EVALUATION OF THE RELATIVE ADEQUACY AND THE ECONOMICS OF THREE TYPES OF RETROREFLECTIVE SHEETING PRODUCTS

By

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table		Page
41.	Hypothesis Testing Results, Controlled Experiments, Paired Observations	163

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Problem Statement

Highway construction work zones are potentially hazardous areas because they present unexpected or unusual situations to the motorists. When a work zone is present, motorists are required to travel a section of highway that may deviate from their expected travel path because of narrow lanes, closed lanes, and detours. These areas become more hazardous at night because of the problem associated with nighttime visibility. The Manual on Uniform Traffic Control Devices (MUTCD) states that adequate warning, delineation, and channelization by means of appropriate signing and channelization devices which are effective under varying light and weather conditions should be provided to assure the motorists of positive guidance throughout the highway construction work zones [1].

Objective and Scope

The overall objective of this study is to evaluate the relative adequacy and economics of engineering grade, super-engineering grade, and high-intensity grade sheetings when used on traffic control devices (signs, barricades, barrels, etc.) at highway construction work zones. The evaluation criteria include: driver visibility needs, durability and economics, and other practical considerations.

Within the context of the main objective of the study, there are four specific major assignments:

Task 1. Literature review and development of measure of performance,

Task 2. a series of controlled field experiments on a closed highway to evaluate the relative dynamic visibility of the three retroreflective sheeting products under varying light and weather conditions,

Task 3. determination of driver response measures regarding the relative adequacy of different retroreflective sheeting products under actual field conditions including one rural real-world construction project and one urban real-world construction project, and

Task 4. evaluation of durability and economics of three retroreflective sheeting products using existing weatherometer test results and data on service life and cost items of sheetings obtained from three major contractors in Oklahoma.

CHAPTER II

LITERATURE REVIEW

This chapter presents the results of Task 1, literature review. The chapter is divided as follows: background, safety problem in highway construction work zones, previous research work on traffic control devices at construction work zones, previous research work related to use of retroreflective sheetings on traffic control devices at construction work zones, and measures of effectiveness in evaluating the retroreflective sheetings.

Background

Reflection of light occurs when the light illuminating an object is reflected from the object. There are three types of reflection: (1) diffuse reflection, (2) mirror (specular) reflection, and (3) retroreflection [2].

In diffuse reflection, the light scatters in all directions and a very small amount of light is reflected back to the source of light. The diffuse reflection results when a beam of light strikes a microscopically rough surface. Mirror reflection results when a beam of light strikes a microscopically smooth surface. The beam of light is reflected from the surface at an angle equal and opposite to the incident angle.

Retroreflection occurs when a beam of light strikes a surface and is reflected back to the source of light. This principle of retroreflection is applied to highway signing and other traffic control devices [2]. The three types of reflection are shown in Figure 1.

There are two common types of reflectors: (a) spherical lens reflector, and (b) cube-corner reflector.

A spherical lens reflector uses a glass bead and reflecting surface placed at the focal point to return light to its source. An incident light beam is refracted as it passes through the surface of the glass bead and strikes the back of the bead. The light beam is reflected from the reflector coat at the back surface of the bead and rebounds back through the bead. The light beam is refracted again as it leaves the bead and returns to the light source. Cube-corner reflectors use microprisms. The light beam enters through the front surface and reflects successfully from the three back faces of the cube at the plastic/air interface and is redirected through the face to the source [2]. Figure 2 shows the two types of reflectors.

Retroreflective sheetings are flexible sheets consisting of countless cube-corners (microprisms) or tiny spherical glass beads embedded in a weather resistant transparent film. To reflect color, pigment or dye is inserted into the film or onto the reflective surface [38]. Figure 3 shows the typical construction of enclosed lens and encapsulated lens retroreflective sheetings.

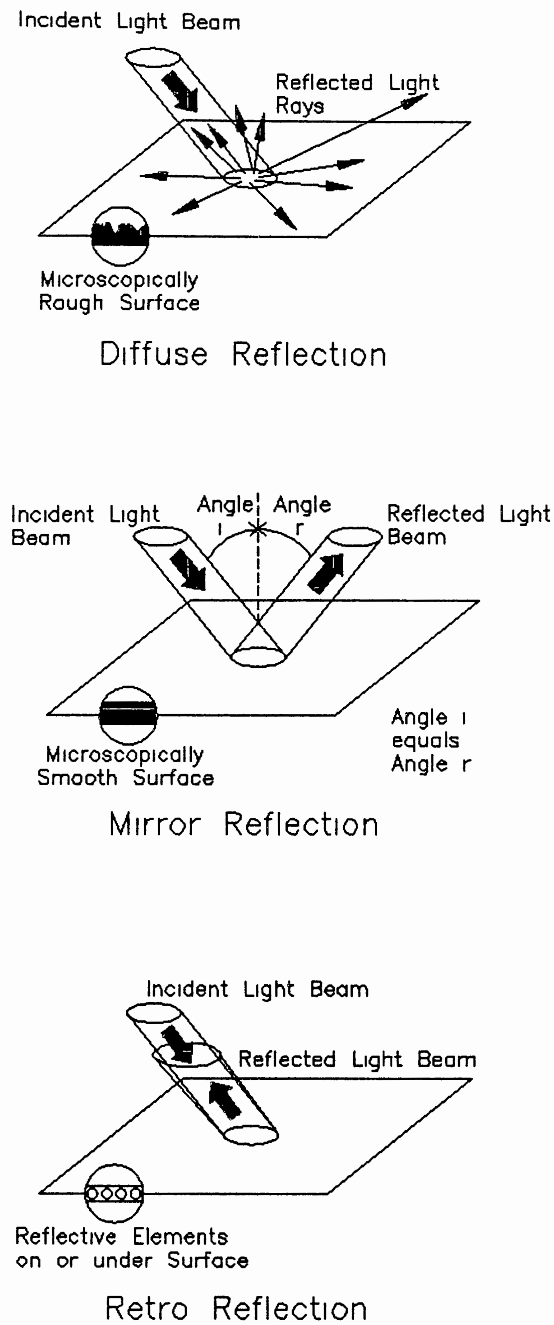


Figure 1. Types of Reflections

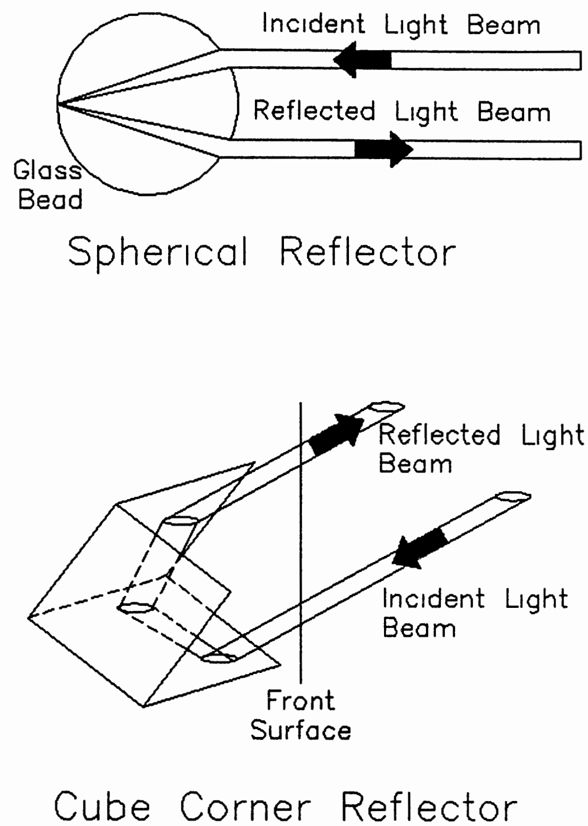


Figure 2. Types of Reflectors

The enclosed lens sheeting consists of a layer of transparent plastic of the appropriate color in which microscopic glass beads are embedded, with a metallic reflector coat behind the bead layer. The encapsulated lens sheeting consists of exposed glass lenses embedded in a plastic resin and protected by a transparent film supported above the beads by walls constructed in a hexagonal or similar pattern. The cube-corner sheeting consists of microprisms enclosed in a transparent plastic film with an air cushion behind the microprisms [2].

The ability of a retroreflective sheeting to return light back to its source is described by the coefficient of retroreflection or luminance. Luminance is described as specific intensity per unit area, SIA, and is expressed in "candelas per foot-candle per square-foot."

The types of retroreflective sheeting as classified by the ASTM standards [3] and the FP-85 specification [2] are presented in Table 1.

Safety Problem in Highway Construction Work Zones

Many highway construction work areas experience an increase in roadway accident rates during construction when compared to a similar period before construction [5, 6, 7, 8]. These areas become more hazardous at night due to the reduced ability of motorists to see traffic control devices in or near the traveled path. Highway fatalities in work

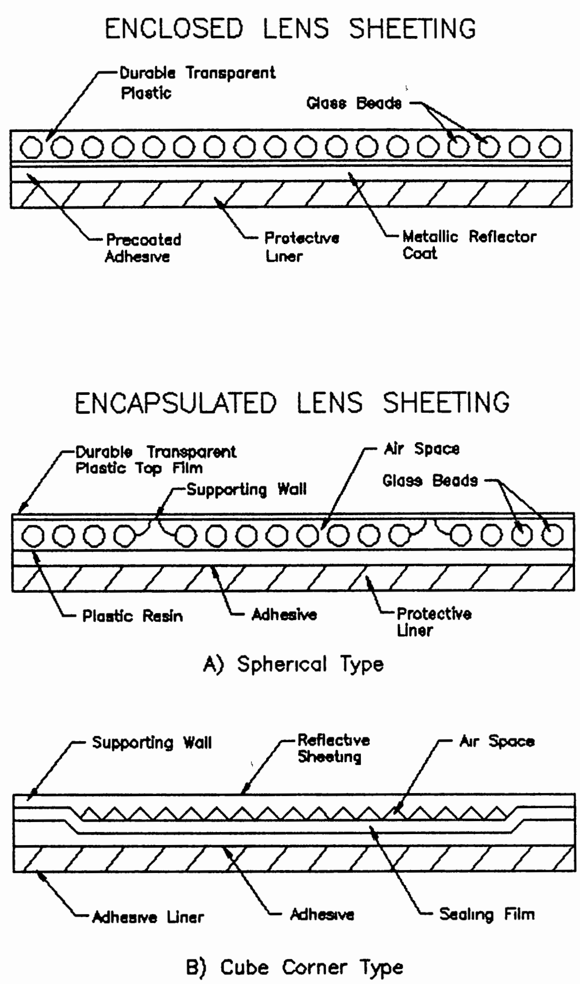


Figure 3. Types of Retroreflective Sheetings

TABLE 1

CLASSIFICATION OF RETROREFLECTIVE SHEETING PRODUCTS

Sheeting Type[a]	Commercial[b] Classification	ASTM Classification	FP-85 Classification
1	E.G.	Type-I	Type-II
2	S.E.G.	Type-II	Type-IIA
3	H.I.G.	Type-III	Type-IIIA
4	H.I.G.	Type-IV	Type-IIIB

a 1. A medium-intensity retroreflective sheeting, typically enclosed lens glass-bead sheeting.

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

3. A high-intensity retroreflective sheeting, typically encapsulated glass-bead retroreflective material.

4. A high-intensity retroreflective sheeting, typically an unmetallized microprismatic retroreflective element material.

b E.G. = Engineering Grade Sheeting

S.E.G. = Super-Engineering Grade Sheeting

H.I.G. = High-Intensity Grade Sheeting

zones increased from 489 in 1982 to 680 in 1985, an increase of 39 percent, in which more than one-half of the fatalities occurred at night [9].

Previous Research Work on Traffic Control Devices at Highway Construction Work Zones

Pain, McGee, and Knapp [6] conducted research to determine the effectiveness of channelization devices like cones, barricades, drums, vertical panels, and steady-burn lights, and the design and use of these devices to guide drivers at highway construction zone on freeway-type facilities. It was found that there was no one type of channelization device or design which provided the maximum effectiveness for both daytime and nighttime conditions. The ranges of array detection distances during daytime were 3100 to 5000 feet and that at nighttime were 2050 to 4000 feet. Considerable variability in array detection distance for most devices and in point of lane changing for larger devices (barricades, panels, drums, etc.) was found among drivers, particularly at nighttime. During the daytime, speed reduction is controlled by the size of device; at nighttime, the amount of visible reflective surface controls speed reduction, array detection distance, and lane changing [6].

In 1984, the Traffic and Safety Division of New York State DOT initiated a recommendation to use plastic drums instead of steel drums for channelization in highway construction zones, because plastic drums, being less rigid and lighter than steel drums, are likely to result in less injuries to highway workers as well as minimal damage to an impacting vehicle [5].

Traffic control devices are often involved in work zone traffic accidents because they are placed close to the traveled lanes. In 1988, full-scale vehicle crash tests were used to evaluate the performance of typical work zone traffic control devices [10]. The traffic control devices tested were steel drums, plastic drums, vertical panels, cones, tubular markers, and Types I and III barricades. Results of 108 full-scale crash tests on 62 combinations of work zone traffic control devices and installation conditions show that some of these devices create hazards when impacted. Performance deficiencies noted include: the tendency of devices to penetrate the passenger compartment or to cause windshield damage, loss of vehicle control, and debris thrown through the work zone that was considered potentially hazardous to workers or passengers of other vehicles. The findings of the study included:

1. Plastic drums, cones, tubes, and vertical panels performed well in most tests when properly deployed and ballasted.
2. Improperly ballasted channelizing devices, especially ballast placed above ground level, might present a significant hazard to motorists and

workers.

3. Steady burn lights attached to channelizing devices became flying objects in a number of tests, which resulted in windshield damage in some tests, although none completely penetrated a windshield. They might also threaten workers when the lights are thrown into the work zone.
4. Most temporary sign supports tested did not perform well. Rigid sign panels mounted at bumper height were thrown onto windshields. In addition, debris from several supports threatened workers and other traffic.
5. Type I barricades tested were thrown on impact and appeared to represent a risk to workers and other traffic. PVC-plastic Type III barricades resulted in considerable debris, although that was not considered a significant threat. However, all PVC Type III barricade tests resulted in windshield damage. A steel Type III barricade performed well, with no debris and no wind-shield damage.

The Ohio Department of Transportation investigated the effect of steady burn lights on drums with high-intensity reflective sheeting in tangent sections of highway construction work zones on rural four-lane divided highways including freeways, under unlighted conditions [11]. It was found that the steady burn lights on drums had very little effect on driver behavior. The study recommended discontinuation of the use of steady burn lights on drums marked with high-intensity reflective sheeting in tangent sections of construction work zones in rural divided highways including interstate freeways under unlighted conditions.

Previous Research work related to use of Retroreflective Sheetings on Traffic Control Devices at Construction Work Zones

Little amount of research has been done in the past to evaluate retroreflective sheetings when used on traffic control devices at highway construction work zones. Only one study by the Wisconsin Department of Transportation (WDOT) was conducted to evaluate the engineering grade, super-engineering grade, and high-intensity grade sheetings at construction work zones [12]. The evaluation criteria were: reflectivity, abrasion resistance, vehicle speeds, and field visual evaluation of the nighttime appearance of devices. The review team consisted of six members from WDOT and one member from FHWA. The findings of that study were based on the subjective opinion of the review team members. The main conclusions of the study were:

1. High-intensity grade sheeting was the most reflective sheeting, super-engineering grade sheeting was second, and engineering grade sheeting was the least reflective.

2. Based on reflectivity, visibility, and guidance, high-intensity grade sheeting was found to be the best for use on barrels and delineator tubes as compared to the other two types of sheeting tested.
3. Based on message legibility, super-engineering grade sheeting was judged to be most effective for use on signs, high-intensity grade sheeting was second, followed by engineering grade sheeting. High-intensity grade sheeting, being more reflective than the other two types of sheeting, was judged to provide strong contrast to surroundings (i.e, conspicuous), but problems with glare led review team members to downgrade it.
4. Engineering grade sheeting was the most damage resistant, super-engineering grade sheeting was second, and high-intensity grade sheeting was the least damage resistant.
5. Vehicle speed differences at construction work zones proved to be small and inconsistent at crossovers marked with different sheeting.

The Kansas Department of Transportation conducted a telephone survey regarding the use of reflective sheetings at construction work zones. Super-engineering grade sheeting was not included in the survey. Forty-four states were involved in the survey. It was found that out of 44 states, 3 states (6.8%) were using engineering grade sheeting as well as high-intensity grade sheeting on signs.

Engineering grade sheeting was being used on signs by 13 states (29.5%) and 28 states (63.6%) were using high-intensity grade sheeting on signs.

A study by Morales [13] measured the performance of stop signs based on their retroreflective properties. A math-ematical relationship was developed between stop sign recognition distance and its retroreflectivity.

Measures of Effectiveness in Evaluating the Retroreflective Sheetings

The selection of retroreflective sheeting to be used depends on driver visibility needs, durability and economics, and practical considerations [2].

Drivers' Visibility Needs

Drivers' visibility requirements are important considerations for selecting the type of sheeting. The ability of a driver to see and recognize a sign depends on many factors including brightness, external luminance contrast, and internal luminance contrast of the sign [2].

Brightness. Brightness refers to the amount of light reflected from the sign that reaches the driver's vision. Brightness is determined by many factors including: color, type of retroreflective material used and luminance (specific intensity per unit area, SIA) of that material, road curvature, mounting height and orientation angle, placement of sign (right shoulder, overhead, median, left mount, etc.), and viewing distance from sign [2].

External and Internal Luminance Contrast. Brightness contrast is more critical to maintain the detectability and legibility of signs than the overall brightness of the sign [2]. External contrast is the ratio of sign luminance to the luminance of the surroundings (i.e., the background against which the entire sign is seen). Internal contrast is the contrast of letters or symbols against the sign background. Conspicuity (critical to external contrast) refers to the probability that a sign located in the visual periphery will be seen at a given distance, whereas legibility (critical to internal contrast) may be described by an index which relates size of letters and symbols, viewing distance, and recognition acuity of the driver. Legibility distance of a given sign is determined by size of letters or symbols, internal contrast, brightness of sign background, and brightness of surrounding or ambient luminance. External contrast may sometimes be changed by relocating the sign, whereas internal contrast is fixed by the choice of materials, color, and sign fabrication process.

Durability of Retroreflective Sheeting

Traffic signs experience deterioration of retroreflective sheeting from the effects of sunlight, weather, airborne abrasives, and air pollution. This deterioration gradually reduces visibility and legibility of a sign to the point at which a driver may no longer perceive the intended message in time to complete the required maneuver.

Retroreflective sheeting may deteriorate by a number of factors, such as:

1. Destruction of the metallic reflector coat,
2. Disruption or distortion of the optical elements within the sheeting,
3. Degradation or destruction of the outermost polymer layer,
4. Fading of dyes or pigments used to produce appropriate color in the sheeting or screen-printed graphics,
5. Failure of bonds between layers,
6. Damage and loss of retroreflectivity from vandalism (gun shots, spray paints, etc.) and from being hit by vehicles.
7. Delamination (i.e., sheeting peeling away from the backing) and cracking of the sheeting may occur due to shrinkage.

One of the desired qualities of retroreflective sheeting is that it maintains its reflectivity, color, and structural integrity within acceptable limits over a long period of time. The ASTM specification [3] states that sheeting should not deteriorate below 50 to 80 percent (depending upon the sheeting type) of the minimum SIA requirement of new material when subjected to accelerated weathering in accordance with the ASTM G-23 test procedure.

The test procedure is described in the ASTM G-23 [4]. Essentially it requires that specimens of sheeting be exposed to artificial weathering effects produced by a weatherometer chamber. There are various weatherometers but, the common characteristics of those required by the FP-85 Specification are employment of a carbon-arc lamp, which attempts to simulate the deleterious effects of the sun, a water apparatus for simulating rain and moisture, a thermometer for maintaining specified temperature, and a circular rack which holds the test specimens. Following the required exposure and other specified preparations, the specimens are tested according to SIA test procedures.

Economic Consideration

The attainment of an objective at low cost is known as economy which is important for any sound decision-making process. In determination of economy, care must be exercised to ensure that the alternatives being evaluated provide identical services. A benefit-cost ratio is computed for evaluating public projects. 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.

The relative durability and service life of different sheetings are important considerations in economic analysis [2]. Several factors should be considered in making a life-cycle cost analysis, such as:

1. Cost of sign fabrication, including the cost of substrate material and sheeting,
2. Cost of sign installation, including post, hardware, and labor,
3. Service life of the sheeting material, and
4. Benefits derived by using a sheeting that maintains higher level of reflectivity over its useful life.

CHAPTER III

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 project. The engineering grade sheeting was evaluated for the rural environment only because 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 construction work zone, (2) rural, real-world 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, whereas westbound traffic was controlled using the sequence of control devices shown in Figure 5. 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 6.

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 7.

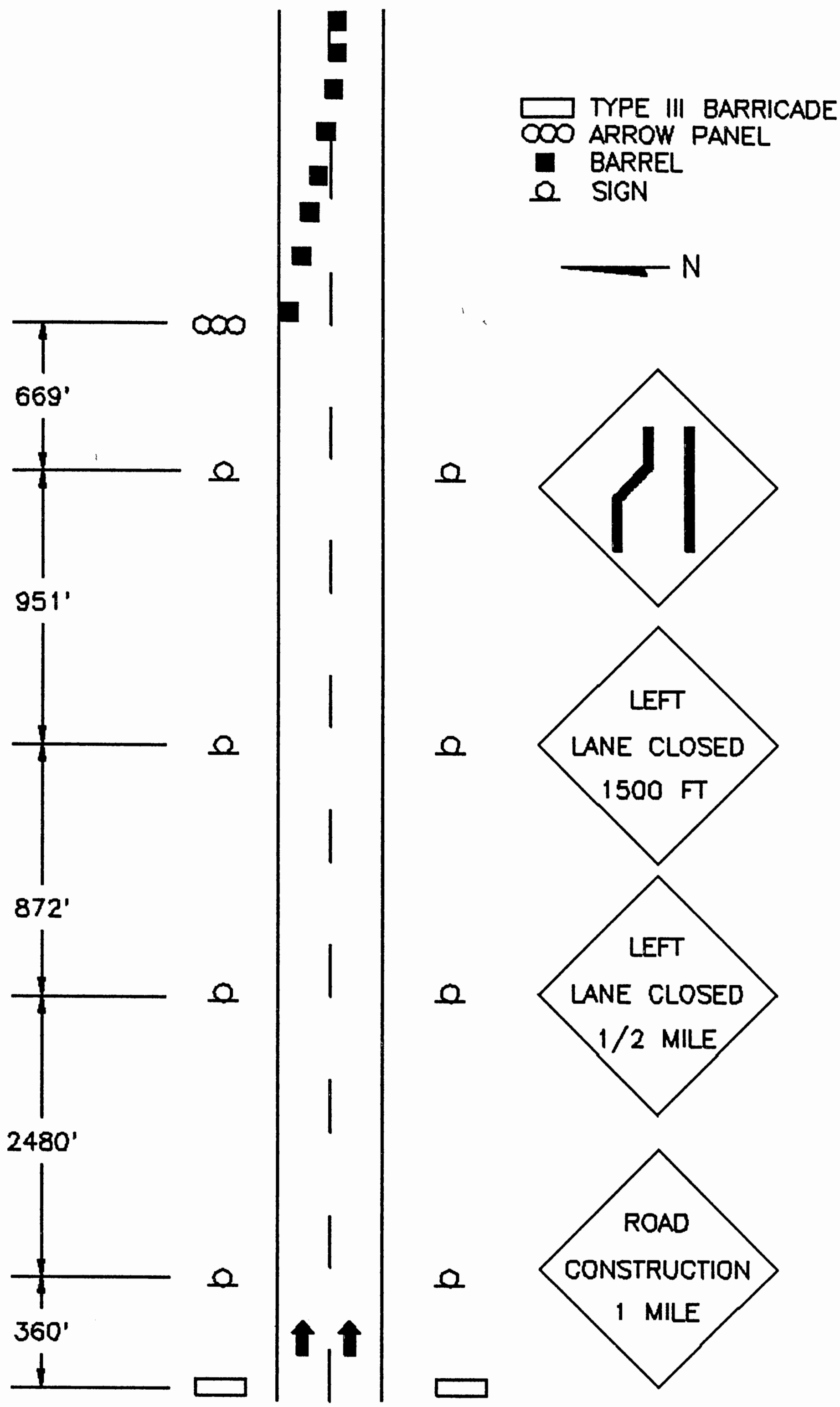


Figure 4. Schematic Drawing of Urban Site (Eastbound)

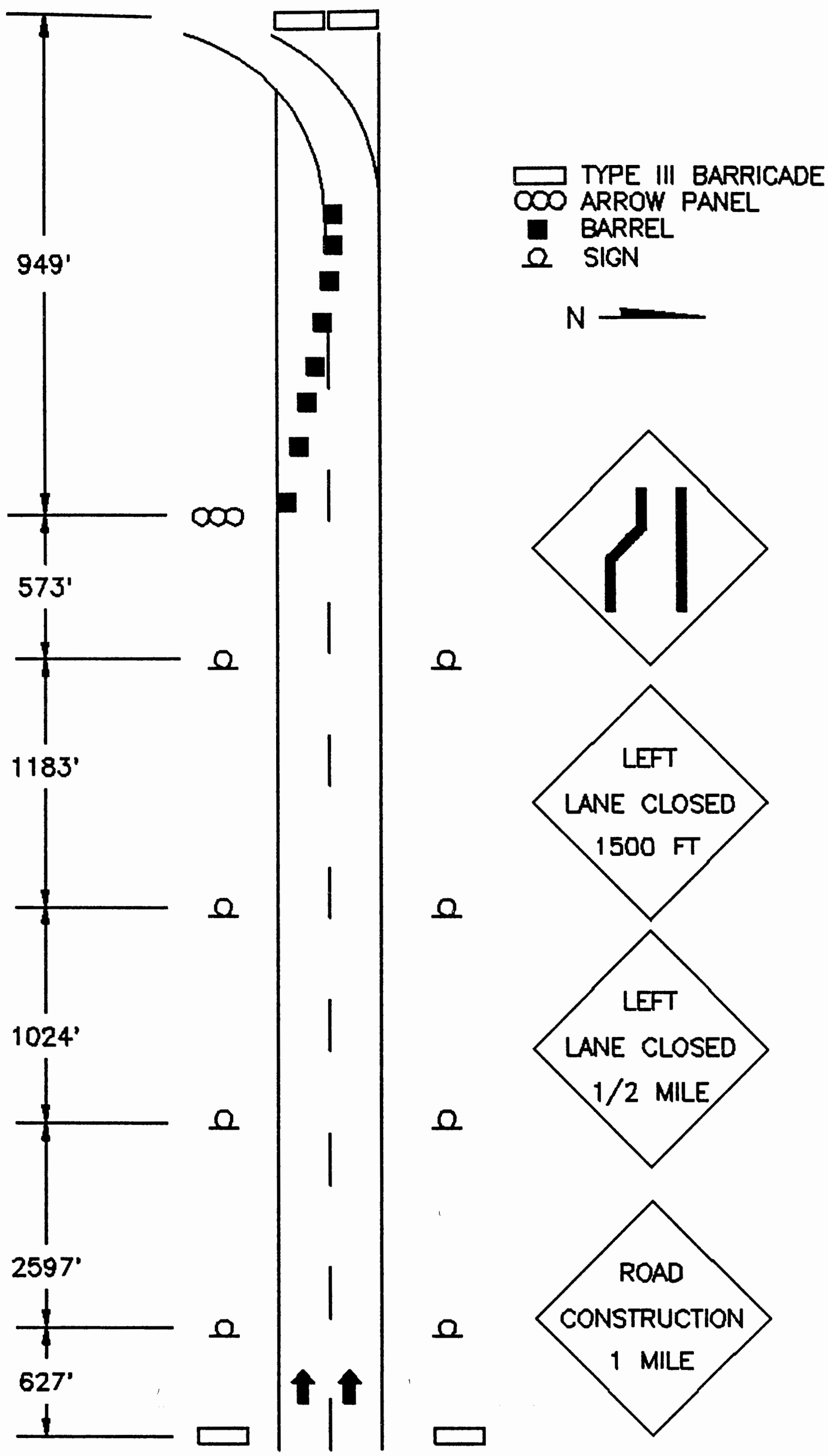


Figure 5. Schematic Drawing of Urban Site (Westbound)

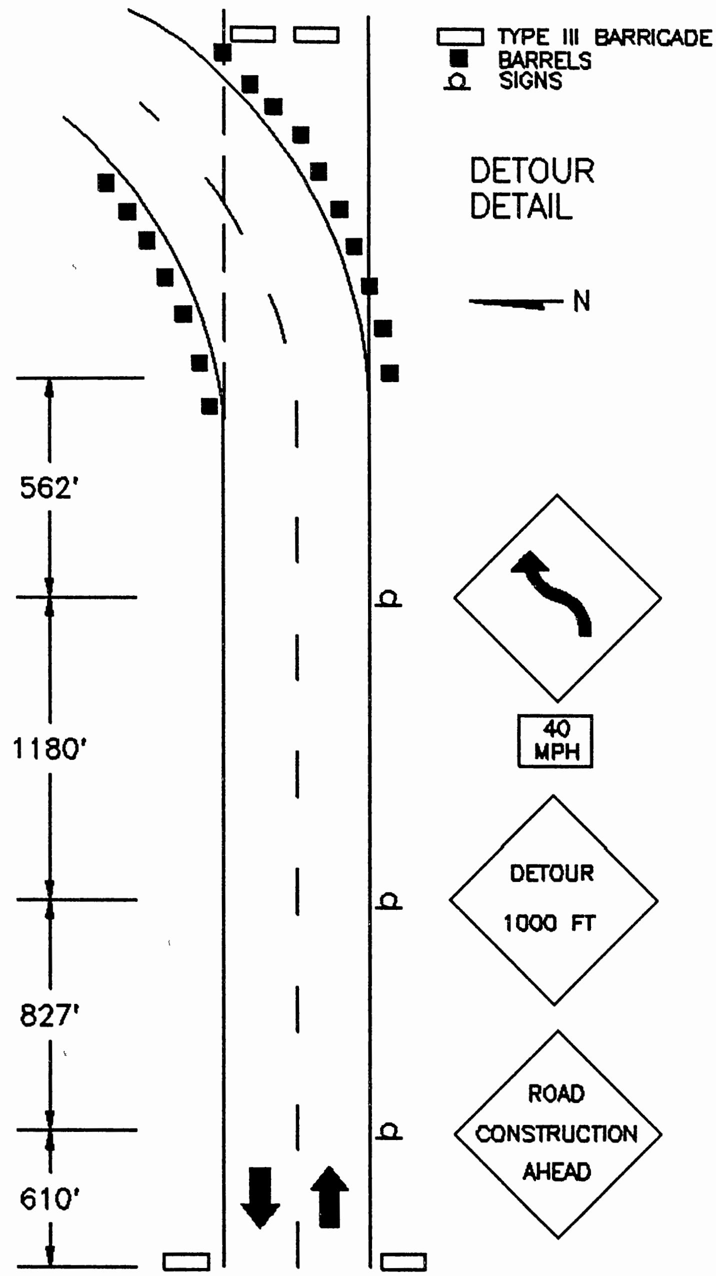


Figure 6. Schematic Drawing of Rural Site

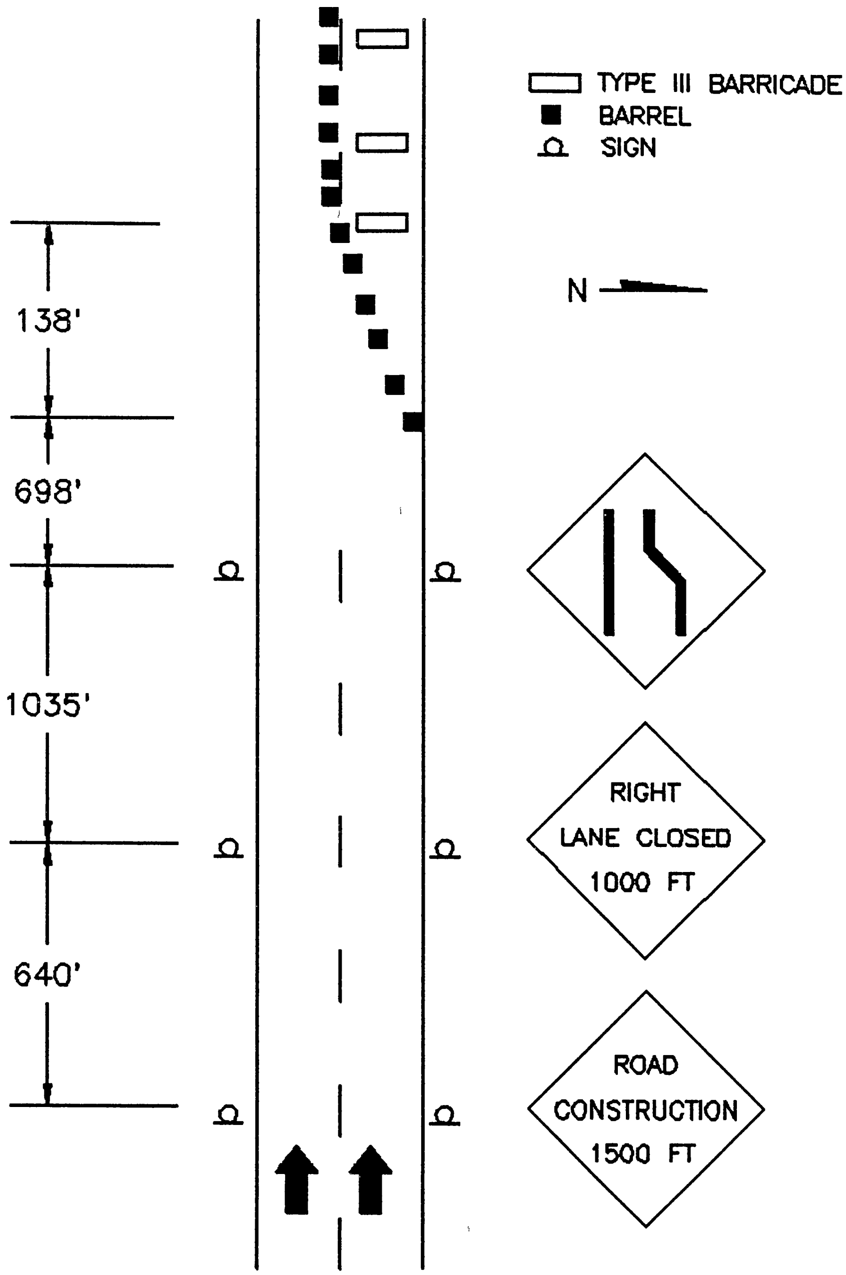


Figure 7. Schematic Drawing of Controlled Experiment Site

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 driver 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 [14]. Other characteristics of the test drivers are given in Tables 13 through 20 (Appendix A).

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 which is manufactured by Nu-Metric, Inc. It is 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	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	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	22 0/20.1	23 2/13 3	6 1/11.7	1 2/12 5

a/b Percentage of drivers used in the study/percentage 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 Percentage of drivers used in the study/percentage of drivers in the state

microprocessor-based device with programmed instructions. A proximity sensor attached to the front left wheel sends an 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. Figure 8 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 the subject's 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.

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 [4]. 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. Different agencies specify the numbers of hours of weathering required. Weatherometer data which have been used in this study were obtained from a number of sources including the ODOT; the Texas DOT; Seibulite International, Inc.; and Industrial Testing Laboratories, Berkeley, California.

INSTRUCTION TO DRIVERS

I <u>Welcome to Test Vehicle</u>

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 <u>Ready to Begin</u>

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 <u>FIVE</u> 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. <u>After Test Drive</u>

Please fill out the questionnaire which will be given to you

Figure 8. Instruction to Drivers

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 types of sheetings used, quantity of sheetings purchased per year, service lives of the sheetings, on number of 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.

CHAPTER IV

DATA ANALYSIS AND RESULTS

This chapter summarizes the results of experimental and theoretical work undertaken on this project. The chapter is organized as follows. First, results of statistical analyses of detection and recognition distances of the three sheeting types are presented. Second, results of the questionnaire on drivers' opinions of the adequacy of the different sheetings are summarized. Third, the weatherometer test results are summarized for the three sheeting types. Fourth, results of the contractors' survey are presented. Finally, economic analyses of the three grades of sheeting.

Statistical Analysis of Detection and Recognition Distances

As described in Chapter III, drivers visibility needs are major criteria for evaluating the adequacy of a particular grade of sheeting. 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 is 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, can 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 answer the following 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/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/nighttime conditions?

Tables 29 through 33 (Appendix D) list the mean detection distances and mean recognition distances of each grade of sheeting at each test site. The numbers in parentheses are standard deviations and "n" is the number of test drivers. In Table 30, 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 III, 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 34 through 36 (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,

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 a 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:

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

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: $\sigma_1^2 = \sigma_2^2$.

If the F-test indicates the variances are equal, then the t-statistic is given by

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

where s_p, the pooled standard deviation, 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 the variances are <u>not equal</u>, then an approximate t value is computed as follows:

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

and the associated degrees of freedom are given by

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

Based on the level of significance of the test and degrees of freedom, the computed t-statistic is compared with a tabulated t value. If the computed t 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 alternative hypothesis and the corresponding rejection regions are as follows:

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

<u>Comparison of Two Population Means Using Paired observations.</u> 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: $\mu_2 - \mu_1 = 0$

H_a: $\mu_2 - \mu_1 > 0$

the t-statistic is given by

$$t = \frac{\overline{D}}{s_D/\sqrt{n}} \tag{7}$$

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

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 percent.

Tables 37 through 40 (Appendix E) summarizes the conclusions of the t-test. The following paragraphs summarize the major findings of the statistical analyses.

Mean Detection Distance, MDD

1. Rural Project, Nighttime Conditions

The MDDs of engineering grade, super-engineering grade, and high-intensity grade sheetings were not significantly different.

2. Rural Project, Daytime Conditions

The MDDs of engineering grade, super-engineering grade, and high-intensity grade sheetings were not significantly different.

3. Urban Project, Nighttime Conditions

The MDD of high-intensity grade sheeting was significantly greater than the MDD of super-engineering grade sheeting.

4. Urban Project, Daytime Conditions

The MDD of high-intensity grade sheeting was significantly greater than the MDD of super-engineering grade sheeting.

5. Controlled Experiments

The MDDs were not considered because the drivers could see the array of devices, regardless of the sheeting type used, as soon as they entered the gate to the test road.

Mean Recognition Distance, MRD

1. 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 Sign. 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 and word signs.

Several drivers indicated 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.

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 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 Sign. 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 a greater MRD than that of engineering grade sheeting. One word sign showed the opposite conclusion.

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 Sign. 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 a 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.

2. 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 Sign. 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 a 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.

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 Sign. 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 Sign. 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.

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. High-intensity grade sheeting on word signs had significantly 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. Urban Project, Nighttime Conditions

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 two of the three word signs analyzed. For the third word sign, the MRDs of both sheetings were not significantly different.

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

Symbol Sign. 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 a 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.

4. Urban Project, Daytime Conditions

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 Sign. 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.

5. Controlled Experiments, Nighttime Conditions

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. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Sign. 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 greater than that of engineering grade sheeting for 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.

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 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 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 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.

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 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 Sign. 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 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 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.

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. The same conclusion was reached when word signs were analyzed individually as well as when they were combined.

Symbol Sign. 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 paired observations given in Tables 34 through 36 (Appendix D) were analyzed using the paired t-test method. These observations were recorded during the controlled experiments at nighttime. Table 41 (Appendix E) lists the results of the paired comparisons. 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 Sign. 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 Sign. 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.

Drivers' Opinions and Comments

Information on drivers' opinions of 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 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 and comments. The following paragraphs summarize the questionnaire findings.

Drivers' Assessment of Signs

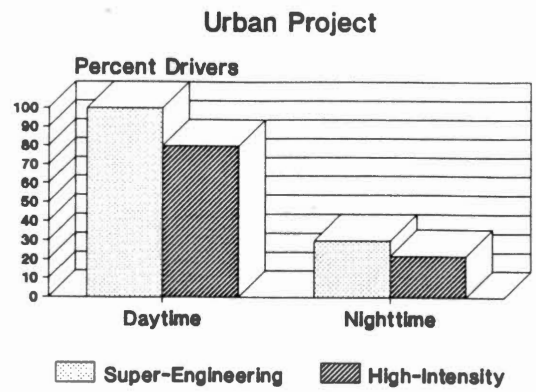
The questionnaire included three questions concerning signs. In the first question, drivers were asked about the ease of reading the signs. The overall adequacy of signs in terms of providing the necessary guidance was the subject of the second question. The third question asked drivers if they had any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

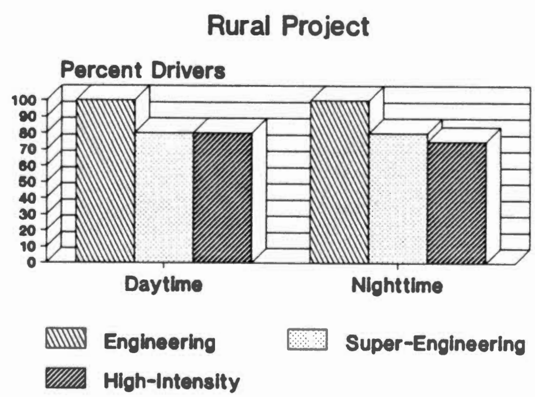
Ease of Reading Signs. Figure 9 depicts the percentages of drivers who rated the signs as adequate to read. In this study, a sign was considered "adequate to read" when the driver's response to question 1 was "easy" or "very easy".

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 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 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 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





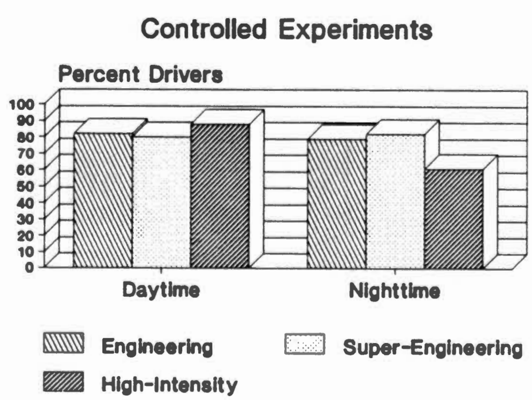


Figure 9. Adequacy of Signs in Terms of Ease of Reading

engineering grade or super-engineering grade sheeting. The percentages of "adequate" responses obtained for signs with engineering grade 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 percent 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 10 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 percent. 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.

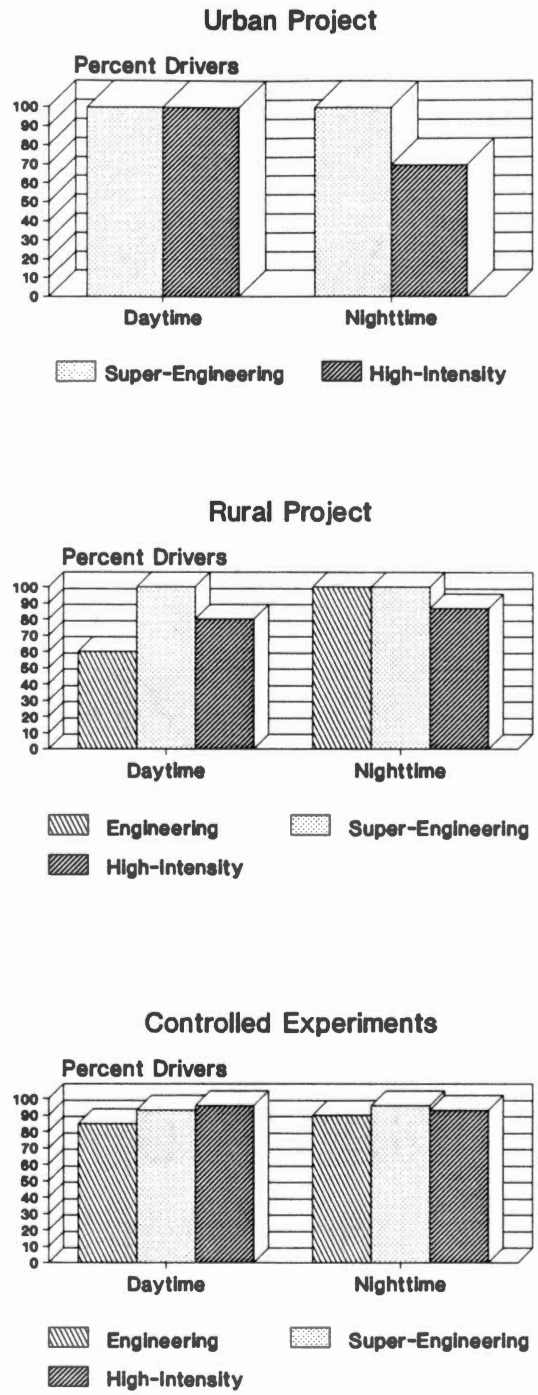


Figure 10. Distribution of Drivers Indicating Signs Provided Adequate Guidance

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

Figures 11 through 14 show the percentages of drivers who indicated that changes were needed in the overall size of signs, size of letter used on word signs, and sign brightness.

Overall Size of Signs. At the urban site, during daytime conditions, 40 percent of the drivers indicated that signs with super-engineering grade sheeting need to be made larger compared to 20 percent for signs with high-intensity grade sheeting. At nighttime, the percentages were 30 and 11 percent for signs with super-engineering grade sheeting

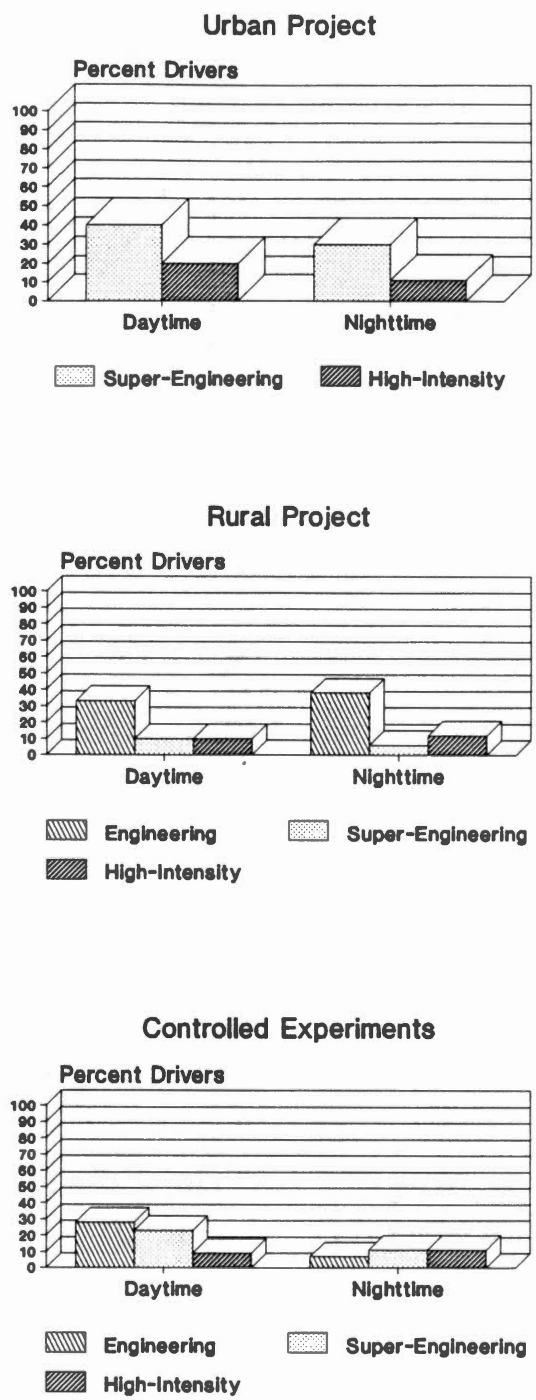


Figure 11. Overall Size of Signs

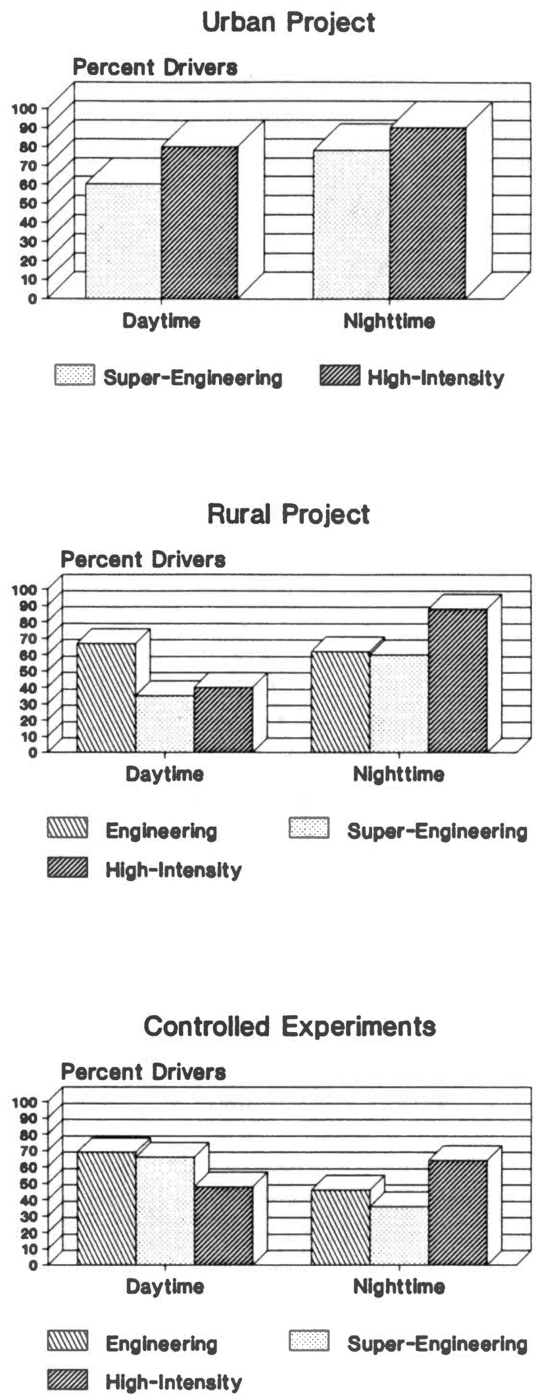
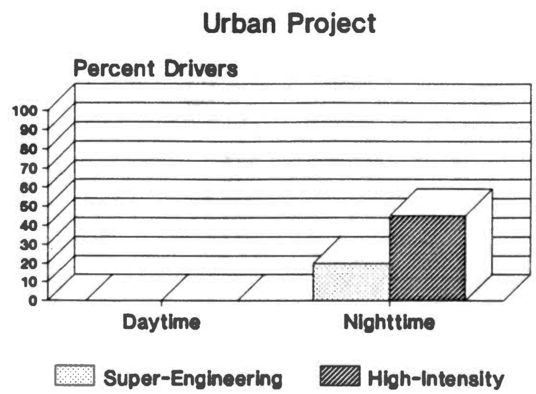
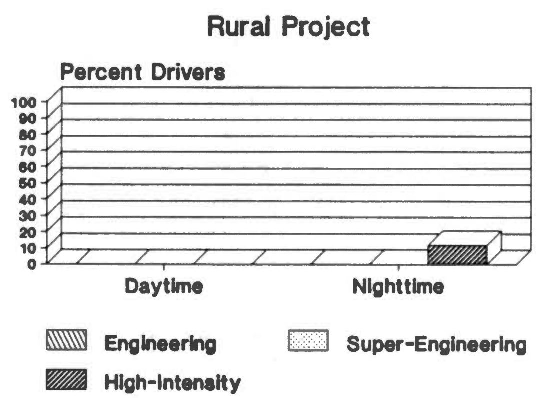


Figure 12. Letter Size on Word Signs





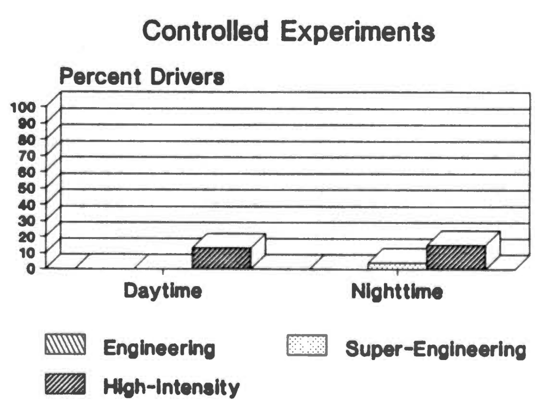
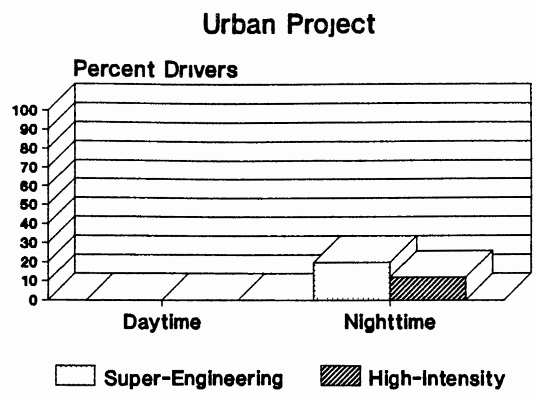
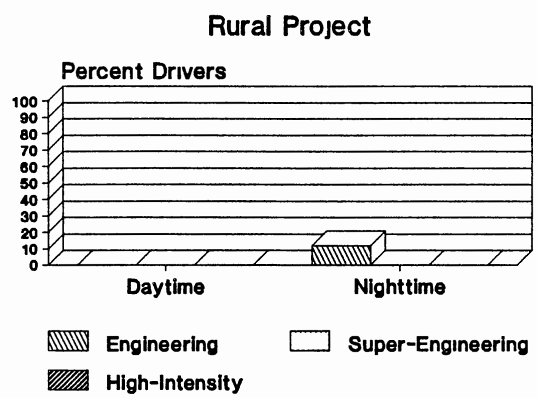


Figure 13. Signs Too Bright





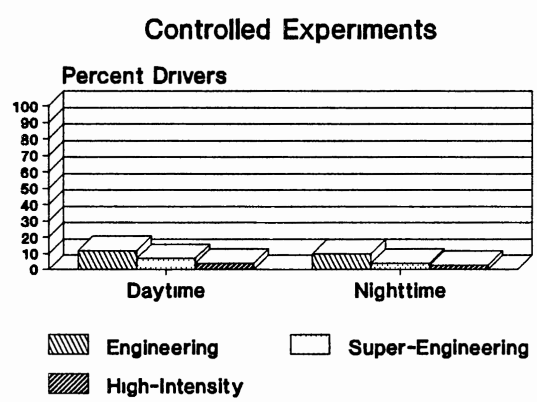


Figure 14. Signs Not Bright Enough

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 during daytime and nighttime conditions. Signs with super-engineering grade and high-intensity grade sheetings received similar responses regardless of time of day.

In the controlled experiments, during daytime conditions, the percentages of drivers recommending an increase the size of signs with engineering grade, super-engineering grade, and high-intensity grade sheetings were 28, 23, and 9 percent, respectively. At nighttime, the percentages were 7, 11, and 11 percent for engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Letter Size. 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 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 percent, respectively. At nighttime, the percentages were 62, 60, and 88 percent 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 percent of the drivers indicated that letter size should be increased on signs with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Brightness. 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 percent, 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 percent 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 percent of the drivers during nighttime conditions.

In the controlled experiments, during daytime conditions, 13 percent of the drivers indicated that signs with high-intensity grade sheeting were too bright compared to 0 percent for signs with engineering grade or super-engineering grade sheetings. At nighttime, 15 percent of the drivers who saw signs with high-intensity grade sheeting judged them as too bright compared to 4 and 0 percent 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.

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 nighttime, there were three comments regarding colors of signs with high-intensity grade sheeting. One driver suggested changing the colors of letters to white. Another driver recommended yellow background with crystal white letters. A third driver indicated the black letters were not easy to read.

For signs with super-engineering grade sheeting, only one remark was made during the nighttime experiments: one driver noted the background colors need to be toned down.

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 the drivers experimenting with super-engineering grade sheeting on signs were satisfied with the colors 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, while another daytime driver noted changing the color of letters to reflective silver. At nighttime, one driver suggested changing the background color to yellow.

Signs with high-intensity grade sheeting received one comment on their colors during the daytime experiments. One driver noted the black letters on an orange background seemed dark.

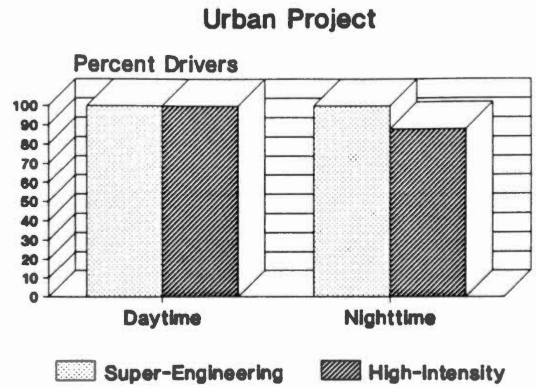
Drivers' Assessment of Barricades and Channelization Devices

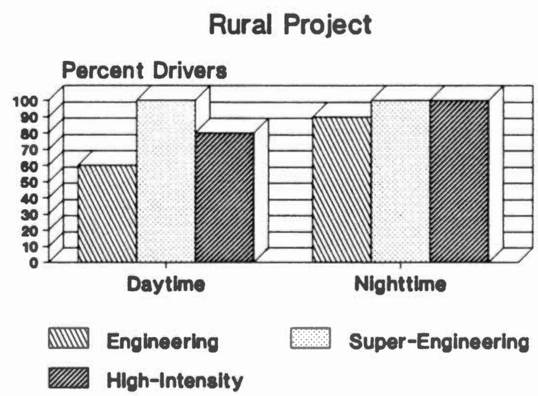
The questionnaire included three questions concerning barrels and barricades. The adequacy of these devices in terms of providing sufficient time to react was the subject of the first question. In the second question, drivers were asked how easy and smooth it was to follow the path provided by the devices.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

<u>Adequacy of Warning Provided.</u> Figure 15 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 percent. At nighttime, barrels and barricades with super-engineering grade sheeting were judged as adequate by 100 percent of the drivers compared to 88 percent 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 percent of the drivers compared to 80 and 60 percent for devices with 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





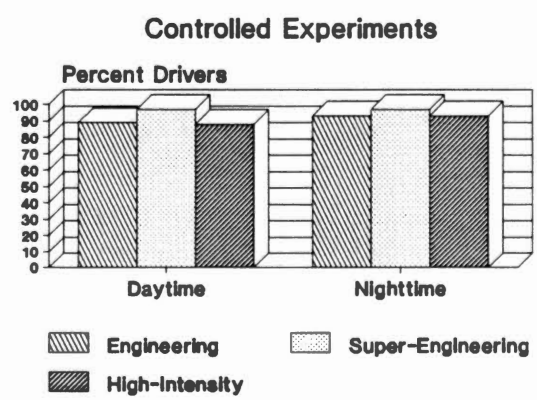


Figure 15. Adequacy of Channelization Devices in Terms of Providing Early Warning

percent of the drivers, whereas devices with engineering grade sheeting received 90 percent "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 during daytime and nighttime conditions.

Adequacy of Guidance Provided. Figure 16 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 percent. At nighttime, barrels and barricades with super-engineering grade sheeting were judged as adequate by 100 percent of the drivers compared to 67 percent 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 percent both during daytime and nighttime conditions.

In the controlled experiments, during daytime

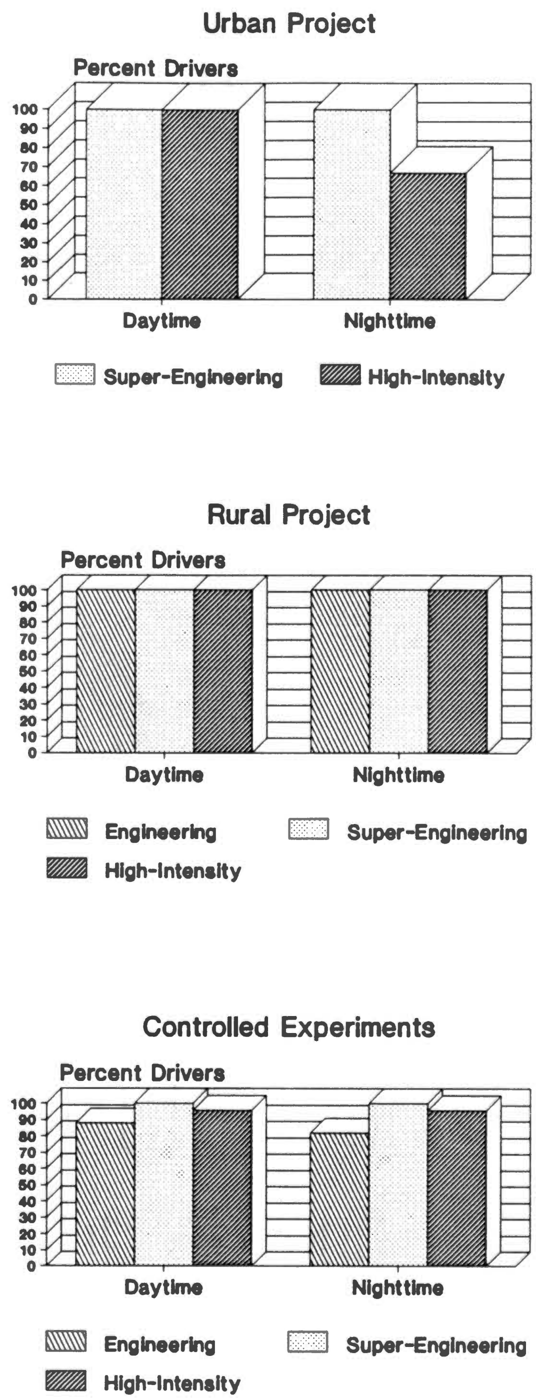


Figure 16. Adequacy of Channelization Devices in Terms of Providing Guidance

conditions, barrels and barricades with super engineering grade sheeting were judged as adequate by 100 percent of the drivers compared to 96 and 88 percent 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 percent for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Drivers' Suggestions for Improving Devices

Figures 17 through 19 show the percentages of drivers who indicated that changes were needed in the overall size of barrels and barricades, and their brightness.

Overall Size of Devices. 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 percent. At nighttime, 12 percent 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 percent of the drivers indicated that barrels and barricades with engineering grade sheeting need to be made larger compared to 33 and 20 percent for devices with super-engineering grade and devices with high-intensity grade

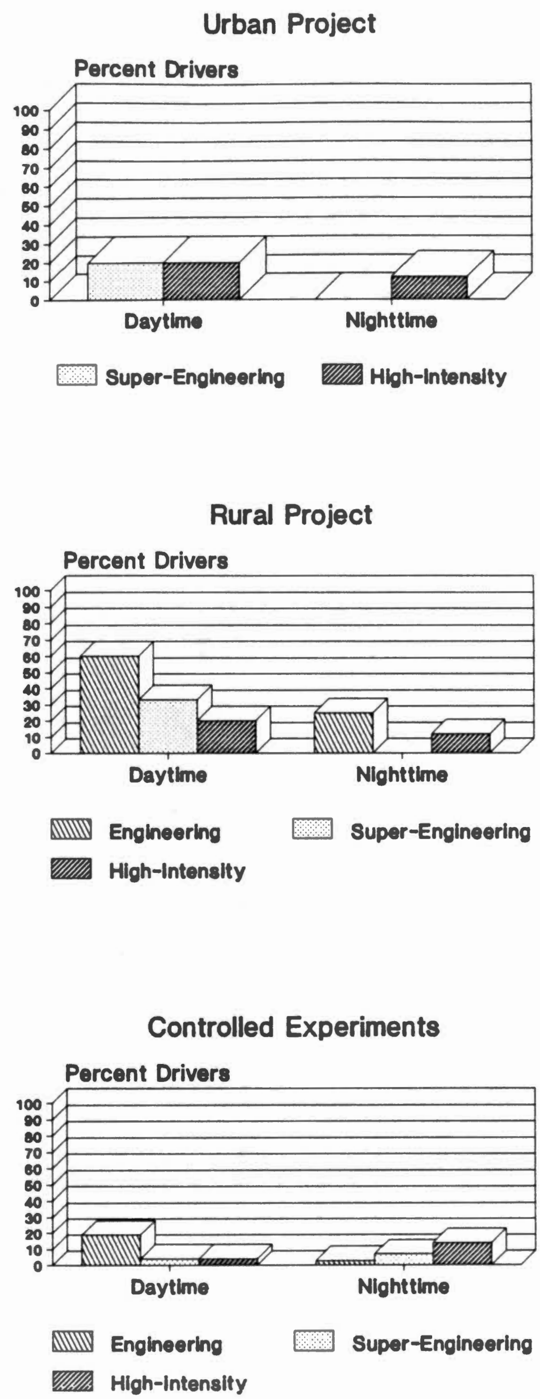
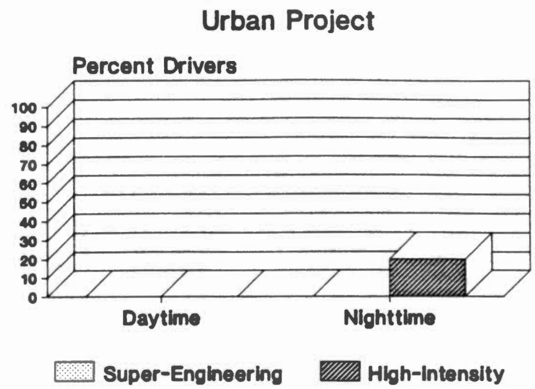
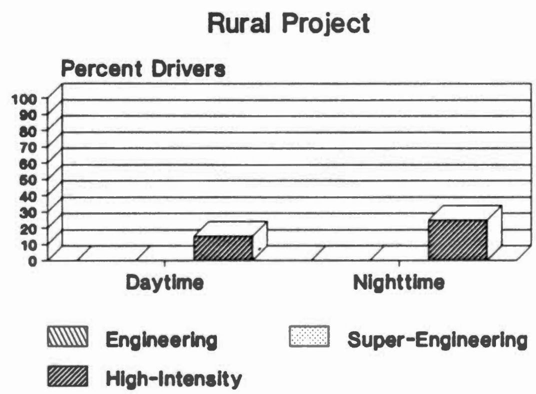


Figure 17. Larger Channelization Devices





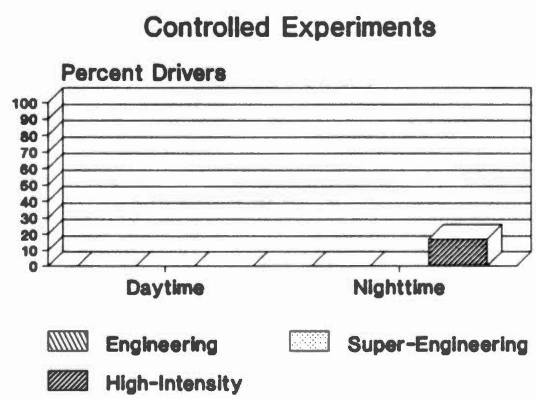
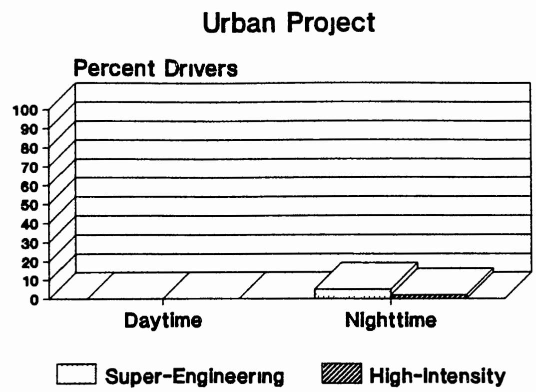
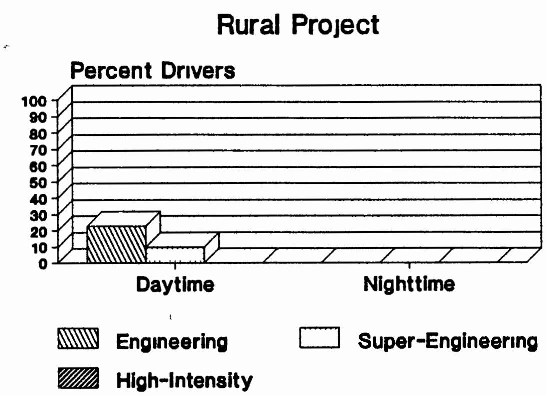


Figure 18. Channelization Devices Too Bright





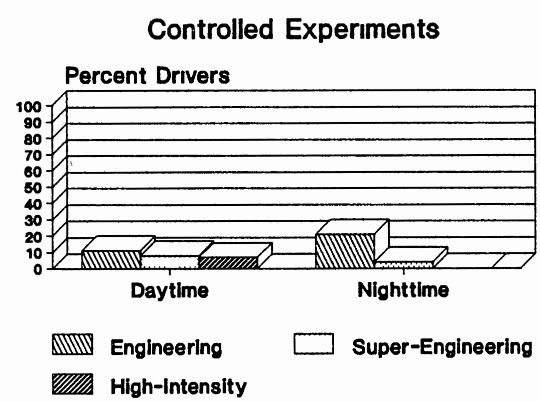


Figure 19. Channelization Devices Not Bright Enough

sheetings, respectively. At nighttime, the percentages were 25, 0, and 12 percent for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

In the controlled experiments, during daytime conditions, 19 percent 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 percent respectively. At nighttime, 14 percent of the drivers recommended that the size of barrels and barricades with high-intensity grade sheeting should be increased compared to 7 and 3 percent for devices with super-engineering grade and devices with engineering grade sheetings, respectively.

<u>Brightness.</u> In the urban project, during nighttime conditions, 20 percent of the drivers who saw barrels and barricades with high-intensity grade sheeting regarded their brightness as <u>too much</u>. Nevertheless, the percentages of drivers indicating that devices were <u>not bright enough</u> at nighttime were 5 and 2 percent 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 <u>too bright</u> both during daytime and nighttime conditions. During daytime conditions, however, 23 percent of the drivers said that barrel and barricades with engineering grade sheeting were not bright enough compared to 10 and 0 percent for devices with super-engineering grade and devices with high-intensity grade sheetings, respectively.

In the controlled experiments, during nighttime conditions, 17 percent 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 percent for barrels and barricades with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively. During daytime conditions, 11 percent of the drivers said that barrels and barricades with engineering grade sheeting were not bright enough compared to 8 and 7 percent for devices with super-engineering grade and devices with high-intensity grade sheetings, respectively.

Colors. In the urban project, the colors of barrels and barricades were judged as "OK" by all the drivers for super-engineering grade and high intensity grade sheetings during daytime and nighttime conditions.

At the rural site, the colors of barrels and barricades were also regarded as "OK" by all the drivers for each of the three grades of sheeting during daytime and nighttime conditions.

In the controlled experiments, all the drivers judged the colors of barrels and barricades as "OK" for each grade of sheeting during daytime and nighttime conditions, except for 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 All Devices (Signs, Barrels and Barricades)

Figure 20 illustrates the percentages of drivers who rated all traffic control devices as adequate in terms of providing 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 percent. At nighttime, the array of devices with super-engineering grade sheeting was judged as adequate by 89 percent of the drivers compared to 80 percent 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 percent 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 percent for each of the three grades of sheeting tested.

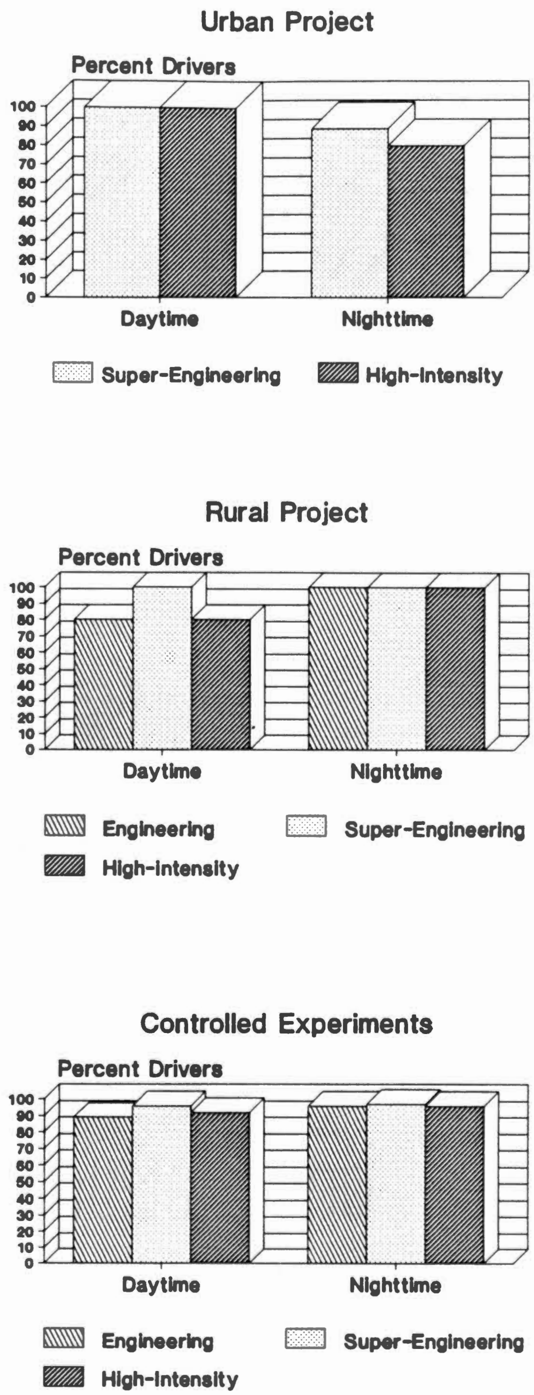


Figure 20. Overall Adequacy of the Entire Array of Devices

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 during daytime and nighttime conditions.

Other Comments

As mentioned earlier, the questionnaire had space for the drivers to provide any additional comments which they would like to share. The following are citations of the drivers' remarks.

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

- Barrels & barricades were excellent. Lettering on signs was blurry until we were almost on top of them.
- To get first attention, a blue light or strobe light will be helpful.

Rural Project, Engineering Grade Sheeting

Nighttime

- I think they were Ok.
- I believe the overall size of signs was a little small.

Rural Project, Engineering Grade Sheeting

Daytime

No comments received.

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 further 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

- Very good, easy to see and read.
- 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

- They were very good.
- 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 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.

Weatherometer Data

The ASTM minimum performance requirements for artificial weathering of the orange colored retroreflective sheetings are given in Table 5. 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 5. 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 6 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

TABLE 5

ASTM ARTIFICIAL WEATHERING REQUIREMENTS FOR ORANGE COLORED SHEETINGS [3]

Sheeting Type	Div angle / Incid angle	Minimum SIA of New Sheeting	Minimum SIA After Artificial Weathering		
			Hours Tested	Percent of Minimum SIA	Minimum SIA
Type I (E G.)	0.2° / -4°	25	1000	50%	12 5
	0 2° / +30°	7			3.5
Type II (S E G)	0.2° / -4°	60	500	65%	39 0
	0 2° / +30°	22			14 3
Type III[a] (H I G)	0 2° / -4°	100	500	80%	80.0
	0 2° / +30°	60			48 0
Type IV[b] (H I G)	0.2° / -4°	100	1500	80%	80 0
	0 2° / +30°	34			27.2

[a] Encapsulated glass-bead

[b] Unmetallized microprismatic retroreflective element material

TABLE 6

ARTIFICIAL WEATHERING TEST RESULTS, ORANGE COLORED SHEETINGS

Sheeting Type	Div angle/ Incid angle	Weatherometer Test Results SIA[a] Hours of Artificial Weathering 500	1000	2000	3000	4000	ASTM Requirements Testing Hours	Minimum SIA
H I G.	0 2°/-4°	121 0	86.77	74 93	45 84	---	500	80
	0 2°/+30°	109.2	73 54	66 63	34 38	---		48
E.G. (P.S.)	0 2°/-4°		44.00	47.27	47.04	49 58	1000	12.5
	0 2°/+30°		23.95	26 65	27.63	28.96		3.5
E G. (H A)	0 2°/-4°		40.52	46 10	45.81	46 80	1000	12 5
	0 2°/+30°		25.84	30 34	30.60	30 90		3.5
S E.G. (H A.)	0.2°/-4°	78.3	78 8				500	39
	0.2°/+30°	62 3						14.3

Remarks on Visual Appearance[a]

H I G.	Slight fading beginning 500 hours Steady fading through 3000 hours Failed required reflectance, testing stopped
E G (P S)	Definite darkening 1000 hours. Progressively darker dullish dark burnt orange at 4000 hours.
E G (H A)	Slight fading 1000 hours No change 4000 hours
S E G (H A)	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] 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

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.

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, 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 7 summarizes the use of retroreflective sheetings by Oklahoma contractors. Engineering grade sheeting has traditionally been used on traffic control devices by all 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.

TABLE 7

USE OF RETROREFLECTIVE SHEETINGS BY OKLAHOMA CONTRACTORS

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

Expected Service Life of Sheetings

Table 8 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.

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.

TABLE 8

EXPECTED SERVICE LIFE OF SHEETINGS ON DIFFERENT DEVICES

Contractor	Engineering Grade		Super-Engineering Grade		High-Intensity Grade	
	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

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

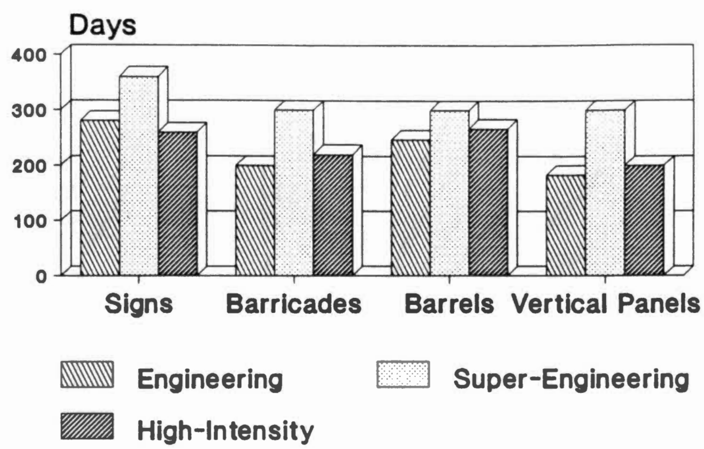
Device Knockdowns and Vandalism

Table 9 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 percent, respectively.

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

Deterioration Modes of Sheetings on Different Devices

Table 10 summarizes the deterioration modes of the three sheeting types when used on different traffic control



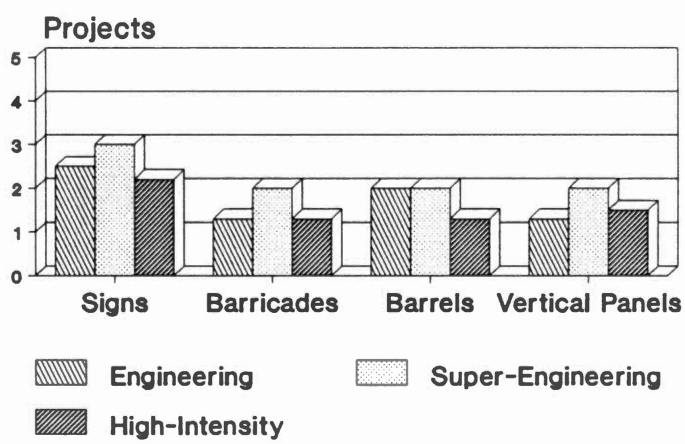


Figure 21. Expected Service Life of Sheetings on Different Traffic Control Devices

TABLE 9

DEVICE KNOCKDOWNS AND VANDALISM

Contractor	Signs	Barricades	Barrels	Vertical Panels
	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%

TABLE 10

DETERIORATION MODES OF SHEETINGS ON DIFFERENT DEVICES

Deterioration Modes	Contractor 1			Contractor 2			Contractor 3		
	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
Temp. 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
Temp 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						
Temp. 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									
Temp. 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 devices as reported by Oklahoma contractors. The most common deterioration modes are color fading, abrasion, peeling, and impact cracking.

Cost of Devices With Different Grades of Sheeting

Table 11 presents 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 percent 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

TABLE 11

COST OF DEVICES WITH DIFFERENT GRADES OF RETROREFLECTIVE SHEETING

	Cost Items[a]								
Contractor	Engineering Grade			Super-Engineering Grade			High-Intensity Grade		
	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 Vertical 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 (material plus fabrication),
B = Cost of entire control device excluding installation,
C = Cost of refurbishing the substrate and applying new sheeting.

b Dollars per panel

$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 percent 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 percent 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.

Problems Related to Fabrication and Handling

One question 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 contractor 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 reprinting a legend, smear marks cannot be completely removed. Problems with wrinkling and cracking were also noted when high-intensity grade sheeting is applied to traffic control devices.

Other Comments

In addition to the specific questions included in the contractors' survey, the questionnaire had space for the contractors to provide any comments 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.

<u>Contractor 2.</u> 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.

<u>Contractor-3.</u> No comments received.

Economic Analyses

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 attain the greatest end results per unit of resource input. 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 public projects is to compute the benefit-cost ratio. 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 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" [38]. 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 22 shows the cost per year as a function of the total cost of a 48 inch x 48 inch sign for the three sheeting types under consideration. Values of the initial luminance, L_n, and the terminal luminance, L_o, are assumed to be equal to those prescribed by the ASTM for new sheeting materials and after the prescribed number of hours of accelerated weathering. These values are shown in Table 5. For example, with high-intensity grade sheeting, the values of L_n and L_o are 100 and 80, respectively.

Figure 22 indicates that the high-intensity grade sheeting will have the least cost followed by super-engineering grade sheeting and then engineering grade sheeting. Equation (9) may be useful in the life-cycle cost analysis of the retroreflective sheetings on signs and devices other than those used at construction work zones. Application of equation (9) to work zone traffic control devices may lead to erroneous results. Therefore, the MOE given by equation (8) was used to evaluate the economics of the retroreflective sheetings in this study.

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

$$C_P = \frac{TC}{N_P} \qquad (10)$$

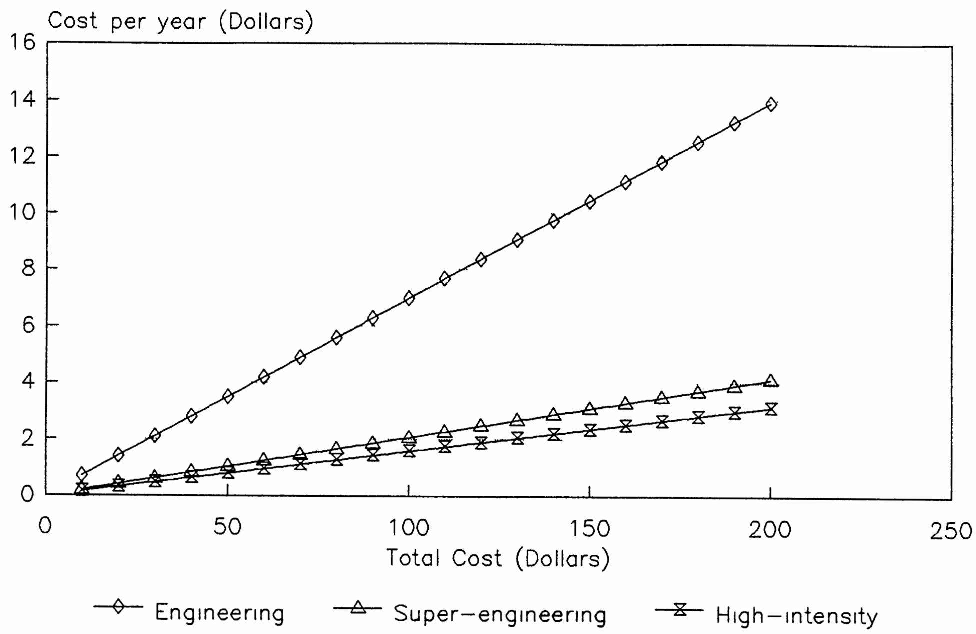


Figure 22. Cost Per Year as a Function of Total Cost of a 48 inch x 48 inch Sign

where

C_p = Cost per project of service life of device,

TC = total cost of the device excluding installation,

N_p = number of projects (on the average), the device can be used.

Table 12 presents the results of the economic analyses using the two MOEs, i.e., cost per year and cost per project.

The following paragraphs summarize the findings of the economic analyses.

Cost per Year

Signs. Based on the economic analysis results, the cost of signs with engineering grade, super-engineering grade, and high-intensity grade sheetings is $40.67, $43.80, and $112.08 per year, respectively.

Barricades. The cost of the entire barricade is $123.19, $64.48, and $237.80 per year with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Barrels. The entire 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. For the entire vertical panel, the cost is $8.14, $9.13, and $25.06 per year with engineering grade, super-engineering grade, and high-intensity grade

TABLE 12

RESULTS OF ECONOMIC ANALYSES

Sheeting Type	TC[a]	Expected Service Life		Measures of Effectiveness	
		N_Y years	N_P projects	Cost per year	Cost per project
SIGNS[b]					
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] Total cost of the entire device

[b] 48 inch x 48 inch sign

sheetings, respectively.

Cost per Project

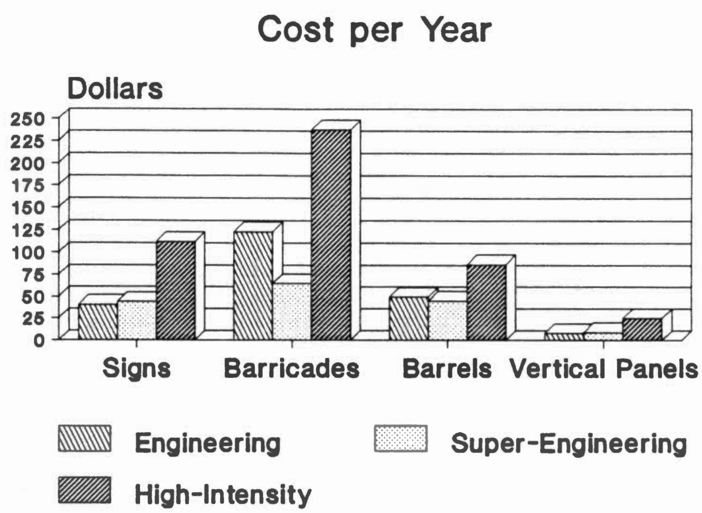
Signs. Results of the economic analysis show that the entire sign with engineering grade, super-engineering grade, and high-intensity grade sheetings costs $12.48, $14.40, and $36.29 per project, respectively.

Barricades. For the entire barricade, the cost is $51.92, $26.50, and $110.25 per project with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Barrels. Cost of the entire 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. The entire vertical panel costs $3.14, $3.75, and $9.15 per project with engineering grade, super-engineering grade, and high-intensity grade sheetings, respectively.

Figure 23 illustrates the cost per year and the cost per project of different traffic control devices with the three sheeting types used in this study.



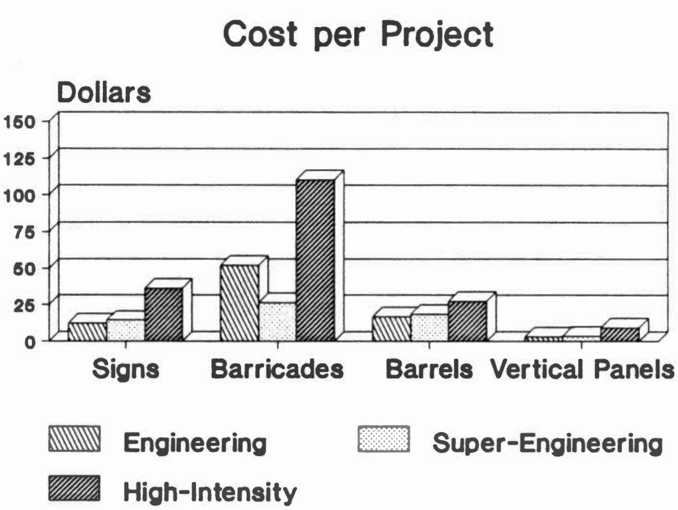


Figure 23. Cost Per Year and Cost Per Project of Different Traffic Control Devices With the Three Sheetings

CHAPTER V

FINDINGS AND CONCLUSIONS

This chapter summarizes and interprets the findings of the different analyses presented in Chapter IV. The chapter is divided as follows: interpretation and appraisal of results, conclusions, and recommendations for further research.

Interpretation and Appraisal of Results

Drivers' Visibility Requirements

As expected with any research effort involving human factors, some conflicting evidence was 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:

Rural Construction Project

Array Detection Distances (MDDs). There was no significant difference between the MDDs of devices with engineering grade, super-engineering grade, and high-intensity grade sheetings during daytime and nighttime conditions. Because of the unique vertical alignment problem associated with the rural highway, there was a large amount of variability in the detection distances. The geometric features of the roadway have made these results somewhat unreliable.

Signs. At nighttime, signs with super-engineering grade sheeting had greater mean recognition distance (MRD) than engineering grade and high-intensity grade sheetings and there was no significant difference between the MRDs of signs with engineering grade and high-intensity grade sheetings. However, in the controlled experiments, signs with super-engineering grade sheeting had the greatest MRD followed by high-intensity grade sheeting and engineering grade sheeting. The signs with super-engineering grade sheeting were clearly legible from long distances. The nighttime drivers noted glare problem with high-intensity grade sheeting which limited the legibility of signs.

During daytime conditions, there was no significant difference between the MRDs of signs with engineering grade and high-intensity grade sheetings, and both sheetings on signs had greater MRDs than super-engineering grade sheeting. However, in the controlled experiments, the MRDs of signs with super-engineering grade and high-intensity grade sheetings were not significantly different, and greater MRDs were recorded for signs with both sheetings compared to engineering grade sheeting. The variability in results may be attributed to the small sample size used in the rural real-world construction site and the differences in visual acuities of the drivers in that small sample.

Several drivers indicated that the size of letters used on word signs was somewhat small, which may have limited the recognition distances of these signs regardless of the type of sheeting used.

Barrels. There was no significant difference between the MRDs of all the sheetings when used on barrels during daytime and nighttime conditions. However, in the controlled experiments, the MRDs of barrels with super-engineering and high-intensity grade sheetings were not significantly different and both sheetings on barrels had greater MRDs than engineering grade sheeting during daytime and nighttime conditions.

Barricades. The MRDs of barricades with super-engineering grade and high-intensity grade sheetings were not significantly different and they were recognized from greater distances compared to barricades with engineering grade sheeting at nighttime. During daytime conditions, the MRDs of the three sheetings on barricades were not significantly different. However, in the controlled experiments, the MRDs of barricades with super-engineering and high-intensity grade sheetings were greater than that of engineering grade sheeting during daytime.

Urban Construction Project

Array Detection Distances. The high-intensity grade sheeting had a greater target value than super-engineering grade sheeting during daytime and nighttime conditions.

Signs. Based on the test results, signs with super-engineering grade sheeting had a greater MRD than high-intensity grade sheeting at nighttime. Nevertheless, during daytime conditions, the MRDs of both sheetings on signs were not significantly different.

Barrels. There was no significant difference between the MRDs of barrels with super-engineering grade and high-intensity grade sheetings during daytime and nighttime conditions.

Durability Evaluation

Based on weatherometer test results, all three grades of sheeting exceeded the ASTM requirements for the minimum SIA after the prescribed number of hours of artificial weathering.

Contractors' Survey

Results of the contractors' survey indicated that the expected service life of retroreflective sheeting used on traffic control devices at construction work zones is less than one year. The primary deterioration modes reported by the contractors were color fading, abrasion, peeling, and impact cracking. The engineering grade and super-engineering grade sheetings were characterized as more durable than high-intensity grade sheeting during handling and fabrication processes. The high-intensity grade sheeting was criticized as being difficult to work with and that it must be carefully packaged and transported to the job site before fabrication.

Economic Analysis

As described in Chapter IV, two measures of effectiveness (MOEs) were used in this study to evaluate the economy of the three sheeting grades. The MOEs were cost per year and cost per project. The following paragraphs summarize the findings of economic analyses.

Signs. Based on the economic analysis results, high-intensity grade sheeting was the most costly sheeting in terms of cost per year and cost per project. It was also found that the difference between costs of engineering grade and super-engineering grade sheetings was smaller than the difference in costs between super-engineering grade and high-intensity grade sheetings.

Barricades. The super-engineering grade sheeting was found to be the least costly sheeting followed by the engineering grade sheeting and high-intensity grade sheeting.

Barrels. The high-intensity grade sheeting was found to be the most costly sheeting. The costs of engineering grade and super-engineering grade sheetings were very close.

Vertical Panel. The cost of high-intensity grade sheeting was more than the other two sheeting types. The engineering grade and the super-engineering grade sheetings had nearly the same cost.

Conclusions

The basic question addressed in this study was: based on drivers' visibility requirements, durability and economics, and other practical considerations, which of the three grades of sheeting is adequate for use on traffic control devices at construction work zones? From the findings of the various analyses, the following conclusions were drawn.

Based on the statistical analysis results, the super-engineering grade sheeting performed better than the other two sheeting types on signs at highway construction work zones. It is not as reflective as high-intensity grade sheeting, but drivers felt comfortable driving through the construction work zone when super-engineering grade sheeting was used on signs. Super-engineering grade sheeting also solves the glare problem created by high-intensity grade sheeting.

Barrels and barricades with super-engineering grade sheeting performed as well as high-intensity grade sheeting. Engineering grade sheeting on these devices looked dull compared to the other two sheetings.

As far as durability is concerned, super-engineering grade sheeting is as durable as engineering grade sheeting during handling and fabrication processes. The contractors indicated that high-intensity grade sheeting is difficult to work with and that problems of wrinkling and cracking are associated with high-intensity grade sheeting. It has to be transported to job sites to keep it from tearing.

Based on the economic analysis, however, super-engineering grade sheeting is a little more costly than engineering grade sheeting, but its performance in highway construction work zones justifies its use on traffic control devices. High-intensity grade sheeting is the most costly sheeting among all other sheeting products and its performance is not as good as super-engineering grade sheeting, especially on signs.

Recommendations for Further Research

It is obvious from the statistical analysis and drivers' comments that the symbol signs performed better than the word signs. It is recommended that an effort should be made to replace word signs with symbol signs conveying the same message, e.g., replacing ROAD CONSTRUCTION AHEAD by a symbol sign displaying the same message. Since it is not possible to replace every word sign by a symbol sign, it is also recommended to increase the size of letters used on word signs.

Further research is recommended to conduct a study to evaluate the retroreflective sheetings on traffic control devices other than those used at highway construction work zones.

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APPENDICES

APPENDIX A

DRIVER BIOGRAPHICAL DATA

DRIVER BIBLOGRAPHICAL DATA SHEET

Driver Number _______ Date _______________________
Day/Night __________ 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
   4. 45-54
   5. 55-64
   6. 65 years or 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 miles
   2. 2000 to 4000
   3. 4001 to 6000
   4. 6001 - 8000
   5. 8001 - 10,000
   6. More than 10,000 miles

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 13

AGE DISTRIBUTION

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 14

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 15

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 16

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 17

MILES DRIVEN ANNUALY

	Percent of Drivers		
Number of Miles	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 18

WEAR EYEGLASSES

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

TABLE 19

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 20

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 _______ Date _________________________

Day/Night ___________ 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:
   1. Larger
   2. Smaller
   3. OK as is

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

   Brightness:
   1. Too Bright
   2. Not Bright Enough
   3. OK as is

   Color:
   1. Colors are OK
   2. Change Colors to ________________

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 21

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 E.G.	Daytime S E G.	Daytime H I G	Nighttime E G.	Nighttime S.E.G	Nighttime 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 22

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

TABLE 23

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 24

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

TABLE 25

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			Nighttime		
		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 26

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 27

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 28

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 <u>only</u> 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.
   Example: 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 <u>only</u> (material plus fabrication).
   B) Cost of entire control device excluding installation.
   C) Cost of refurbishing the substrate and applying new sheeting.

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

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

Question 8 (continued)

Control Device	High-Intensity Grade Sheeting 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?

<u>Engineering Grade</u>:

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

Question 10 (continued)

High-Intensity Grade:

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

APPENDIX D

DETECTION AND RECOGNITION DISTANCES

TABLE 29

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 30

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	251 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 31

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 32

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 1	76 9	3 0	40 1	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 = 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 33

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 34

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 35

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 36

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: $\mu_1 = \mu_2$ H_a: $\mu_1 > \mu_2$	**Hypothesis 2:** H_o: $\mu_1 = \mu_2$ H_a: $\mu_1 < \mu_2$
Hypothesis 3: H_o: $\mu_2 = \mu_3$ H_a: $\mu_2 > \mu_3$	**Hypothesis 4:** H_o: $\mu_2 = \mu_3$ H_a: $\mu_2 < \mu_3$
Hypothesis 5: H_o: $\mu_1 = \mu_3$ H_a: $\mu_1 > \mu_3$	**Hypothesis 6:** H_o: $\mu_1 = \mu_3$ H_a: $\mu_1 < \mu_3$
Hypothesis 7: H_o: $\mu_D = \mu_1 - \mu_2 = 0$ H_a: $\mu_D = \mu_1 - \mu_2 > 0$	**Hypothesis 8:** H_o: $\mu_D = \mu_1 - \mu_2 = 0$ H_a: $\mu_D = \mu_1 - \mu_2 < 0$
Hypothesis 9: H_o: $\mu_D = \mu_2 - \mu_3 = 0$ H_a: $\mu_D = \mu_2 - \mu_3 > 0$	**Hypothesis 10:** H_o: $\mu_D = \mu_2 - \mu_3 = 0$ H_a: $\mu_D = \mu_2 - \mu_3 < 0$
Hypothesis 11: H_o: $\mu_D = \mu_1 - \mu_3 = 0$ H_a: $\mu_D = \mu_1 - \mu_3 > 0$	**Hypothesis 12:** H_o: $\mu_D = \mu_1 - \mu_3 = 0$ H_a: $\mu_D = \mu_1 - \mu_3 < 0$
Hypothesis 13: H_o: $\mu_{S1} = \mu_{W1}$ H_a: $\mu_{S1} > \mu_{W1}$	**Hypothesis 14:** H_o: $\mu_{S1} = \mu_{W1}$ H_a: $\mu_{S1} < \mu_{W1}$
Hypothesis 15: H_o: $\mu_{S2} = \mu_{W2}$ H_a: $\mu_{S2} > \mu_{W2}$	**Hypothesis 16:** H_o: $\mu_{S2} = \mu_{W2}$ H_a: $\mu_{S2} < \mu_{W2}$
Hypothesis 17: H_o: $\mu_{S3} = \mu_{W3}$ H_a: $\mu_{S3} > \mu_{W3}$	**Hypothesis 18:** H_o: $\mu_{S3} = \mu_{W3}$ H_a: $\mu_{S3} < \mu_{W3}$

a See definitions of different symbols in page 154

TABLE 37

HYPOTHESIS TESTING RESULTS
URBAN PROJECT

Case No	Light Condition	Device	Attribute[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 155
c Level of Significance α = 5%
S E G. = Super-Engineering Grade, H I.G = High-Intensity Grade

TABLE 38

HYPOTHESIS TESTING RESULTS
RURAL PROJECT

Case No	Light Condition	Device	Attribute[a]	Hypothesis Tested[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 38 (continued)

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
39	Nighttime	Barrels	MRD	Hypothesis 5	MRDs of H I.G and E.G are not significantly different

TABLE 38 (continued)

Case No	Light Condition	Device	Attribute[a]	Hypothesis Tested [c]	Test Conclusion [b]
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 155
c Level of Significance α = 5%
E.G = Engineering Grade, S E G. = Super-Engineering Grade, H.I G = High-Intensity Grade

TABLE 39

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 39 (continued)

Case No.	Light Condition	Device	Attribute[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 155
c Level of Significance α = 5%
E G. = Engineering Grade, S E G. = Super-Engineering Grade, H I G. = High-Intensity Grade

TABLE 40

HYPOTHESIS TESTING RESULTS, WORD SIGNS VERSUS SYMBOL SIGNS

Case No	Light Condition	Device	Attribute[a]	Hypothesis Tested[c]	Test Conclusion[b]
			URBAN PROJECT		
1	Daytime	Signs (S.E G.)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs (H I G)	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Nighttime	Signs (S E.G.)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs (H I.G)	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
			RURAL PROJECT		
1	Daytime	Signs (E.G.)	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs (S E.G.)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Daytime	Signs (H.I.G.)	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs (E.G.)	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
5	Nighttime	Signs (S E.G.)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
6	Nighttime	Signs (H.I.G.)	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
			CONTROLLED EXPERIMENTS		
1	Daytime	Signs (E G.)	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
2	Daytime	Signs (S.E.G.)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
3	Daytime	Signs (H.I.G.)	MRD	Hypothesis 13	MRD of Symbol signs is significantly greater than MRD of Word signs
4	Nighttime	Signs (E.G.)	MRD	Hypothesis 17	MRD of Symbol signs is significantly greater than MRD of Word signs
5	Nighttime	Signs (S.E.G)	MRD	Hypothesis 15	MRD of Symbol signs is significantly greater than MRD of Word signs
6	Nighttime	Signs (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 155
c Level of Significance $\alpha = 5\%$
E G. = Engineering Grade, S.E.G = Super-Engineering Grade, H.I.G. = High-Intensity Grade

TABLE 41

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 155
c Level of Significance $\alpha = 5\%$
E.G = Engineering Grade, S.E.G = Super-Engineering Grade, H I G = High-Intensity Grade

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