffic control devices using these sheetings. Details of the contractors' questionnaire are given in Appendix C. The following paragraphs summarize the findings of the contractors survey.

USE OF RETROREFLECTIVE SHEETINGS

Table 5 summarizes the use of retroreflective sheetings by Oklahoma contractors. Engineering grade sheeting has traditionally been used on traffic control devices by all the three major contractors in Oklahoma. Years of experience with engineering grade sheeting range from 8 to 20 years and the average number of square yards purchased each year is approximately 6,000 per contractor.

High-intensity grade sheeting has also been used on traffic control devices by the three major contractors, albeit with a lesser number of years of experience. The average number of years of experience with high-intensity grade sheeting is 4.7 years and the average number of square yards purchased each year is approximately 1,200 per contractor.

Super-engineering grade sheeting has been around for a number of years; nevertheless, Oklahoma contractors have limited experience with this types of sheeting. Only one contractor reported using 200 square yards of super-engineering grade sheeting during the past year.

EXPECTED SERVICE LIFE OF SHEETINGS

Table 6 presents the expected service lives of the different sheetings when used on traffic control devices at construction work zones. The expected service lives of engineering grade, super-engineering grade, and high-intensity grade sheetings when used on signs average 280, 360, and 260 days, respectively. The corresponding number of projects, where a sign can be used without having to replace the retroreflective sheeting, averages 2.5, 3, and 2.2 projects for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

When used on barricades, the average service lives of engineering grade, super-engineering grade, and high-intensity grade sheetings are 200, 300, and 220 days, respectively. In terms of number of projects, where a barricade can be used without having to replace the retroreflective sheeting, the averages are 1.3, 2, and 1.3 projects for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

TABLE 5. USE OF RETROREFLECTIVE SHEETINGS BY OKLAHOMA CONTRACTORS

Contractor	Type of Sheeting		
	Engineering Grade	Super-Engineering Grade	High-Intensity Grade
Use of Sheetings			
1	xx		xx
2	xx		xx
3	xx	xx	xx
Years of Experience			
1	16	0	9
2	8	0	2
3	20	1	3
Square Yards Purchased Each Year			
1	4,765	0	2,100
2	7,200	0	1,000
3	6,000	200	600

TABLE 6. EXPECTED SERVICE LIFE OF SHEETINGS ON DIFFERENT DEVICES

	Engineering Grade		Super-Engineering Grade		High-Intensity Grade	
Contractor	Days	Projects	Days	Projects	Days	Projects
			SIGNS			
1	240	2 - 4	---	---	240	2
2	240	1 - 2	---	---	180	1 - 2
3	360	3	360	3	360	3
Average	280	2.5	360	3	260	2.2
			BARRICADES			
1	120	1	---	---	180	1
2	180	1	---	---	180	1
3	300	2	300	2	300	2
Average	200	1.3	300	2	220	1.3
			BARRELS			
1	180	2	---	---	240	2 - 3
2	260	2	---	---	260	2 - 3
3	300	2	300	2	300	2
Average	247	2.0	300	2	267	2.3
			VERTICAL PANELS			
1	100	1	---	---	150	1 - 2
2	150	1	---	---	150	1
3	300	2	300	2	300	2
Average	183	1.3	300	2	200	1.5

Reflective sheetings on barrels have expected service lives of 247, 300, and 267 days for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. In terms of number of projects, where a barrel can be used without having to replace the reflective sheeting, the average number of projects is 2, 2, and 2.3 for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

When used on vertical panels, the average service lives of engineering grade, super-engineering grade, and high-intensity grade sheetings are 183, 300, and 200 days, respectively. The corresponding number of projects, where a vertical panel can be used without having to replace the reflective sheeting, averages 1.3, 2, and 1.5 projects for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Figure 29 depicts the expected service lives of the three sheetings when used on different traffic control devices.

DEVICE KNOCKDOWNS AND VANDALISM

Table 7 shows the frequency of device knockdowns and vandalism at construction work zones. The average percentages of device knockdowns for signs, barricades, barrels, and vertical panels are 7.67%, 19.17%, 20.83%, and 20%, respectively.

On the average, the percentages of devices vandalized at construction work zones are 17%, 36.33%, 14.33%, and 18.67% for signs, barricades, barrels, and vertical panels, respectively.

TABLE 7. DEVICE KNOCKDOWNS AND VANDALISM

	Signs	Barricades	Barrels	Vertical Panels
Contractor	Percent Knockdowns			
1	10%	15% - 20%	10% - 15%	10%
2	6%	30%	26%	40%
3	7%	10%	10%	10%
Average	8%	19%	21%	20%
Contractor	Percent Vandalized			
1	40%	80%	20% - 30%	15% - 25%
2	8%	28%	15%	33%
3	3%	3%	3%	3%
Average	17%	36%	14%	19%

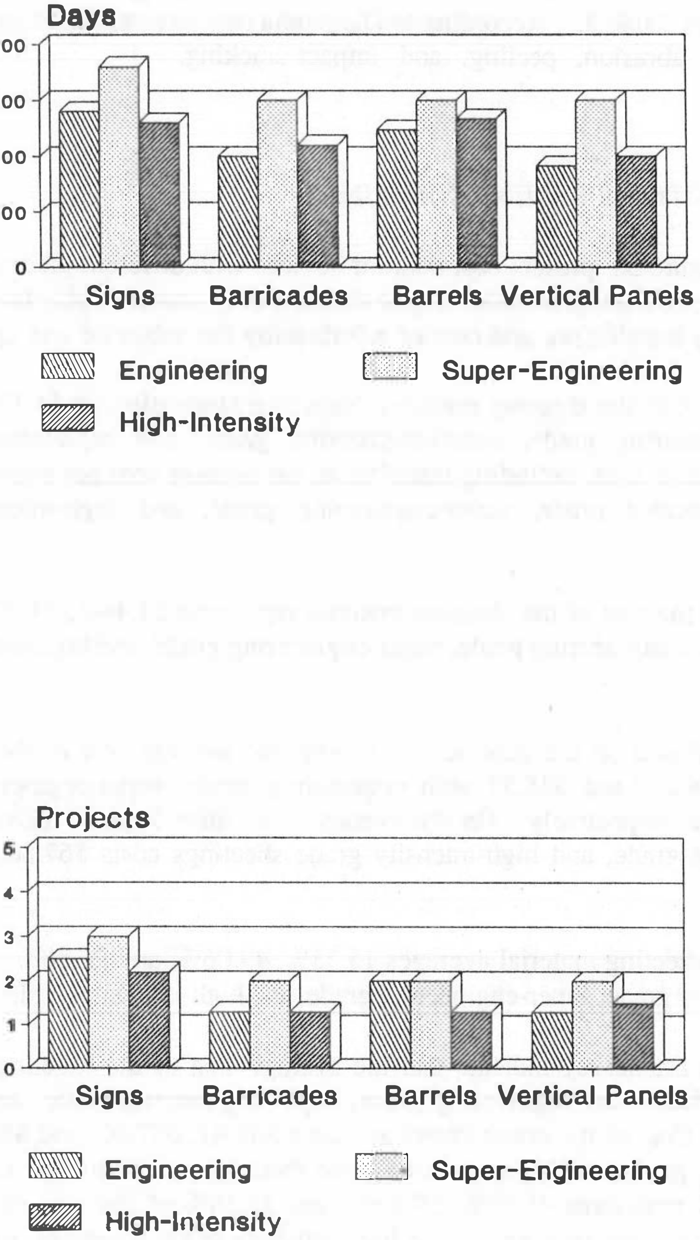


Figure 29. Expected Service Life of Sheetings

DETERIORATION MODES OF SHEETINGS ON DIFFERENT DEVICES

A summary of the deterioration modes of the three sheeting types when used on different traffic control devices is given in Table 8. According to Oklahoma contractors, the most common deterioration modes are color fading, abrasion, peeling, and impact cracking.

COST OF DEVICES WITH DIFFERENT SHEETINGS

Table 9 and Figure 30 present cost data for devices with different grades of sheeting. For each traffic control device, the cost items include: cost of sheeting only (material plus fabrication), cost of entire control device excluding installation, and cost of refurbishing the substrate and applying new sheeting.

Signs - The average cost of the sheeting material, including fabrication, is $1.12, $2.00, and $4.07 per square foot with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. For the entire sign, excluding installation, the average cost per square foot is $1.95, $2.70, and $4.99 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

On the average, the cost of the sheeting material represents 57.44%, 74.07%, and 81.56% of the cost of the entire sign with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Type-III Barricades - Based on the contractors' survey, the average cost of the sheeting material per barricade is $10.36, $26.00, and $38.53 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. On the average, the entire Type-III barricade with engineering grade, super-engineering grade, and high-intensity grade sheetings costs $67.50, $53.00, and $143.33, respectively.

The cost of the sheeting material averages 15.35%, 49.06%, and 26.88% of the cost of the entire barricade with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Barrels - Responses to the survey indicate that the average cost of the sheeting material per barrel is $15.45, $22.00, and $35.83 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. Cost of the entire barrel averages $33.67, $37.00, and $63.33, with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. On the average, the cost of the sheeting material represents 45.89%, 59.46%, and 56.58% of the cost of the entire barrel with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Vertical Panels - Cost of the sheeting material required on a vertical panel averages $1.83, $5.00, and $6.28 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. For the entire vertical panel, the average cost is $4.08, $7.50, and $13.73 with engineering grade, super-engineering grade, and high-intensity grade sheetings respectively.

On the average, the cost of the sheeting material represents 44.85%, 66.67%, and 45.74% of the cost of the entire vertical panel with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

TABLE 8. DETERIORATION MODES OF SHEETINGS ON DIFFERENT DEVICES

	Contractor 1			Contractor 2			Contractor 3		
Deterioration Modes	E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
SIGNS									
Color Fading	xx		xx	xx			xx	xx	xx
Temperature Cracking									
Abrasion			xx			xx			
Peeling							xx	xx	xx
Impact Cracking						xx			
Dirt Accumulation	xx		xx				xx	xx	xx
Other (Specify)									
BARRICADES									
Color Fading							xx	xx	xx
Temperature Cracking									
Abrasion	xx		xx			xx	xx	xx	xx
Peeling				xx		xx			
Impact Cracking						xx	xx	xx	xx
Dirt Accumulation	xx		xx	xx		xx	xx	xx	xx
Other (Specify)	xx		xx						
BARRELS									
Color Fading	xx		xx						
Temperature Cracking	xx		xx						
Abrasion	xx		xx				xx	xx	xx
Peeling	xx						xx	xx	xx
Impact Cracking	xx		xx	xx		xx	xx	xx	xx
Dirt Accumulation	xx		xx	xx		xx	xx	xx	xx
Other (Specify)	xx		xx						
VERTICAL PANELS									
Color Fading									
Temperature Cracking									
Abrasion	xx						xx	xx	xx
Peeling				xx		xx			
Impact Cracking							xx	xx	xx
Dirt Accumulation	xx		xx	xx		xx	xx	xx	xx
Other (Specify)	xx		xx						

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE 9. COST OF DEVICES WITH DIFFERENT GRADES OF REFLECTIVE SHEETING

	Cost Items[a]								
	Engineering Grade			Super-Engineering Grade			High-Intensity Grade		
Contractor	A	B	C	A	B	C	A	B	C
SIGNS (Dollars per Square Foot)									
1	0.95	1.50	N/A				4.15	4.93	N/A
2	1.41	2.65	1.95				4.35	5.85	5.10
3	1.00	1.71	N/A	2.00	2.70	N/A	3.70	4.20	N/A
Average	1.12	1.95	1.95	2.00	2.70	N/A	4.07	4.99	5.10
TYPE-III BARRICADES (Dollars per Barricade)									
1	6.80	82.50	2.88[b]				32.80	155.00	7.58[b]
2	11.28	80.00	N/A				34.80	200.00	N/A
3	13.00	40.00	N/A	26.00	53.00	N/A	48.00	75.00	N/A
Average	10.36	67.50	2.88[b]	26.00	53.00	N/A	38.53	143.33	7.58[b]
BARRELS (Dollars per Barrel)									
1	13.33	36.00	18.15				34.50	57.00	21.78
2	22.00	39.00	29.00				40.00	85.00	N/A
3	11.00	26.00	N/A	22.00	37.00	N/A	33.00	48.00	N/A
Average	15.45	33.67	23.57	22.00	37.00	N/A	35.83	63.33	21.78
VERTICAL PANELS (Dollars per Panel)									
1	1.13	3.72	N/A				5.53	13.38	N/A
2	1.88	3.53	N/A				5.80	7.80	N/A
3	2.50	5.00	N/A	5.00	7.50	N/A	7.50	10.00	N/A
Average	1.83	4.08	N/A	5.00	7.50	N/A	6.28	13.73	N/A

a: A = Cost of sheeting only (materials plus fabrication);
B = Cost of entire control device excluding installation;
C = Cost of refurbishing the substrate and applying new sheeting.

b: Dollars per panel

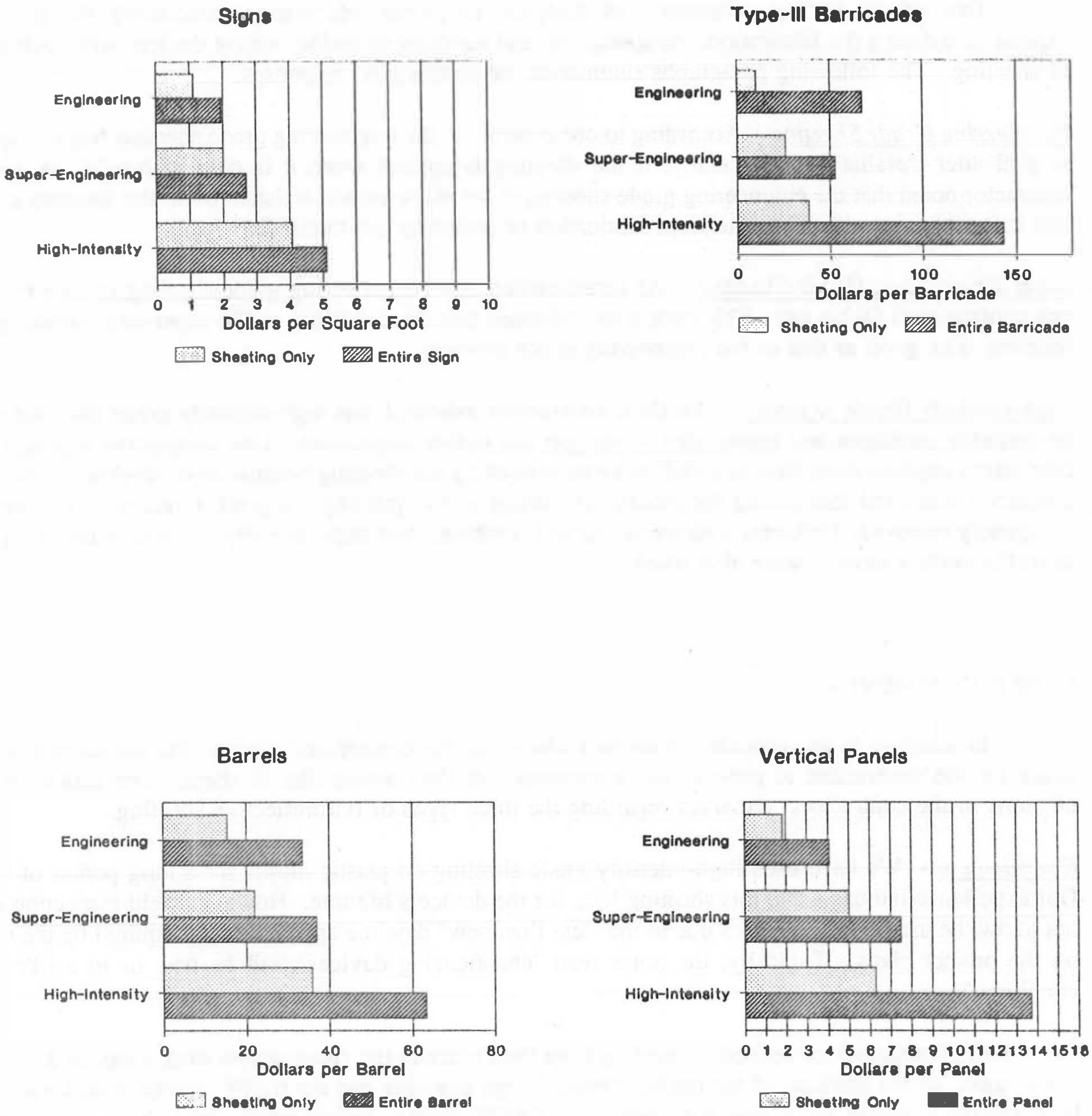


Figure 30. Cost Data for Devices with Different Grades of Sheeting

PROBLEMS RELATED TO FABRICATION AND HANDLING

One of the survey questions was designed to gather information concerning the problems experienced during the fabrication, transportation, and handling of traffic control devices with each grade of sheeting. The following paragraphs summarize the contractors' responses.

Engineering Grade Sheeting - According to one contractor, the engineering grade sheeting has a tendency to peel after installation, particularly, if the sheeting is applied when it is cold or humid. A second contractor noted that the engineering grade sheeting is the most scratch resistant of all the sheeting grades and that problems with its application, fabrication or screening are minimal.

Super-Engineering Grade Sheeting - As noted earlier, super-engineering grade sheeting is used by only one contractor in Oklahoma. This contractor indicated that the durability of the super-engineering grade sheeting is as good as that of the engineering grade sheeting.

High-Intensity Grade Sheeting - All three contractors indicated that high-intensity grade sheeting must be carefully packaged and transported to the job site before fabrication. One contractors reported that fabrication requires more time and skill to avoid scratching the sheeting because of its thickness. Another contractor remarked that during the process of erasing and re-printing a legend, smear marks cannot be completely removed. Problems with wrinkling and cracking when high-intensity grade sheeting is applied to traffic control devices were also noted.

OTHER COMMENTS

In addition to the specific questions included in the contractors' survey, the questionnaire had space for the contractors to provide any comments that they would like to share. The following are citations of the contractors' remarkes regarding the three types of retroreflective sheeting.

Contractor-1 - We have used high-intensity grade sheeting on plastic drums for a long period of time. Our experience indicates that this sheeting lasts for the device's lifetime. However, field inspection may not allow the use of some devices due to the "less than new" daytime appearance as required by the notes on the project plans. Typically, the notes read "channelizing devices shall be new or in a like new condition."

High performance reflective sheeting have their place in the construction work zone, as do all the other "tools" at the disposal of the traffic control design engineer and the traffic control contractor. The best approach would be a few meetings with ODOT traffic design people and the traffic control contractors to discuss revisions to the standard drawings that would allow the engineer to specify minimum values for given situations, and the traffic control contractor the flexibility to use the devices that work best for the given conditions. I would like to discuss an outline of my ideas at your convenience.

Contractor-2 - I would like to see a "universal" sheeting for construction work zones manufactured by several companies. We have used both engineering grade and 3M high-intensity grade sheetings for a number of years. Engineering grade sheeting is much easier to work with in every aspect. Recently, however, we have had the opportunity to experiment with super-engineering grade sheeting and have found that it resembles the engineering grade sheeting in its ease of fabrication. Also, information provided by private companies and state agencies who utilize super-engineering grade sheeting are all very favorable to its performance.

Construction signing is subject to numerous changes. Signs are constantly moved, removed, and reinstalled. Devices are knocked over, reset, and washed constantly. The reflective material used needs to be one that can sustain this type of treatment.

Contractor-3

No comments were received.

CHAPTER 7

ACCELERATED WEATHERING TEST RESULTS

PERFORMANCE REQUIREMENTS

The ASTM minimum performance requirements for artificial weathering of the orange colored retroreflective sheetings are given in Table 10. The specific intensities per unit area, SIA, are expressed in candelas per foot-candle per square-foot (cd/fc/ft^2). Retroreflectivity measurements are typically made after the prescribed number of hours of artificial weathering in a weatherometer chamber. The measurement are obtained at 0.2° divergence angle, and at two incidence angles; -4° and +30°. The minimum SIA values of the weathered sheetings are given in the last column of Table 10. These values are calculated by multiplying the minimum SIA of the new sheeting, given in the third column, by the percentages given in the fifth column of the table.

TABLE 10. ASTM PERFORMANCE REQUIREMENTS FOR ORANGE COLORED SHEETINGS

Sheeting Type	Test Conditions		Minimum SIA of New Sheeting	Minimum SIA After Artificial Weathering		
	Divergence Angle	Incidence Angle		Hours Tested	Percent of New Sheeting Minimum SIA	Minimum SIA
Type I (E.G.)	0.2° 0.2°	- 4° + 30%	25 7	1000	50%	12.5 3.5
Type II (S.E.G.)	0.2° 0.2°	- 4° + 30°	60 22	500	65%	39.0 14.3
Type III[a] (H.I.G.)	0.2% 0.2°	- 4° + 30°	100 60	500	80%	80.0 48.0
Type IV[b] (H.I.G.)	0.2° 0.2°	- 4° + 30°	100 34	1500	80%	80.0 27.2

a Encapsulated glass-bead

b Unmetallized microprismatic retroreflective element material

ACCELERATED WEATHERING TEST RESULTS

Table 11 summarizes the artificial weathering test results for the three types of sheeting used in this study. The engineering grade and high-intensity grade sheetings were tested by the ODOT

Materials Laboratory on November 29, 1982 and September 9, 1986. The SIA values were recorded after 500, 1000, 2000, 3000, and 4000 hours of artificial weathering.

Weatherometer data for the super-engineering grade sheeting were provided by the Seibulite International Inc., Rancho Dominguez, California, and the Industrial Testing Laboratories, Berkeley, California. The SIA values were recorded after 500 and 1000 hours of artificial weathering.

The retroreflective sheetings were also inspected visually during the artificial weathering and any change in their appearance was recorded.

The 500 and 1000 hours of exposure in the weatherometer chamber are approximately equivalent to 2.5 and 7 years of outdoor weathering, respectively. All the three grades of sheeting exceeded the ASTM requirements for the minimum SIA after the prescribed number of hours of artificial weathering. Nevertheless, since the expected service life of retroreflective sheetings at construction work zones is usually less than one year, the ASTM requirements for artificial weathering are not critical in this study.

TABLE 11. ARTIFICIAL WEATHERING TEST RESULTS

Sheeting Type [a]	Test Conditions		Weatherometer Test Results SIA [b]					ASTM Requirements	
			Hours of Artificial Weathering						
	Divergence Angle	Incidence Angle	500	1000	2000	3000	4000	Testing Hours	Minimum SIA
H.I.G.	0.2°	- 4°	121.0	86.8	74.9	45.8	---	500	80
	0.2°	+ 30°	109.2	73.5	66.6	34.4	---		48
E.G.	0.2°	- 4°		44.0	47.3	47.0	49.6	1000	12.5
(P.S.A.)	0.2°	+ 30°		23.9	26.7	27.6	29.0		3.5
E.G.	0.2°	- 4°		40.5	46.1	45.8	46.8	1000	12.5
(H.A.A.)	0.2°	+ 30°		25.8	30.3	30.6	30.9		3.5
S.E.G.	0.2°	- 4°	78.3	78.8				500	39
(H.A.A.)	0.2°	+ 30°	62.3						14.3

REMARKS ON VISUAL APPEARANCE [b]

High-Intensity Grade - Slight fading beginning 500 hours. Steady fading through 3000 hours. Failed required reflectance, testing stopped.

Engineering Grade (Pressure Sensitive Adhesive) - Definite darkening 1000 hours. Progressively darker dullish dark burnt orange at 4000 hours.

Engineering Grade (Heat Activated Adhesive) - Slight fading 1000 hours. No change 4000 hours.

Super-Engineering Grade (Heat Activated Adhesive) - After 500 hours, no perceptible change in appearance, no discoloration, cracking, blistering or dimensional change. After 1319 hours of exposure, no lifting or peeling had occurred at any of the edges.

---

[a] E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade
P.S.A. = Pressure Sensitive Adhesive, H.A.A. = Heat Activated Adhesive

[b] Engineering grade and high-intensity grade sheetings were tested by the ODOT on 11-29-1982 and 9-9-1986. Data on super-engineering grade sheeting were provided by Seibulite International, Inc.

CHAPTER 8

ECONOMIC ANALYSIS

Economy, the attainment of an objective at low cost, is critical to any sound decision making process. One of the primary goals of the ODOT management and engineers has been to achieve the greatest end results per unit of resource used. This is essentially an expression of economic efficiency which may be defined as worth divided by cost. It is often possible to accomplish a desired result by several means, each of which is both feasible and adequate from an engineering point of view. The most desirable mean is the one that has the least cost. In determination of economy, care must be exercised to ensure that the alternatives being evaluated provide identical services.

A popular method of evaluating alternatives is to compute the benefit-cost ratio of each alternative. This ratio reflects the tax payer's dollar benefits per each dollar of costs. The alternative that yields the highest benefit-cost ratio is usually selected. If the benefits offered by each alternative are the same, then the least cost alternative should be sought. In the following discussion, it is assumed that all the retroreflective sheetings meet the drivers' visibility needs as well as the ASTM performance requirements.

Two measures of effectiveness (MOEs) that can be employed in the economic analysis of retroreflective sheetings are described in the FHWA report "Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide" [7]. The first MOE is the ratio of the total cost of the device to the service life of the device, i.e.,

$$C_Y = \frac{TC}{N_Y} \tag{8}$$

where:

C_Y = cost per year of service life of device,
TC = total cost of the entire device excluding installation, and
N_Y = expected service life of device in years.

In the second MOE, the average luminance of the retroreflective sheeting is incorporated in computing the cost per year as follows:

$$C_Y = \frac{TC}{\frac{(L_n + L_o)}{2} N_Y} \tag{9}$$

where:

L_n = luminance of new sheeting in SIA units, and
L_o = luminance of sheeting at end of useful life in SIA units.

Equation 9 tends to favor those retroreflective sheetings which have higher initial luminance values regardless of their cost. To help demonstrate, Figure 31 depicts the cost per year as a function of the total cost for a 48" x 48" sign with the three sheeting types under consideration. Values of the initial luminance, L_n, and the terminal luminance, L_o, were assumed to be equal to those prescribed by the ASTM for new sheeting materials and after the specified number of hours of accelerated weathering, respectively. These values are given in Table 10. For example the values of L_n and L_o for high-intensity grade sheeting are 100 and 80, respectively. The expected service life, N_y, of signs with each sheeting type were taken from the contractors survey. These values are summarized in Table 6.

Figure 31 indicates that the higher the initial luminance of the reflective sheeting, the lower is the average cost of the sign per year. Nonetheless, very high initial luminance is not as critical to the sheetings used on devices at construction work zones as it is for non-work-zone traffic control devices. This is primarily due to the short service lives of the devices used at construction work zones. Equation 9 may be useful in the life-cycle cost analysis of retroreflective sheetings on signs and devices other than those used at construction work zones. Application of this equation to work zone traffic control devices may lead to erroneous conclusions. Therefore, the MOE given by equation 8 was used to evaluate the economics of the retroreflective sheetings in this study.

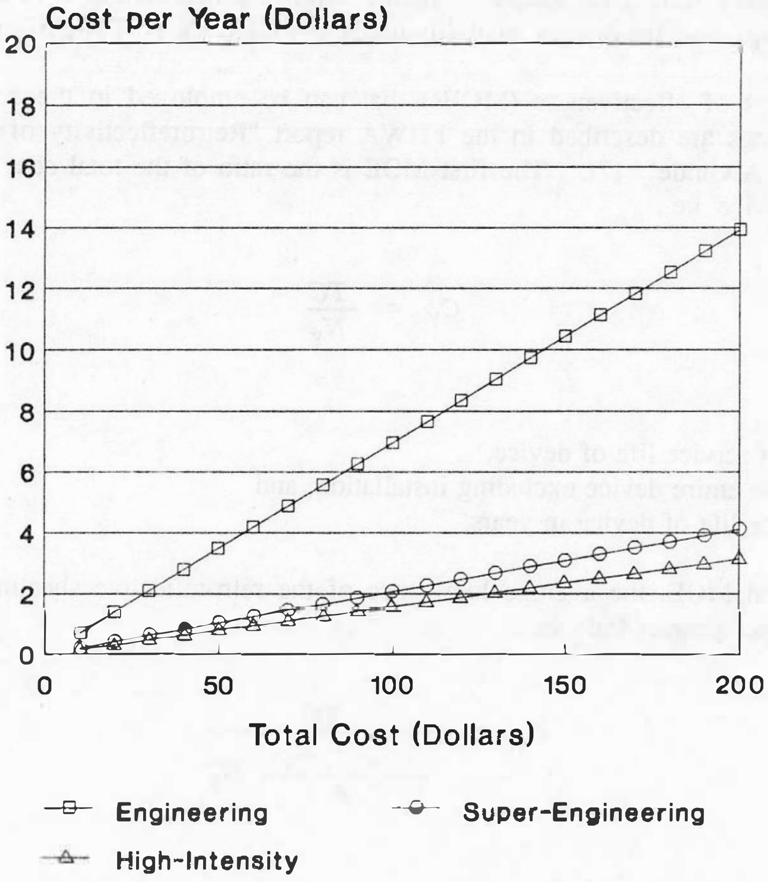


Figure 31a Cost per Year of Service Life Using Equation 9

Another MOE which has been proposed in this study is the cost of the device per construction project, i.e.,

$$C_P = \frac{TC}{N_P} \tag{10}$$

where

C_P = cost per project,
TC = total cost of the device excluding installation, and
N_P = average number of projects where the device can be used.

Values of the MOEs given by equations 8 and 10 are presented in Table 12 and Figure 32. The following paragraphs summarize the findings of the economic analysis.

AVERAGE COST PER YEAR OF SERVICE LIFE

Signs - The average cost per year of a 48" x 48" orange-colored sign with engineering grade, super-engineering grade, and high-intensity grade sheetings is $40.67, $43.80, and $112.08, respectively.

Barricades - On the average, the cost of a type-III barricade is $123.19, $64.48, and $237.80 per year with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Barrels - A barrel with engineering grade, super-engineering grade, and high-intensity grade sheetings costs $49.76, $45.02, and $86.57 per year, respectively.

Vertical Panel - The average cost per year of a vertical panel is $8.14, $9.13, and $25.06 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

AVERAGE COST PER PROJECT

Signs - Results of the economic analysis indicate that a 48" x 48" sign with engineering grade, super-engineering grade, and high-intensity grade sheetings costs an average of $12.48, $14.40, and $36.29 per construction project, respectively.

Barricades - For a type-III barricade, the cost per project averages $51.92, $26.50, and $110.25 with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Barrels - The average cost of a barrel with engineering grade, super-engineering grade, and high-intensity grade sheetings is $16.84, $18.50, and $27.53 per project, respectively.

Vertical Panels - On the average, a vertical panel costs $3.14, $3.75, and $9.15 per project with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

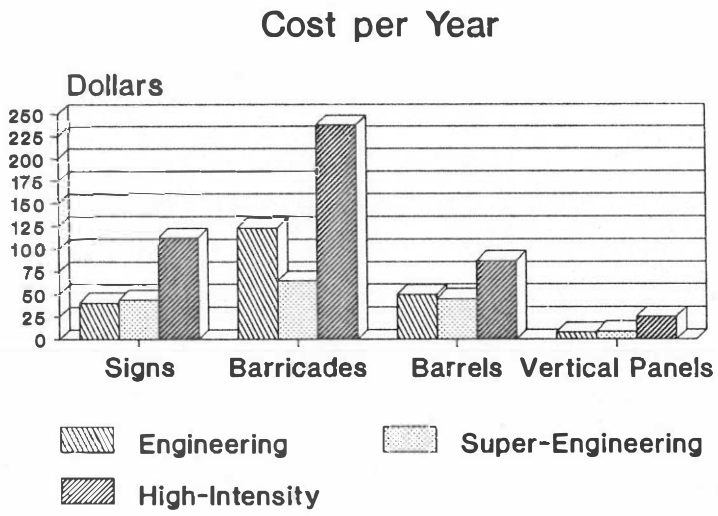
TABLE 12. ECONOMIC ANALYSIS RESULTS

Sheeting Type[a]	TC[b]	Expected Service Life		Measures of Effectiveness	
		N_Y, Years	N_P, Projects	Cost per year	Cost per project
			SIGNS[c]		
E.G.	$31.2	0.767	2.5	$40.67	$12.48
S.E.G.	$43.2	0.986	3.0	$43.80	$14.40
H.I.G.	$79.84	0.712	2.2	$112.08	$36.29
			BARRICADES		
E.G.	$67.50	0.584	1.3	$123.19	$51.92
S.E.G.	$53.00	0.822	2.0	$64.48	$26.50
H.I.G.	$143.33	0.603	1.3	$237.80	$110.25
			BARRELS		
E.G.	$33.67	0.676	2.0	$49.76	$16.84
S.E.G.	$37.00	0.822	2.0	$45.02	$18.50
H.I.G.	$63.33	0.731	2.3	$86.57	$27.53
			VERTICAL PANELS		
E.G.	$4.08	0.502	1.3	$8.14	$3.14
S.E.G.	$7.50	0.822	2.0	$9.13	$3.75
H.I.G.	$13.73	0.548	1.5	$25.06	$9.15

[a] E.G.n= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

[b] Total cost of entire device excluding installation

[c] 48" x 48" orange-colored signs



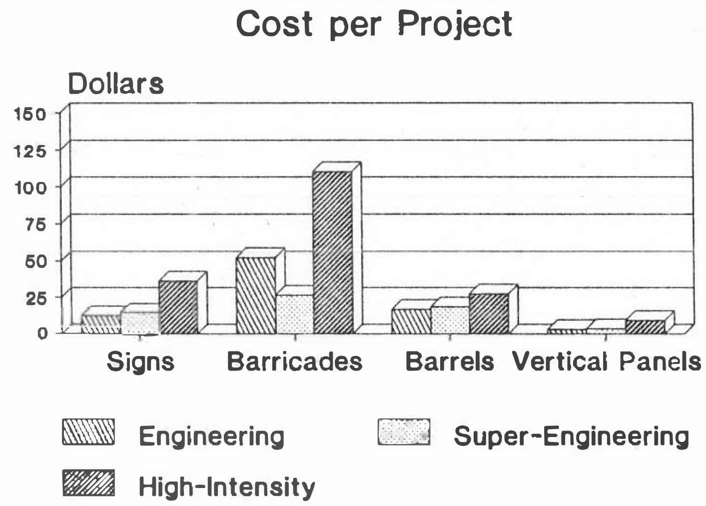


Figure 32. Cost Comparison

CHAPTER 9

FINDINGS AND CONCLUSIONS

This chapter summarizes and interprets the findings of Chapters 4 through 8 pertaining to the adequacy of the engineering grade, super-engineering grade, and high-intensity grade sheetings for use on traffic control devices at construction work zones. Recommendations and implications for the application of these sheeting products are presented.

INTERPRETATION AND APPRAISAL OF RESULTS

Driver's Visibility Requirements

As it is expected with any research effort involving human factors, some conflicting evidence were noted in the findings. The weakest point in the data obtained during the field experiments was the large amount of variability in the drivers' responses that could not be explained. Another weak point was the small sample size employed during the real-world experiments. Fortunately, larger sample sizes were available during the controlled experiments. The strongest point in the appraisal of drivers visibility needs was the questionnaire response data concerning the adequacy of the different sheetings and other comments provided by the drivers.

The visibility distance analyses conducted in this study and the drivers questionnaire findings are interpreted as follows:

Urban Construction Project

Array Detection Distance - The high-intensity grade sheeting demonstrated greater target value, in terms of mean array detection distance, than the super-engineering grade sheeting both during daytime and nighttime conditions.

Legibility of Signs - At nighttime, signs with super-engineering grade sheeting were more often legible than signs with high-intensity grade sheeting. During daylight conditions, the mean recognition distances of both sheetings were not significantly different.

Questionnaire ratings concerning the legibility and adequacy of signs favored the super-engineering grade. Some drivers reported glare problems with the high-intensity grade sheeting particularly at nighttime.

Conspicuity of Barrels - In terms of mean recognition distance, there was no significant difference in the conspicuity of barrels with super-engineering grade and high-intensity grade sheetings both during daytime and nighttime conditions.

Rural Construction Project

Array Detection Distances - Based on the array detection distances observed, there was no significant difference in the target values of the engineering grade, super-engineering grade, and high-intensity grade sheetings both during daytime and nighttime conditions. Problems with the roadway vertical alignment at the rural test site limit the validity of this finding.

Legibility of Signs - At nighttime, signs with super-engineering grade sheeting were more legible than signs with high-intensity grade and engineering grade sheetings. This finding was also corroborated by the results of the controlled experiments. No statistically significant difference was found between the mean recognition distances of signs with high-intensity grade and engineering grade sheetings at the rural test site. Nevertheless, results of the controlled experiments indicated that signs with high-intensity grade sheeting had greater recognition distance than signs with engineering grade sheeting.

Questionnaire responses concerning the nighttime legibility and adequacy of signs favored the super-engineering grade. Glare problems with the high-intensity grade sheeting were noted by some drivers. Another questionnaire finding was that larger letters were needed on word signs with all types of sheetings, particularly the high-intensity grade.

During daytime conditions, there was no significant difference between the legibility of signs with high-intensity grade and engineering grade sheetings, whereas signs with the super-engineering grade sheeting had the least legibility distance. Highway geometrics and traffic conditions at the rural site were frequently found to affect driver recognition of signs. These findings were refuted by the results of controlled experiments where signs with super-engineering grade and high-intensity grade sheetings were not significantly different in terms of legibility, and signs with engineering grade sheeting had the least recognition distance.

Conspicuity of Barrels - No statistically significant differences were found between the mean recognition distances of barrels with the three types of sheetings at the rural test site, both during daytime and nighttime conditions. Similar findings were obtained from the controlled experiments, albeit that barrels with engineering grade sheeting were less conspicuous than those with high-intensity grade and super-engineering grade sheetings.

Conspicuity of Barricades - Differences between the recognition distances of barricades with high-intensity grade and super-engineering grade were not significantly different. Barricades with engineering-grade sheeting were less conspicuous than those with high-intensity grade and super-engineering grade sheetings.

Contractors' Survey Results

Engineering grade sheeting has traditionally been used on traffic control devices by all the three major contractors in Oklahoma. The average number of square yards of this sheeting grade purchased each year is approximately 6,000 per contractor. High-intensity grade sheeting has also been used on traffic control devices by the three major contractors, albeit with a lesser number of years of experience. The average number of square yards of high-intensity grade purchased each year is approximately 1,200 per contractor. Although super-engineering grade sheeting has been around for a number of years, Oklahoma contractors have limited experience with this types of sheeting. Only one contractor reported using 200 square yards of super-engineering grade sheeting during the past year.

Results of the contractors' survey indicate that the expected service life of traffic control devices at construction work zones is less than one year. Typical modes of retroreflective sheeting deterioration include color fading, abrasion, peeling, and impact cracking. Issues of frequent vandalism and device knockdowns by traffic were noted by the contractors. Usually, devices are replaced because they do not meet the "like-new" requirement specified in the contract documents.

Issues of sheeting durability and ease of fabrication were emphasized in the contractor's comments. Engineering grade sheeting was characterized as being the most durable and the easiest to work with during device fabrication. Super-engineering grade was praised for its resemblance to the engineering grade in durability and ease of fabrication and handling. High-intensity grade received low ratings from the durability point of view. Problems with the handling, fabrication, and transportation of high-intensity sheetings were reported by one contractor.

Weathering

Very limited data on the performance of the different sheetings under natural exposure conditions were available in the published literature. Based on weatherometer test results, all the three grades of sheeting exceeded the minimum SIA requirements specified by the ASTM after the prescribed number of hours of artificial weathering.

Economics

Two measures of economic efficiency were employed in the evaluation of the different sheetings: cost per year of device service life and cost of device per construction project. High-intensity grade was found to be the most costly when used on signs, barrels, barricades, and vertical panels. Differences between the cost per year of engineering grade and super-engineering grade sheetings were insignificant when used on signs, barrels, and vertical panels. Similar findings were obtained for the cost per project. Barricades with super engineering grade demonstrated lower cost per year and cost per project than barricades with engineering grade.

CONCLUSIONS AND RECOMMENDATIONS

Improving the visibility of traffic control devices should be helpful to drivers in all age groups, particularly the elderly drivers. The basic question addressed in this study was; based on driver's visibility needs, durability and economics, and other practical considerations, which of the three grades of retroreflective sheeting available in the market is most adequate for use on traffic control devices at construction work zones.

While the high-intensity grade sheeting has the highest target value of the three sheeting grades, the tradeoff between detection and legibility of traffic control signs was interpreted to favor the use of the super-engineering grade on signs in both urban and rural construction projects. Durability, economics, and other practical issues emphasized by traffic control contractors support this conclusion. Nevertheless, use of the high-intensity grade sheeting in urban construction projects may be warranted at locations with visual clutter and excessive background lights.

The beneficial effects of upgrading the type of sheeting used on barrels, barricades, and vertical panels from engineering grade to high-intensity grade or super-engineering grade were demonstrated by the significant increase in both the detection and recognition distances of these devices. Yet, the benefits of upgrading to the high-intensity grade were found to be offset by the significant increase in cost, the less durability of the sheeting material, and the problems with fabrication and handling. Upgrading to super-engineering grade offers the most cost-effective and balanced solution.

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APPENDIX A

DRIVER BIOGRAPHICAL DATA

DRIVER BIOGRAPHICAL DATA QUESTIONNAIRE

Driver Number __________
Day/Nighti______________
Datei______________________
Test Location ______________

****

Instructions:

Please Circle ONE Number that best answers each of the dollowing.

****

1. What is your present age?

1. 24 years and younger
2. 25 - 34
3. 35 - 44
5. 45 - 54
5. 55 - 64
6. 65 and older

2. What is your sex?

1. Male
2. Female

3. How long have you been driving a vehicle?

1. Less than 1 year
2. 1 to 2 years
3. 3 to 5 years
4. More than 5 years

4. What is the type of driving you usually do?

1. Mostly city
2. Mostly highway
3. A little city & highway both
4. A lot of city & highway both
5. Drive infrequently

5. How many miles do you typically drive in a year?

1. Less than 2000
2. 2000 to 4000
3. 4001 - 6000
4. 6001 - 8000
5. 8001 - 10,000
6. More than 10,000

6. Do you wear glasses, bifocals, or contact lenses?

1. Yes
2. No

7. What is the last formal education you have completed?

1. Grade school
2. High school
3. College

8. What is your present occupation?

____

____

TABLE A-1. AGE DISTRIBUTION

Years of Age	Percent of Drivers		
	Urban Project	Rural Project	Controlled Experiments
< 25	17.2%	11.8%	14.0%
25 - 34	55.2%	64.7%	33.5%
35 - 44	20.7%	14.7%	22.0%
45 - 54	3.5%	5.9%	23.2%
55 - 64	3.4%	2.9%	6.1%
> 65	0.0%	0.0%	1.2%

TABLE A-2. SEX DISTRIBUTION

Sex	Percent of Drivers		
	Urban Project	Rural Project	Controlled Experiments
Male	79.3%	85.3%	52.4%
Female	20.7%	14.7%	47.6%

TABLE A-3. DRIVING EXPERIENCE

Number of Years	Percent of Drivers		
	Urban Project	Rural Project	Controlled Experiments
< 1	0.0%	0.0%	0.0%
1 - 2	0.0%	0.0%	0.0%
3 - 5	3.4%	5.9%	4.3%
> 5	94.6%	94.1%	95.7%

TABLE A-4. TYPE OF DRIVING

Type	Percent of Drivers		
	Urban Project	Rural Project	Controlled Experiments
Mostly City	20.7%	26.5%	6.7%
Mostly Highway	10.3%	2.9%	14.6%
A Little of Both	27.6%	29.4%	40.9%
A Lot of Both	41.4%	41.2%	37.2%
Drive Infrequently	0.0%	0.0%	0.6%

TABLE A-5. MILES DRIVEN ANNUALY

Number of Miles	Percent of Drivers Urban Project	Rural Project	Controlled Experiments
< 2,000	0.0%	2.9%	1.2%
2,000 - 4,000	6.9%	8.8%	17.1%
4,001 - 6,000	6.9%	0.0%	11.6%
6,001 - 8,000	6.9%	2.9%	4.9%
8,001 - 10,000	24.1%	11.8%	17.7%
> 10,000	55.2%	73.6%	47.6%

TABLE A-6. WEAR EYEGLASSES

Wear Eyeglasses	Percent of Drivers Urban Project	Rural Project	Controlled Experiments
Yes	44.8%	47.1%	47.6%
No	55.2%	52.9%	52.4%

TABLE A-7. EDUCATION COMPLETED

Education Level	Percent of Drivers Urban Project	Rural Project	Controlled Experiments
Grade School	0.0%	0.0%	3.7%
High School	55.2%	58.8%	69.5%
College	44.8%	41.2%	26.8%

TABLE A-8. OCCUPATION

Occupation	Percent of Drivers Urban Project	Rural Project	Controlled Experiments
Farmer	0.0%	0.0%	6.0%
Technician	33.0%	12.0%	33.0%
Draftsperson	33.0%	52.0%	0.0%
Clerical	3.0%	2.0%	20.0%
Salesperson	0.0%	0.0%	5.0%
Homemaker	0.0%	0.0%	9.0%
Student	7.0%	0.0%	5.0%
Teacher	0.0%	0.0%	9.0%
Professional	7.0%	25.0%	0.0%
Other	17.0%	9.0%	13.0%

APPENDIX B

TRAFFIC CONTROL DEVICE ADEQUACY QUESTIONNAIRE

TRAFFIC CONTROL DEVICE ADEQUACY QUESTIONNAIRE

Driver Number ______
Day/Night ________
Date ____________________
Test Location ______________

****
Instructions:

In the driving test you have just completed, you passed a highway area which is under construction. Several traffic control devices (signs, barricades, barrels, etc.) were present to advise you that your lane was closed ahead and to guide you along. Please Circle ONE Number that best answers each of the following questions.

****

1. How easy were you able to read the SIGNS?

    1. Very easy
    2. Easy
    3. Borderline
    4. Difficult
    5. Very Difficult

2. Please rate the overall adequacy of the SIGNS which were present in terms of advising you that your lane was closed ahead and to guide you along.

    1. Very Poor
    2. Poor
    3. Borderline
    4. Good
    5. Very Good

3. What changes would you want to see made to these SIGNS?

Overall Size:	Letter Size:	Brightness:	Colors:
1. Larger	1. Larger	1. Too Bright	1. Colors are Ok
2. Smaller	2. Smaller	2. Not Bright Enough	2. Change Colors to
3. OK as is	3. OK as is	3. Ok as is	____________

4. As you approached the construction area, there were sets of DEVICES (barricades, barrels, etc.) that closed off your driving lane and caused you to change your lane. Consider these DEVICES as you first saw them and rate their adequacy in giving you an early warning and sufficient time to react.

    1. Very Poor
    2. Poor
    3. Borderline
    4. Good
    5. Very Good

5. Consider the DEVICES as you were driving by them, rate how smoothly and easy the devices guided you past the closed lane.

    1. Very easy path to follow
    2. Not as clear as I needed to pass through
    3. Seemed unsafe and hazardous to drive through

6. What changes would you want to see made to these DEVICES?

Overall Size:
1. Larger
2. Smaller
3. OK as is

Brightness:
1. Too bright
2. Not bright enough
3. OK as is

Colors:
1. Colors are Ok
2. Change colors to
----

7. Please rate the overall adequacy of ALL the SIGNS and OTHER DEVICES (signs, barricades, barrels, etc.) which you have seen in terms advising you that your lane was closed ahead and to guide you along.

1. Very Poor
2. Poor
3. Borderline
4. Good
5. Very Good

8. How often have you driven by this highway construction area?

1. Never before
2. Once or twice before
3. Once every month
4. Once or more every week

9. Do you have any comments that you like to share with us concerning the signs and other devices you have seen in this driving experiment?

____

____

____

____

____

____

____

____

TABLE B-1. DRIVERS RESPONSES TO QUESTION 1

How easy were you able to read the SIGNS?

1. Very East
2. Easy
3. Borderline
4. Difficult
5. Very Difficult

Test Site	Response	Daytime			Nightime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	20%	20%	---	0%	0%
	2	---	80%	60%	---	30%	22%
	3	---	0%	20%	---	50%	56%
	4	---	0%	0%	---	20%	22%
	5	---	0%	0%	---	0%	0%
Rural Project	1	33%	20%	20%	50%	0%	25%
	2	67%	60%	60%	50%	80%	50%
	3	0%	0%	20%	0%	20%	12%
	4	0%	20%	0%	0%	0%	13%
	5	0%	0%	0%	0%	0%	0%
Controlled Experiments	1	41%	30%	32%	31%	32%	32%
	2	41%	48%	56%	48%	50%	29%
	3	18%	22%	12%	17%	18%	36%
	4	0%	0%	0%	4%	0%	0%
	5	0%	0%	0%	0%	0%	3%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-2. DRIVERS RESPONSES TO QUESTION 2

Please rate the overall adequacy of the SIGNS which were present in terms of advising you that your lane was closed ahead and to guide you along.

1. Very Poor
2. Poor
3. Borderline
4. Good
5. Very Good

Test Site	Response	Daytime			Nightime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	0%	0%	---	0%	0%
	2	---	0%	0%	---	0%	0%
	3	---	0%	0%	---	0%	30%
	4	---	40%	80%	---	80%	60%
	5	---	60%	20%	---	20%	10%
Rural Project	1	0%	0%	0%	0%	0%	0%
	2	0%	0%	0%	0%	0%	0%
	3	40%	0%	20%	0%	0%	13%
	4	60%	67%	60%	62%	60%	62%
	5	0%	33%	20%	38%	40%	25%
Controlled Experiments	1	4%	0%	0%	0%	0%	4%
	2	4%	8%	4%	0%	0%	0%
	3	7%	7%	0%	10%	4%	3%
	4	59%	45%	48%	59%	68%	50%
	5	26%	48%	48%	31%	28%	43%

E.G.s= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-3. DRIVERS RESPONSES TO QUESTION 3

What changes would you want to see made to these SIGNS?

Overall Size:	Letter Size:	Brightness:	Colors:
1. Larger	1. Larger	1. Too Bright	1. Colors are Ok
2. Smaller	2. Smaller	2. Not Bright enough	2. Change Colors to
3. Ok as is	3. Ok as is	3. Ok as is	________

Test Site	Response		Daytime			Nighttime		
			E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	Overall Size:	1	---	40%	20%	---	30%	11%
		2	---	0%	0%	---	0%	0%
		3	---	60%	80%	---	70%	89%
	Letter Size:	1	---	60%	80%	---	78%	90%
		2	---	0%	0%	---	0%	0%
		3	---	40%	20%	---	22%	10%
	Brightness:	1	---	0%	0%	---	20%	45%
		2	---	0%	0%	---	20%	12%
		3	---	100%	100%	---	60%	43%
Rural Project	Overall Size:	1	33%	10%	10%	38%	6%	12%
		2	0%	0%	0%	0%	0%	0%
		3	67%	90%	90%	62%	94%	88%
	Letter Size:	1	67%	35%	40%	62%	60%	88%
		2	0%	0%	0%	0%	0%	0%
		3	33%	65%	60%	38%	40%	12%
	Brightness:	1	0%	0%	0%	0%	0%	12%
		2	0%	0%	0%	12%	0%	0%
		3	100%	100%	100%	88%	100%	88%
Controlled Experiments	Overall Size:	1	28%	23%	9%	7%	11%	11%
		2	0%	0%	0%	0%	0%	0%
		3	72%	77%	91%	93%	89%	89%
	Letter Size:	1	69%	66%	48%	46%	36%	64%
		2	0%	0%	0%	0%	0%	0%
		3	31%	34%	52%	54%	64%	36%
	Brightness:	1	0%	0%	13%	0%	4%	15%
		2	12%	7%	4%	10%	4%	3%
		3	88%	93%	83%	90%	92%	82%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-4. DRIVERS RESPONSES TO QUESTION 4

As you approached the construction area, there were sets of DEVICES (barricades, barrels, etc.) that closed off your driving lane and caused you to change your lane. Consider these DEVICES as you first saw them and rate their adequacy in giving you an early warning and sufficient time to react.

1. Very Poor
2. Poor
3. Borderline
4. Good
5. Very Good

Test Site	Response	Daytime			Nightime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	0%	0%	---	0%	0%
	2	---	0%	0%	---	0%	12%
	3	---	0%	0%	---	0%	0%
	4	---	60%	80%	---	45%	33%
	5	---	40%	20%	---	55%	55%
Rural Project	1	0%	0%	0%	0%	0%	0%
	2	0%	0%	0%	0%	0%	0%
	3	40%	0%	20%	10%	0%	0%
	4	40%	0%	80%	52%	60%	50%
	5	20%	100%	0%	38%	40%	50%
Controlled Experiments	1	0%	0%	0%	0%	0%	0%
	2	0%	0%	4%	0%	0%	0%
	3	11%	3%	8%	7%	3%	7%
	4	63%	56%	52%	71%	35%	47%
	5	26%	41%	36%	22%	62%	46%

E.G.s= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-5. DRIVERS RESPONSES TO QUESTION 5

Consider the DEVICES as you were driving by them, rate how smoothly and easy the devices guided you past the closed lane.

1. Very easy path to follow
2. Not as clear as I needed to pass through
3. Seemed unsafe and hazardous to drive through

Test Site	Response	Daytime			Nightime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	100%	100%	---	100%	67%
	2	---	0%	0%	---	0%	22%
	3	---	0%	0%	---	0%	11%
Rural Project	1	100%	100%	100%	100%	100%	100%
	2	0%	0%	0%	0%	0%	0%
	3	0%	0%	0%	0%	0%	0%
Controlled Experiments	1	88%	100%	96%	82%	100%	96%
	2	8%	0%	4%	14%	0%	4%
	3	4%	0%	0%	4%	0%	0%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-6. DRIVERS RESPONSES TO QUESTION 6

What changes would you want to see made to these DEVICES?

Overall Size:	Brightness:	Colors:
1. Larger	1. Too Bright	1. Colors are Ok
2. Smaller	2. Not Bright enough	2. Change Colors to ________
3. Ok as is	3. Ok as is	

Test Site	Response		Daytime			Nighttime		
			E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	Overall Size:	1	---	20%	20%	---	0%	12%
		2	---	0%	0%	---	0%	0%
		3	---	80%	80%	---	100%	88%
	Brightness:	1	---	0%	0%	---	0%	20%
		2	---	0%	0%	---	5%	2%
		3	---	100%	100%	---	95%	78%
Rural Project	Overall Size:	1	60%	33%	20%	38%	6%	12%
		2	0%	0%	0%	0%	0%	0%
		3	40%	67%	80%	62%	94%	88%
	Brightness:	1	0%	0%	15%	0%	0%	25%
		2	23%	10%	0%	0%	0%	0%
		3	77%	90%	85%	100%	100%	75%
Controlled Experiments	Overall Size:	1	19%	4%	4%	3%	7%	14%
		2	0%	0%	0%	0%	0%	0%
		3	81%	96%	96%	97%	93%	86%
	Brightness:	1	0%	0%	0%	0%	0%	17%
		2	11%	8%	7%	21%	4%	0%
		3	89%	92%	93%	79%	96%	83%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-7. DRIVERS RESPONSES TO QUESTION 7

Please rate the overall adequacy of ALL the SIGNS and OTHER DEVICES (signs, barricades, barrels, etc.) which you have seen in terms advising you that your lane was closed ahead and to guide you along.

1. Very Poor
2. Poor
3. Borderline
4. Good
5. Very Good

Test Site	Response	Daytime			Nighttime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	0%	0%	---	0%	0%
	2	---	0%	0%	---	0%	0%
	3	---	0%	0%	---	11%	20%
	4	---	60%	80%	---	56%	80%
	5	---	40%	20%	---	33%	0%
Rural Project	1	0%	0%	0%	0%	0%	0%
	2	0%	0%	0%	0%	0%	0%
	3	20%	0%	20%	0%	0%	0%
	4	80%	100%	60%	75%	80%	100%
	5	0%	0%	20%	25%	20%	0%
Controlled Experiments	1	3%	0%	0%	0%	0%	0%
	2	4%	0%	0%	0%	0%	4%
	3	4%	4%	8%	4%	3%	0%
	4	63%	73%	46%	70%	59%	57%
	5	26%	23%	46%	26%	38%	39%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE B-8. DRIVERS RESPONSES TO QUESTION 8

How often have you driven by this highway construction area?

1. Never before
2. Once or twice before
3. Once every month
4. Once or more every week

Test Site	Response	Daytime			Nightime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Urban Project	1	---	40%	60%	---	30%	56%
	2	---	60%	40%	---	30%	33%
	3	---	0%	0%	---	10%	0%
	4	---	0%	0%	---	30%	11%
Rural Project	1	67%	100%	80%	75%	100%	76%
	2	33%	0%	20%	12%	0%	12%
	3	0%	0%	0%	0%	0%	0%
	4	0%	0%	0%	13%	0%	12%
Controlled Experiments	1	73%	63%	54%	48%	19%	61%
	2	4%	18%	13%	32%	65%	29%
	3	7%	4%	25%	10%	4%	3%
	4	16%	15%	8%	10%	12%	7%

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

APPENDIX C

CONTRACTORS QUESTIONNAIRE

CONTRACTOR's SURVEY

REFLECTIVE SHEETING PRODUCTS USED ON TRAFFIC CONTROL DEVICES AT CONSTRUCTION WORK AREAS

1. Which of the following reflective sheetings are used by your Company at construction work areas?

Engineering Grade _____ Used _____ Not Used
Super-Engineering Grade _____ Used _____ Not Used
High-Intensity Grade _____ Used _____ Not Used

2. How long has your company been using each grade of sheeting at construction work areas? Fill in number of years and months for those sheetings that apply.

Engineering Grade ____ Years, _____ Months
Super-Engineering Grade ____ Years, _____ Months
High-Intensity Grade ____ Years, _____ Months

3. On the average, how many square yards of each grade of sheeting are purchased by your company each year for use at construction work areas?
Fill in number of square yards for those sheetings that apply.

Engineering Grade ____________ Square Yards/Year
Super-Engineering Grade ____________ Square Yards/Year
High-Intensity Grade ____________ Square Yards/Year

4. Based on your company's experience, what is the expected service life of the reflective sheeting only when used on each of the following traffic control devices at construction work areas? Fill in number of days for each grade of sheeting that your company uses.

	Expected Service Life of Sheeting (Days)		
Control Device	Enginreering Grade	Super-Engineering Grade	High-Intensity Grade
Signs	--------	--------	--------
Barricades	--------	--------	--------
Barrels	--------	--------	--------
Vertical Panels	--------	--------	--------

5. Based on your company's experience, on how many construction projects can you use each of the following traffic control devices without having to replace the refelective sheeting? Fill in number of projects for each grade of sheeting that your company uses.

Control Device	Average Number of Projects		
	Enginreering Grade	Super-Engineering Grade	High-Intensity Grade
Signs	--------	--------	--------
Barricades	--------	--------	--------
Barrels	--------	--------	--------
Vertical Panels	--------	--------	--------

6. For each of the following traffic control devices, please indicate the frequency of device knockdowns by traffic and device vandalism at construction work zones per year? Fill in number and percent of devices.
<u>Example:</u> Suppose your company installs an average of 1000 signs per year, and 40 of them are knocked down. The number of knockdowns is 40 and the percent knockdowns is (40/1000)x100 = 4%.

Control Device	Knockdowns		Vandalism	
	Number	Percent	Number	Percent
Signs	--------	--------	--------	--------
Barricades	--------	--------	--------	--------
Barrels	--------	--------	--------	--------
Vertical Panels	--------	--------	--------	--------

7. Which of the following deterioration modes, if any, do you experience with the listed grades of sheetings when used on traffic control devices at construction work areas? Check all modes that apply for each sheeting that your company uses.

Deterioration Mode	Engineering Grade Sheeting			
	Signs	Barricades	Barrels	Vertical Panels
Color Fading	--------	--------	--------	--------
Temperature	--------	--------	--------	--------
Cracking	--------	--------	--------	--------
Abrasion	--------	--------	--------	--------
Peeling	--------	--------	--------	--------
Impact Cracking	--------	--------	--------	--------
Dirt Accumulation	--------	--------	--------	--------
Other (Specify)	--------	--------	--------	--------

Question 7 (continued)

Deterioration Mode	Super-Engineering Grade Sheeting			
	Signs	Barricades	Barrels	Vertical Panels
Color Fading	--------	--------	--------	--------
Temperature	--------	--------	--------	--------
Cracking	--------	--------	--------	--------
Abrasion	--------	--------	--------	--------
Peeling	--------	--------	--------	--------
Impact Cracking	--------	--------	--------	--------
Dirt Accumulation	--------	--------	--------	--------
Other (Specify)	--------	--------	--------	--------

Deterioration Mode	High-Intensity Grade Sheeting			
	Signs	Barricades	Barrels	Vertical Panels
Color Fading	--------	--------	--------	--------
Temperature	--------	--------	--------	--------
Cracking	--------	--------	--------	--------
Abrasion	--------	--------	--------	--------
Peeling	--------	--------	--------	--------
Impact Cracking	--------	--------	--------	--------
Dirt Accumulation	--------	--------	--------	--------
Other (Specify)	--------	--------	--------	--------

8. For each of the following construction work zone traffic control devices, please complete the following cost information for each sheeting used by your company:

A) Cost of sheeting only (material plus fabrication).
B) Cost of entire control device excluding installation.
C) Cost of refurbishing the substrate and applying new sheeting.

Control Device	Engineering Grade Sheeting		
	A	B	C
Signs	--------	--------	--------
Barricades	--------	--------	--------
Barrels	--------	--------	--------
Vertical Panels	--------	--------	--------

Question 8 (continued)

	Super-Engineering Grade Sheeting		
Control Device	A	B	C
Signs	---------	---------	---------
Barricades	---------	---------	---------
Barrels	---------	---------	---------
Vertical Panels	---------	---------	---------

	High-Intensity Grade Sheeting		
Control Device	A	B	C
Signs	---------	---------	---------
Barricades	---------	---------	---------
Barrels	---------	---------	---------
Vertical Panels	---------	---------	---------

9. For those grades of sheetings used by your company, please indicate the manufacturer's warranty life and luminance (SIA) of the new sheeting material?

Control Device	Warranty Life		Luminance (SIA)
	Years	Months	
Signs	---------	---------	---------
Barricades	---------	---------	---------
Barrels	---------	---------	---------
Vertical Panels	---------	---------	---------

10. For those grades of sheetings used by your company, please indicate the problems you have been experiencing with the fabrication, transportation, and handling of traffic control devices at construction work areas?

Engineering Grade:

Question 8 (continued)

<u>Super-Engineering Grade:</u>

<u>High-Intensity Grade:</u>

11. Please add any comments you may have regarding the three types of retroreflective sheetings.

APPENDIX D

DETECTION AND RECOGNITION DISTANCES

TABLE D-1. ARRAY DETECTION DISTANCE (FEET), URBAN PROJECT

	Daytime		Nighttime	
	S.E.G.	H.I.G.	S.E.G.	H.I.G.
x	816.8	1771.0	1088.9	1592.3
s	373.7	62.7	342.3	149.5
n	5	4	9	10

S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE D-2. DEVICE RECOGNITION DISTANCE (FEET), URBAN PROJECT

Traffic Control Device		Daytime		Nighttime	
		S.E.G.	H.I.G.	S.E.G.	H.I.G.
Sign A	x	455.8	499.0	408.1	371.4
	s	28.0	80.2	71.1	132.3
	n	4	5	10	9
Sign B	x	481.0	504.6	499.9	202.1
	s	62.4	91.2	90.3	91.9
	n	5	5	10	8
Sign C	x	468.3	453.4	497.9	162.3
	s	21.0	25.3	189.0	57.6
	n	4	5	10	8
Sign D	x	902.8	1146.8	1194.0	1015.2
	s	145.2	170.3	348.5	204.9
	n	5	5	10	9
Barrels	x	1251.5	1258.2	1379.6	1381.8
	s	325.8	2511.4	325.8	594.9
	n	4	5	9	8
Barricades	x	Not Used	1182.8	Not Used	750.6
	s		294.2		334.9
	n		5		9

Sign A: Road construction 1 Mile, Sign B: Left Lane Closed 1/2 Mile
Sign C: Left Lane Closed 1500 ft., Sign D: Symbol Merge Right
S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE D-3. ARRAY DETECTION DISTANCE (FEET), RURAL PROJECT

	Daytime			Nighttime		
	E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
x	2055.0	2062.6	2084.6	1054.8	1329.0	1099.1
s	44.2	56.5	105.5	470.7	394.0	532.6
n	3	5	5	8	5	8

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE D-4. DEVICE RECOGNITION DISTANCE (FEET), RURAL PROJECT

Traffic Control Device		Daytime			Nighttime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Sign A	x	530.3	432.0	572.0	307.5	383.4	343.9
	s	80.il	76.9	3.0	40.il	106.7	68.5
	n	3	5	3	6	5	8
Sign B	x	500.7	455.4	581.5	386.1	443.2	416.3
	s	29.0	51.0	66.9	82.8	85.8	65.6
	n	3	5	4	7	5	7
Sign C	x	1224.7	1218.2	1303.8	773.5	924.2	794.4
	s	121.9	264.5	135.1	119.8	100.6	80.6
	n	3	5	5	8	5	7
Sign D	x	667.0	453.0	717.3	479.0	446.2	399.8
	s	42.3	28.5	27.3	56.0	34.5	35.5
	n	3	5	4	7	5	6
Barrels	x	451.2	512.3	470.0	308.3	302.8	303.1
	s	58.1	27.0	99.6	58.3	44.5	38.3
	n	3	4	5	8	4	8
Barricades	x	489.3	451.2	415.8	306.7	404.6	415.0
	s	191.0	145.8	88.6	92.3	60.2	43.4
	n	3	5	5	7	5	8

E.G.i= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade
Sign A: Road Construction Ahead, Sign B: Detour 1000 ft.
Sign C: Symbol Reverse Curve to the Left & 40 mph Advisory Speed
Sign D: Detour 1000 ft.

TABLE D-5. DEVICE RECOGNITION DISTANCE (FEET), CONTROLLED EXPERIMENTS

Traffic Control Device		Daytime			Nighttime		
		E.G.	S.E.G.	H.I.G.	E.G.	S.E.G.	H.I.G.
Sign A	x	381.4	394.6	376.3	244.8	344.4	302.1
	s	74.1	55.6	56.1	75.1	43.2	64.0
	n	23	24	22	15	18	17
Sign B	x	379.9	392.9	393.7	243.7	317.7	269.7
	s	83.2	65.9	61.6	70.3	30.5	67.7
	n	26	24	22	18	16	16
Sign C	x	643.5	1014.6	1035.0	476.6	973.7	925.5
	s	106.0	118.3	156.1	66.1	106.1	201.6
	n	26	26	24	14	15	17
Barrels and Barricades	x	1102.9	1301.4	1288.5	674.8	1355.7	1355.8
	s	421.1	246.6	330.8	257.8	187.8	409.1
	n	25	27	24	19	18	18

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade
Sign A: Road Construction 1500 ft.
Sign B: Right Lane Closed 1000 ft.
Sign C: Symbol Merge Left

TABLE D-6. PAIRED OBSERVATIONS ON RECOGNITION DISTANCES OF ENGINEERING GRADE AND SUPER-ENGINEERING GRADE SHEETINGS

Driver Number	Difference Between Device Recognition Distances[a]			
	Signs			Barricades
	A	B	C	
1	- 4	58	506	719
2	131	86	665	1015
3	111	76	509	1139
4	109	78	517	570
5	--[b]	132	346	724
6	124	74	534	710
7	59	70	--[b]	910
8	52	39	--[b]	769
9	47	12	496	726
10	91	--[b]	350	1022
Average	80.0	69.4	490.4	830.4
Standard Deviation	44.5	32.9	103.0	180.5

a Distance for super-engineering grade - distance for engineering grade

b Driver did not follow the instructions

TABLE D-7. PAIRED OBSERVATIONS ON RECOGNITION DISTANCES OF ENGINEERING GRADE AND HIGH-INTENSITY GRADE SHEETINGS

Driver Number	Difference Between Device Recognition Distances[a]			
	Signs			Barricades
	A	B	C	
1	- 54	- 5	509	832
2	72	--[b]	472	941
3	97	127	640	653
4	125	53	563	1267
5	35	34	442	220
6	--[b]	58	323	568
7	--[b]	- 21	--[b]	456
8	6	--[b]	498	981
9	--[b]	17	--[b]	1494
10	- 42	16	347	640
11	28	--[b]	340	938
Average	33.4	34.9	459.3	817.3
Standard Deviation	63.3	45.9	108.0	364.0

a Distance for high-intensity grade - distance for engineering grade

b Driver did not follow the instructions

TABLE D-8. PAIRED OBSERVATIONS ON RECOGNITION DISTANCES OF SUPER-ENGINEERING GRADE AND HIGH-INTENSITY GRADE SHEETINGS

Driver Number	Difference Between Device Recognition Distances[a]			
	Signs			Barricades
	A	B	C	
1	53	--[b]	--[b]	- 71
2	--[b]	95	--[b]	254
3	74	44	75	350
4	- 9	74	23	156
5	--[b]	22	--[b]	- 725
6	89	- 4	149	86
7	63	--[b]	10	84
8	50	63	- 3	- 113
9	59	--[b]	193	74
10	- 14	23	- 54	- 128
11	- 18	17	- 288	- 946
12	118	--[b]	522	95
13	- 2	--[b]	116	- 98
14	55	42	- 65	340
15	145	135	25	- 98
16	122	59	- 45	23
17	13	41	--[b]	481
18	74	--[b]	--[b]	86
19	72	38	- 23	- 5
20	- 40	- 53	23	74
21	136	94	--[b]	395
22	- 81	--[b]	--[b]	60
23	42	52	- 106	- 464
24	57	68	45	- 190
Average	48.1	47.6	35.1	- 11.7
Standard Deviation	58.2	42.3	165.47	328.5

a Distance for super-engineering grade - distance for high-intensity grade

b Driver did not follow the instructions

APPENDIX E

SUMMARY OF HYPOTHESIS TESTING RESULTS

TERMINOLOGY

The following symbols are used throughout this Appendix:

μ_1 = Population mean detection/recognition distance of High-Intensity Grade Sheeting

μ_2 = Population mean detection/recognition distance of Super-Engineering Grade Sheeting

μ_3 = Population mean detection/recognition distance of Engineering Grade Sheeting

μ_{S1} = Population mean recognition distance of Symbol Signs with High-Intensity Grade Sheeting

μ_{W1} = Population mean recognition distance of Word Signs with High-Intensity Grade Sheeting

μ_{S2} = Population mean recognition distance of Symbol Signs with Super-Engineering Grade Sheeting

μ_{W2} = Population mean recognition distance of Word Signs with Super-Engineering Grade Sheeting

μ_{S3} = Population mean recognition distance of Symbol Signs with Engineering Grade Sheeting

μ_{W3} = Population mean recognition distance of Word Signs with Engineering Grade Sheeting

DESCRIPTION OF HYPOTHESES TESTED [a]

Hypothesis 1:

$H_o: \quad \mu_1 = \mu_2$

$H_a: \quad \mu_1 > \mu_2$

Hypothesis 2:

$H_o: \quad \mu_1 = \mu_2$

$H_a: \quad \mu_1 < \mu_2$

Hypothesis 3:

$H_o: \quad \mu_2 = \mu_3$

$H_a: \quad \mu_2 > \mu_3$

Hypothesis 4:

$H_o: \quad \mu_2 = \mu_3$

$H_a: \quad \mu_2 < \mu_3$

Hypothesis 5:

$H_o: \quad \mu_1 = \mu_3$

$H_a: \quad \mu_1 > \mu_3$

Hypothesis 6:

$H_o: \quad \mu_1 = \mu_3$

$H_a: \quad \mu_1 < \mu_3$

Hypothesis 7:

$H_o: \quad \mu_D = \mu_1 - \mu_2 = 0$

$H_a: \quad \mu_D = \mu_1 - \mu_2 > 0$

Hypothesis 8:

$H_o: \quad \mu_D = \mu_1 - \mu_2 = 0$

$H_a: \quad \mu_D = \mu_1 - \mu_2 < 0$

Hypothesis 9:

$H_o: \quad \mu_D = \mu_2 - \mu_3 = 0$

$H_a: \quad \mu_D = \mu_2 - \mu_3 > 0$

Hypothesis 10:

$H_o: \quad \mu_D = \mu_2 - \mu_3 = 0$

$H_a: \quad \mu_D = \mu_2 - \mu_3 < 0$

Hypothesis 11:

$H_o: \quad \mu_D = \mu_1 - \mu_3 = 0$

$H_a: \quad \mu_D = \mu_1 - \mu_3 > 0$

Hypothesis 12:

$H_o: \quad \mu_D = \mu_1 - \mu_3 = 0$

$H_a: \quad \mu_D = \mu_1 - \mu_3 < 0$

Hypothesis 13:

$H_o: \quad \mu_{S1} = \mu_{W1}$

$H_a: \quad \mu_{S1} > \mu_{W1}$

Hypothesis 14:

$H_o: \quad \mu_{S1} = \mu_{W1}$

$H_a: \quad \mu_{S1} < \mu_{W1}$

Hypothesis 15:

$H_o: \quad \mu_{S2} = \mu_{W2}$

$H_a: \quad \mu_{S2} > \mu_{W2}$

Hypothesis 16:

$H_o: \quad \mu_{S2} = \mu_{W2}$

$H_a: \quad \mu_{S2} < \mu_{W2}$

Hypothesis 17:

$H_o: \quad \mu_{S3} = \mu_{W3}$

$H_a: \quad \mu_{S3} > \mu_{W3}$

Hypothesis 18:

$H_o: \quad \mu_{S3} = \mu_{W3}$

$H_a: \quad \mu_{S3} < \mu_{W3}$

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[a] See definitions of different symbols in page 109

TABLE E-1. HYPOTHESIS TESTING RESULTS, URBAN PROJECT

Case No.	Light Condition	Device	Attributes[a]	Hypothesis Tested [c]	Test Conclusion [b]
1	Daytime	Array	MDD	Hypothesis 1	MDD of H.I.G. is significantly greater than MDD of S.E.G.
2	Daytime	Sign A	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
3	Daytime	Sign B	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
4	Daytime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
5	Daytime	Sign D	MRD	Hypothesis 1	MRD of H.I.G. is significantly greater than MRD of S.E.G.
6	Daytime	Barrels	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
7	Daytime	Word Signs Combined	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
8	Nighttime	Array	MDD	Hypothesis 1	MDD of H.I.G. is significantly greater than MDD of S.E.G.
9	Nighttime	Sign A	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
10	Nighttime	Sign B	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
11	Nighttime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
12	Nighttime	Sign D	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
13	Nighttime	Barrels	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
14	Nighttime	Word Signs Combined	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.

a MDD = Mean Detection Distance, MRD = Mean Recognition Distance

b See description of hypotheses in page 110

c Level of Significance $\alpha = 5\%$

S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE E-2. HYPOTHESIS TESTING RESULTS, RURAL PROJECT

Case No.	Light Condition	Device	Attributes[a]	Hypothesis Testeds[c]	Test Conclusion [b]
1	Daytime	Array	MDD	Hypothesis 3	MDDs of S.E.G. and E.G. are not significantly different
2	Daytime	Sign A	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
3	Daytime	Sign B	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
4	Daytime	Sign C	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
5	Daytime	Sign D	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
				Hypothesis 4	MRD of E.G. is significantly greater than MRD of S.E.G.
6	Daytime	Word Signs A & B	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
7	Daytime	Barrels	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
8	Daytime	Barricades	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
9	Daytime	Array	MDD	Hypothesis 5	MDDs of H.I.G. and E.G. are not significantly different
10	Daytime	Sign A	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
11	Daytime	Sign B	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
12	Daytime	Sign C	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
13	Daytime	Sign D	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
14	Daytime	Word Signs Combined	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
15	Daytime	Barrels	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
16	Daytime	Barricades	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
17	Daytime	Array	MDD	Hypothesis 1	MDDs of H.I.G. and S.E.G. are not significantly different
18	Daytime	Sign A	MRD	Hypothesis 1	MRD of H.I.G. is significantly greater than MRD of S.E.G.
19	Daytime	Sign B	MRD	Hypothesis 1	MRD of H.I.G. is significantly greater than MRD of S.E.G.

TABLE E-2 (continued). HYPOTHESIS TESTING RESULTS, RURAL PROJECT

Case No.	Light Condition	Device	Attribute[a]	Hypothesis Tested[c]	Test Conclusion[b]
20	Daytime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
21	Daytime	Sign D	MRD	Hypothesis 1	MRD of H.I.G. is significantly greater than MRD of S.E.G.
22	Daytime	Word Signs A & B	MRD	Hypothesis 1	MRD of H.I.G. is significantly greater than MRD of S.E.G.
23	Daytime	Barrels	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
24	Daytime	Barricades	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
25	Nighttime	Array	MDD	Hypothesis 3	MDDs of S.E.G. and E.G. are not significantly different
26	Nighttime	Sign A	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
27	Nighttime	Sign B	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
28	Nighttime	Sign C	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
29	Nighttime	Sign D	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
30	Nighttime	Word Signs Combined	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
31	Nighttime	Barrels	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
32	Nighttime	Barricades	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
33	Nighttime	Array	MDD	Hypothesis 5	MDDs of H.I.G. and E.G. are not significantly different
34	Nighttime	Sign A	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
35	Nighttime	Sign B	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
36	Nighttime	Sign C	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
37	Nighttime	Sign D	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
				Hypothesis 6	MRD of E.G. is significantly greater than MRD of H.I.G.
38	Nighttime	Word Signs Combined	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different

TABLE E-2 (continued). HYPOTHESIS TESTING RESULTS, RURAL PROJECT

Case No.	Light Condition	Device	Attributes[a]	Hypothesis Tested [c]	Test Conclusion [b]
39	Nighttime	Barrels	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
40	Nighttime	Barricades	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
41	Nighttime	Array	MDD	Hypothesis 1	MDDs of H.I.G. and S.E.G. are not significantly different
42	Nighttime	Sign A	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
43	Nighttime	Sign B	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
44	Nighttime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
45	Nighttime	Sign D	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
46	Nighttime	Word Signs Combined	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
47	Nighttime	Barrels	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
48	Nighttime	Barricades	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different

a MDD = Mean Detection Distance, MRD = Mean Recognition Distance
b See description of hypotheses in page 110
c Level of Significance $\alpha = 5\%$
E.G.s= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE E-3. HYPOTHESIS TESTING RESULTS, CONTROLLED EXPERIMENTS

Case No.	Light Condition	Device	Attribute[a]	Hypothesis Tested [c]	Test Conclusion [b]
1	Daytime	Sign A	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
2	Daytime	Sign B	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
3	Daytime	Sign C	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
4	Daytime	Word Signs Combined	MRD	Hypothesis 3	MRDs of S.E.G. and E.G. are not significantly different
5	Daytime	Barrels and Barricades	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
6	Daytime	Sign A	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
7	Daytime	Sign B	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
8	Daytime	Sign C	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
9	Daytime	Word Signs Combined	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
10	Daytime	Barrels and Barricades	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
11	Daytime	Sign A	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
12	Daytime	Sign B	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
13	Daytime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
14	Daytime	Word Signs Combined	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
15	Daytime	Barrels and Barricades	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
16	Nighttime	Sign A	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
17	Nighttime	Sign B	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
18	Nighttime	Sign C	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
19	Nighttime	Word Signs Combined	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.
20	Nighttime	Barrels and Barricades	MRD	Hypothesis 3	MRD of S.E.G. is significantly greater than MRD of E.G.

TABLE E-3 (continued). HYPOTHESIS TESTING RESULTS, CONTROLLED EXPERIMENTS

Case No.	Light Condition	Device	Attributes[a]	Hypothesis Tested [c]	Test Conclusion [b]
21	Nighttime	Sign A	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
22	Nighttime	Sign B	MRD	Hypothesis 5	MRDs of H.I.G. and E.G. are not significantly different
23	Nighttime	Sign C	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
24	Nighttime	Word Signs Combined	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
25	Nighttime	Barrels and Barricades	MRD	Hypothesis 5	MRD of H.I.G. is significantly greater than MRD of E.G.
26	Nighttime	Sign A	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
27	Nighttime	Sign B	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
28	Nighttime	Sign C	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
29	Nighttime	Word Signs Combined	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 2	MRD of S.E.G. is significantly greater than MRD of H.I.G.
30	Nighttime	Barrels and Barricades	MRD	Hypothesis 1	MRDs of H.I.G. and S.E.G. are not significantly different

a MRD = Mean Recognition Distance

b See description of hypotheses in page 110

c Level of Significance $\alpha = 5\%$

E.G.s= Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE E-4. HYPOTHESIS TESTING RESULTS, WORD SIGNS VERSUS SYMBOL SIGNS

Case No.	Light Condition	Device	Attributei[a]	Hypothesis Tested [c]	Test Conclusion [b]
					URBAN PROJECT
1	Daytime	Signs with S.E.G.	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Nighttime	Signs with S.E.G.	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
					RURAL PROJECT
1	Daytime	Signs with E.G.	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs with S.E.G.	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Daytime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs with E.G.	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
5	Nighttime	Signs with S.E.G	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
6	Nighttime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
					CONTROLLED EXPERIMENTS
1	Daytime	Signs with E.G.	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs with S.E.G.	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Daytime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs with E.G.	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
5	Nighttime	Signs with S.E.G.	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
6	Nighttime	Signs with H.I.G.	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs

[a] MRD = Mean Recognition Distance

[b] See description of hypotheses in page 110

[c] Level of Significance $\alpha = 5\%$

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE E-5. HYPOTHESIS TESTING RESULTS, CONTROLLED EXPERIMENTS, PAIRED OBSERVATIONS

Case No.	Light Condition	Device	Attribute [a]	Hypothesis Tested [c]	Test Conclusion [b]
1	Nighttime	Sign A	MRD	Hypothesis 9	MRD of S.E.G. is significantly greater than MRD of E.G.
2	Nighttime	Sign B	MRD	Hypothesis 9	MRD of S.E.G. is significantly greater than MRD of E.G.
3	Nighttime	Sign C	MRD	Hypothesis 9	MRD of S.E.G. is significantly greater than MRD of E.G.
4	Nighttime	Word Signs Combined	MRD	Hypothesis 9	MRD of S.E.G. is significantly greater than MRD of E.G.
5	Nighttime	Barrels and Barricades	MRD	Hypothesis 9	MRD of S.E.G. is significantly greater than MRD of E.G.
6	Nighttime	Sign A	MRD	Hypothesis 11	MRDs of H.I.G. and E.G. are not significantly different
7	Nighttime	Sign B	MRD	Hypothesis 11	MRD of H.I.G. is significantly greater than MRD of E.G.
8	Nighttime	Sign C	MRD	Hypothesis 11	MRD of H.I.G. is significantly greater than MRD of E.G.
9	Nighttime	Word Signs Combined	MRD	Hypothesis 11	MRD of H.I.G. is significantly greater than MRD of E.G.
10	Nighttime	Barrels and Barricades	MRD	Hypothesis 11	MRD of H.I.G. is significantly greater than MRD of E.G.
11	Nighttime	Sign A	MRD	Hypothesis 7	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 8	MRD of S.E.G. is significantly greater than MRD of H.I.G.
12	Nighttime	Sign B	MRD	Hypothesis 7	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 8	MRD of S.E.G. is significantly greater than MRD of H.I.G.
13	Nighttime	Sign C	MRD	Hypothesis 7	MRDs of H.I.G. and S.E.G. are not significantly different
14	Nighttime	Word Signs Combined	MRD	Hypothesis 7	MRDs of H.I.G. and S.E.G. are not significantly different
				Hypothesis 8	MRD of S.E.G. is significantly greater than MRD of H.I.G.
15	Nighttime	Barrels and Barricades	MRD	Hypothesis 7	MRDs of H.I.G. and S.E.G. are not significantly different

a MRD = Mean Recognition Distance

b See description of hypotheses in page 110

c Level of Significance $\alpha = 5\%$

E.G. = Engineering Grade, S.E.G. = Super-Engineering Grade, H.I.G. = High-Intensity Grade