EVALUATION OF RETROREFLECTIVE SHEETINGS FOR USE ON ROADWAY TRAFFIC SIGNS

Final Report

by

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16. ABSTRACT

The primary objectives of this research were to evaluate the ODOT's policy on use of retroreflective sheeting products, and to identify any necessary changes to this policy based on driver visibility needs, durability of sheeting materials, life-cycle cost, and other practical considerations. The scope of the study included three types of retroreflective sheetings (engineering grade, super-engineering grade, and encapsulated-lens high-intensity sheeting), five sheeting colors (white, red, yellow, green, and blue), and two sign fabrication methods (screening and overlay). To meet the objectives of this project, a research plan consisting of literature review, controlled field experiments, survey of ODOT field divisions, durability data collection and analysis, and life-cycle cost analysis was adopted.

The findings of this study suggest that the specification of type III-A (high-intensity, encapsulated glass-bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways is sound and defensible. The requirement that type II-A (super-engineering grade sheeting) be used on all other traffic signs, except orange colored signs, needs to be examined. Although the initial cost of sign face fabrication for type-IIIA sheeting is 25% to 65% higher than that of type-IIA, life-cycle cost analysis indicates that type-IIIA is more cost-effective than type-IIA. Evidence from visibility distance analyses and subjective evaluations made by the test subjects suggests that, in addition to upgrading sign materials to provide greater luminance, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

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NOTICE

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EXECUTIVE SUMMARY

In 1991, the Oklahoma Department of Transportation (ODOT) adopted a policy which requires the use of type III-A (high-intensity, encapsulated glass-bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways. Further, the policy calls for using type II-A (super-engineering grade sheeting) on all other signs. Although this policy is well in agreement with the move by many transportation agencies toward increasing sign brightness, there have been concerns about the limited performance data upon which the policy was based.

The primary objectives of this research were to evaluate the ODOT's policy on use of retroreflective sheeting products, and to identify any necessary changes to this policy based on driver visibility needs, durability of sheeting materials, life-cycle cost, and other practical considerations. The scope of the study included three types of retroreflective sheetings (engineering grade, super-engineering grade, and encapsulated-lens high-intensity sheeting), five sheeting colors (white, red, yellow, green, and blue), and two sign fabrication methods (screening and overlay).

To meet the objectives of this project, a research plan consisting of literature review, controlled field experiments, survey of ODOT field divisions, durability data collection and analysis, and life-cycle cost analysis was adopted. Two field experiments were conducted at a rural site and an urban site to obtain measurements of sign detection and recognition distances at night under automobile low-beam illumination. The first experiment involved a total of nine signs: three sign types (stop, speed limit, and merge symbol) × three sheeting types (II, IIA, and IIIA). In the second experiment, a total of twelve signs were used: two sign types (exit and rest area) × six combinations of sheeting types. Signs used in the first experiment were made using the screening method, whereas those used in the second experiment were made using the overlay method. A total of 120 paid test subjects participated in the experiments. The experimental program was planned based on the principles of statistical experimental design.

Results of the field experiments and visibility distance analyses suggest the following:

- *White-on-Red, Black-on-White, and Black-on-Yellow Signs*: Overall, signs with type-IIIA sheeting had significantly greater target value, in terms of mean detection distance under automobile low-beam illumination at night, than signs with type-IIA or type-II sheeting materials. In terms of sign legibility, there was no statistically significant difference between the mean recognition distances of types II, IIA, and IIIA sheeting materials, when new. Therefore, materials should be specified based on life-cycle cost, durability, and the need for added conspicuity. These conclusions were reached at both urban and rural environments.

- *White-on-Green and White-on-Blue Signs*: Of the six sheeting combinations included in this study, signs with type-II sheeting on the background showed the lowest target value in terms of mean detection distance under automobile low-beam illumination at night. There was no statistically significant difference between the mean detection distances of type-IIIA legend on type-IIIA background, type-IIIA legend on type-IIA background, and type-IIA legend on type-IIA background. With respect to sign legibility, there was no significant difference between the mean recognition distances of type-IIIA legend on type-IIIA background, type-IIIA legend on type-IIA background, and type-IIA legend on type-IIA background. These conclusions were reached at both urban and rural environments.

- Brightness is just one of several factors that influence sign legibility and conspicuity. Evidence from visibility distance analyses and subjective evaluations made by the test subjects indicates that, even with new sheeting materials, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

The measures of effectiveness (MOEs) used in the life-cycle cost analysis were the ratio of total cost to service life, and the equivalent uniform annual cost (EUAC). Average service lives of 7, 12, and 15 years were assumed for sheeting types II, IIA, and IIIA, respectively, based on data obtained from ODOT field divisions, sheeting manufacturers, and the published literature. The EUAC computations were made using a 7-year analysis period (shortest service life among alternatives). Results of the life-cycle cost analysis indicate that type-IIIA has the least ratio of total cost to service life and the least EUAC, followed by type-IIA, and type-II retroreflective sheeting materials. This conclusion was reached for new signs as well as refurbished signs.

To allow for any uncertainty in estimating service lives, sensitivity analyses were performed to explore the effect of changes in the service lives of types IIA and IIIA sheeting materials on the MOEs. These analyses supplemented the results obtained using point estimates of service lives. The service life of type-II sheeting was held constant at 7 years as a base condition for comparison purposes. Sensitivity analysis results suggest that type-IIIA sheeting is preferred if it were to outlast type-IIA sheeting by one year or more. Furthermore, both types IIIA and IIA sheeting materials have less EUAC than type-II sheeting for the ranges of service lives used in the analysis.

Based on a survey of ODOT field divisions and the literature review, the typical in-service deterioration modes experienced by retroreflective sheeting materials are loss of retroreflectivity, color fading, cracking, abrasion, peeling, and dirt accumulation. Cracking appears to be more prevalent in type-II than type-IIIA sheeting materials. Peeling was observed in type-IIIA sheeting, particularly at bends on the sign face and dents at the mounting bolts. Deterioration modes of type-IIA are not well documented because it has not been in service long enough.

Unpublished results of five-year, accelerated outdoor exposure at 45° facing south were obtained from the FHWA Photometric and Visibility Laboratory at Turner-Fairbank Highway Research Center. The results covered a five-year period (1989 through 1993) which is equivalent to approximately 10 years of normal outdoor weathering. On the basis of these results, the following observations were made at concerning the coefficient of retroreflectivity (R_A) at the end of five years of accelerated weathering:

- *White color* - All sheeting materials exceeded the minimum required R_A values established by the FHWA for ground mounted black-on-white regulatory and guide signs. Furthermore, the R_A of type-IIIA sheeting was about 2.3 times higher than the R_A of type-IIA and 3.5 times higher than the R_A of type-II sheeting materials.

- *Red color* - The R_A of type-IIIA sheeting was about 2.0 times higher than the R_A of type-IIA and 2.3 times higher than the R_A of type-II sheeting materials. All three sheeting materials, exceeded the minimum required R_A values for the red background of white-on-red regulatory signs. Nevertheless, sheeting types II and IIA failed to maintain the minimum contrast ratio of 4:1 between the white and red colors.

- *Yellow color* - All sheeting materials exceeded the minimum required R_A values for black-on-yellow warning signs. Furthermore, the R_A of type-IIIA sheeting was about 2.5 times higher than the R_A of type-IIA and 3.0 times higher than the R_A of type-II sheeting materials.

- *Green color* - The R_A of type-IIIA sheeting was about 2.2 times higher than the R_A of type-IIA and 4.5 times higher than the R_A of type-II sheeting materials. All sheeting materials exceeded the minimum required R_A values for the green background of ground-mounted guide signs as well as the minimum contrast ratio of 4:1 between the white legend and green background. For overhead guide signs, type-II sheeting failed to meet the minimum required R_A value for the green background, and type-IIA appeared to be marginal.

- *Blue color* - The R_A of type-IIIA sheeting was about 3.5 times higher than the R_A of type-IIA and 5.4 times higher than the R_A of type-II sheeting materials. There are no minimum R_A requirements for blue color signs.

On the basis of the findings of this study, the following recommendations are made concerning the current ODOT policy on retroreflective sheetings:

- The specification of type III-A (high-intensity, encapsulated glass-bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways is sound and defensible.

- The requirement that type II-A (super-engineering grade sheeting) be used on all other traffic signs needs to be examined. Although the initial cost of sign face fabrication (sheeting material, aluminum substrate, equipment, labor, and overhead) for type-IIIA sheeting is 25% to 65% higher than that of type-IIA, life-cycle cost analysis indicates that type-IIIA is more cost-effective than type-IIA.

- Evidence from visibility distance analyses and subjective evaluations made by the test subjects suggests that, in addition to upgrading sign materials to provide greater luminance, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

- The findings of this study should not be generalized to sheeting types that were not included in the evaluation.

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CHAPTER 1

INTRODUCTION

PROBLEM STATEMENT

Nighttime visibility of traffic signs is usually accomplished through the use of retroreflective sheetings on the sign face. When illuminated by the vehicle's headlamps, signs appear bright in proportion to their ability to reflect the incident illumination back toward the driver. At present, there are at least six manufacturers of retroreflective sheeting products which are marketed under the generic names of engineering grade, super-engineering grade, high-intensity sheeting (encapsulated glass-bead or micro-prismatic element material), and super-high intensity sheeting.

Over time, traffic signs experience deterioration of the retroreflective sheeting due to the effects of numerous environmental and climatic factors. This progressive loss of retroreflectivity gradually reduces the sign's visibility and legibility to the point that the intended information may no longer be perceived early enough to complete the required response safely. Recently, the FHWA established minimum retroreflectivity standards for in-service traffic signs based on driver visibility needs. It is expected that these standards will be included in the 1996 edition of the MUTCD. When a sign fails to supply the prescribed minimum retroreflectivity, the sign face should be replaced or refurbished. Other reasons for traffic sign replacement or refurbishment include vandalism, theft, accidental knockdown by vehicles, and metrication.

Perhaps one of the important questions that transportation agencies must address is what type of retroreflective sheeting to specify for use on different traffic signs (regulatory, warning, guidance, and motorist information). While national specifications such as the FP-85 or ASTM D-4956 set minimum retroreflectivity requirements for new sheeting materials, these specifications are merely purchase standards and they have little or no implications as to the in-service performance. In addition, the artificial weathering tests which have been widely used for acceptance purposes appear to be of very limited significance in predicting the durability of retroreflective sheetings.

In 1991, the Oklahoma Department of Transportation (ODOT) adopted a policy which requires the use of type III-A (high-intensity, encapsulated glass-bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways. Further, the policy calls for using type II-A (super-engineering grade sheeting) on all other signs. Although this policy is well in agreement with the move by many transportation agencies toward increasing sign brightness, there have been concerns about the limited performance data upon which the policy was based. Key among the factors that should be considered in developing defensible retroreflective sheeting specifications are driver visibility needs, durability, and life-cycle cost.

OBJECTIVES AND SCOPE

The primary objectives of this research were to evaluate the ODOT's policy on use of retroreflective sheeting products, and to identify any necessary changes to this policy based on driver visibility needs, durability of sheeting materials, life-cycle cost, and other practical considerations.

The scope of the study included three types of retroreflective sheetings (engineering grade, super-engineering grade, and encapsulated-lens high-intensity sheeting), five sheeting colors (white, red, yellow, green, and blue), and two sign fabrication methods (screening and overlay).

RESEARCH APPROACH

To meet the objectives of this project, a research plan consisting of six major tasks was adopted. These tasks are described as follows:

Task* 1. *Literature Review - Review, evaluate, and document available literature on: 1) in-service performance of retroreflective sheeting products, 2) national and local practices concerning the use of sheeting materials, and 3) the recent results of the FHWA retroreflectivity research program (minimum retroreflectivity requirements, service life of sheeting materials, economic assessment of implementing minimum retroreflectivity standards, and sign management systems).

Task* 2. *Controlled Field Experiments - Conduct controlled experiments at a rural site and an urban site to obtain measurements of sign detection and recognition distances at night under automobile low-beam illumination. All experiments were planned based on the principles of statistical experimental design. The rural experiments were performed on a 4,800 ft long, 150 ft wide unused runway at the Stillwater Municipal Airport, whereas a straight segment of a two-lane access roadway (2,200 ft long and 22 ft wide) near the airport served as the test grounds for the urban experiments. This segment of the roadway was closed to traffic during the experiments.

Two experiments were performed at each site. The first experiment involved a total of nine signs: three sign types (stop sign, speed limit sign, and merge symbol sign) × three retroreflective sheeting types (engineering grade, super-engineering grade, and encapsulated-lens high-intensity sheeting). In the second experiment, a total of twelve signs were used: two sign types (exit sign and rest area sign) × six combinations of sheeting types. Signs used in the first experiment were made using the screening method, whereas those used in the second experiment were made using the overlay method. All signs were fabricated by the ODOT Sign Shop.

Four samples, each consisting of 30 paid test subjects, were selected from a large pool of licensed drivers who expressed interest in participating in a 'traffic sign study'. Stratified random sampling was used to select each sample of 30 subjects so that their age and sex distributions closely matched those of the population of drivers in Oklahoma.

A videotape presentation was used to explain the test procedure to each test subject upon arrival to the test site. Next, each subject viewed the traffic signs while setting in a test vehicle under low-beam illumination. Detection and recognition distances of each sign were recorded by an experimenter. The order in which the signs were viewed by the test subjects was randomized so that each subject viewed the signs in a unique sequence. Randomization was a two-step process; sign types were randomly assigned to the test subjects, and then sheeting types were randomly assigned to the signs. After viewing each sign type (e.g., three stop signs made of different sheeting materials), each subject completed a questionnaire form concerning the adequacy of these particular signs.

Task* 3. *Analysis of Visibility Distances - Analysis of variance procedures for a two-factor split-plot design were applied to the visibility distances obtained in Task 2 to test hypotheses concerning the mean detection distances and mean recognition distances of each traffic sign with different sheeting materials. This was followed by pairwise comparisons of treatment means using the Newman-Keuls' test to delineate any significant differences among treatment means. Further, the visibility distances obtained from the field experiments were compared against the minimum required distances obtained from the MRVD microcomputer program.

Task 4. Survey of ODOT Divisions - A questionnaire survey was developed to gather data from the ODOT field divisions on: 1) average service life and deterioration modes of the different sheeting materials, and 2) sign installation cost (excluding sign face fabrication cost). In addition, the survey instrument included questions concerning sign population, use of different types of retroreflective sheetings, sign replacement and maintenance practices (performance review process, reasons for replacement, and annual cost), and existence and format of sign inventory. The scope of the survey was limited to traffic signs which are under ODOT's control.

Task 5. Durability Data Collection and Analysis - Data on average service life and typical deterioration modes of the different sheeting materials were obtained from the results of Task 4 and were supplemented by the findings of recently completed research projects on the subject. Results of accelerated outdoor exposure of the sheeting materials at 45° angle from the horizontal and facing the equator per ASTM G7 were obtained from the FHWA photometric and visibility laboratory.

Task 6. Life-Cycle Cost Analysis - Perform life-cycle cost analysis for the different sheeting materials included in the study. Two measures of effectiveness were used: 1) the equivalent uniform annual cost, and 2) the ratio of total cost to service life. Data on sign face fabrication cost (sheeting material, aluminum substrate, equipment, labor, and overhead) were obtained from the ODOT Sign Shop. Sign installation cost data (sign supports, fasteners, footings, equipment, labor, travel, and overhead) were obtained from the ODOT Divisions using the survey instrument of Task 4.

OVERVIEW OF NEXT CHAPTERS

Chapter 2 presents background material on retroreflective sheeting typology and measures of performance, sign detection and recognition, and the recent results of the FHWA retroreflectivity research program. Details of the research methodology including statistical experimental design are described in Chapter 3. Chapter 4 summarizes the results of the analysis of visibility distances obtained from the field experiments. Durability and service lives of the sheeting materials are addressed in Chapter 5. In Chapter 6, life-cycle cost analysis procedures and results are discussed. Finally, Chapter 7 presents an appraisal of the research findings and the conclusions and recommendations of this study.

The material presented in Chapters 3 through 6 is supplemented by Appendices A through G. Appendix A includes the findings of the ODOT divisions survey. Results of the analysis of variance and the pairwise comparisons are given in Appendices B and C, respectively. The minimum required visibility distances are listed in Appendix D. Appendix E includes biographical data of the test subjects. Appendices F and G provide summary of the sign/sheeting evaluations made by the test subjects.

CHAPTER 2

BACKGROUND

This chapter provides background information on the typology and performance measures of retroreflective sheeting materials, the visual processes involved in sign detection and recognition, and the results of recently completed research projects on minimum retroreflectivity requirements, service life of sheeting materials, economic assessment of implementing minimum retroreflectivity standards, and sign management systems.

RETROREFLECTIVE SHEETINGS

Retroreflective sheeting materials are the most commonly used means of making traffic signs visible to drivers at night. A retroreflective sheeting is thin flexible sheet preassembled of retroreflective elements (micro cube-corners or spheres) enclosed in a weather resistant transparent plastic film. The back of a sheeting has a layer of adhesive and a protective liner that is removed when the sheeting is applied to the sign panel. Sign face fabrication is usually done using one of two methods: silk screening and overlay. In the screening method, the message and borders (called copy) are printed on the sheeting using either a direct or reverse screen process. Direct screening involves applying the process color through the copy portions of the screen onto the sheeting. Typical of this method is the application of black, opaque ink onto white sheeting for regulatory signs. In reverse screening, the process color is applied through the background allowing the base sheeting to provide the message. For example, a stop sign is made by applying red, transparent ink onto white sheeting. Manufacturer's recommendations concerning inks must be followed because using the wrong ink can result in early failure of the sign. The second method, overlay fabrication, involves applying retroreflective cut-out letters or shapes to a background retroreflective sheetings. The letters or shapes may be purchased precut from suppliers or cut in-house using a CAD system.

When illuminated by vehicle's headlamps, traffic signs appear bright in proportion to their ability to reflect the incident illumination back toward the driver. Luminance, expressed as candelas per square meter (cd/m^2), is used to quantify the amount of light that is redirected by the sign. The measure of retroreflection is the *coefficient of retroreflection* (R_A) which is defined as the ratio of the luminance of the sign surface viewed from a particular direction, to the illuminance at that sign on a plane perpendicular to the direction of the incident light In the English system of units, R_A has units of candelas per foot-candle per square feet and is referred to as *specific intensity per unit area* (*SIA*). The metric units of R_A are candelas per lux per square meter ($cd/lx/m^2$). No conversion is required from one system of units to the other, i.e., the conversion factor equals one.

There are three generic types of retroreflective sheeting materials available from different manufacturers: *engineering grade* (EG), *super-engineering grade* (SEG), and *high intensity* (HI). Both EG and SEG sheetings are of the *enclosed lens type*, a layer of transparent plastic in which glass beads are imbedded, with the main distinction between the two being a higher quality glass beads in manufacturing the SEG. A reflecting surface is placed at the focal point behind the plastic to reflect the light back through the beads. The plastic covering enables the sheeting to be equally bright under dry and wet weather conditions.

Unlike EG and SEG, high intensity sheeting is of the *encapsulated lens type*. The glass beads are protected by a transparent film that is sealed in a mesh pattern and is supported slightly above the beads by walls leaving an air filled compartment. The back of the beads is covered with a reflective surface. The resulting airspace in front of the beads makes it more reflective. Microprismatic reflectors are sometimes used instead of the glass beads

The R_A of a retroreflective sheeting material depends on the entrance angle of the incident light and the observation angle of the driver. The entrance angle is the angle formed between the incident light path and a reference axis perpendicular to the sign surface. For laboratory testing purposes, the observation angle is measured at the sign surface between the paths of the incident light from the light source (illumination axis) and the reflected light to the receiver (observation axis). In an actual roadway driving situation, there are two different observation angles formed by each of the vehicle's headlamps. Since the driver's eye setback relative to each headlamp is fixed, the observation angles increase as the driver approaches the sign. For most retroreflective sheetings, the change in R_A is not significant for entrance angles less than 30°, which is considered wide angle for highway signing. Unlike the effect of the entrance angle, even the slightest change in the observation angle can have significant effects on R_A. A computer program that calculates the observation angles of traffic signs as seen by approaching drivers was developed by Uding [20].

For the purpose of grouping available products, the types and properties of retroreflective sheetings are presented in four national specifications:

- FP-85: Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects;
- L-S-300C: General Services Administration Specification;
- AASHTO M-268: Retroreflective Sheeting for Traffic Control; and
- ASTM D-4956: Reflective Sheeting Standards.

Table 1 presents the retroreflective sheeting classifications employed in these specifications. Minimum R_A values are prescribed in each specification for each sheeting type, two observation angles, two entrance angles, and seven colors (white, red, orange, yellow, green, blue, and brown). The two observation angles are +0.2° and +0.5° corresponding to viewing distances of 500 ft and 200 ft, respectively, assuming that the driver's eye height is 21 inches above the vehicle headlight. The two entrance angles are -4° and +30°. The +30° is considered to be the widest angle between the driver and any sign that have to be seen, whereas the -4° is intended for signs placed close to the roadway edge and oriented away from the perpendicular to avoid specular reflection.

The minimum R_A standards prescribed by the national specifications are shown in Table 2. It should be noted that these standards are used in connection with purchasing new sheeting materials. Moreover, the standards do not apply to reverse screened colors. For example, the FP-85 standard for red sheeting does not apply to a sign with red background when the red color is reverse-screened onto a white sheeting.

SIGN DETECTION & RECOGNITION

The process of obtaining information from a sign in the roadway environment begins with the sensory detection, that is, seeing the sign panel as a separate target although not recognizing or perceiving it as such, and continues to recognition of the sign legend when it becomes legible. Sign

Table 1. Retroreflective Sheeting Classifications

Specification	Engineering Grade	Super Engineering Grade	High Intensity Grade	Super High Intensity Grade
FP-85	Type II	Type IIA	Types IIIA, B, C[b]	ns[a]
ASTM D-4956	Type I	Type II	Types III, IV[c]	Type VII[d]
L-S-300C	Reflectivity 1	ns[a]	Reflectivities 2, 4	ns[a]
AASHTO M-268	Class II	ns[a]	Classes IIA, B	ns[a]

a) ns: not specified.

b) Type IIIA: High intensity sheeting, encapsulated glass beads.
Type IIIB: High intensity sheeting, encapsulated prismatic reflectors.
Type IIIC: High intensity sheeting, encapsulated prismatic reflectors.

c) Type III: High intensity sheeting, encapsulated glass bead or prismatic reflectors.
Type IV: High intensity sheeting, non-metallized micro-prismatic reflectors.

d) Type VII: Proposed -- Super high intensity sheeting, non-metallized micro-prismatic reflectors.

Table 2. Retroreflective Sheeting Specifications[a]

Sheeting Color	L-S-300C			AASHTO			FP-85			ASTM			
	EG	SEG	HI	EG	SEG	HI[c]	EG	SEG	HI[d]	EG	SEG	HI (III)	HI (IV)
White	80	ns[b]	250	70	ns	250	70	140	250	70	140	250	250
Red	18	ns	45	14.5	ns	45	14.5	30	45	14	30	45	35
Orange	30	ns	100	25	ns	100	25	60	100	25	60	100	100
Yellow	50	ns	170	50	ns	170	50	100	170	50	100	170	170
Green	12	ns	45	9	ns	45	9	30	45	9	30	45	35
Blue	6	ns	20	4	ns	20	4	10	20	4	10	20	20
Brown	25	ns	ns	1	ns	ns	2	5	ns	1	5	ns	7

a) $cd/1x/m^2$.

b) ns: not specified.

c) Applies to both types IIIA & IIIB.

d) Applies to types IIIA, IIIB, & IIIC.

detection is characterized by progressive differentiation of the visual field as the driver moves closer to the sign. The sensory detection threshold of a sign is generally taken as the minimum external contrast necessary for the driver to become aware that something is present. External contrast is the ratio between the luminance of sign-panel's edge divided by the luminance of the background environment. Perhaps, if the contrast ratio is close to one, the driver would not be able to detect the sign.

The likelihood of detecting a traffic sign in the presence of other competing targets (e.g., light sources, billboards, commercial signs, etc.) depends on its conspicuity, that is, how it stands out compared to its visual surroundings. Sign conspicuity is a function of its luminance, size, color, and shape; external contrast; viewing or observation time; angle of eccentricity; as well as the number, size, similarity, proximity and the relative position of other nearby visual targets in the surround.

After a sign has been detected, successive levels of identification and recognition take place where various perceptual qualities about the sign become apparent, such as its specific location in space, its general shape and color, and message. Legibility is the end point of the recognition continuum when the driver can read a text message or accurately identify a symbolic message.

Sign recognition depends on the luminance and internal contrast of the sign; the critical detail of the legend; and the presence of glare from opposing headlights and other light sources. Internal contrast is defined as the ratio between the luminance of the sign legend and the luminance of the sign panel. The critical detail of the legend is the smallest part of that legend which must be discerned for recognition to occur. Knowledge of the critical detail for a sign legend coupled with an individual's visual acuity enables fairly accurate estimates of the legibility distance for that sign. For text messages, the critical detail is defined in terms of the stroke width of the letters. Because there is no consistent aspect of symbolic legends, the critical detail is estimated analytically or determined empirically [14].

THE FHWA RETROREFLECTIVITY RESEARCH PROGRAM

In the late 1980's, the FHWA initiated a comprehensive research program to address the retroreflectivity issues of in-service traffic signs and markings. The objectives of this program were to provide the information required to support decisions for national policy on minimum retroreflectivity requirements, and to develop management programs and measurement devices that will be needed by the states and others to implement the guidelines. Studies in this cooperative program were categorized into five topics: (1) service life of retroreflective traffic signs, (2) minimum retroreflectivity requirements, (3) economic assessment of strategies for implementing sign retroreflectivity standards, (4) mobile systems for measuring retroreflectivity of traffic signs and pavement marking, and (5) sign management systems. The following sections provide a brief summary of the results of these studies.

Service Life of Retroreflective Sheetings

As they age, traffic signs experience deterioration of the retroreflective sheeting from the effects of sunlight, weather, airborne abrasive particles, and air pollution. The ability to predict the R_A of in-service signs is essential to implementing a cost-effective sign management system. To that end, the FHWA undertook a national data collection effort of in-service sign sheeting retroreflectivity.

The objective was to identify those factors which contribute to the deterioration of R_A and to develop mathematical equations that can be used to predict the in-service R_A and/or contrast ratios [2]. Four sheeting colors (red, yellow, green, and white) and two sheeting types (engineering grade, and high-intensity type-IIIA) were surveyed using a total of 6,275 traffic signs at 18 sites throughout the United States. The signs ranged from 1 to 12 years in age.

Table 3 summarizes the nine regression equations developed by Bellomo-McGee, Inc., to predict the in-service R_A and contrast ratios. The explanatory variables employed by these models include sheeting age, precipitation level, ground elevation, and heating degree-days. Unlike white, yellow, and green colored sheetings which experience consistent decrease in R_A with age, the R_A of red colored, high intensity sheeting was found to increase over time as exhibited by the positive coefficient of the age variable in equation 3. Red colored sheeting, as used on 'stop' and 'yield' signs, is typically manufactured by screening red ink over white retroreflective sheeting. Over time, the red ink fades and more of the white becomes exposed, causing an increase in R_A of the sign background and a decrease in the internal contrast between the legend and background R_A. With red and white engineering grade sheetings, the deterioration rates of both colors were found to be similar, therefore, little variation in the contrast ratio was observed. The contrast between the sign background and legend R_A has a major impact on the overall sign legibility. A legend/background contrast ratio of 5:1 was suggested by Forbes for increased legibility distance [5]. Other studies recommended contrast ratios in the range of 8:1 to 12:1 for optimum legibility [2, 13]. Because of the problem of the red color fade, equation 10 was developed to predict the in-service contrast ratio of red and white signs with high intensity sheetings, ages 5 to 12 years. For red and white signs with engineering grade sheeting, the contrast ratio can be estimated by combining the results of equations 1 and 6.

The coefficient of determination, R^2, listed in the last column of Table 3, represents the fraction of the total variation in the R_A measurements that is explained by the respective regression equation. As seen, the predictive equations failed to explain most of the variation in R_A measurements. The reasons for this poor precision of the developed models are discussed in Chapter 7 "Durability Considerations".

Minimum Retroreflectivity Requirements

Establishing minimum R_A standards for in-service traffic signs is central to managing sign replacement and maintenance programs. Currently, the Manual on Uniform Traffic Control Devices (MUTCD) is lacking objective measures that can be used to determine if a sign should be replaced because of inadequate nighttime visibility. To address these issues, a 1987 contract study was initiated by the FHWA to determine: (a) the minimum distances at which traffic control devices should be visible to the driver, and (b) the level of retroreflectivity that is necessary to satisfy these requirements. A computer program called CARTS (an acronym for Computer Analysis of Retroreflectorized Traffic Signs) was developed for this purpose. The CARTS program consists of three models: the Minimum Required Visibility Distance (MRVD) model; the Inverse-Programmed Detect (IPDET) model; and the Standardized Retroreflectivity Measurement (SRM) model.

The MRVD model computes the minimum distance at which a sign must be visible to enable drivers of varying capabilities to detect the sign, recognize the message, decide on the proper course of action, and complete the required maneuver, if any. It is based on the concept of decision sight distance, supplemented by controlled field experiments as well as engineering judgment. Traffic signs

Table 3. Regression Equations for Predicting R_A and Contrast Ratios

Case No.	Sheeting			Regression Equation[d]	Adjusted R^2
	Color	Type[b]	Age Category[c]		
1	Red	II	All	$\hat{R}_A = 21.466 - 1.269x_1 - 0.0004x_2 + 0.124x_3 + 0.0003x_4$	0.210
2	Red	III-A	1, 3	$\hat{R}_A = 38.970 - 3.574x_1 + 0.0001x_2 + 0.240x_3 + 0.001x_4$	0.216
3	Red	III-A	5, 7, 9, 11	$\hat{R}_A = 19.765 + 2.496x_1 + 0.00003x_2 + 0.067x_3 + 0.0001x_4$	0.129
4	Yellow	II	All	$\hat{R}_A = 78.794 - 3.906x_1 + 0.002x_2 + 0.115x_3 + 0.002x_4$	0.389
5	Yellow	III-A	All	$\hat{R}_A = 247.850 - 4.578x_1 - 0.001x_2 + 0.174x_3 + 0.002x_4$	0.309
6	White	II	All	$\hat{R}_A = 103.085 - 5.451x_1 + 0.002x_2 + 0.178x_3 + 0.002x_4$	0.519
7	White	III-A	All	$\hat{R}_A = 304.089 - 4.815x_1 + 0.002x_2 + 0.06x_3 + 0.001x_4$	0.187
8	Green	II	All	$\hat{R}_A = 15.990 - 0.637x_1 + 0.0003x_2 - 0.036x_3 + 0.0001x_4$	0.311
9	Green	III-A	All	$\hat{R}_A = 53.386 - 1.345x_1 - 0.002x_2 + 0.337x_3 + 0.003x_4$	0.479
10	White/Red[a]	III-A	5, 7, 9, 11	$\hat{CR} = 12.700 - 0.682x_1$	0.156

a Legend/background.

b FP-85 retroreflective sheeting typology.

c There are six age categories (1, 3, 5, 7, 9 & 11), each representing a 2-year time period (for example, age category 5 indicates in-service ages of 5 and 6 years).

d The equations do not apply for sheeting age = 0. The following notation is used:

$\hat{R}_A$ = predicted mean value of in-service coefficient of retroreflection;

CR = predicted mean value of in-service contrast ratio (legend/background) for white on red signs with high intensity sheeting, ages 5 to 12 years;

x_1 = age in years;

x_2 = heating degree-days;

x_3 = precipitation, inches;

x_4 = ground elevation, ft.

listed in the MUTCD are grouped into three classes depending on those components of decision sight distance which apply to a given sign. This classification system is embodied in the sign dictionary of the CARTS program.

Having determined the minimum visibility distance from the MRVD model, the required sign retroreflectivity is computed using the IPDET model. This is a complex process that involves many factors including driver characteristics, vehicle headlight characteristics, sign size and placement, roadway geometry, traffic volume and speed, and the presence of glare from opposing vehicles. IPDET is based on the human visual performance model published by the International Commission on Illumination [7].

As discussed earlier, the R_A value for a given retroreflective sheeting is sensitive to the observation angle and the entrance angle. Moreover, the observation angle depends on the viewing distance between the driver and the sign. Since the R_A values determined by the IPDET model are computed at the minimum required visibility distance, these R_A values must be converted to required R_A values at the standard observation and entrance angles that can be measured by reflectometers, typically 0.2° and -0.4°, respectively. The third component in the CARTS program, the Standardized Retroreflectivity Measurement (SRM) model, performs this conversion based on calibrated relationships between R_A and the entrance and observation angles.

To simplify the development of minimum R_A values, reference conditions were assumed for many of the variables included in the CARTS program [14]. Tables 4 through 7 present the minimum retroreflectivity guidelines recommended by the FHWA. These values meet the demand of the 85th percentile driver in most driving situations. At locations with excessive visual noise or unusual roadway geometry, higher levels of retroreflectivity, larger signs, and/or supplemental signs may be necessary for sign detection and recognition.

Table 8 summarizes the overall impact of the recommended minimum R_A vales on the current sign inventory. Estimates of sign replacement were based on retroreflectivity measurements taken on a random sample of 8,000 regulatory, warning, and guide signs. These data were collected in 1989 as part of an NCHRP study to investigate the economic impact of various sign replacement strategies [3]. Because of the structure of the data from the NCHRP study did not allow direct comparison to the values specified in tables 4 through 7, minimum aggregate R_A values were developed for the different retroreflective sheeting colors. These aggregate values were used to estimate the percent sign replacement values shown in Table 8. Based on these estimates, implementation of the recommended minimum aggregate R_A values would require between 8% to 16% of existing signs to be replaced with the greatest impact at the city level.

Sign Management Systems

Like other transportation infrastructure management systems, a sign management system (SMS) is a systematic procedure that can assist highway agencies in tracking the condition of traffic signs and identifying those signs with an immediate need for replacement. As depicted in Figure 1, an SMS consists of three major components: sign inventory database, an R_A demand model, and an R_A supply model. With the ability to predict in-service R_A (supply), and with the establishment of minimum R_A standards (demand), signs nearing the end of life could be highlighted in a computer inventory. Field inspection of those identified signs would then permit the final determination as to which signs need immediate replacement and which ones could be left in service until the next

Table 4. Minimum R_A Values for White-on-Red Regulatory Signs[a]

Traffic Speed (mph)[b]	Sign Size (inch)[c]					
	≥ 48		36		≤ 30	
	White	Red	White	Red	White	Red
≥ 45	50	10	60	12	70	14
≤ 40	30	6	35	7	40	8

a) cd/1x/m²
b) 1 mph = 1.6 km/hr
c) 1 inch = 25.4 mm

Table 5. Minimum R_A Values for Black-on-White Regulatory and Guide Signs[a]

Traffic Speed (mph)[b]	Sign Placement	Sheeting Type[c]	Sign Size (inch)[d] ≥ 48	30 - 36	≤ 24
≥ 45	Ground Mounted	I	20	35	50
		II	25	45	70
		III	30	60	90
		IV&VII	40	80	120
≤ 40	Ground Mounted	I	15	20	35
		II	20	30	55
		III	25	45	75
		IV&VII	35	60	100
	Over-head Mounted	I	40	50	100
		II	50	75	135
		III	65	115	185

a) cd/1x/m²
b) 1 mph = 1.6 km/hr
c) ASTM retroreflective sheeting typology
d) 1 inch = 25.4 mm

Table 6. Minimum R_A Values for White-on-Green Guide Signs[a]

Traffic Speed (mph)[b]	Sign Placement			
	Ground Mounted		Overhead Mounted	
	White	Green	White	Green
≥ 45	35	7	110	22
≤ 40	25	5	80	16

a) cd/1x/m²
b) 1 mph = 1.6 km/hr

Table 7. Minimum R_A Values for Black-on-Yellow and Black-on-Yellow Warning Signs[a]

Legend Type	Sheeting Type[b]	Sign Size (inch)[c]		
		≥ 48	36	≤ 30
Bold Symbol[d]	All	15	20	25
Fine Symbol & Word	I	20	30	45
	II	25	40	60
	III	30	50	80
	IV&VII	40	70	120

a) cd/1x/m²
b) ASTM retroreflective sheeting typology
c) 1 inch = 25.4 mm
d) warning signs with bold symbols include the following:

MUTCD Code	Sign Type	MUTCD Code	Sign Type
W1-1	Turn	W2-2	Side Road
W1-2	Curve	W2-4	T Intersection
W1-3	Reverse Turn	W2-5	Y Intersection
W1-4	Reverse Curve	W4-2	Lane Reduction
W1-5	Winding Road	W6-1	Divided Highway Begins
W1-6	Large Arrow	W6-2	Divided Highway Ends
W1-8	Chevron	W6-3	Two-Way Traffic
W2-1	Cross Road		

Table 8. Estimated Sign Replacement by Jurisdiction Type

Sign Type	Aggregate R_A Replacement Value[a]	Percent of Signs Requiring Replacement				
		State	County	City	Town	Overall
Warning (Yellow)	42	7%	4%	10%	1%	8%
Regulatory (Red)	11	10%	6%	23%	16%	16%
Regulatory (White)	58	7%	8%	17%	4%	10%
Guide (Green)	6	12%	7%	11%	0%	11%

a) cd/1x/m²

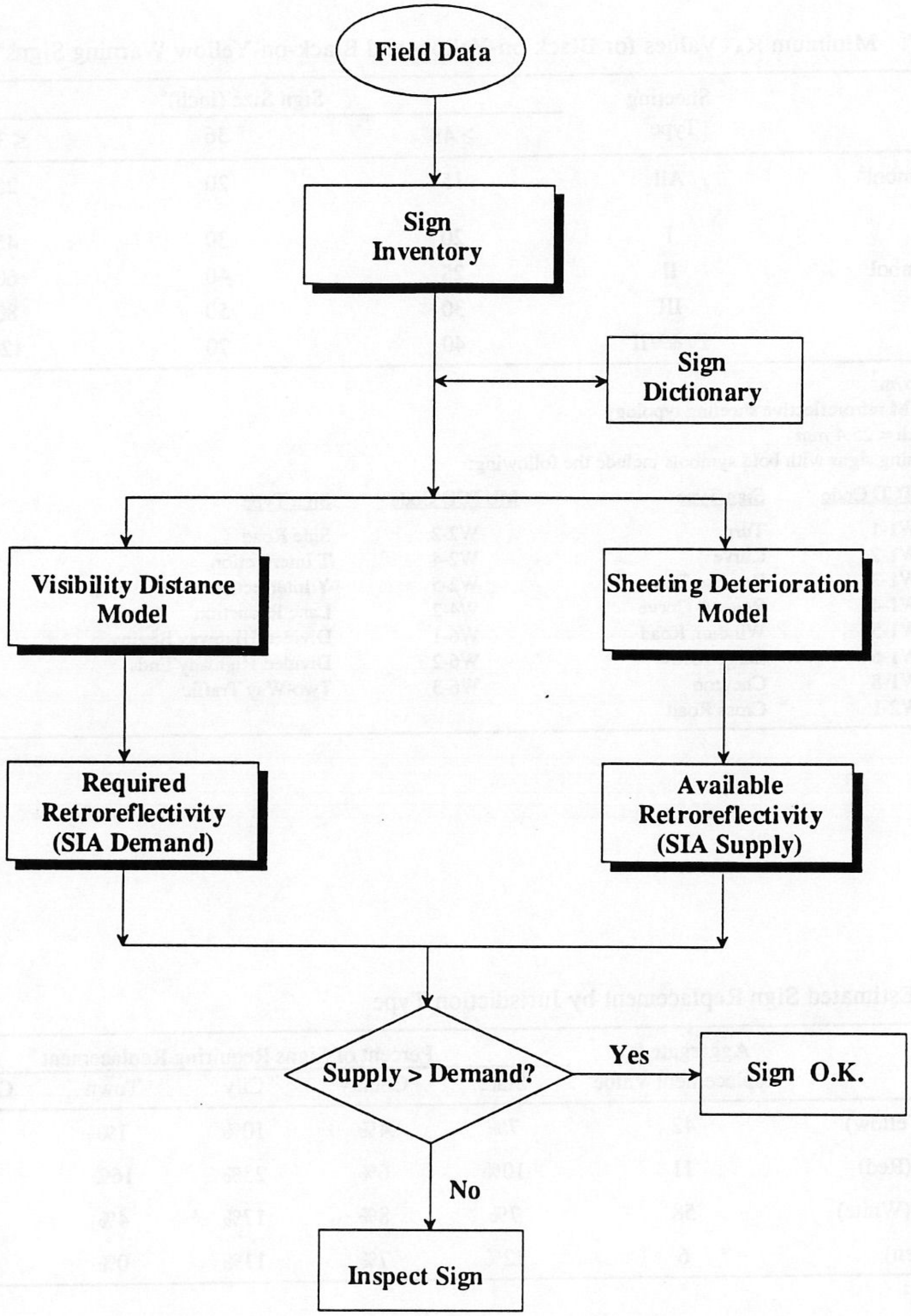


Figure 1. Structure of Sign Management System [15]

periodic field review. The system could also be used to develop future budgets by forecasting sign replacement needs.

A microcomputer program has been developed by the FHWA to provide state and local highway agencies with an automated sign management capability. At present, version 3.4 of the SMS software has an operational inventory and reporting module which allows the user to create an updateable sign inventory database. The database includes information on sign type (MUTCD code, legend, size), sign location and position, retroreflective sheeting (type and manufacturer), type of material used on sign panel and post, visual complexity, traffic speed, installation date, inspection date, and measurement of R_A made with calibrated reflectometer. Of course, the SMS software will go beyond a computer-based sign inventory. Results of the recently completed research projects on predicting service life of retroreflective signs and minimum retroreflectivity requirements have been incorporated into version 4.0 of the software which is currently being tested and verified. Refinement of the predictive models, using local data, will be available to the user.

Mobile Sign Reflectometer

At present, portable reflectometers are the only available means of measuring R_A of traffic signs in the field. The basic unit consists of light source, detector, amplifier, and digital liquid crystal display, all enclosed in an optical head that can be attached to an extension pole. The power supply is a rechargeable 12 volt battery. The typical geometry is fixed at an entrance angle of -4° and an observation angle of 0.2°. A reference sample of sheeting materials, in six colors, is used to calibrate the instrument. For a given sign, four R_A readings per sheeting color are usually taken and an average R_A is computed for each color.

Although portable reflectometers have been in widespread use, their usefulness is limited by the slow rate of data acquisition. If the retroreflectivity of a large number of signs is to be measured in the field, a mobile reflectometer would be more cost-effective. A prototype instrument that can be operated from a moving vehicle in daylight hours has been developed under an NCHRP research project [10]. This instrument uses a video camera to collect sign images, with an electronic flash gun that provides a short burst of light, sufficiently bright to overcome the daylight illumination. The video image is analyzed by a computer to determine the average R_A values of the sign legend and background. Field evaluation of this system is currently being performed by the FHWA.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter summarizes the methods which were used in this study to evaluate the adequacy of the engineering grade, super-engineering grade, and the high intensity retroreflective sheetings for use on permanent roadway traffic signs. The chapter is divided as follows: first, the controlled field experiments required by task 2 are briefly described along with the experimental design. Second, the methods used to obtain data on sign fabrication and installation cost, durability, and service life of the different sheeting materials are presented.

FIELD EXPERIMENTS

Controlled field experiments were conducted at a rural site and an urban site to obtain measurements of sign detection and recognition distances during nighttime conditions. Two experiments were performed at each site. The first experiment involved a total of nine signs: three sign types (stop sign, speed limit sign, and merge symbol sign) × three retroreflective sheeting types (FP-85 types II, IIA, and IIIA). In the second experiment, a total of twelve signs were used: two sign types (exit sign and rest area sign) × six combinations of sheeting types. To ensure uniformity and adherence to manufacturer's recommendations, all signs were fabricated by the ODOT Sign Shop. Signs used in the first experiment were fabricated using the screening method, whereas those used in the second experiment were fabricated using the overlay method. Table 9 presents the characteristics of the 21 signs used in the experiments.

Experimental Design

Designing an experiment means specifying the experiment's desired architecture from a statistical point of view so that the information obtained at the conclusion of the experiment will provide reliable answer to the question(s) that prompted the study. Experimental design then serves as a blueprint for conducting the experiment; it summarizes the means of controlling extraneous sources of variation, the required randomization scheme(s), the underlying theoretical model and assumptions, and the appropriate methods of analyzing the observations. There are literally hundreds of experimental designs, and for a particular objective and physical setting there might be several designs that could be used. The most appropriate design is the one that strikes a balance between statistical efficiency and cost considerations.

In experiments involving human subjects, the response will vary widely from subject to subject, even under the same treatment. The effects of subject-to-subject variation can be minimized by giving all treatments to each subject in succession, so that comparisons are made within subjects. In this type of experiment, treatment effects for a particular subject are measured relative to the average response made by that subject on all treatments, that is, each subject serves as their own control. This method of controlling extraneous sources of variation is referred to as *blocking*. Nevertheless, learning, fatigue or delayed consequences of previously applied treatments may influence the response actually measured after a particular treatment.

Table 9. Traffic Signs Used in Field Experiments

Experiment No.	Sign Type	Sign Size[a]	Sign Color[b]	Critical Detail[c]			Sheeting Type[d]	
				Letters	Numerals	Symbol		
1	Stop (R1-1)	30″ × 30″	White/Red	10″ × 1.5″	-----	-----	II, IIA, IIIA	
	Speed Limit (R2-1)	24″ × 30″	Black/White	4″ × 13/16″	10″ × 2″	-----	II, IIA, IIIA	
	Merge Symbol (W4-1)	30″ × 30″	Black/Yellow	-----	-----	24″ × 4″	II, IIA, IIIA	
							Legend	Background
2	Exit (E5-1)	36″ × 48″	White/Green	12″ × 2.5″	-----	16″ × 3.5″	IIIA	IIIA
	Rest Area (D5-2)	24″ × 48″	White/Blue	6″ × 1-5/16″	-----	13.5″ × 3.5″	IIIA	IIA
							IIIA	II
							IIA	IIA
							IIA	II
							II	II

a) 1 inch = 25.4 mm

b) Legend/Background

c) Height × Width

d) FP-85 retroreflective sheeting typology

The experimental design used in this study is known as the *split-plot design* which has its origin in agriculture experimentation. It is a special form of factorial experiment where levels of certain factors are embedded within blocks representing levels of other factors. This design is particularly useful in experiments where greater precision is desired for comparisons among certain factors than for others.

Figure 2 depicts the layout of a two-factor, split-plot design with randomized complete blocks. Factor *A* represents sign type at three levels: stop, speed limit, and merge symbol. Factor *T* represents reflective sheeting type at three levels: type-II (engineering grade), type-IIA (super-engineering grade), and type-IIIA (high intensity). The dependent variable (response) is the visibility distance obtained from each of the randomly selected subject drivers.

In the split-plot design of Figure 2, the top stage is often referred to as main units or main plots, and the lower stage is referred to as subunits or subplots. Randomization is a two-step process; levels of factor *A* are randomly assigned to the main units within each driver block, and then levels of factor *T* are randomly assigned to the subunits within each main unit. Each main unit may be considered as a block as far as factor *T* is concerned but only as an incomplete block as far as the full set of treatments is concerned. The objective of randomization is to avoid bias in comparisons among treatment means by ensuring that a particular treatment will not be consistently favored or penalized by an extraneous source of variation. Since variation among subunits is normally less than that among main units, levels of the factor for which greater precision is desired are assigned to the subunits [18]. Detailed discussion of the mathematical model, analysis of variance, and hypothesis testing is presented in Chapter 4.

Test Subjects

Four samples, each consisting of 30 paid test subjects, were selected from a large pool of licensed drivers who expressed interest in participating in a 'Traffic Sign Study'. Stratified random sampling was used to select each sample of 30 subjects so that their age and sex distributions closely matched those of the population of drivers in Oklahoma. The age distribution of the test subjects is shown in Table 10. The sex distribution in each sample was a 50-50 male/female ratio. Other characteristics of the test subjects (years of driving experience, type of driving, miles driven per year, use of eye glasses or contact lenses, level of formal education, and occupation) are given in Tables E-1 through E-8 (Appendix E).

Table 10. Age Distribution of Test Subjects

Test Site	Experiment No.	Age[a]					
		< 25	25 - 34	35 - 44	45 - 54	55 - 64	≥ 65
Rural	1	10.0/13.3	23.3/26.7	20.0/20.0	20.0/13.3	13.3/13.3	13.3/13.3
	2	13.3/13.3	26.7/26.7	20.0/20.0	10.0/13.3	13.3/13.3	16.7/13.3
Urban	1	13.3/13.3	23.3/26.7	26.7/20.0	10.0/13.3	13.3/13.3	13.3/13.3
	2	13.3/13.3	26.7/26.7	20.0/20.0	10.0/13.3	16.7/13.3	13.3/13.3

a) a/b: a = percent of test subjects used in the study, b = percent of drivers in the state

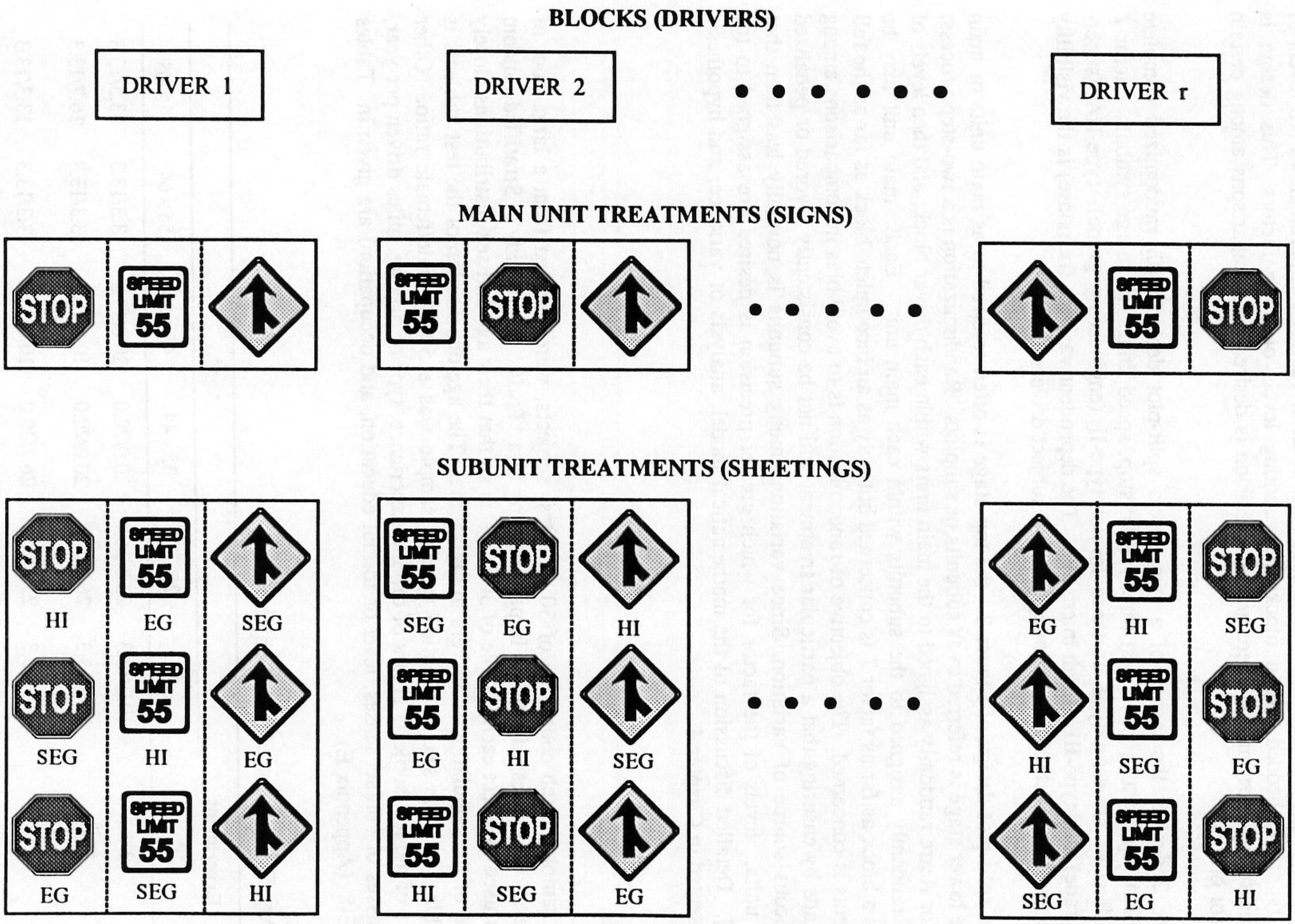


Figure 2. Layout of Two-Factor, Split-Plot Design

Test Sites

The conduct of the field experiments required the availability of test grounds that can be closed to the public at nighttime for approximately one month. An unused runway at the Stillwater Municipal Airport offered the best site for the rural experiments, and an access road near the airport was chosen as the site for the urban experiments.

Runway 13-31, the site of the rural experiments, is 4,800 ft long, 150 ft wide, and has a concrete pavement. A few runway edge lights installed at the other two runways (17-33 and 4-22) were within the test subject's field of view. In general, the background environment was very dark at night. It simulated rural conditions very well.

At the urban site, a straight segment of a two-lane roadway, approximately 2,200 ft long, was closed to traffic at night. The asphalt pavement is 22 ft wide. This segment provides access to aircraft maintenance hangers and a few aviation related businesses. Light sources included several luminaries, terminal building lights, and lights from roadside developments.

Test Procedure

Figure 3 illustrates the setup of the rural test site. A 1991 Buick Century with properly aimed Halogen 9006 low beams was positioned so that the longitudinal centerline of the car formed a 3° angle to the left of the runway centerline. The test vehicle remained stationary throughout the experiment. Each test subject sat in the driver's seat of the test car next to an experimenter.

A dark colored truck equipped with a distance measuring instrument was positioned at approximately 3,300 ft far from the test vehicle. The distance measuring instrument is the Nitestar, manufactured by Nu-metrics®, Inc. It had a 'display-hold' feature which freezes the display while the instrument is continuing to compute the distance traveled. This feature enabled an experimenter setting in the truck, next to the truck driver, to record the necessary distances.

On the truck bed, a custom made frame with a pulley mechanism was installed for raising, mounting, and lowering the traffic signs. The frame was designed so that when a sign is in the 'up' position, the sign's face is vertical and the bottom of the sign is 7 ft above pavement. Signs were identified by numbers and were stored in a wood box loaded on the truck. Figures 4 through 8 show photographs of the truck, frame, sign storage box, and the mounted signs.

Communications between the stationary test vehicle and the truck were made via two-way portable radios (Motorola model P110). Upon receiving instructions from the experimenter in the test vehicle, the truck moved toward the test vehicle at approximately 20 mph with its headlights turned off. To assist the truck driver in maintaining a straight path, type-C steady-burn lights were used to delineate a straight line parallel to the runway centerline. These lights were not visible to the stationary test vehicle. The approach path of the signs was offset 18 ft to the right of the test vehicle centerline. This simulated a 6 ft lateral clearance between the sign and the edge of a 6 ft highway shoulder.

Test subjects were scheduled to arrive at the airport terminal at a rate of one person per hour. Upon arrival, each subject was asked to complete a biographical data sheet. Next, the subject viewed

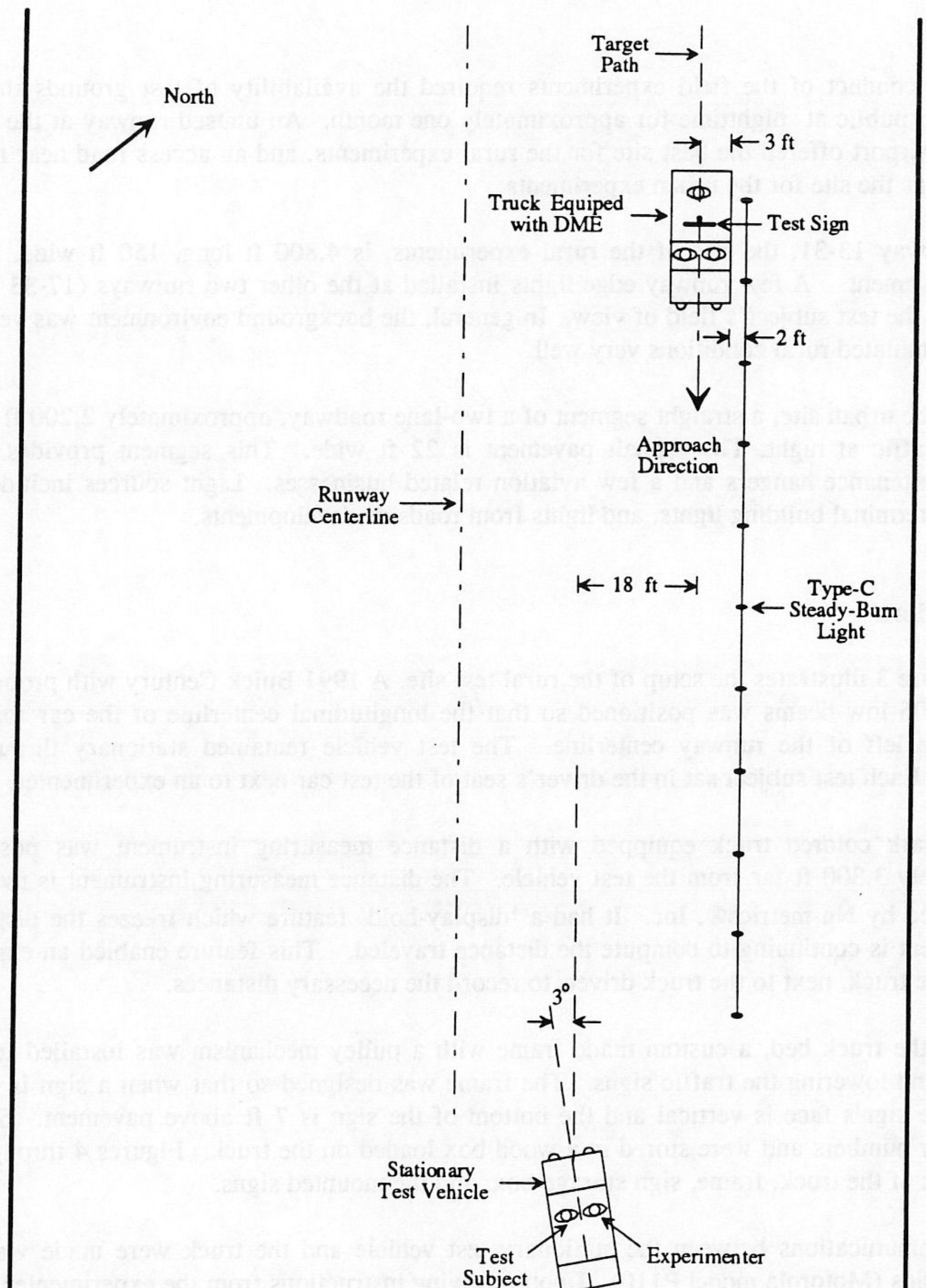


Figure 3. Setup of Rural Test Site

Figure 4. Photograph of Truck, Sign Mounting Frame, and Sign Storage Box

Figure 5. Photograph of Sign Storage Box

Figure 6. Photograph of Sign Mounting Frame

Figure 7. Photograph of Mounted Sign

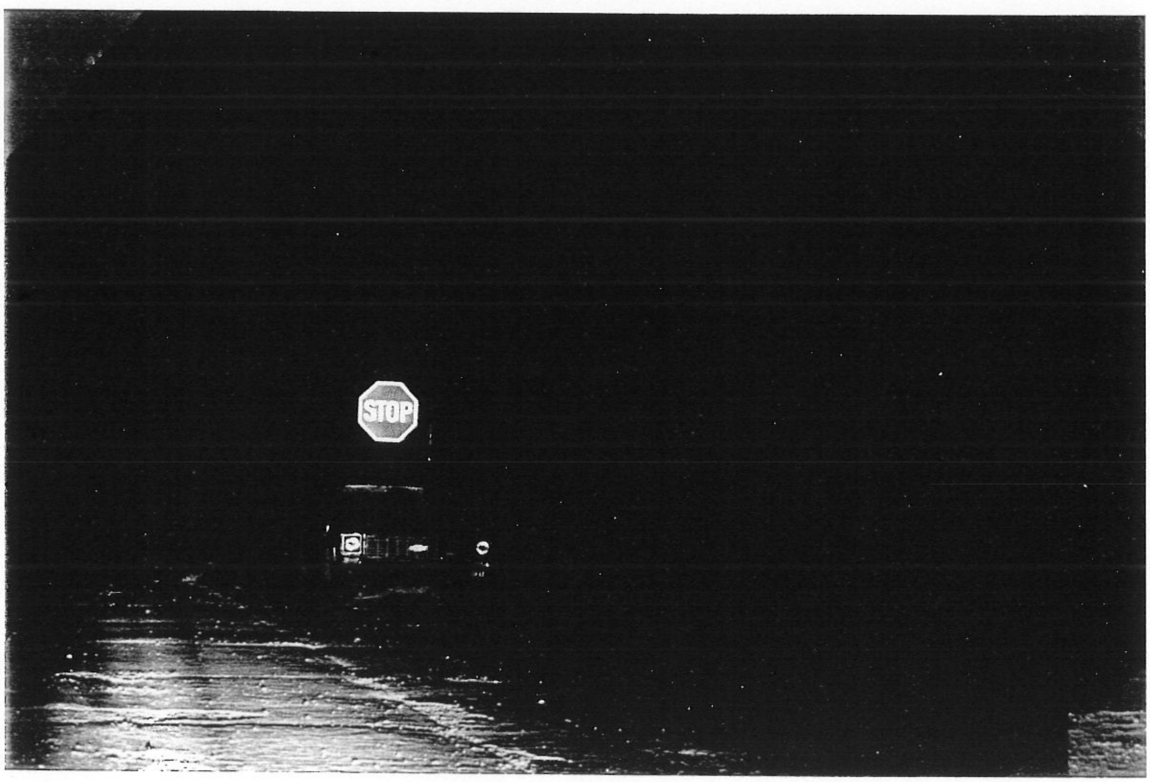


Figure 8. Photograph of Mounted Sign at Nighttime

a videotape that explained the different tasks involved in the field test, and was given an instruction sheet similar to that shown in Exhibit 1. The subject was then transported to the location of the test vehicle. Setting in the driver's seat with the car engine idling and the low beams on, the subject practiced the use of the communications radio. When ready, an experimenter setting next to the subject instructed the truck driver to start. Using the radio, the subject indicated when he/she first detected the sign and when the sign became legible. The corresponding detection and recognition distances were recorded by the experimenter setting in the truck. This process was repeated for all signs included in the experiment. The order in which the signs were viewed by the test subjects was randomized so that each subject viewed the signs in a unique sequence. As explained earlier in experimental design, randomization was a two-step process; sign types were randomly assigned to the test subjects, and then sheeting types were randomly assigned to the signs within the test subjects. After viewing each sign type (e.g., three stop signs made of different sheeting materials), each subject completed a questionnaire form concerning the adequacy of these particular signs.

The experimental setup at the urban site was similar to that at the rural site, except that the approach path of the signs was offset 8 ft to the right of the test vehicle centerline. This simulated a lateral clearance of 2 ft from the edge of the traveled way. Figure 9 illustrates the setup of the urban test site.

COST AND DURABILITY DATA

Sign replacement and refurbishing cost data were compiled from two sources: the ODOT Sign Shop and the ODOT Divisions. The sign shop provided cost items for: 1) fabrication of new sign faces (sheeting materials, aluminum backing, labor, and overhead), and 2) refurbishing old sign faces using a mechanical stripper. Sign installation cost items (sign support, equipment, labor, and overhead) were obtained from the eight ODOT divisions using a questionnaire survey instrument. In addition to sign installation cost, the survey included questions concerning the number and type of traffic signs in each division; average service life and primary deterioration modes of the different sheeting materials; reasons for sign replacement; and the availability and format of sign inventory system. A summary of the survey findings is included in Appendix A.

The coefficient of retroreflection, R_a, and the colorimetric properties of the new sheeting materials used in this study were determined by the ODOT Materials Laboratory per ASTM E-810 and E-811. Table 11 summarizes the laboratory test results.

Unpublished results of accelerated outdoor exposure for sheeting types II, IIA, and IIIA with red, white, yellow, green, and blue colors were obtained from the FHWA Photometric and Visibility Laboratory at Turner-Fairbank Highway Research Center, McLean, Virginia. Testing was performed for a period of five years (1989 through 1993). Sheeting samples were 4" × 6" in size with pressure sensitive adhesive. The samples were attached to aluminum panels (0.063" thick) by pressure and exposed on a stainless steel wire-mesh (0.03" diameter wire with 0.25" square openings) rack at 45° facing south. The R_A measurements were made at 0.2° observation angle and -4° entrance angle on the new sheeting materials (year 0) and at the end of each year of exposure thereafter.

Exhibit 1

INSTRUCTION TO TEST SUBJECTS

Welcome to Test Vehicle

You will sit in the driver's seat with the car engines idling and the low beams on. The test car will remain stationary. Practice using the two-way radio. If you have any questions please ask.

Ready to Begin

As the test proceeds, you will see traffic signs approaching the test vehicle. You need to do FOUR things during the test:

1. Look in the direction of the approaching target.

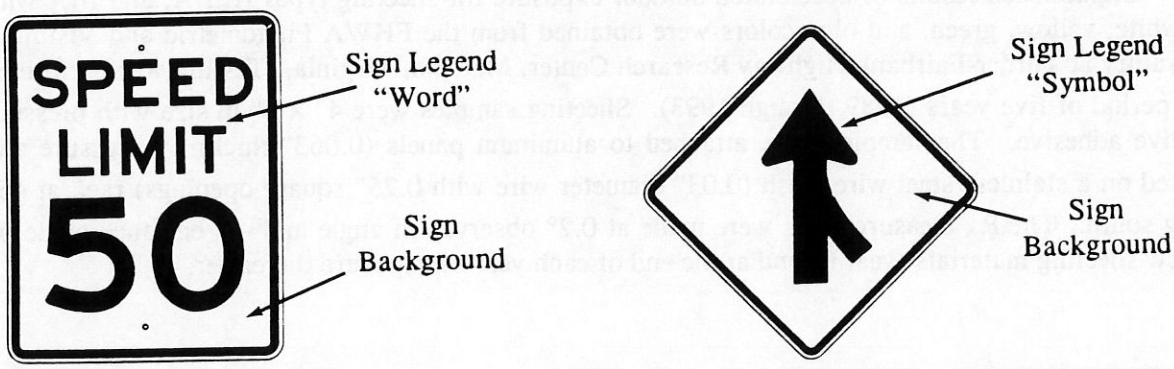
2. When you can see a traffic sign ahead of you, press the talk button on the radio immediately, and say "I CAN SEE A SIGN". This is the first time the sign appears to you on the horizon, even if you cannot tell what the sign means.

3. Whenever you are able to read the legend on the sign ahead of you, press the talk button on the radio immediately, and READ THE LEGEND LOUD.

   Some signs will have symbols drawn on them. Whenever you are able to recognize the symbol, press the talk button on the radio immediately, and SAY WHAT THE SYMBOL MEANS or DESCRIBE THE SHAPE OF THE SYMBOL.

4. Fill out the questionnaires which will be given to you.

Please ask if you have any questions. Thank you for your participation.



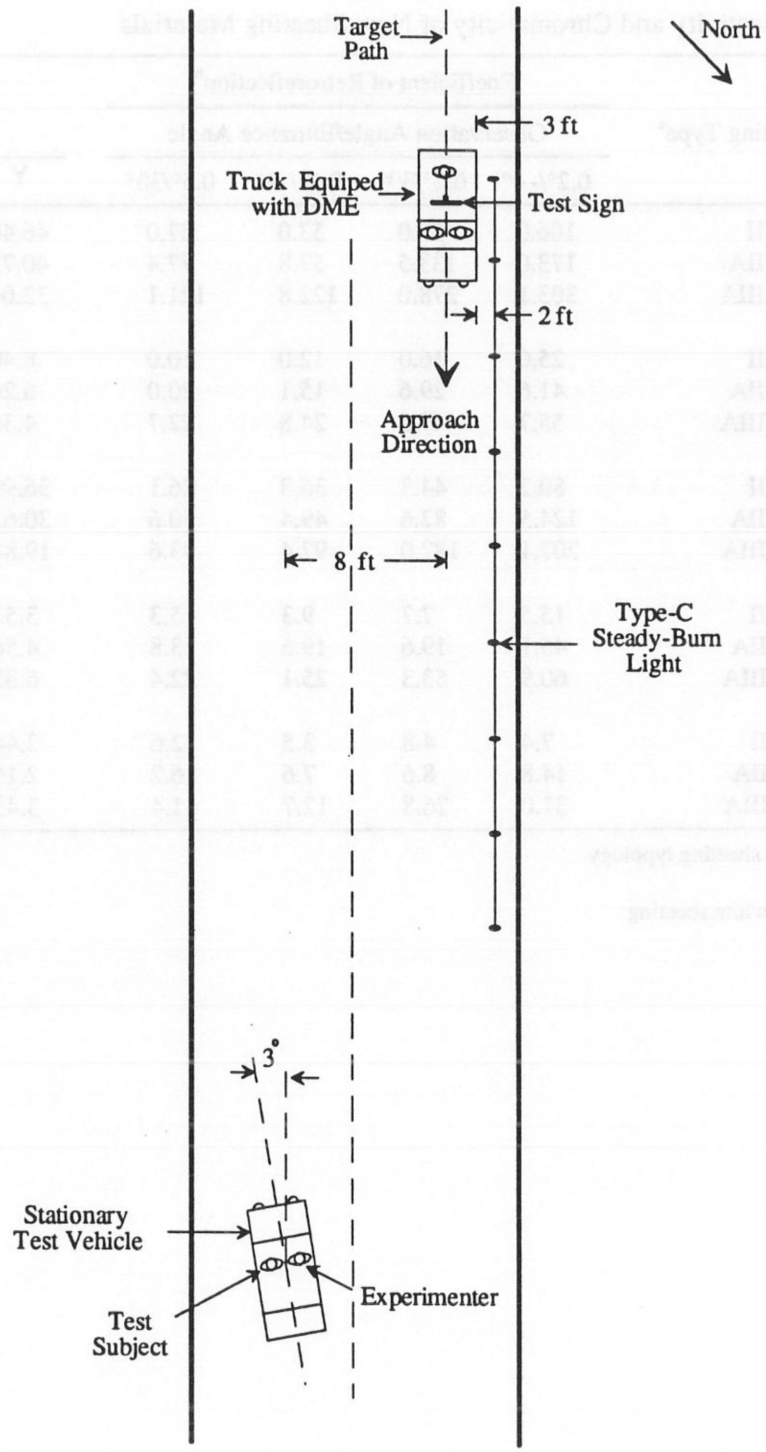


Figure 9. Setup of Urban Test Site

Table 11. Retroreflectivity and Chromaticity of New Sheeting Materials

Sheeting Color	Sheeting Type[a]	Coefficient of Retroreflection[b] Observation Angle/Entrance Angle				Chromaticity Coordinates		
		0.2°/-4°	0.2°/30°	0.5°/-4°	0.5°/30°	Y	x	y
White	II	106.0	57.0	53.0	37.0	46.40	0.3095	0.3213
	IIA	173.0	133.5	57.8	77.4	40.73	0.3078	0.3189
	IIIA	303.1	278.0	122.8	121.1	32.06	0.3054	0.3149
Red[c]	II	25.0	16.0	12.0	10.0	8.40	0.6468	0.3317
	IIA	41.6	29.6	15.1	20.0	6.20	0.6400	0.3228
	IIIA	55.7	47.5	24.8	22.7	4.35	0.6380	0.3193
Yellow	II	80.2	44.3	36.8	26.1	36.99	0.5045	0.4783
	IIA	124.5	82.6	49.4	50.6	30.63	0.5083	0.4755
	IIIA	207.1	182.0	97.4	93.6	19.80	0.5194	0.4684
Green	II	15.5	7.7	9.3	5.3	3.53	0.1310	0.4019
	IIA	45.1	19.6	19.6	13.8	4.56	0.1216	0.4158
	IIIA	60.9	53.3	25.1	22.4	6.85	0.1426	0.4154
Blue	II	7.4	4.8	3.5	2.6	2.44	0.1429	0.1002
	IIA	14.8	8.6	7.6	6.2	2.16	0.1461	0.0951
	IIIA	31.0	26.8	12.7	11.4	3.43	0.1431	0.1192

a) FP-85 retroreflective sheeting typology
b) cd/lx/m^2
c) Red ink screened on white sheeting

CHAPTER 4

ANALYSIS OF SIGN VISIBILITY DISTANCES

This chapter summarizes results of the analyses of visibility distances of traffic signs which were recorded during the field experiments. The chapter is organized as follows. First, general summary statistics of visibility distances are presented. Second, a brief background on the theory of the statistical tests performed is introduced. Third, the major findings of the statistical analyses of mean detection distances (MDDs) and mean recognition distances (MRDs) are discussed. Finally, the MDDs and MRDs are compared against the minimum required visibility distances.

VISIBILITY DISTANCES

Two measures of sign visibility distance were recorded during the field experiments: detection distance and recognition distance. Detection distance is the distance upstream of a traffic sign where the test subject first saw the sign as a separate target although not recognizing or perceiving it as such. Recognition distance is the distance upstream of the sign where the test subject recognized the sign legend. A brief discussion of sign detection and recognition is presented in Chapter 2.

Tables 12 through 15 list general statistics of the visibility distance measurements obtained from the field experiments. The distribution of visibility distances is illustrated by the box-and-whisker plots of Figures 10 through 13. Each plot depicts the mean response for each sample of 30 test subjects as a horizontal line inside a box, standard deviations above and below the mean as the box itself, and the maximum and minimum observations as a pair of whiskers.

The field experiments were designed to address the following three questions:

1. Is there statistically significant difference between the MDDs of traffic signs with different retroreflective sheeting materials during nighttime conditions?
2. Is there statistically significant difference between the MRDs of traffic signs with different retroreflective sheeting materials during nighttime conditions?
3. How do the MDDs and MRDs of traffic signs with different retroreflective sheeting materials compare to the minimum required visibility distances?

The first and second questions require performing analysis of variance (ANOVA) of visibility distance measurements, and testing hypotheses concerning the effect of the different retroreflective sheeting materials used in this study. The answer to the third question invoves comparing the MDDs and MRDs with the minimum visibility distances computed using the MRVD microcomputer program.

SPLIT-PLOT DESIGN

As discussed in Chapter 3, the experimental design used in this study is a special form of factorial experiments known as the *split-plot design*. Factor *A* represents sign type and factor *T*

Table 12. Sign Visibility Distances, Rural Environment, Experiment 1

Sign Type		Detection Distance, ft[a] EG	SEG	HI	Recognition Distance, ft[a] EG	SEG	HI
Stop Sign	$\bar{x}$	1466.0	1656.0	1805.0	657.2	657.0	702.7
	s	476.3	497.5	526.8	230.7	204.9	298.5
	n	30	30	30	30	30	30
Speed Limit Sign	$\bar{x}$	1661.0	1732.0	1829.0	471.9	477.9	510.9
	s	509.0	486.0	492.3	112.0	118.3	153.2
	n	30	30	30	30	30	30
Merge Symbol Sign	$\bar{x}$	1783.0	1883.0	1950.0	534.0	567.2	593.3
	s	474.8	434.4	463.1	210.3	198.7	216.3
	n	30	30	30	30	30	30

a) 1 ft = 0.3048 meter
EG = engineering grade, SEG = super-engineering grade, HI = high-intensity (FP-85 type III-A) sheeting materials
$\bar{x}$ = average, s = standard deviation, n = sample size

Table 13. Sign Visibility Distances, Urban Environment, Experiment 1

Sign Type		Detection Distance, ft[a] EG	SEG	HI	Recognition Distance, ft[a] EG	SEG	HI
Stop Sign	$\bar{x}$	955.0	1171.0	1208.0	522.6	537.1	542.2
	s	328.6	425.1	335.9	198.9	168.6	142.6
	n	30	30	30	30	30	30
Speed Limit Sign	$\bar{x}$	1104.0	1134.0	1223.0	391.1	414.7	415.9
	s	352.9	395.5	433.7	142.1	135.9	132.3
	n	30	30	30	30	30	30
Merge Symbol Sign	$\bar{x}$	1329.0	1391.0	1497.0	470.5	512.9	491.7
	s	340.0	350.9	380.3	162.8	132.9	143.8
	n	30	30	30	30	30	30

a) 1 ft = 0.3048 meter
EG = engineering grade, SEG = super-engineering grade, HI = high-intensity (FP-85 type III-A) sheeting materials
$\bar{x}$ = average, s = standard deviation, n = sample size

Table 14. Sign Visibility Distances, Rural Environment, Experiment 2

Sign Type		Detection Distance, ft[a]						Recognition Distance, ft[a]					
		HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
Exit Sign	$\bar{x}$	1640.0	1553.0	1487.0	1555.0	1462.0	1402.0	739.8	752.7	753.6	652.5	758.7	714.3
	s	317.1	310.1	386.2	370.0	278.0	263.6	165.3	179.6	179.4	151.5	177.5	160.9
	n	30	30	30	30	30	30	30	30	30	30	30	30
Rest Area Sign	$\bar{x}$	1298.0	1323.0	1258.0	1237.0	1182.0	1117.0	397.6	416.7	440.8	408.2	422.9	417.7
	s	350.7	363.9	334.8	352.7	340.8	272.6	97.9	100.0	114.0	98.0	105.1	109.0
	n	30	30	30	30	30	30	30	30	30	30	30	30

a) 1 ft = 0.3048 meter
A/B = Legend/Background, EG = engineering grade, SEG = super-engineering grade, HI = high-intensity (FP-85 type III-A) sheeting materials
$\bar{x}$ = average, s = standard deviation, n = sample size

Table 15. Sign Visibility Distances, Urban Environment, Experiment 2

Sign Type		Detection Distance, ft[a]						Recognition Distance, ft[a]					
		HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
Exit Sign	$\bar{x}$	1387.0	1353.0	1250.0	1369.0	1273.0	1233.0	674.1	675.0	705.9	620.4	672.6	667.2
	s	373.0	329.7	284.3	351.5	292.1	273.4	194.7	167.4	204.8	206.9	212.6	214.1
	n	30	30	30	30	30	30	30	30	30	30	30	30
Rest Area Sign	$\bar{x}$	1159.0	1127.0	1098.0	1089.0	996.7	1066.0	343.9	378.3	422.3	386.0	361.8	361.8
	s	379.5	415.1	303.3	312.1	325.4	281.6	123.7	132.6	250.8	130.9	135.8	117.4
	n	30	30	30	30	30	30	30	30	30	30	30	30

a) 1 ft = 0.3048 meter
A/B = Legend/Background, EG = engineering grade, SEG = super-engineering grade, HI = high-intensity (FP-85 type III-A) sheeting materials
$\bar{x}$ = average, s = standard deviation, n = sample size

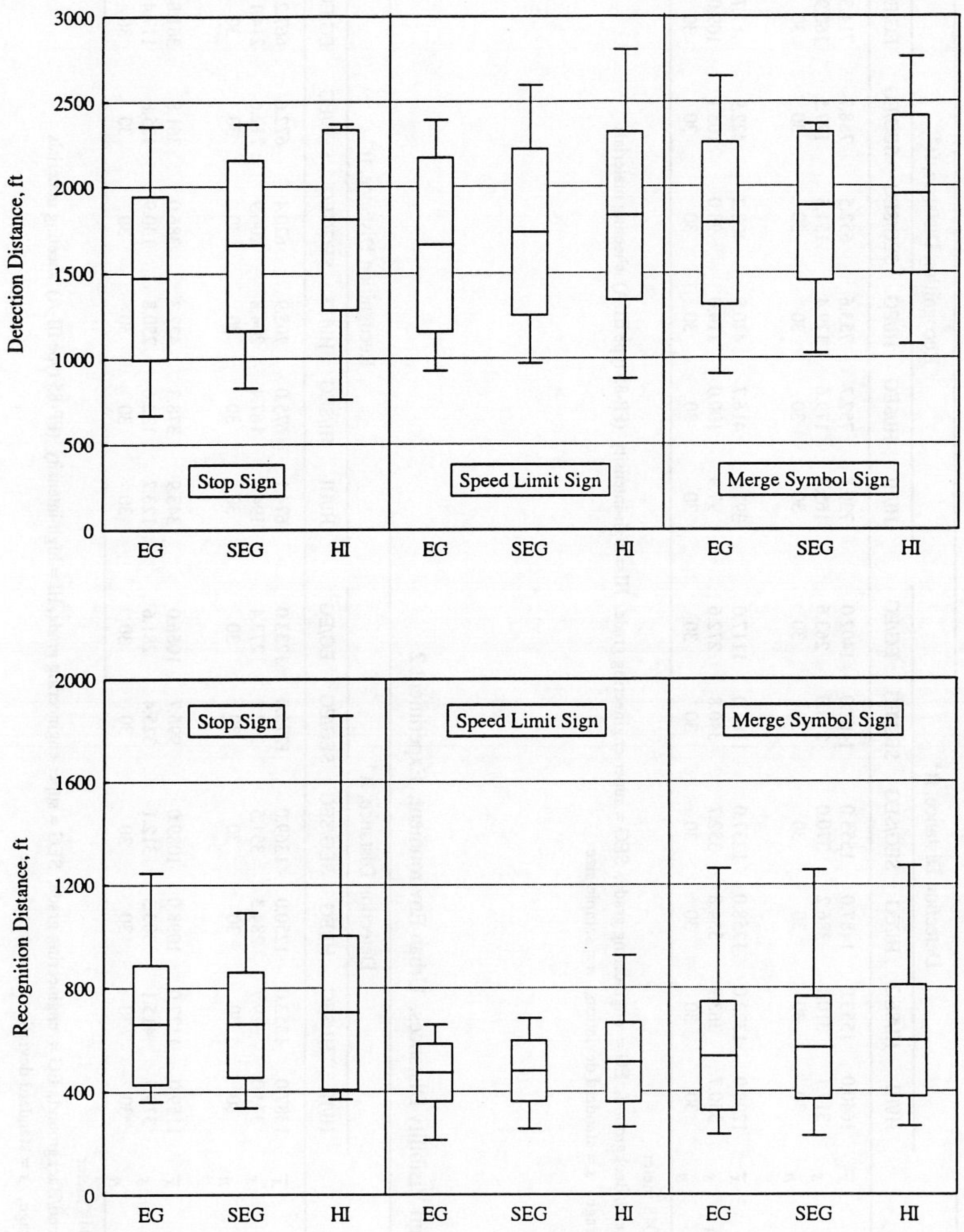


Figure 10. Box-and-Whisker Plots of Sign Visibility Distances, Rural Environment, Experiment 1

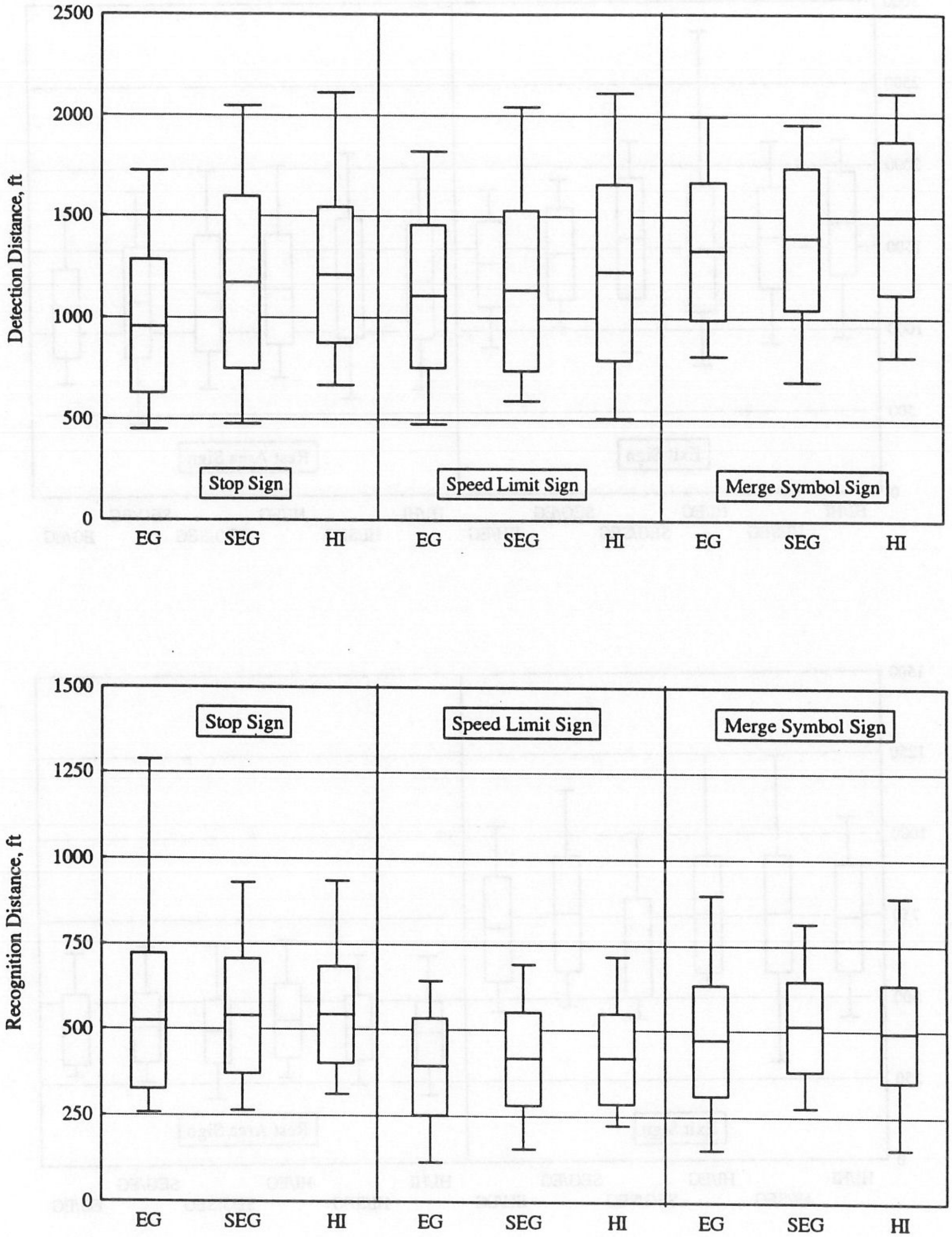


Figure 11. Box-and-Whisker Plots of Sign Visibility Distances, Urban Environment, Experiment 1

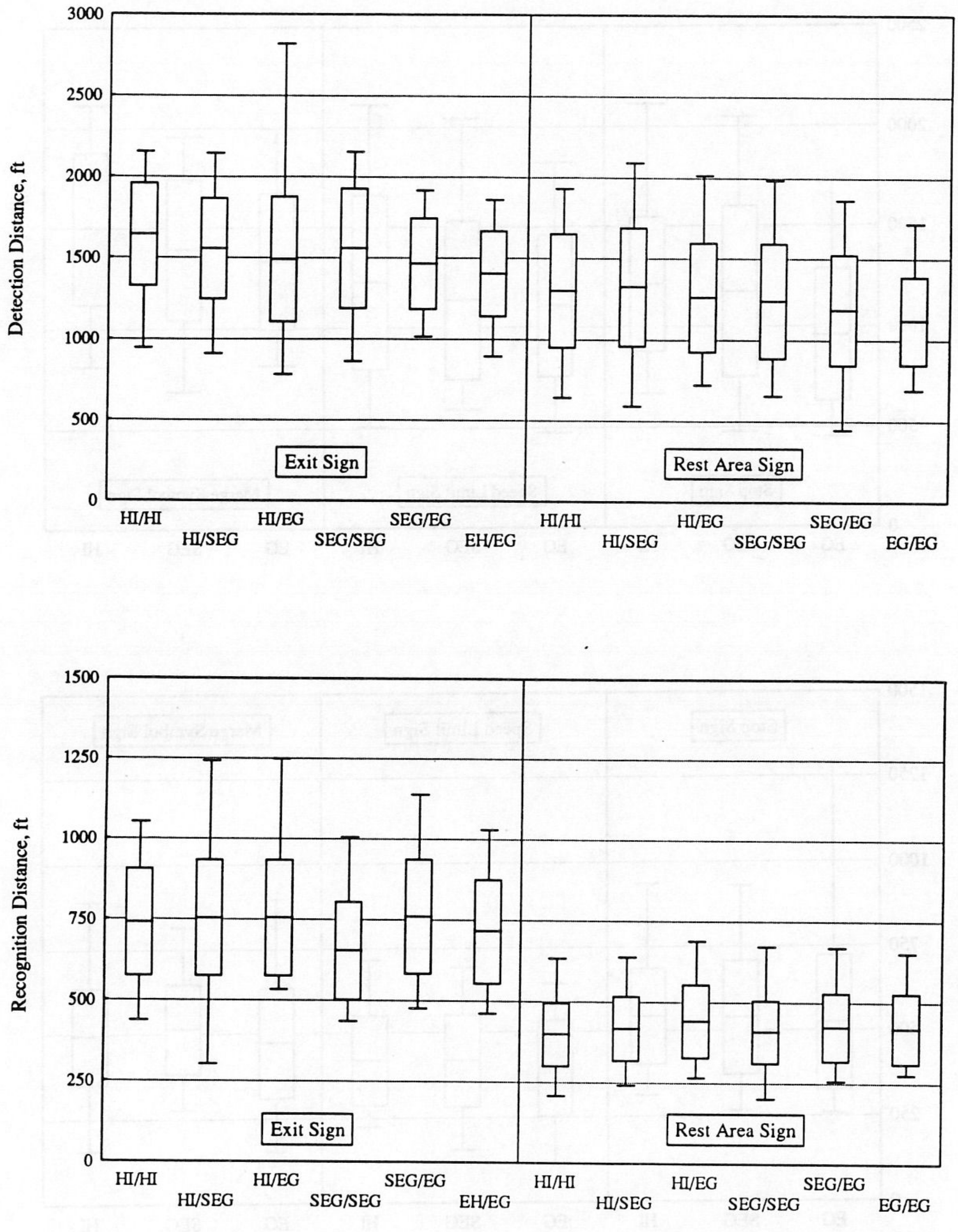


Figure 12. Box-and-Whisker Plots of Sign Visibility Distances, Rural Environment, Experiment 2

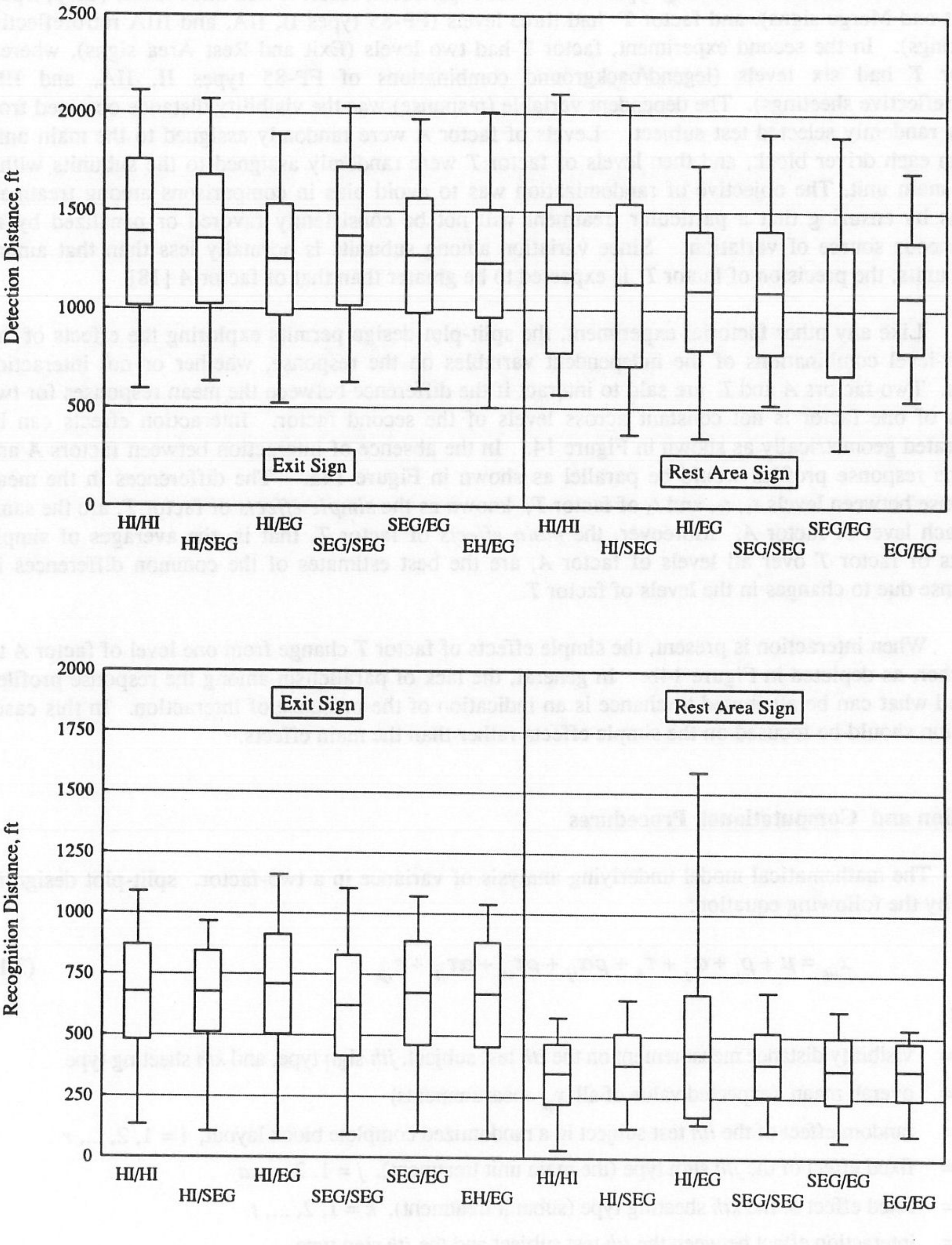


Figure 13. Box-and-Whisker Plots of Sign Visibility Distances, Urban Environment, Experiment 2

represents retroreflective sheeting type. In the first experiment, factor A had three levels (Stop, Speed Limit and Merge signs), and factor T had three levels (FP-85 types II, IIA, and IIIA retroreflective sheetings). In the second experiment, factor T had two levels (Exit and Rest Area signs), whereas factor T had six levels (legend/background combinations of FP-85 types II, IIA, and IIIA retroreflective sheetings). The dependent variable (response) was the visibility distance obtained from thirty randomly selected test subject. Levels of factor A were randomly assigned to the main units within each driver block, and then levels of factor T were randomly assigned to the subunits within each main unit. The objective of randomization was to avoid bias in comparisons among treatment means by ensuring that a particular treatment will not be consistently favored or penalized by an extraneous source of variation. Since variation among subunits is normally less than that among main units, the precision of factor T is expected to be greater than that of factor A [18].

Like any other factorial experiment, the split-plot design permits exploring the effects of all factor-level combinations of the independent variables on the response, whether or not interaction exists. Two factors A and T are said to interact if the difference between the mean responses for two levels of one factor is not constant across levels of the second factor. Interaction effects can be illustrated geometrically as shown in Figure 14. In the absence of interaction between factors A and T, the response profiles would be parallel as shown in Figure 14a. The differences in the mean response between levels t_1, t_2, and t_3 of factor T, known as the *simple effects* of factor T, are the same for each level of factor A. Moreover, the *main effects* of factor T, that is, the averages of simple effects of factor T over all levels of factor A, are the best estimates of the common differences in response due to changes in the levels of factor T.

. When interaction is present, the simple effects of factor T change from one level of factor A to the other, as depicted in Figure 14b. In general, the lack of parallelism among the response profiles beyond what can be attributed to chance is an indication of the presence of interaction. In this case, attention should be focused on the simple effects rather than the main effects.

Notation and Computational Procedures

The mathematical model underlying analysis of variance in a two-factor, split-plot design is given by the following equation:

$$x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk} \tag{3.1}$$

where:

x_{ijk} = visibility distance measurement on the *ith* test subject, *jth* sign type, and *kth* sheeting type

μ = overall mean (expected value of all x_{ijk} measurements)

ρ_i = random effect of the *ith* test subject in a randomized complete block layout, $i = 1, 2, ..., r$

α_j = fixed effect of the *jth* sign type (the main unit treatment), $j = 1, 2, ..., a$

τ_k = fixed effect of the *kth* sheeting type (subunit treatment), $k = 1, 2, ..., t$

$\rho\alpha_{ij}$ = interaction effect between the *ith* test subject and the *jth* sign type

$\rho\tau_{ik}$ = interaction effect between the *ith* test subject and the *kth* sheeting type

$\alpha\tau_{jk}$ = interaction effect between the *jth* sign type and the *kth* sheeting type

ε_{ijk} = random error component.

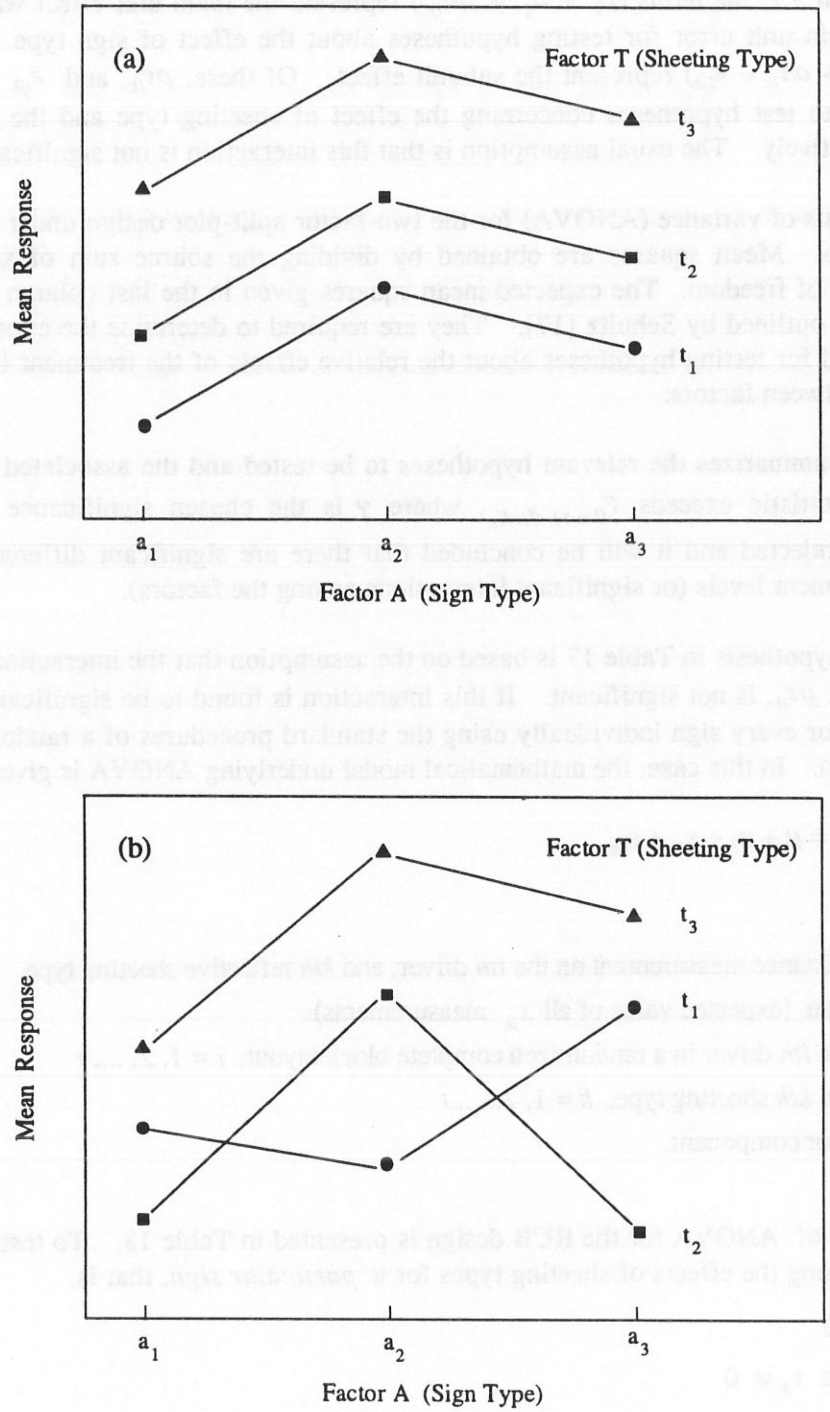


Figure 14. Geometric Interpretation of Interaction

In equation 3.1, the terms ($\rho_i + \alpha_j + \rho\alpha_{ij}$) represent the main unit effect with the $\rho\alpha_{ij}$ term serving as the main unit error for testing hypotheses about the effect of sign type. Moreover, the terms ($\tau_k + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$) represent the subunit effect. Of these, $\rho\tau_{ik}$ and ε_{ijk} are synthesized error terms used to test hypotheses concerning the effect of sheeting type and the sign × sheeting interaction, respectively. The usual assumption is that this interaction is not significant [6, 18].

The analysis of variance (ANOVA) for the two-factor split-plot design under consideration is given in Table 16. Mean squares are obtained by dividing the source sum of squares by their respective degrees of freedom. The expected mean squares given in the last column were developed using the methods outlined by Schultz [17]. They are required to determine the appropriate form of the F-ratios needed for testing hypotheses about the relative effects of the treatment levels as well as the interactions between factors.

Table 17 summarizes the relevant hypotheses to be tested and the associated F-statistics. If the computed F-statistic exceeds $F_{(1-\gamma), df_1, df_2}$, where γ is the chosen significance level, the null hypothesis H_0 is rejected and it will be concluded that there are significant differences among the means of the treatment levels (or significant interactions among the factors).

The third hypothesis in Table 17 is based on the assumption that the interaction between signs and sheeting types, $\rho\tau_{ik}$, is not significant. If this interaction is found to be significant, the analysis must be repeated for every sign individually using the standard procedures of a randomized complete block (RCB) design. In this case, the mathematical model underlying ANOVA is given by:

$$x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik} \qquad (3.2)$$

where:

x_{ik} = visibility distance measurement on the *ith* driver, and *kth* reflective sheeting type

μ = overall mean (expected value of all x_{ik} measurements)

ρ_i = effect of the *ith* driver in a randomized complete block layout, $i = 1, 2, ..., r$

τ_k = effect of the *kth* sheeting type, $k = 1, 2, ..., t$

ε_{ik} = random error component.

A summary of ANOVA for the RCB design is presented in Table 18. To test the hypothesis of no difference among the effects of sheeting types for a *particular sign*, that is,

H_0: all $\tau_k = 0$

H_1: at least one $\tau_k \neq 0$

the F-statistic is given by $MS(T)/MS(E)$, with degrees of freedom $df_1 = (t-1)$ and $df_2 = (r-1)(t-1)$.

Multiple Comparison Procedures

The ANOVA procedures discussed in the previous section are used to test the hypothesis that all treatment effects are equal. If this hypothesis is rejected, it is concluded that there is at least one inequality

Table 16. ANOVA for a Two-Factor, Split-Plot Design with Randomized Complete Block Layout

Source	Degrees of Freedom df	Sum of Squares SS	Mean Square MS	Expected Mean Square E(MS)
Test Subjects, R	$r-1$	$\frac{\sum_i x_{i..}^2}{at} - \frac{x_{...}^2}{rat}$	$MS(R)$	$\sigma_\varepsilon^2 + at\,\sigma_\rho^2$
Signs, A	$a-1$	$\frac{\sum_j x_{.j.}^2}{rt} - \frac{x_{...}^2}{rat}$	$MS(A)$	$\sigma_\varepsilon^2 + t\,\sigma_{\rho\alpha}^2 + rt\frac{\sum_j \alpha_j^2}{a-1}$
$R \times A$ Interaction [a]	$(r-1)(a-1)$	$\frac{\sum_{i,j} x_{ij.}^2}{t} - \frac{x_{...}^2}{rat} - SS(R) - SS(A)$	$MS(RA)$	$\sigma_\varepsilon^2 + t\,\sigma_{\rho\alpha}^2$
Sheetings, T	$t-1$	$\frac{\sum_k x_{..k}^2}{ra} - \frac{x_{...}^2}{rat}$	$MS(T)$	$\sigma_\varepsilon^2 + a\,\sigma_{\rho\tau}^2 + ra\frac{\sum_k \tau_k^2}{t-1}$
$R \times T$ Interaction [b]	$(r-1)(t-1)$	$\frac{\sum_{i,k} x_{i.k}^2}{a} - \frac{x_{...}^2}{rat} - SS(R) - SS(T)$	$MS(RT)$	$\sigma_\varepsilon^2 + a\,\sigma_{\rho\tau}^2$
$A \times T$ Interaction	$(a-1)(t-1)$	$\frac{\sum_{j,k} x_{.jk}^2}{r} - \frac{x_{...}^2}{rat} - SS(A) - SS(T)$	$MS(AT)$	$\sigma_\varepsilon^2 + r\frac{\sum_{j,k}(\alpha\tau)_{jk}^2}{(a-1)(t-1)}$
$R \times A \times T$ Interaction [c]	$(r-1)(a-1)(t-1)$	$\frac{\sum_{i,j,k} x_{ijk}^2}{a} - \frac{\sum_{i,j,k} x_{ij.}^2}{t} - \frac{2x_{...}^2}{rat} - SS(T) - SS(RT) - SS(AT)$	$MS(E)$	σ_ε^2
Total	$rat-1$	$\sum_{i,j,k} x_{ijk}^2 - \frac{x_{...}^2}{rat}$		

a) Main unit treatment error
b) Subunit treatment error
c) $A \times T$ interaction error

Table 17. Hypothesis Testing for Two-Factor, Split-Plot Design

Hypothesis[a]	Meaning	F-Statistic	Degrees of Freedom
H_0: all $\alpha_j = 0,\ j = 1,2,3$ H_1: at least one $\alpha_j \neq 0$	No significant difference among signs considering *all* sheeting types.	$\frac{MS(A)}{MS(RA)}$	$df_1 = a-1$ $df_2 = (r-1)(a-1)$
H_0: all $\alpha\tau_{jk} = 0$ H_1: otherwise	No significant interaction between signs and sheeting types.	$\frac{MS(A \times T)}{MS(E)}$	$df_1 = (a-1)(t-1)$ $df_2 = (r-1)(a-1)(t-1)$
H_0: all $\tau_k = 0,\ k = 1,2,3$ H_1: at least one $\tau_k \neq 0$	No significant difference among sheeting types considering *all* signs.	$\frac{MS(T)}{MS(RT)}$	$df_1 = t-1$ $df_2 = (r-1)(t-1)$

a) The third hypothesis is based on the assumption that the sign × sheeting interaction is not significant. If this interaction is significant, see the analysis in Table 18.

Table 18. Analysis of Variance for a Randomized Complete Block Design

Source	Degrees of Freedom df	Sum of Squares SS	Mean Square MS	Expected Mean Square E(MS)
Drivers, R	$r-1$	$\frac{\sum_i x_{i.}^2}{t} - \frac{x_{..}^2}{rt}$	$MS(R)$	$\sigma_\varepsilon^2 + t\,\sigma_\rho^2$
Sheetings, T	$t-1$	$\frac{\sum_k x_{.k}^2}{r} - \frac{x_{..}^2}{rt}$	$MS(T)$	$\sigma_\varepsilon^2 + r\frac{\sum_k \tau_k^2}{t-1}$
Error	$(r-1)(t-1)$	$\sum_{i,k} x_{ik}^2 - \frac{x_{..}^2}{rt} - SS(R) - SS(T)$	$MS(E)$	σ_ε^2
Total	$rt-1$	$\sum_{i,k} x_{ik}^2 - \frac{x_{..}^2}{rt}$		

among the treatment means. Further conclusions concerning differences between pairs of treatment means require the use of multiple comparison procedures.

Pairwise comparisons of treatment means were conducted using the Newman-Keuls' test which utilizes the studentized range statistic in a result-guided procedure. To help explain, consider a set of treatment means arranged in an ascending order of magnitude and labeled as: $\overline{T}_1$, $\overline{T}_2$, ..., $\overline{T}_t$, where $\overline{T}_1$ is the smallest and $\overline{T}_t$ is the largest. The test procedure begins by comparing the maximum and the minimum means. If the difference is not significant, no further testing is performed and the entire set of treatment means is declared homogeneous. If this maximum difference is found significant, it is concluded that $\overline{T}_1 \neq \overline{T}_t$ and testing continues as though this were fact. At the next stage, the differences $\left|\overline{T}_1 - \overline{T}_{t-1}\right|$ and $\left|\overline{T}_2 - \overline{T}_t\right|$ are tested using a test statistic for $(t-1)$ means. At any stage, where a difference is not significant, testing terminates and the subset is declared homogeneous, otherwise, testing continues.

Two sample averages $\overline{T}_i$ and $\overline{T}_j$ which span p ordered averages are considered to be significantly different if:

$$\left|\overline{T}_i - \overline{T}_j\right| \geq q_{\gamma,p,df_e} \sqrt{\frac{MSE}{r}}$$

where:

q_{γ,p,df_e}	=	critical value of the studentized range statistic
MSE	=	pooled estimate of the error variance of the treatments
df_e	=	degrees of freedom associated with MSE
p	=	number of ordered averages falling between $\overline{T}_i$ and $\overline{T}_j$
r	=	sample size
γ	=	level of significance of the test.

RESULTS OF STATISTICAL ANALYSES

The computations required by the split-plot analysis of variance and the Newman-Keuls' test were performed using the PC_SAS™ and the STATISTICA™ microcomputer programs. All tests were made at the 95% confidence level.

To facilitate the discussion, the notation 'a/b' will be used to refer to the 'legend/background' sheeting materials included in experiment 2. The following conventional codes are used to replace 'a' and 'b': 'EG' for engineering grade, 'SEG' for super-engineering grade, and 'HI' for high-intensity (FP-85 type III-A) sheeting materials. For example, an 'HI/SEG' Exit sign means that the sign copy was made of high-intensity sheeting, whereas the sign background was made of super-engineering grade sheeting.

Tables B-1 through B-13 (Appendix B) summarize the ANOVA results and the conclusions of hypothesis testing. Results of the Newman-Keuls' test are given in Tables C-1 through C-26 (Appendix C). The following paragraphs present the major findings of statistical analyses.

Mean Detection Distance, MDD

1. *Rural Environment, Experiment* 1

- Analysis of variance results indicated that the sheeting material had a significant effect on the *overall* MDD of *all* sign types (Stop, Speed Limit, and Merge Symbol). The sign × sheeting interaction was not significant.

- Considering *all* sign types, pairwise comparisons showed that the *overall* MDD of high-intensity sheeting was significantly larger than those of the engineering grade and super-engineering grade sheeting materials. Furthermore, the *overall* MDD of super-engineering grade was significantly larger than that of the engineering grade sheeting.

- For the Stop sign, pairwise comparisons indicated that the high-intensity sheeting had a significantly larger MDD than the engineering grade and super-engineering grade sheeting materials. Moreover, the super-engineering grade had a significantly larger MDD than the engineering grade sheeting.

- For the Speed Limit sign, pairwise comparisons indicated that the high-intensity sheeting had a significantly larger MDD than the engineering grade sheeting; the MDDs of high-intensity and super-engineering grade sheeting materials were not significantly different; and the MDDs of super-engineering and engineering grade sheeting materials were not significantly different.

- Results of pairwise comparisons for the Merge Symbol sign were similar to those of the Speed Limit sign. The MDD of high-intensity sheeting was significantly larger than that of the engineering grade sheeting; the MDDs of high-intensity and super-engineering grade sheeting materials were not significantly different; and the MDDs of super-engineering and engineering grade sheeting materials were not significantly different

2. *Rural Environment, Experiment* 2

- Analysis of variance results indicated that the combination of sheeting materials used in fabricating the sign legend and the sign background had a significant effect on the *overall* MDD of *both* the Exit and Rest Area signs. The sign × sheeting interaction was not significant.

- Considering *both* sign types, pairwise comparisons showed that the *overall* MDD of high-intensity legend on high-intensity background (HI/HI) was significantly larger than the those of the EG/EG, SEG/EG, HI/EG, and SEG/SEG sheeting materials. There was no significant difference between the *overall* MDDs of HI/HI and HI/SEG.

  Likewise, the *overall* MDD of HI/SEG was significantly larger than those of EG/EG and SEG/EG; the *overall* MDD of SEG/SEG was significantly larger than those of EG/EG and SEG/EG; the *overall* MDD of HI/EG was significantly larger than that of EG/EG; and the *overall* MDD of SEG/EG was significantly larger than that of EG/EG.

- For the Exit sign, pairwise comparisons indicated that the HI/HI had a significantly larger MDD than the EG/EG, SEG/EG, and HI/EG. There were no significant differences between the MDDs of HI/HI, HI/SEG, and SEG/SEG. Moreover, the MDDs of both the HI/SEG and SEG/SEG were significantly larger than the MDD of EG/EG.

- Results of pairwise comparisons for the Rest Area sign showed that there were only three significant differences between the MDDs of the different legend/background sheeting material combinations. The MDD of HI/HI was significantly larger than that of the EG/EG; the HI/SEG was significantly larger than the EG/EG; and the HI/EG was significantly larger than the EG/EG.

3. *Urban Environment, Experiment* 1

- The ANOVA results indicated that the sign × sheeting interaction was significant, and therefore, the analysis was repeated for each sign separately using a randomized complete block design. For each *individual* sign (Stop, Speed Limit, and Merge symbol), the sheeting material had a significant effect on MDD.

- For the Stop sign, pairwise comparisons indicated that the high-intensity sheeting had a significantly larger MDD than the engineering grade sheeting; the MDDs of high-intensity and super-engineering grade sheeting materials were not significantly different; and the MDD of super-engineering grade was significantly larger than that of the engineering grade sheeting.

- For the Speed Limit sign, pairwise comparisons indicated that the high-intensity sheeting had a significantly larger MDD than the engineering grade and the super-engineering grade sheeting materials; and the MDDs of super-engineering grade and engineering grade sheeting materials were not significantly different.

- Results of pairwise comparisons for the Merge Symbol sign were similar to those of the Speed Limit sign. The MDD of high-intensity sheeting was significantly larger than those of the engineering grade and the super-engineering grade sheeting materials; and the MDDs of super-engineering grade and engineering grade sheeting materials were not significantly different.

4. *Urban Environment, Experiment* 2

- Analysis of variance results indicated that the combination of sheeting materials used in fabricating the sign legend and the sign background had a significant effect on the *overall* MDD of *both* the Exit and Rest Area signs. The sign × sheeting interaction was not significant.

- Considering *both* sign types, pairwise comparisons showed that the *overall* MDD of high-intensity legend on high-intensity background (HI/HI) was significantly larger than the those of the EG/EG, SEG/EG, and HI/EG sheeting materials. There was no significant difference between the *overall* MDDs of HI/HI, HI/SEG, and SEG/SEG.

  Likewise, the *overall* MDD of HI/SEG was significantly larger than those of the HI/EG, SEG/SEG, and SEG/EG. Also, the *overall* MDD of EG/EG was significantly larger than those of the HI/EG, SEG/EG and EG/EG.

- For the Exit sign, pairwise comparisons indicated that the HI/HI had a significantly larger MDD than the EG/EG and HI/EG. There were no significant differences between the MDDs of HI/HI, HI/SEG, SEG/SEG, and SEG/EG. Moreover, the MDD of the SEG/SEG was significantly larger than the MDD of EG/EG.

- Results of pairwise comparisons for the Rest Area sign showed that there were only two significant differences between the MDDs of the different legend/background sheeting material combinations. The MDD of HI/HI was significantly larger than that of the SEG/EG; and the MDD of HI/SEG was significantly larger than that of the SEG/EG.

Mean Recognition Distance, MRD

1. *Rural Environment, Experiment* 1

- Analysis of variance results indicated that the sheeting material had a significant effect on the *overall* MRD of *all* sign types (Stop, Speed Limit, and Merge symbol). The sign × sheeting interaction was not significant.

- Considering *all* sign types, pairwise comparisons showed that the *overall* MRD of high-intensity sheeting was significantly larger than that of the engineering grade sheeting; the *overall* MRDs of high-intensity and super-engineering grade sheeting materials were not significantly different; and the *overall* MRDs of super-engineering and engineering grade sheeting materials were not significantly different

- For the Stop sign, pairwise comparisons indicated that the MRD of high-intensity sheeting was significantly larger than that of the engineering grade sheeting; the MRDs of high-intensity and super-engineering grade sheeting materials were not significantly different; and the MRDs of super-engineering and engineering grade sheeting materials were not significantly different.

- For the Speed Limit sign, pairwise comparisons showed that the MRDs of the high-intensity, super-engineering grade, and the engineering grade sheeting were not significantly different. Similar results were found for the Merge Symbol sign.

2. *Rural Environment, Experiment* 2

- The ANOVA results indicated that the sign × sheeting interaction was significant, and therefore, the analysis was repeated for each sign separately using a randomized complete block design. For the Exit sign, the combination of sheeting materials used in fabricating the sign legend and the sign background had a significant effect on the MRD. The sheeting material had no significant effect on the MRD of the Rest Area sign.

- For the Exit sign, pairwise comparisons indicated that the HI/HI had a significantly larger MRD than the SEG/SEG. There were no significant differences between the MRDs of HI/HI, HI/SEG, HI/EG, SEG/EG, and EG/EG.

  Likewise, the MRD of HI/SEG was significantly larger than that of SEG/SEG; the MRD of HI/EG was significantly larger than that of SEG/SEG; the MRD of SEG/EG was significantly larger than that of SEG/SEG; and the MRD of EG/EG was significantly larger than that of SEG/SEG.

- Results of pairwise comparisons for the Rest Area sign were consistent with the ANOVA results, that is, sheeting material had no significant effect on the MRD.

3. *Urban Environment, Experiment* 1

- The ANOVA results indicated that the effect of sheeting material on the *overall* MRD of *all* sign types (Stop, Speed Limit, and Merge symbol) was not significant. Furthermore, the sign × sheeting interaction was not significant.

- Considering *all* sign types, pairwise comparisons showed that the *overall* MRDs of the high-intensity, super-engineering grade, and engineering grade sheeting materials were not significantly different.

- For the Stop sign, pairwise comparisons indicated that the MRDs of the high-intensity, super-engineering grade, and engineering grade sheeting materials were not significantly different. Similar results were obtained for the Speed Limit sign, and the Merge Symbol sign.

4. *Urban Environment, Experiment* 2

- Analysis of variance results indicated that the combination of sheeting materials used in fabricating the sign legend and the sign background had a significant effect on the *overall* MRD of *both* the Exit and Rest Area signs. The sign × sheeting interaction was not significant.

- Considering *both* sign types, pairwise comparisons showed that the *overall* MRD of high-intensity legend on engineering grade background (HI/EG) was significantly larger than the those of the HI/HI, HI/SEG, SEG/SEG, SEG/EG, and EG/EG sheeting materials. There were no significant differences between the *overall* MRDs of HI/HI, HI/SEG, SEG/SEG, SEG/EG, and EG/EG.

- For the Exit sign, pairwise comparisons indicated that the HI/EG had a significantly larger MRD than the SEG/SEG. There were no significant differences between the MRDs of HI/HI, HI/SEG, SEG/SEG, SEG/EG, and EG/EG.

- Results of pairwise comparisons for the Rest Area sign showed that there were no significant differences between the MRDs of the different legend/background sheeting material combinations (HI/HI, HI/SEG, HI/EG, SEG/SEG, SEG/EG, and EG/EG).

MINIMUM REQUIRED VISIBILITY DISTANCES

Tables D-1 through D-5 (Appendix D) list the minimum required visibility distances for the traffic signs used in this study. These values were computed using the MRVD microcomputer program, version 1.0 [11]. Input data required by MRVD include the MUTCD code of a standard sign, sign placement (height above road surface and offset from the right edge of pavement), visual complexity of the location (low, medium, or high), number of lanes, lane width, driver's lane, traffic volume (low, medium, or high), posted speed limit, desired vehicle speed upon reaching the sign, and driver characteristics (age, vision percentile, or Snellen acuity). The MRVD program supplements this input data with information stored in the sign dictionary for the specific sign in question (number of lines of text, number of symbols, number of choices, type of response required, etc.), and computes the required detection and legibility distances. For traffic signs that do not have standard dimensions, version 8.04 of the MRVD program includes 'generic' signs representative of typical guide and motorist information signs. This version of MRVD has not been released by the FHWA.

Comparisons of the visibility distances obtained from the field experiments with the minimum values obtained from the MRVD program indicated the following:

Stop Sign (R1-1)

1. *Rural Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.

- MRD exceeded the minimum required recognition distance except for the following cases:

  1) Engineering grade sheeting: speed limit ≥ 50 mph and high traffic volume.
  2) Super-engineering grade sheeting: speed limit ≥ 50 mph and high traffic volume.
  3) High-intensity sheeting: speed limit ≥ 55 mph and high traffic volume.

2. *Urban Environment*

- MDD exceeded the minimum required detection distance except for the following cases:

  1) Engineering grade sheeting: speed limit of 50 mph, high traffic volume and high visual complexity; and speed limit ≥ 55 mph, high traffic volume, and medium or high visual complexity.

  2) Super-engineering grade sheeting: speed limit ≥ 55 mph, high traffic volume and high visual complexity.

- MRD exceeded the minimum required recognition distance except for the cases of speed limit 45-50 mph and high traffic volume; and the cases of speed limit ≥ 55 mph regardless of traffic volume.

Speed Limit Sign (R2-1)

1. *Rural Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, an assumed 10 mph reduction in speed upon reaching the sign, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.

- MRD exceeded the minimum required recognition distance except for the following cases:

  1) Engineering grade sheeting: speed limit ≥ 45 mph and high traffic volume.

  2) Super-engineering grade sheeting: speed limit ≥ 45 mph and high traffic volume.

  3) High-intensity sheeting: speed limit ≥ 50 mph and high traffic volume.

2. *Urban Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, an assumed 10 mph reduction in speed upon reaching the sign, all levels of traffic volume and visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.
- MRD exceeded the minimum required recognition distance except for the following cases:
  1) Engineering grade sheeting: speed limit ≥ 55 mph regardless of traffic volume; and all cases of high traffic volume.
  2) Super-engineering grade sheeting: speed limit ≥ 45 mph and high traffic volume.
  3) High-intensity sheeting: speed limit ≥ 45 mph and high traffic volume.

Merge Symbol Sign (W4-1)

1. *Rural Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.
- MRD exceeded the minimum required recognition distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.

2. *Urban Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.
- MRD exceeded the minimum required recognition distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.

Exit Sign (E5-1)

1. *Rural Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, , an assumed exit speed that is 10 mph less than the posted speed limit, all levels of traffic volume, and all levels of visual complexity. This was true for all six combinations of retroreflective sheeting materials evaluated in this study.
- MRD exceeded the minimum required recognition distance except for the following cases:
  1) EG/EG: speed limit 45-50 mph and high traffic volume; and speed limit ≥ 55 mph regardless of traffic volume.
  2) HI/HI, HI/SEG, HI/EG, SEG/SEG, SEG/EG: speed limit ≥ 50 mph and high traffic volume.

2. *Urban Environment*

- MDD exceeded the minimum required detection distance except for the cases of HI/EG, SEG/EG, and HI/EG with high traffic volume and high visual complexity.

- MRD exceeded the minimum required recognition distance except for the following cases:

  1) HI/HI, HI/SEG, HI/EG, and SEG/EG: speed limit 45-50 mph and high traffic volume; and speed limit ≥ 55 mph regardless of traffic volume.

  2) SEG/SEG: speed limit ≥ 50 mph and medium traffic volume; and all cases of high traffic volume.

  3) EG/EG: Speed limit ≥ 45 and high traffic volume; and speed limit ≥ 50 mph and medium traffic volume.

Rest Area Sign (D5-2)

1. *Rural Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all six combinations of retroreflective sheeting materials evaluated in this study.

- MRD exceeded the minimum required recognition distance except for the following cases:

  1) HI/HI: speed limit ≥ 45 mph and high traffic volume.

  2) HI/SEG, SEG/SEG, SEG/EG, and EG/EG: speed limit ≥ 50 mph and high traffic volume.

  3) HI/EG: speed limit ≥ 55 mph and high traffic volume.

2. *Urban Environment*

- MDD exceeded the minimum required detection distance for speed limit of 55 mph or less, all levels of traffic volume, and all levels of visual complexity. This was true for all three retroreflective sheeting materials evaluated in this study.

- MRD exceeded the minimum required recognition distance except for the following cases:

  1) HI/HI, SEG/EG, and EG/EG: high traffic volume regardless of speed limit or visual complexity.

  2) HI/SEG, SEG/SEG: speed limit ≥ 45 mph and high traffic volume.

  3) HI/EG: speed limit ≥ 50 mph and high traffic volume.

CHAPTER 5

DURABILITY CONSIDERATIONS

This chapter addresses the in-service deterioration modes of retroreflective sheeting materials, the shortcomings of the recently developed regression equations for predicting service life, and the methods of accelerated weathering. Results of outdoor exposure at 45° angle are presented.

DETERIORATION MODES

The typical deterioration modes encountered by in-service retroreflective signs include loss of retroreflectivity, color fading, cracking, abrasion, peeling, and dirt accumulation [4, 8]. The following paragraphs provide brief description of these deterioration modes:

Loss of Retroreflectivity - Except for screened background colors, sheeting retroreflectivity decreases with age due to natural weathering. Environmental stresses (solar radiation, humidity, temperature, air pollution, etc.) cause gradual oxidation of the metallic reflector coat and/or the outermost polymer layer which results in loss of retroreflectivity. The rate of deterioration depends on several factors including sheeting type (enclosed lens, encapsulated lens, or cube corner), sheeting color, geographic location, area type, and seasonal as well as year-to-year changes in climate.

Color fading - Exposure to sunlight and air pollutants causes fading of the pigments used in the production of colored retroreflective sheetings or screened inks used in sign fabrication. This leads to progressive degradation in color recognition and loss of internal contrast, particularly red screened backgrounds used in the production of "stop" signs. As the screened red ink fades over time, more of the white sheeting is exposed, resulting in lower contrast with the white legend and border.

Cracking - Differences in thermal expansion between the sheeting and backing substrate may cause cracking of the sheeting. This affects both daytime appearance and nighttime retroreflectivity due to the distortion of the optical elements within the sheeting and the damage of the metallic reflector coat.

Abrasion - Coarse particles blown by wind, deicing salt/sand spray, and industrial pollutants lead to deterioration of the outermost polymer layer, causing roughness and cloudiness of the originally smooth, transparent sign face. Consequently, nighttime retroreflectivity is diminished, and daytime appearance becomes dull.

Peeling - Full-depth separation of the sheeting from the substrate results from failure of the adhesive bond between layers of the composite. This is caused by either poor sign fabrication processes or problems with the manufacturing of the sheeting material. As a result, nighttime brightness and day time appearance are adversely affected.

Dirt Accumulation - Airborne dirt affects most signs during their service life. Unless the dirt becomes deeply embedded into the sign face, it is usually removed by rainfall. A New York DOT study involving 213 signs with engineering grade sheeting found that most signs receive little added increase in retroreflectivity due to maintenance washing [8].

Sheeting deterioration is usually initiated or accelerated by a particular combination of environmental conditions that may only occur in certain geographical locations or climates. In a recent study [2], retroreflcetivity measurements were taken on 5,722 signs with engineering grade (type-II) and high-intensity (type-IIIA) sheetings from 18 sites throughout the United States. The following observations were made during the data collection process:

- Signs close to the coast (Virginia site) and signs subjected to severe weather conditions (Vermont site) experienced considerable peeling and cracking of the sheeting material than signs at the sites in New York, Ohio, and Tennessee. Significant cracking and peeling was also observed at the sites in Louisiana and Wisconsin.
- Cracking was more prevalent in engineering grade than high-intensity sheeting materials. Peeling was observed in high-intensity sheeting, particularly at bends on the sign face and dents at the mounting bolts.
- Color fading of engineering grade and high-intensity sheetings was generally uniform across the sign face, but some fading in spots of the engineering grade signs was observed in the mid-west. On stop signs, fading of the screened red ink on white-color, high-intensity sheeting led to much higher reflectivity of the sign background.
- Traffic signs made with wood substrate appeared to be more weather worn than signs with aluminum substrate. Scratches, bends, and dents of aluminum panels seemed to have a greater impact on the overall condition of signs with high-intensity sheetings.
- Some instances of north facing signs having lower retroreflectivity readings than comparable south facing signs were found on milepost and street name signs in Oregon. The north facing signs experienced lingering moisture and absence of direct sunlight which resulted in mildew and moss formation. This affected the north facing signs more than the solar radiation affected comparable south facing signs.
- Signs with engineering grade sheeting seemed to benefit more from sign washing than those with high-intensity sheeting due to the slippery surface of the latter.
- Sign vandalism (spray paint, stickers, bullet holes, etc.) was more prevalent in rural areas.

In addition, contrary to the popular belief that signs facing south deteriorate faster than those facing north, the study found that there was no distinct pattern of sheeting deterioration based on sign orientation [2].

PREDICTION OF SHEETING DETERIORATION

As discussed in Chapter 2, an FHWA contract study lead to the development of nine regression equations to predict the in-service R_A and/or contrast ratios of types II and IIIA sheeting materials [2]. The independent variables used in these equations were in-service age, precipitation level, ground elevation, and heating degree-days. Not surprisingly, the models failed to explain a significantly large percentage of the total variation in the measured R_A values as exhibited by the low values of the coefficient of determination, R^2, listed in the last column of Table 3. The primary reason for this low precision is data aggregation. The models were developed using data which were collected from 18 sites with different climatic and environmental characteristics. Perhaps, one of the key lessons learned from this study is that analytical models of sheeting deterioration cannot be developed at the national level. Other reasons for the inadequacy of these models are statistical in nature. Climatic variables are highly correlated among themselves, and therefore several important variables that influence sheeting deterioration cannot be included in the same regression model.

Mathematical models of sheeting deterioration should be site specific. Since prevailing climatic and environmental variables would be automatically accounted for, the only independent variable to be included in the model is the in-service age of the sheeting. Nevertheless, the very large variability in R_A of new sheeting materials represents a major problem that complicates the development of reliable deterioration models. This variability can be encountered in the same roll of a new sheeting material and among rolls of the same material.

ACCELERATED WEATHERING

Evaluating the durability of retroreflective sheeting materials under normal weathering conditions is a long-term undertaking. Because of the lack of systematic monitoring and testing efforts, useful performance data are often unavailable. Furthermore, durability results obtained at one location may not be indicative of the sheeting performance at another location. Yet, another problem with durability testing is that sheeting manufacturers keep improving and changing their products which invalidates the results of long-term exterior exposure.

Much of the durability testing of retroreflective sheeting materials is accomplished through accelerated weathering. The two common methods used for this purpose are artificial or "machine" weathering, known as weatherometer testing, and outdoor exposure at 45° angle. The former method is described in the ASTM Standard Practice G23-84, whereas the latter method is described in the ASTM G7-83.

The primary use of artificial weathering is in purchase specifications. For example, the FP-85 specifies that after the retroreflective sheeting is subjected to accelerated weathering in accordance with ASTM G23 (type E or EH weatherometer with the humidifier off), the sheeting shall have no less than a prescribed percentage of the minimum R_A for new sheeting materials. The prescribed percentages and the corresponding hours of testing are: 50% after 1,000 hours of exposure for type-II sheeting, 65% after 2,200 hours of exposure for type-IIA sheeting, and 80% after 2,200 hours of exposure for type-III sheeting. In addition, the sheeting shall show no appreciable discoloration, cracking, blistering, or dimensional change at the conclusion of the artificial weathering test.

Correlation factors which relate hours of artificial weathering per ASTM G23 and years of natural exposure have been proposed in the literature, e.g., 5,000 hours in a weatherometer is the equivalent of sixteen to seventeen years of outdoor exposure. Nevertheless, there are several reasons why such "acceleration factors" are meaningless. Poor replication of exterior stresses in weathering chambers; variation in exterior climates with respect to time, geography, and topography; and the large variability associated with the test procedure are among the reasons cited in the literature [9].

Unlike artificial weathering, accelerated outdoor exposure per ASTM G7 offers a satisfactory method for obtaining reliable indications of the long-term durability of retroreflective sheeting materials in a relatively short time frame. Materials exposed at 45° angle from the horizontal and facing south receive significantly higher levels of the key factors that cause sheeting degradation (ultraviolet radiation, moisture, and temperature) than those exposed vertically. The acceleration rate is approximately 2:1 depending on the property being measured [9]. Because sheeting performance at one location will not be indicative of its performance at a different environment, test racks should be constructed at representative sites. Exterior exposure testing should continue for more than one year to minimize seasonal and year-to-year effects that contribute to variability of the results. Furthermore, the testing should employ replicate test specimens selected at random to improve the reliability of results.

Figures 15 through 19 depict unpublished results of outdoor exposure for sheeting types II, IIA, and IIIA with red, white, yellow, green, and blue colors. The different plots for each sheeting type and color represent different manufacturers and/or replicate samples from the same manufacturer. Testing was performed by the FHWA Photometric and Visibility Laboratory at Turner-Fairbank Highway Research Center, McLean, Virginia, for a period of five years (1989 through 1993). Sheeting samples were 4" × 6" in size with pressure sensitive adhesive. The samples were attached to aluminum panels (0.063" thick) by pressure and exposed on a stainless steel wire-mesh (0.03" diameter wire with 0.25" square openings) rack at 45° facing south. The R_A measurements were made at 0.2° observation angle and -4° entrance angle on the new sheeting materials (year 0) and at the end of each year of exposure thereafter.

The plots in Figures 15 through 19 reveal large variation in R_A of sheeting materials of the same type and color, even when they are new. As noted, all new sheeting materials exceeded the minimum initial R_A values specified in the FP-85 for purchasing purposes. In addition, the following observations can be made concerning R_A of the sheeting materials after 5 years of accelerated outdoor exposure (approximately 10 years of normal weathering):

<u>White color</u> - All sheeting materials exceeded the minimum required R_A values established by the FHWA for ground mounted black-on-white regulatory and guide signs. Furthermore, the R_A of type-IIIA sheeting was about 2.3 times higher than the R_A of type-IIA and 3.5 times higher than the R_A of type-II sheeting materials.

<u>Red color</u> - The R_A of type-IIIA sheeting was about 2.0 times higher than the R_A of type-IIA and 2.3 times higher than the R_A of type-II sheeting materials. All three sheeting materials, exceeded the minimum required R_A values for the red background of white-on-red regulatory signs. Nevertheless, sheeting types II and IIA failed to maintain the minimum contrast ratio of 4:1 between the white and red colors.

<u>Yellow color</u> - All sheeting materials exceeded the minimum required R_A values for black-on-yellow warning signs. Furthermore, the R_A of type-IIIA sheeting was about 2.5 times higher than the R_A of type-IIA and 3.0 times higher than the R_A of type-II sheeting materials.

<u>Green color</u> - The R_A of type-IIIA sheeting was about 2.2 times higher than the R_A of type-IIA and 4.5 times higher than the R_A of type-II sheeting materials. All sheeting materials exceeded the minimum required R_A values for the green background of ground-mounted guide signs as well as the minimum contrast ratio of 4:1 between the white legend and green background. For overhead guide signs, type-II sheeting failed to meet the minimum required R_A value for the green background, and type-IIA appeared to be marginal.

<u>Blue color</u> - The R_A of type-IIIA sheeting was about 3.5 times higher than the R_A of type-IIA and 5.4 times higher than the R_A of type-II sheeting materials. There are no minimum R_A requirements for blue color signs.

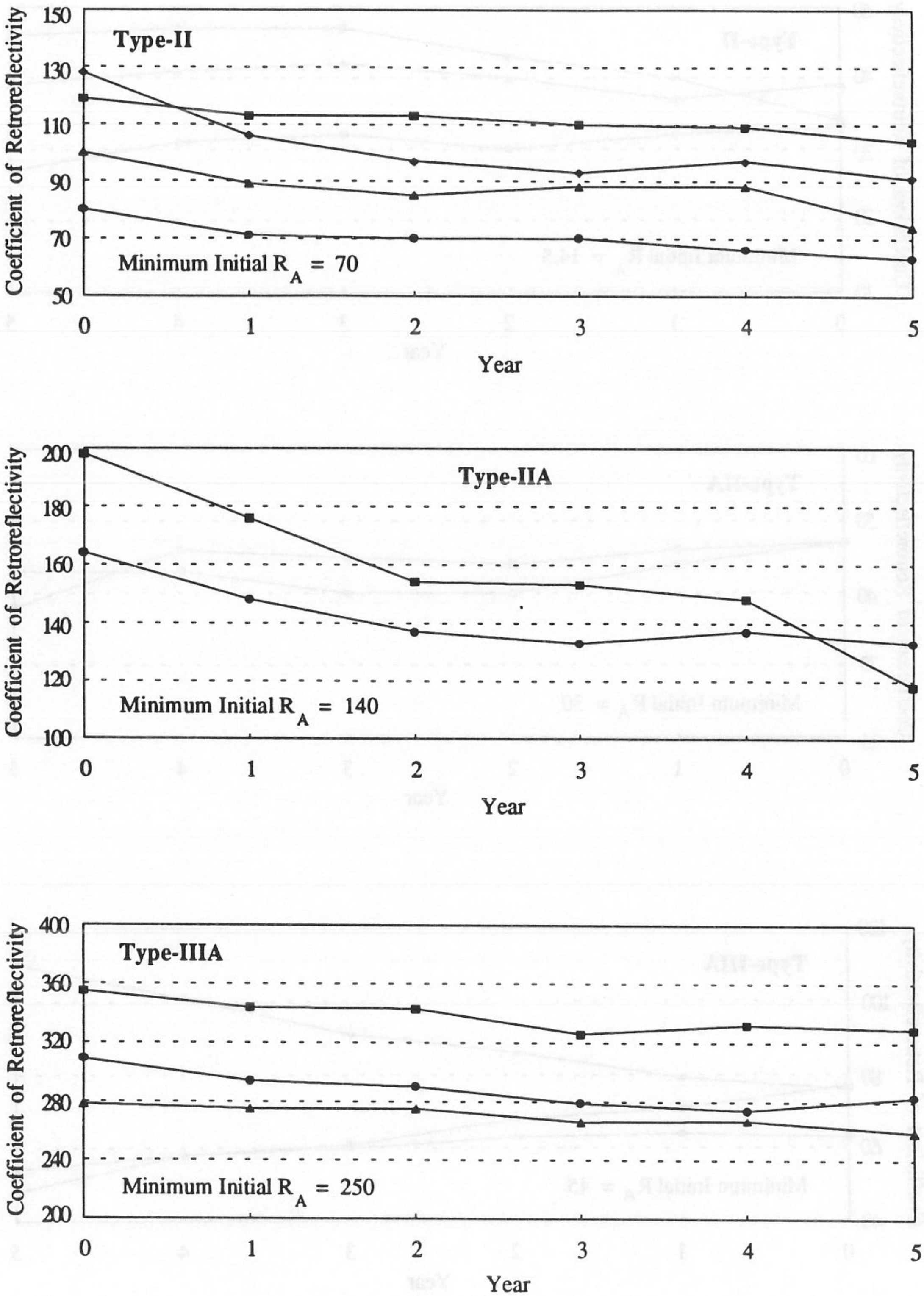


Figure 15. Results of Outdoor Exposure at 45° Facing South, White Color

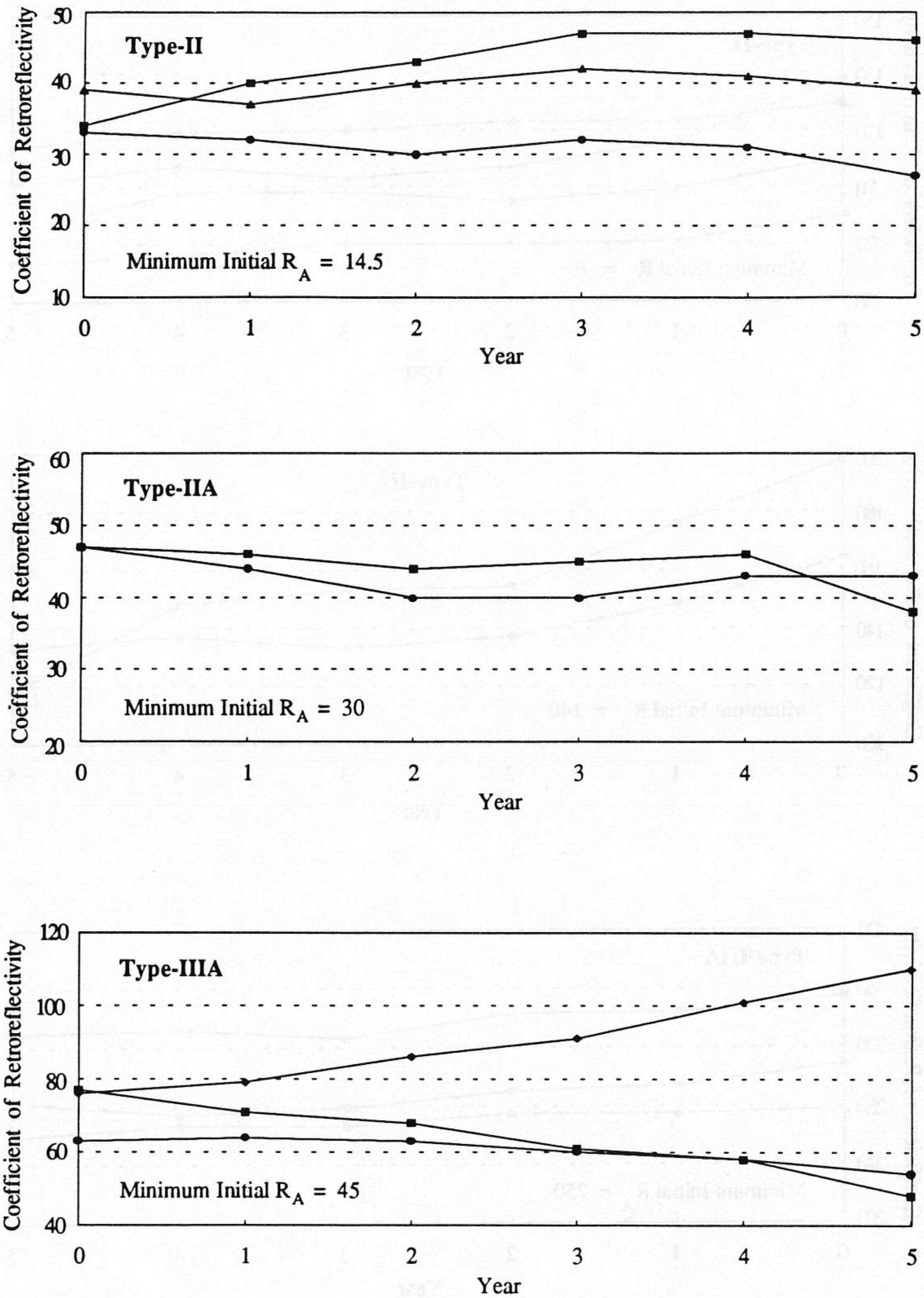


Figure 16. Results of Outdoor Exposure at 45° Facing South, Red Color

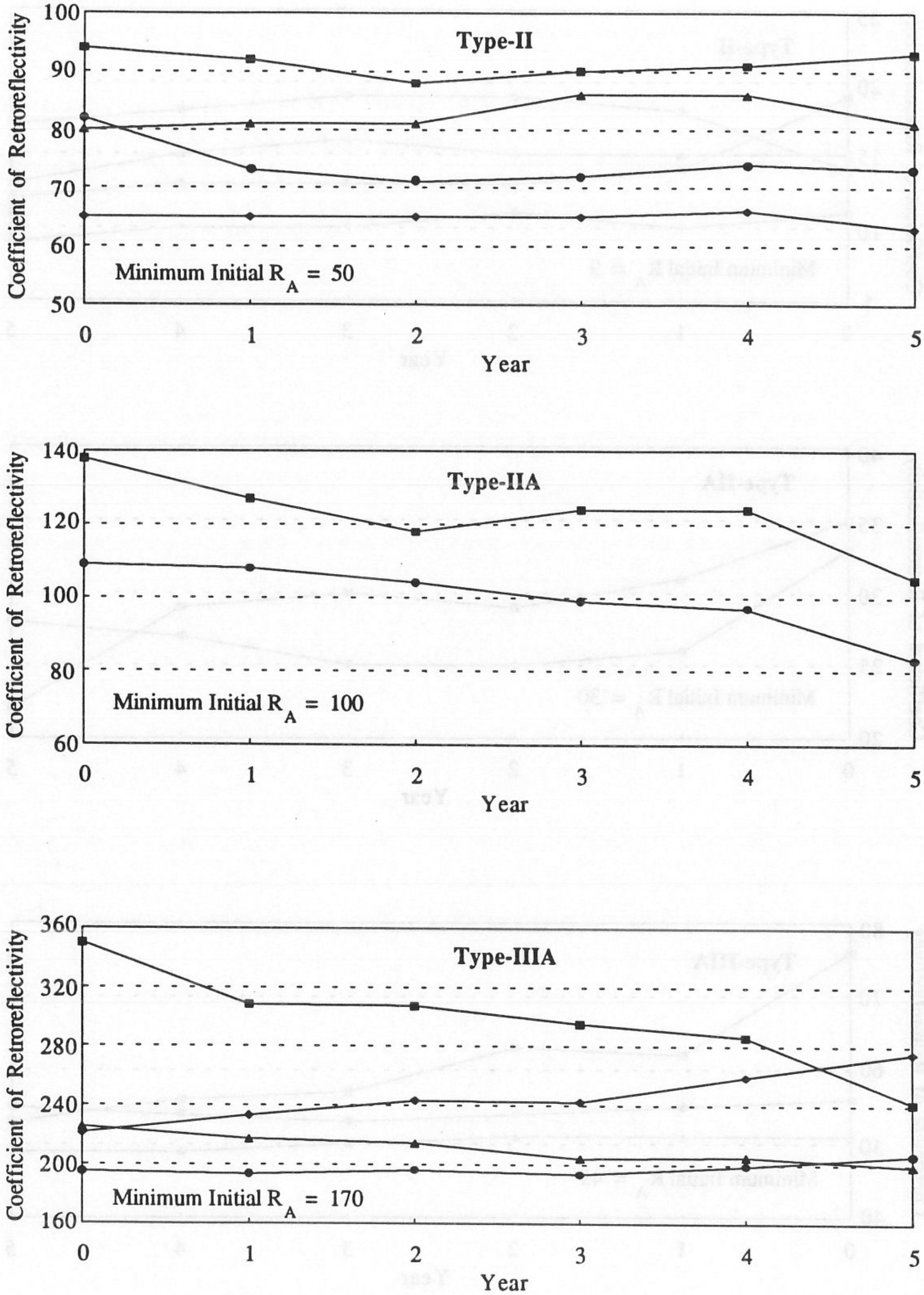
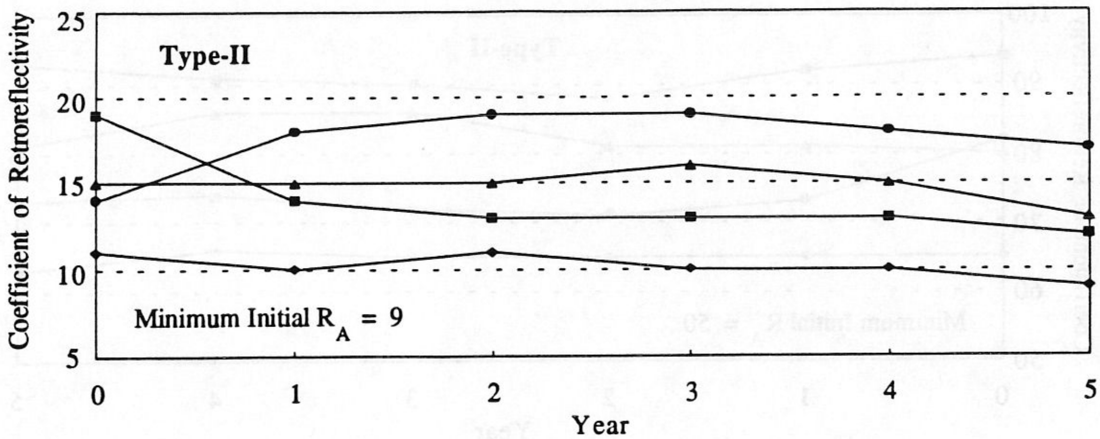
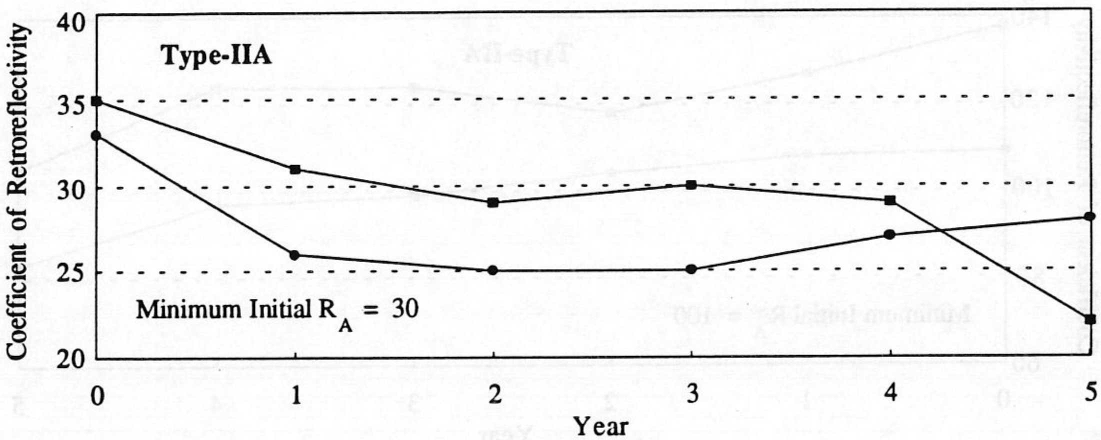


Figure 17. Results of Outdoor Exposure at 45° Facing South, Yellow Color





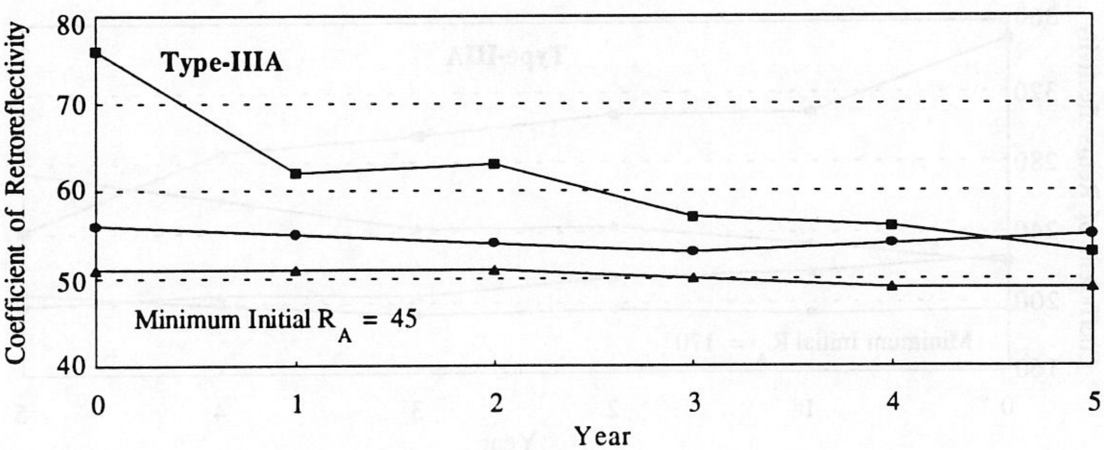


Figure 18. Results of Outdoor Exposure at 45° Facing South, Green Color

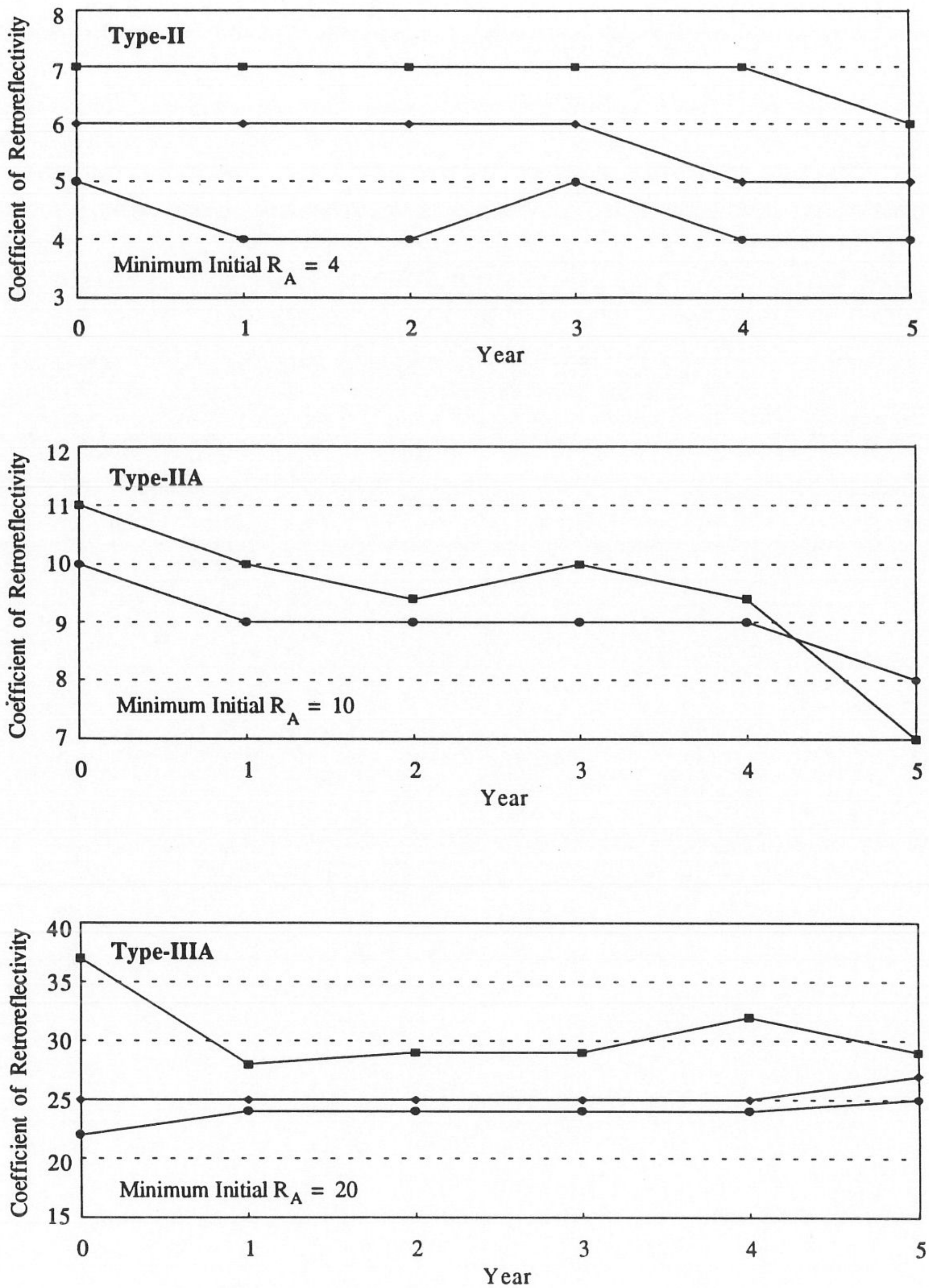


Figure 19. Results of Outdoor Exposure at 45° Facing South, Blue Color

CHAPTER 6

LIFE-CYCLE COST ANALYSIS

This chapter summarizes the results of life-cycle cost analysis for types II, IIA, and IIIA retroreflective sheeting materials. The chapter is organized as follows. First, measures of economic effectiveness are introduced. Second, cost data for sign face fabrication and sign installation are presented. Third, the service lives of sheeting materials are discussed. Finally, the findings of the economic analysis including sensitivity analyses are reported.

MEASURES OF EFFECTIVENESS

Alternatives that offer identical benefits or provide the same service are usually compared to each other on the basis of life-cycle cost. The life-cycle cost of a given alternative includes all costs anticipated throughout its service life. Two measures of effectiveness (MOEs) have been proposed by McGee and Mace for evaluating the economic worth of retroreflective sheeting materials [12]. The first MOE is the ratio of total cost to service life of the sign, i.e.,

$$C = \frac{C_T}{n} \tag{6.1}$$

where C is the cost per year of service life; C_T is the total cost; and n is the expected service life of sign in years. For new signs, C_T includes the cost of sign fabrication (sheeting material, aluminum substrate, equipment, labor, and overhead) and the cost of sign installation (sign supports, fasteners, footings, equipment, labor, travel, and overhead). When a sign is refurbished, C_T includes the cost of fabricating a new sign face (sheeting material, aluminum panel, equipment, labor, and overhead) and the cost of overlaying the new sign face over the existing one (equipment, labor, travel, and overhead). The service life is the time period during which the luminance supplied by the sign exceeds or equals the luminance demanded by the drivers for sign detection and recognition.

In the second MOE proposed by McGee and Mace, the average luminance provided by the sheeting material over its service life is included in computing the cost per year as follows:

$$C = \frac{C_T}{\frac{L_n + L_o}{2} \times n} \tag{6.2}$$

where C, C_T, and n are as defined earlier; L_n and L_o are the SIA values of the sheeting material when it is new and at the end of its service life, respectively.

Unlike the MOEs given by equations 6.1 and 6.2, methods of engineering economic analysis provide a host of other MOEs which account for the time-value-of-money [19, 23]. Of these, the equivalent uniform annual cost (EUAC) appears to be the most appropriate MOE for life-cycle cost analysis of sheeting materials. Mathematically, EUAC is computed by multiplying the present worth of total cost by the capital-recovery factor (CRF) at a given interest rate, that is,

$$EUAC_j = PW_j \times \frac{i(1+i)^n}{(1+i)^n - 1} \tag{6.3}$$

where PW_j is the present worth of cost of alternative j, n is its service life, and i is the interest rate.

When the alternatives under consideration have unequal service lives, as it is the case in retroreflective sheeting materials, it is necessary to compare them over a common period of time referred to as the planning horizon or study period. Typical planning horizons which are commonly used in economy studies include the *least common multiple of service lives of the different alternatives*, and the *shortest life among alternatives* [19, 23].

In using the *least common multiple of service lives* of the different alternatives as the planning horizon, it is assumed that life-cycle cost profile of each alternative will be repeated until all alternatives conclude at the same time. For example, if the service lives of types II, IIA, and IIIA sheeting materials were 6, 12, and 15 years, respectively, a planning horizon of 60 years would be used. The cost profiles of types II, IIA, and IIIA sheeting materials will be replicated 10, 5, and 4 times, respectively, throughout the planning horizon. Nevertheless, inflation effects, technological developments, and future replacement decisions tend to invalidate the assumption that identical cost profiles will take place during these repeating life cycles of each alternative [23].

If the *shortest life among alternatives* is used as the planning horizon, an adjustment must be made for the remaining value of those alternatives with longer service lives. Perhaps, this adjustment may be in the form of an implied salvage or residual value of the unused capital costs. Alternatively, a credit for the remaining value may be applied to the annual cost during the planning horizon. The latter approach was used in a recent study of retroreflective sheeting use in Kansas [16]. Computing the value of the credit involves two steps. First, the present worth of the remaining value at the end of the planning horizon is determined using the expression:

$$PW_j' = EUAC_j \times \frac{(1+i)^{n-n'} - 1}{i(1+i)^{n-n'}} \tag{6.4}$$

where n is the service life of the alternative under consideration, and n' is the shortest life among alternatives, i.e., the planning horizon. For example, if the service lives of types II, IIA, and IIIA sheeting materials were 7, 12, and 15 years, respectively, n' would be 7 years and n would be 12 years and 15 years for types IIA and IIIA, respectively. The next step is to convert this present worth to an equivalent uniform annual worth using the appropriate sinking fund factor as follows:

$$A_j = PW_j' \times \frac{i}{(1+i)^{n'} - 1} \tag{6.5}$$

Table 19 illustrates an example of EUAC computations for an n' of 7 years and an i of 8%.

COST DATA

Table 20 summarizes the cost of sign face fabrication (sheeting material, aluminum substrate, equipment, labor, and overhead) based on cost items provided by the ODOT Sign Shop. For type-II sheeting material, the cost per square foot of the sign face is \$2.7 for 'standard' signs and \$4.15 for 'special' signs. Standard signs are those signs which are fabricated in relatively large numbers and do not deviate from established pattern library. They usually require less labor than the 'special' signs. For type-IIA sheeting material, the cost per square foot of the sign face is \$4.15 for 'standard' signs and \$5.45 for 'special' signs. For type-IIIA sheeting material, the cost per square foot of the sign face is \$6.85 for all signs.

Table 19. Example of EUAC Computations (Interest Rate = 8%, Analysis Period = 7 Years)

Item	Stop Sign 30″ × 30″			Speed Limit Sign 24″ × 30″		
	Sheeting Type			Sheeting Type		
	II	IIA	IIIA	II	IIA	IIIA
Fabrication Cost ($)	12.94	25.94	42.81	10.35	20.75	34.25
Installation Cost ($)	130.00	130.00	130.00	130.00	130.00	130.00
Total Cost ($)	142.94	155.94	172.81	140.35	150.75	164.25
Service Life of Sheeting (years)	7	12	15	7	12	15
CRF	0.1921	0.1327	0.1168	0.1921	0.1327	0.1168
Uniform Annual Cost ($)	27.45	20.69	20.19	26.96	20.00	19.19
Adjustment Factor	0.0000	0.4475	0.6440	0.0000	0.4475	0.6440
Adjustment ($)	00.00	9.26	13.00	00.00	8.95	12.36
EUAC ($)	27.45	11.43	7.19	26.96	11.05	6.83

Table 20. Sign Face Fabrication Cost in 1994 Dollars

Sign Type	Sign Size[a]	Area ft^2	Sheeting Type (FP-85)		
			II	IIA	IIIA
Stop					
	30″ × 30″	6.25	12.94	25.94	42.81
	36″ × 36″	9.00	37.35	49.05	61.65
	48″ × 48″	16.00	66.40	87.20	109.60
Speed Limit					
	24″ × 30″	5.00	10.35	20.75	34.25
	36″ × 48″	12.00	49.80	65.40	82.20
	48″ × 60″	20.00	83.00	109.00	137.00
Merge Symbol					
	30″ × 30″	6.25	12.94	25.94	42.81
	36″ × 36″	9.00	37.35	49.05	61.65
	48″ × 48″	16.00	66.40	87.20	109.60
Exit					
	66″ × 72″	33.00	136.95	179.85	226.05
Rest Area					
	66″ × 132″	60.50	251.07	329.73	414.43

a) 1 inch = 25.4 mm, 1 ft = 0.3048 meter

Sign installation cost data (sign supports, fasteners, footings, equipment, labor, travel, and overhead) were obtained from a survey of the ODOT Divisions. For new, ground-mounted signs up to 50 ft^2 in area, the installation cost ranged from \$78 to \$175 (four responses) with an average of \$130 per sign. Installation cost of new, ground-mounted signs with an area greater than 50 ft^2 ranged from \$340 to \$1,886 (three responses) with an average of \$1,275 per sign. Cost data for new, overhead-mounted signs were provided by only one ODOT Division; \$125 and \$245 per sign for small and large signs, respectively.

The cost of overlaying a new sign face onto an old one in the field was estimated by subtracting the cost of sign supports from the cost of installing a new sign. For ground-mounted signs, the average cost of on-site overlay is \$100 for small signs and \$525 for large signs (two responses). For overhead-mounted signs, the average overlay cost is \$100 for small signs and \$165 for large signs (one response).

SERVICE LIFE

As discussed in Chapter 2, the FHWA study '*Service Life of Retroreflective Traffic Signs*' resulted in nine regression models for predicting the R_A and/or contrast ratios of types II and IIIA retroreflective sheeting materials, albeit with low coefficients of determination. The FHWA study recommended that the developed models could be used to predict the in-service R_A of new sheeting materials by adjusting the constant terms of the regression equations to the R_A of new sheetings as measured in the sign shop, and assuming that the coefficient of the age variable is accurate.

Application of the regression equations in Table 3 and the minimum R_A values established by the FHWA to the new sheeting materials used in this study, resulted in very long service lives that do not agree with the published literature. Due to the shortcomings of the predictive equations which were addressed in Chapter 5, and after discussions with representatives from the FHWA and Bollomo-McGee, Inc, it was decided not to use these equations.

Estimates of service lives were made based on data obtained from ODOT Divisions, sheeting manufacturers, and the published literature. Average service lives of 7, 12, and 15 years were assumed for FP-85 sheeting types II, IIA, and IIIA, respectively. To allow for the uncertainty in estimating service lives, sensitivity analysis were performed to explore their effect on the MOEs.

RESULTS OF LIFE-CYCLE COST ANALYSIS

The MOEs used in this study were the ratio of total cost to service life given by equation 6.1, and the equivalent uniform annual cost defined by equations 6.3 through 6.5. Table 21 summarizes the values of these MOEs for new signs. The EUAC computations were based on a 7-year analysis period (shortest service life among alternatives), and an interest rate of 8%. As indicated by the life-cycle cost analysis, type-IIIA has the least ratio of total cost to service life, followed by type-IIA, and type-II retroreflective sheeting materials. The same conclusion was reached using the EUAC.

Results of the economic analysis of refurbished signs are presented in Table 22. The EUAC computations were based on a 7-year analysis period (shortest service life among alternatives), and an interest rate of 8%. The MOEs indicate that type-IIIA has the least ratio of total cost to service life and the least EUAC, followed by type-IIA, and type-II retroreflective sheeting materials.

Table 21. Values of MOEs for New Signs[a]

Sign Type	Sign Size[b]	Total Cost[c]			Ratio of Total Cost to Service Life			EUAC[d]		
		Sheeting Type[e]			Sheeting Type[e]			Sheeting Type[e]		
		II	IIA	IIIA	II	IIA	IIIA	II	IIA	IIIA
Stop										
	30″ × 30″	142.94	155.94	172.81	20.42	13.00	11.52	27.45	11.43	7.19
	36″ × 36″	167.35	179.05	191.65	23.91	14.92	12.78	32.14	13.13	7.97
	48″ × 48″	196.40	217.20	239.60	28.06	18.10	15.97	37.72	15.92	9.96
Speed Limit										
	24″ × 30″	140.35	150.75	164.25	20.05	12.56	10.95	26.96	11.05	6.83
	36″ × 48″	179.80	195.40	212.20	25.69	16.28	14.15	34.53	14.33	8.82
	48″ × 60″	213.00	239.00	267.00	30.43	19.92	17.80	40.91	17.52	11.10
Merge Symbol										
	30″ × 30″	142.94	155.94	172.81	20.42	13.00	11.52	27.45	11.43	7.19
	36″ × 36″	167.35	179.05	191.65	23.91	14.92	12.78	32.14	13.13	7.97
	48″ × 48″	196.40	217.20	239.60	28.06	18.10	15.97	37.72	15.92	9.96
Exit										
	66″ × 72″	266.95	309.85	356.05	38.14	25.82	23.74	51.27	22.72	14.81
Rest Area										
	66″ × 132″	381.07	459.73	544.43	54.44	38.31	36.30	73.19	33.71	22.64

a) Service lives of types II, IIA, and IIIA are 7, 12, and 15 years, respectively
b) 1 inch = 25.4 mm, 1 ft = 0.3048 meter
c) 1994 Dollars
d) Analysis period = 7 years, interest rate = 8%
e) FP-85 retroreflective sheeting typology

Table 22. Values of MOEs for Refurbished Signs[a]

Sign Type	Sign Size[b]	Total Cost[c]			Ratio of Total Cost to Service Life			EUAC[d]		
		Sheeting Type[e]			Sheeting Type[e]			Sheeting Type[e]		
		II	IIA	IIIA	II	IIA	IIIA	II	IIA	IIIA
Stop										
	30″ × 30″	112.94	125.94	142.81	16.13	10.50	9.52	21.69	9.23	5.94
	36″ × 36″	137.35	149.05	161.65	19.62	12.42	10.78	26.38	10.93	6.72
	48″ × 48″	166.40	187.20	209.60	23.77	15.60	13.97	31.96	13.73	8.72
Speed Limit										
	24″ × 30″	110.35	120.75	134.25	15.76	10.06	8.95	21.20	8.85	5.58
	36″ × 48″	149.80	165.40	182.20	21.40	13.78	12.15	28.77	12.13	7.58
	48″ × 60″	183.00	209.00	237.00	26.14	17.42	15.80	35.15	15.32	9.86
Merge Symbol										
	30″ × 30″	112.94	125.94	142.81	16.13	10.50	9.52	21.69	9.23	5.94
	36″ × 36″	137.35	149.05	161.65	19.62	12.42	10.78	26.38	10.93	6.72
	48″ × 48″	166.40	187.20	209.60	23.77	15.60	13.97	31.96	13.73	8.72
Exit										
	66″ × 72″	236.95	279.85	326.05	33.85	23.32	21.74	45.51	20.52	13.56
Rest Area										
	66″ × 132″	351.07	429.73	514.43	50.15	35.81	34.30	67.43	31.51	21.39

a) Service lives of types II, IIA, and IIIA are 7, 12, and 15 years, respectively
b) 1 inch = 25.4 mm, 1 ft = 0.3048 meter
c) 1994 Dollars
d) Analysis period = 7 years, interest rate = 8%
e) FP-85 retroreflective sheeting typology

To gain insight into the behavior of the MOEs under conditions of imperfect information, sensitivity analyses were performed for: 1) changes in the service lives of types IIA and IIIA sheeting materials, and 2) changes in the value of interest rate. These analyses supplement the results of Table 21 which were obtained using point estimates of service lives and interest rate. The service life of type-II sheeting was held constant at 7 years as a base condition for comparison purposes.

Tables 23 and 24 summarize the effect of changes in service lives of types IIA and IIIA sheeting materials on EUAC using an analysis period of 7 years (service life of type-II sheeting). The results indicate that type-IIIA sheeting is preferred if it were to outlast type-IIA sheeting by one year or more. Furthermore, both types IIIA and IIA sheeting materials have less EUAC than type-II sheeting for the ranges of service lives shown in Tables 23 and 24.

Sensitivity analysis of changes in interest rate are presented in Table 25. The EUAC values were computed using an analysis period of 7 years. As indicated, type-IIIA has the least cost per year, followed by type-IIA, and type-II retroreflective sheeting materials. The same conclusion was reached earlier using an interest rate of 8% as shown in Table 21.

Table 23. Sensitivity Analysis of Changes in Service Life of Type-IIA Sheeting
(Interest Rate = 8%, Analysis Period = 7 Years)

Sign Type	Sign Size[a]	EUAC						
		Service Life, Years						
		10	11	12	13	14	15	16
Stop								
	30″ × 30″	16.53	13.74	11.43	9.51	7.88	6.49	5.28
	36″ × 36″	18.98	15.77	13.13	10.92	9.05	7.45	6.07
	48″ × 48″	23.02	19.33	15.92	13.24	10.97	9.03	7.36
Speed Limit								
	24″ × 30″	15.98	13.28	11.05	9.19	7.62	6.27	5.11
	36″ × 48″	20.71	17.21	14.33	11.91	9.87	8.13	6.62
	48″ × 60″	25.33	21.05	17.52	14.57	12.07	9.94	8.10
Merge Symbol								
	30″ × 30″	16.53	13.74	11.43	9.51	7.88	6.49	5.28
	36″ × 36″	18.98	15.77	13.13	10.92	9.05	7.45	6.07
	48″ × 48″	23.02	19.33	15.92	13.24	10.97	9.03	7.36
Exit								
	66″ × 72″	32.84	27.29	22.72	18.89	15.65	12.89	10.50
Rest Area								
	66″ × 132″	48.73	40.49	33.71	28.03	23.23	19.12	15.58

a) 1 inch = 25.4 mm, 1 ft = 0.3048 meter

Table 24. Sensitivity Analysis of Changes in Service Life of Type-IIIA Sheeting (Interest Rate = 8%, Analysis Period = 7 Years)

Sign Type	Sign Size[a]	EUAC						
		Service Life, Years						
		12	13	14	15	16	17	18
Stop								
	30″ × 30″	12.67	10.54	8.73	7.19	5.86	4.70	3.69
	36″ × 36″	14.05	11.69	9.68	7.97	6.49	5.21	4.09
	48″ × 48″	17.57	14.61	12.10	9.96	8.12	6.51	5.11
Speed Limit								
	24″ × 30″	12.04	10.01	8.30	6.83	5.57	4.47	3.50
	36″ × 48″	15.56	12.94	10.72	8.82	7.19	5.77	4.53
	48″ × 60″	19.58	16.28	13.49	11.10	9.05	7.26	5.70
Merge Symbol								
	30″ × 30″	12.67	10.54	8.73	7.19	5.86	4.70	3.69
	36″ × 36″	14.05	11.69	9.68	7.97	6.49	5.21	4.09
	48″ × 48″	17.57	14.61	12.10	9.96	8.12	6.51	5.11
Exit								
	66″ × 72″	26.10	21.71	17.99	14.81	12.06	9.36	7.60
Rest Area								
	66″ × 132″	39.92	33.19	27.51	22.64	18.45	14.80	11.61

a) 1 inch = 25.4 mm, 1 ft = 0.3048 meter

Table 25. Sensitivity Analysis of Changes in Interest Rate [a] (Analysis Period = 7 Years)

Sign Type	Sign Size[b]	EUAC i = 5% Sheeting Type II	IIA	IIIA	i = 10% Sheeting Type II	IIA	IIIA
Stop							
	30″ × 30″	24.70	8.24	3.43	29.36	13.74	9.94
	36″ × 36″	28.92	9.46	3.81	34.37	15.78	11.03
	48″ × 48″	33.94	11.47	4.76	40.34	19.14	13.79
Speed Limit							
	24″ × 30″	24.26	7.96	3.26	28.83	13.28	9.45
	36″ × 48″	31.07	10.32	4.22	36.93	17.22	12.21
	48″ × 60″	36.81	12.63	5.30	43.75	21.06	15.36
Merge Symbol							
	30″ × 30″	24.70	8.24	3.43	29.36	13.74	9.94
	36″ × 36″	28.92	9.46	3.81	34.37	15.78	11.03
	48″ × 48″	33.94	11.47	4.76	40.34	19.14	13.79
Exit							
	66″ × 72″	65.83	24.29	10.81	78.27	40.51	31.33
Rest Area							
	66″ × 132″	46.13	16.37	7.07	54.83	27.30	20.49

a) Service lives of types II, IIA, and IIIA are assumed 7, 12, and 15 years, respectively
b) 1 inch = 25.4 mm, 1 ft = 0.3048 meter
c) FP-85 retroreflective sheeting typology

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The primary objectives of this research were to evaluate the ODOT's policy on use of retroreflective sheeting products, and to identify any necessary changes to this policy based on driver visibility needs, durability of sheeting materials, life-cycle cost, and other practical considerations. The scope of the study included three types of retroreflective sheetings (engineering grade, super-engineering grade, and encapsulated-lens high-intensity sheeting), five sheeting colors (white, red, yellow, green, and blue), and two sign fabrication methods (screening and overlay). The major conclusions of this study are summarized in the following sections.

Visibility Distances

White-on-Red, Black-on-White, and Black-on-Yellow Signs: For *new* sheeting materials, results of the field experiments and visibility distance analyses suggest the following:

- In terms of sign legibility under automobile low-beam illumination at night, there was no statistically significant difference between the mean recognition distances of types II, IIA, and IIIA sheeting materials, when new. This conclusion was reached at both urban and rural environments. Materials should be specified based on life-cycle cost, durability, and the need for added conspicuity.
- Overall, signs with high-intensity (type-IIIA, encapsulated-lens) sheeting had significantly greater target value, in terms of mean detection distance under automobile low-beam illumination at night, than signs with super-engineering grade (type-IIA) or engineering grade (type-II) sheeting materials. Yet, there were cases where the difference between types IIIA and IIA was not statistically significant. Furthermore, signs with type-IIA had significantly larger mean detection distance than signs with type-II sheeting. These conclusions were reached at both urban and rural environments.
- Brightness is just one of several factors that influence sign legibility and conspicuity. Evidence from visibility distance analyses and subjective evaluations made by the test subjects indicates that, even with new sheeting materials, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

White-on-Green and White-on-Blue Signs: For *new* sheeting materials, results of the field experiments and visibility distance analyses suggest the following:

- Of the six sheeting combinations included in this study, signs with type-II sheeting on the background showed the lowest target value in terms of mean detection distance under automobile low-beam illumination at night. There was no statistically significant difference between the mean detection distances of type-IIIA legend on type-IIIA background, type-IIIA legend on type-IIA background, and type-IIA legend on type-IIA background. These conclusions were reached at both urban and rural environments.

- With respect to sign legibility under automobile low-beam illumination at night, there was no significant difference between the mean recognition distances of type-IIIA legend on type-IIIA background, type-IIIA legend on type-IIA background, and type-IIA legend on type-IIA background at both rural and urban environments. The only exception was the white-on-green guide sign at the rural environment where the mean recognition distance of type-IIIA legend on type-IIIA background was significantly larger than that of type-IIA legend on type-IIA background.

- Visibility distance analyses and subjective evaluations made by the test subjects indicates that, even with new sheeting materials, larger sign size and letter size than those used in the field experiments are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

Life-Cycle Cost

The measures of effectiveness (MOEs) used in this study were the ratio of total cost to service life, and the equivalent uniform annual cost (EUAC). Average service lives of 7, 12, and 15 years were assumed for sheeting types II, IIA, and IIIA, respectively, based on data obtained from ODOT field divisions, sheeting manufacturers, and the published literature. The EUAC computations were made using a 7-year analysis period (shortest service life among alternatives). To allow for any uncertainty in estimating service lives, sensitivity analyses were performed to explore the effect of changes in the service lives of types IIA and IIIA sheeting materials on the MOEs. These analyses supplemented the results obtained using point estimates of service lives. The service life of type-II sheeting was held constant at 7 years as a base condition for comparison purposes.

Results of the life-cycle cost analysis indicate that type-IIIA has the least ratio of total cost to service life and the least EUAC, followed by type-IIA, and type-II retroreflective sheeting materials. This conclusion was reached for new signs as well as refurbished signs.

Sensitivity analysis results suggest that type-IIIA sheeting is preferred if it were to outlast type-IIA sheeting by one year or more. Furthermore, both types IIIA and IIA sheeting materials have less EUAC than type-II sheeting for the ranges of service lives used in the analysis.

Durability Considerations

Based on a survey of ODOT field divisions and the literature review, the typical in-service deterioration modes experienced by retroreflective sheeting materials are loss of retroreflectivity, color fading, cracking, abrasion, peeling, and dirt accumulation. Cracking appears to be more prevalent in type-II than type-IIIA sheeting materials. Peeling was observed in type-IIIA sheeting, particularly at bends on the sign face and dents at the mounting bolts. Deterioration modes of type-IIA are not well documented because it has not been in service long enough.

Unpublished results of five-year, accelerated outdoor exposure at 45° facing south were obtained from the FHWA Photometric and Visibility Laboratory at Turner-Fairbank Highway Research Center. The results covered a five-year period (1989 through 1993) which is equivalent to approximately 10 years of normal outdoor weathering. On the basis of these results, the following observations were made at concerning R_A at the end of five years of accelerated weathering:

White color - All sheeting materials exceeded the minimum required R_A values established by the FHWA for ground mounted black-on-white regulatory and guide signs. Furthermore, the R_A of type-IIIA sheeting was about 2.3 times higher than the R_A of type-IIA and 3.5 times higher than the R_A of type-II sheeting materials.

Red color - The R_A of type-IIIA sheeting was about 2.0 times higher than the R_A of type-IIA and 2.3 times higher than the R_A of type-II sheeting materials. All three sheeting materials, exceeded the minimum required R_A values for the red background of white-on-red regulatory signs. Nevertheless, sheeting types II and IIA failed to maintain the minimum contrast ratio of 4:1 between the white and red colors.

Yellow color - All sheeting materials exceeded the minimum required R_A values for black-on-yellow warning signs. Furthermore, the R_A of type-IIIA sheeting was about 2.5 times higher than the R_A of type-IIA and 3.0 times higher than the R_A of type-II sheeting materials.

Green color - The R_A of type-IIIA sheeting was about 2.2 times higher than the R_A of type-IIA and 4.5 times higher than the R_A of type-II sheeting materials. All sheeting materials exceeded the minimum required R_A values for the green background of ground-mounted guide signs as well as the minimum contrast ratio of 4:1 between the white legend and green background. For overhead guide signs, type-II sheeting failed to meet the minimum required R_A value for the green background, and type-IIA appeared to be marginal.

Blue color - The R_A of type-IIIA sheeting was about 3.5 times higher than the R_A of type-IIA and 5.4 times higher than the R_A of type-II sheeting materials. There are no minimum R_A requirements for blue color signs.

RECOMMENDATIONS

On the basis of the findings of this study, the following recommendations are made concerning the current ODOT policy on retroreflective sheetings:

- The specification of type III-A (high-intensity, encapsulated glass-bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways is sound and defensible.

- The requirement that type II-A (super-engineering grade sheeting) be used on all other traffic signs, except orange colored signs, needs to be examined. Although the initial cost of sign face fabrication (sheeting material, aluminum substrate, equipment, labor, and overhead) for type-IIIA sheeting is 25% to 65% higher than that of type-IIA, life-cycle cost analysis indicates that type-IIIA is more cost-effective than type-IIA.

- Evidence from visibility distance analyses and subjective evaluations made by the test subjects suggests that, in addition to upgrading sign materials to provide greater luminance, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

- The findings of this study should not be generalized to sheeting types that were not included in the evaluation.

SUGGESTED RESEARCH

- There is a need for reliable performance data of in-service traffic signs to develop site-specific models of retroreflective sheeting deterioration. These models are prerequisite for implementing sign management systems at the different ODOT field divisions.

- Empirical data are needed to evaluate the effect of sign size and letter size on visibility distances, particularly for older drivers. For example, which of the standard sizes for yellow warning signs included in ODOT specifications (30"×30", 36"×36", or 48"×48") will meet the minimum required distances for sign detection? sign legibility?

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APPENDIX A

ODOT DIVISIONS SURVEY RESULTS

ODOT DIVISIONS SURVEY RESULTS

A questionnaire survey was used to obtain data on sign population, retroreflective sheetings (use, average service life, and deterioration modes), sign replacement and maintenance practices (performance review process, reasons for replacement, and annual cost), sign installation cost, and existence and format of sign inventory. The scope of the survey was limited to traffic signs which are under ODOT's control. The survey instrument was mailed to the traffic engineers in the eight ODOT field divisions. Responses were received from seven divisions, albeit with partial answers to some of the questions. The following paragraphs summarize the survey results.

PART 1 - GENERAL INFORMATION

This part of the questionnaire included two questions concerning the number of highway miles and the number of traffic signs which are under the division's control. Responses to these questions were used to estimate the average number of traffic signs per mile. Table A-1 summarizes the sign density estimates per mile for regulatory, warning, guide, and motorist information signs. The overall average sign density is 24 signs per mile in urban areas, and 7 signs per mile in rural areas. For all state controlled highways, the overall average density is 9 signs per mile which is less than the national average of 11 signs per state highway mile [xx].

Table A-1. Sign Density per State Highway Mile

Sign Type	Signs per Mile		
	Urban	Rural	Overall
Regulatory	18.00	4.00	5.75
Warning	2.80	2.00	2.00
Guide	2.80	0.80	1.00
Motorist Information	0.40	0.20	0.25
Total	24.00	7.00	9.00

PART 2 - RETROREFLECTIVE SHEETINGS

Part 2 of the questionnaire consisted of three questions concerning the average service life of the different sheeting types; the percentage of traffic signs made of each sheeting type; and the in-service deterioration modes which have been encountered. Estimates of the average service lives of types II and IIIA retroreflective sheeting materials are 7 and 15 years, respectively. Because type-IIA sheeting has not been in service long enough, approximately one half of the responses did not provide an answer. Nevertheless, the other half of the responses suggested an average service life of 12 years for type IIA sheeting.

Table A-2 presents the percentages of in-service signs by sheeting material type. The survey results indicated that Type-II sheeting is more prevalent in regulatory and motorist information signs, whereas type IIA is more prevalent in warning signs.

The primary deterioration modes of the different sheeting materials are shown in Table A-3. Most of the responses noted the lack of complete information on type-IIA sheeting because it has not been in service long enough to evaluate all deterioration modes.

Table A-2. Percent of In-Service Signs on State Highways by Sheeting Type

Sheeting Type[a]	Regulatory Signs	Warning Signs	Guide Signs	Motorist Information Signs
II	47%	23%	33%	50%
IIA	24%	52%	35%	13%
IIIA	29%	25%	32%	37%

a) FP-85 retroreflective sheeting typology

Table A-3. Primary Deterioration Modes

Deterioration Modes	Sheeting Type[a]		
	II	IIA	IIIA
Loss of retroreflectivity	XXX	XXX	XXX
Color fading	XXX	XXX	
Cracking	XXX	na	XXX
Abrasion	XXX	XXX	XXX
Peeling	XXX	na	XXX

a) FP-85 retroreflective sheeting typology
b) Information not available

PART 3 - SIGN REPLACEMENT & MAINTENANCE

Five questions were included in this part of the questionnaire. The first question asked about the average number of signs replaced each year due to poor reflectivity, color fading, vandalism, knockdown, and other causes. Table A-4 summarizes the responses to this question.

Table A-4. Average Number of Signs Replaced Each Year

Reason for Replacement	Number of Signs	Percent
Poor reflectivity	4,700	40%
Color fading	2,100	18%
Vandalism	1,300	11%
Knockdown	3,500	30%
Other	100	1%
Total	11,700	100%

Sign maintenance and replacement cost was the subject of the second question. The annual cost ranged from $880 to $150 per mile with an average of $450 per mile. The total annual cost for the seven divisions which responded to the survey is approximately $3 million.

The third question asked about the average cost to install a sign which has been fabricated by the ODOT Sign Shop. This cost does not include the cost of sign sheeting or substrate. Table A-5 summarizes the average cost items.

Table A-5. Average Sign Installation Cost

Cost Item	Installation Cost ($/sign)			
	Shoulder Mount[a]		Overhead Mount[b]	
	Small Sign[c]	Large Sign[d]	Small Sign[c]	Large Sign[d]
Sign Support Materials	30	750	25	80
Labor Cost	40	220	60	120
Equipment Cost	40	170	20	25
Overhead Cost	20	135	20	20
Total Installation Cost	130	1,275	125	245

a) Average of four responses
b) Based on one response
c) Less than or equal to 50 ft^2
d) Greater than 50 ft^2

The last two questions in this part of the survey inquired about the existence and format of a sign performance review process. Four out of the seven ODOT Divisions responding (57%) indicated that they conduct sign performance review on a routine, systematic basis. The format of the review process was limited to biannual visual check of the sign visibility and appearance twice a year, during both day and night time conditions. Personnel shortage and lack of reflectometers were among the problems expressed by the divisions.

PART 4 - SIGN INVENTORY

Three of the seven divisions responding (43%) maintain a sign inventory at the division level. Of these three divisions, one division has their system on a microcomputer spreadsheet format, and the other two divisions use paper records. Almost all inventories had the sign type, location, and inspection date. Nevertheless, none of the inventory systems included the type of retroreflective sheeting used nor the date of sign installation/replacement.

APPENDIX B

ANALYSIS OF VARIANCE RESULTS

Table B-1. Stop, Speed Limit & Merge Signs - Detection Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	44325171.66	1528454.20		
Sign	2	2386839.03	1193419.51	8.59	0.0005
Driver × Sign	58	8055904.75	138894.91		
Sheeting	2	2275535.87	1137767.94	17.72	0.0001
Driver × Sheeting	58	3724996.57	64224.08		
Sign × Sheeting	4	305581.70	76395.43	1.66	0.1629
Driver × Sign × Sheeting	116	5323423.19	45891.58		
Total	269	66397452.77			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)
   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0, \ k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)
   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0, \ j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)
   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-2. Stop, Speed Limit & Merge Signs - Recognition Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	5247457.57	180946.81		
Sign	2	1560206.94	780103.47	16.79	0.0001
Driver × Sign	58	2694289.73	46453.27		
Sheeting	2	110579.05	55289.53	3.70	0.0309
Driver × Sheeting	58	867816.28	14962.35		
Sign × Sheeting	4	10396.95	2599.24	0.17	0.9531
Driver × Sign × Sheeting	116	1769613.72	15255.29		
Total	269	12260360.24			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0$, $j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)

   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-3. Stop, Speed Limit & Merge Signs - Detection Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	28165297.99	971217.17		
Sign	2	4554677.21	2277338.60	37.60	0.0001
Driver × Sign	58	3513361.24	60575.19		
Sheeting	2	1467609.25	733804.63	22.69	0.0001
Driver × Sheeting	58	1853640.53	31959.32		
Sign × Sheeting	4	315925.44	78981.36	3.24	0.0148
Driver × Sign × Sheeting	116	2831786.79	24411.96		
Total	269	42702298.43			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Reject H_0 at the 5% level of significance.

2. Sheeting effect:

   See ANOVA results in pages 81 through 83.

Table B-4. Stop Sign - Detection Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	9568899.66	329962.06		
Sheeting	2	1121411.82	560705.91	15.66	0.0001
Error	58	2077084.84	35811.81		
Total	89	12767396.32			

Hypothesis Testing

Model: $x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik}$

1. Sheeting effect:

H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials for the stop sign)
H_1: at least one $\tau_k \neq 0$

Conclusion: Reject H_0 at the 5% level of significance.

Table B-5. Speed Limit Sign - Detection Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	12388174.40	427178.43		
Sheeting	2	232203.47	116101.73	5.55	0.0062
Error	58	1212702.53	20908.66		
Total	89	13833080.40			

Hypothesis Testing

Model: $x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik}$

1. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials for the speed limit sign)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-6. Merge Sign - Detection Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	9721585.17	335227.08		
Sheeting	2	429919.40	214959.70	8.93	0.0004
Error	58	1395639.93	24062.76		
Total	89	11547144.50			

Hypothesis Testing

Model: $x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik}$

1. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials for the merge sign)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-7. Stop, Speed Limit & Merge Signs - Recognition Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	4008064.80	138209.13		
Sign	2	749303.82	374651.91	22.26	0.0001
Driver × Sign	58	976136.18	16829.93		
Sheeting	2	36685.40	18342.70	2.84	0.0667
Driver × Sheeting	58	374768.60	6461.53		
Sign × Sheeting	4	8240.04	2060.01	0.34	0.8532
Driver × Sign × Sheeting	116	711078.62	6129.99		
Total	269	6864277.47			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Accept H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0$, $j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)

   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-8. Exit & Rest Area Signs - Detection Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	23342366.00	804909.17		
Sign	1	7090762.71	7090762.71	63.63	0.0001
Driver × Sign	29	3231899.62	111444.81		
Sheeting	5	1764717.37	352943.47	9.09	0.0001
Driver × Sheeting	145	5631323.63	38836.71		
Sign × Sheeting	5	155294.06	31058.81	0.77	0.5719
Driver × Sign × Sheeting	145	5838998.61	40268.96		
Total	359	47055362.00			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0$, $j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)

   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-9. Exit & Rest Area Signs - Recognition Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	4127711.93	142334.89		
Sign	1	8721069.51	8721069.51	415.59	0.0001
Driver × Sign	29	608561.82	20984.89		
Sheeting	5	175461.90	35092.38	4.72	0.0005
Driver × Sheeting	145	1077621.77	7431.87		
Sign × Sheeting	5	103164.79	20632.96	2.81	0.0188
Driver × Sign × Sheeting	145	1064699.88	7342.76		
Total	359	15878291.60			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Reject H_0 at the 5% level of significance.

2. Sheeting effect:

   See ANOVA results in pages 87 and 88.

Table B-10. Exit Sign - Recognition Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	3617183.11	124730.45		
Sheeting	5	246895.11	49379.02	5.21	0.0002
Error	145	1373146.56	9469.98		
Total	179	5237224.78			

Hypothesis Testing

Model: $x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik}$

1. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials for the exit sign)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-11. Rest Area Sign, Recognition Distances, Rural Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	1119090.64	38589.33		
Sheeting	5	31731.58	6346.32	1.20	0.3139
Error	145	769175.09	5304.66		
Total	179	1919997.31			

Hypothesis Testing

Model: $x_{ik} = \mu + \rho_i + \tau_k + \varepsilon_{ik}$

1. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials for the rest area sign)
   H_1: at least one $\tau_k \neq 0$

   Conclusion: Accept H_0 at the 5% level of significance.

Table B-12. Exit & Rest Area Signs - Detection Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	24366824.56	840235.33		
Sign	1	4408296.00	4408296.03	34.36	0.0001
Driver × Sign	29	3720709.89	128300.34		
Sheeting	5	917590.13	183518.02	5.39	0.0001
Driver × Sheeting	145	4941102.79	34076.57		
Sign × Sheeting	5	214252.79	42850.56	1.30	0.2655
Driver × Sign × Sheeting	145	4765342.79	32864.43		
Total	359	43334118.98			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0$, $j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)

   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

Table B-13. Exit & Rest Area Signs - Recognition Distances, Urban Environment

Source	df	SS	MS	F-value	Pr > F
Driver	29	7209503.18	248603.56		
Sign	1	7752509.00	7752509.00	241.62	0.0001
Driver × Sign	29	930468.25	32085.11		
Sheeting	5	143881.28	28776.26	2.93	0.0149
Driver × Sheeting	145	1421745.30	9805.14		
Sign × Sheeting	5	80761.41	16152.28	1.41	0.2229
Driver × Sign × Sheeting	145	1657213.84	11429.06		
Total	359	19196082.26			

Hypothesis Testing

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

1. Interaction between signs and sheetings:

   H_0: all $\alpha\tau_{jk} = 0$ (no interaction)

   H_1: otherwise

   Conclusion: Accept H_0 at the 5% level of significance.

2. Sheeting effect:

   H_0: all $\tau_k = 0$, $k = 1, 2, 3$ (no difference among sheeting materials considering all sign types)

   H_1: at least one $\tau_k \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

3. Sign effect:

   H_0: all $\alpha_j = 0$, $j = 1, 2, 3$ (no difference among sign types considering all sheeting materials)

   H_1: at least one $\alpha_j \neq 0$

   Conclusion: Reject H_0 at the 5% level of significance.

APPENDIX C

PAIRWISE COMPARISONS RESULTS
(NEWMAN-KEULS TEST)

Table C-1. Stop, Speed Limit & Merge Symbol Signs, Detection Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	1637	1757	1861

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,58}$	$q_{0.05,p,58}\sqrt{\frac{MSRT}{ra}}$
EG	---	120	224	3	3.40	90.82
SEG		---	104	2	2.83	75.60

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$	All signs considered, reject H_0 at the 95% level of confidence.
H_1: $\tau_3 - \tau_1 \neq 0$	MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$	All signs considered, reject H_0 at the 95% level of confidence.
H_1: $\tau_3 - \tau_2 \neq 0$	MDD of HI is significantly larger than that of SEG.
H_0: $\tau_2 - \tau_1 = 0$	All signs considered, reject H_0 at the 95% level of confidence.
H_1: $\tau_2 - \tau_1 \neq 0$	MDD of SEG is significantly larger than that of EG.

Table C-2. Stop Sign, Detection Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	1466	1656	1805

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	190	339	3	3.36	131.42
SEG		---	149	2	2.80	109.51

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of SEG is significantly larger than that of EG.

Table C-3. Speed Limit Sign, Detection Distance, Rural Environment

Sheeting Type[a]	EG	SEG	HI
MDD, ft[b]	1661	1732	1829

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	71	168	3	3.36	131.42
SEG		---	97	2	2.80	109.51

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG is not significantly different from that of EG.

Table C-4. Merge Symbol Sign, Detection Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	1783	1883	1905

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	100	167	3	3.36	131.42
SEG		---	67	2	2.80	109.51

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG is not significantly different from that of EG.

Table C-5. Stop, Speed Limit & Merge Symbol Signs, Recognition Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	554.37	567.37	602.30

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,58}$	$q_{0.05,p,58}\sqrt{\frac{MSRT}{ra}}$
EG	---	13	47.93	3	3.40	43.84
SEG		---	34.93	2	2.83	36.49

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.

Table C-6. Stop Sign, Recognition Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	657.20	657.00	702.70

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 SEG	2 EG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
SEG	---	0.20	45.70	3	3.36	75.77
EG		---	45.50	2	2.80	63.14

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
$H_0: \tau_3 - \tau_1 = 0$ $H_1: \tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MRD of HI is significantly larger than that of SEG.
$H_0: \tau_3 - \tau_2 = 0$ $H_1: \tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.
$H_0: \tau_2 - \tau_1 = 0$ $H_1: \tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG is not significantly different from that of SEG.

Table C-7. Speed Limit Sign, Recognition Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	471.90	477.90	510.90

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	6.00	39.00	3	3.36	75.77
SEG		---	33.00	2	2.80	63.14

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.

Table C-8. Merge Symbol Sign, Recognition Distance, Rural Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	534.00	567.20	593.30

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	33.20	59.30	3	3.36	75.77
SEG		---	26.10	2	2.80	63.14

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.

Table C-9. Stop Sign, Detection Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	955	1171	1208

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	216	253	3	3.36	95.85
SEG		---	37	2	2.80	79.87

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of SEG is significantly larger than that of EG.

Table C-10. Speed Limit Sign, Detection Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	1104	1134	1223

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	30	119	3	3.36	95.85
SEG		---	89	2	2.80	79.87

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG is not significantly different from that of EG.

Table C-11. Merge Symbol Sign, Detection Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MDD, ft [b]	1329	1391	1497

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	62	168	3	3.36	95.85
SEG		---	106	2	2.80	79.87

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI is significantly larger than that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG is not significantly different from that of EG.

Table C-12. Stop, Speed Limit & Merge Symbol Signs, Recognition Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	461.40	488.23	483.27

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 HI	3 SEG	p	$q_{0.05,p,58}$	$q_{0.05,p,58}\sqrt{\frac{MSRT}{ra}}$
EG	---	21.87	26.83	3	3.40	28.81
HI		---	4.96	2	2.83	23.98

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of HI.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.

Table C-13. Stop Sign, Recognition Distance, Urban Environment

Sheeting Type[a]	EG	SEG	HI
MRD, ft[b]	522.60	537.10	542.20

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order / Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	14.50	19.60	3	3.36	48.03
SEG		---	5.10	2	2.80	40.02

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.

Table C-14. Speed Limit Sign, Recognition Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	391.10	414.70	415.90

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 SEG	3 HI	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	23.60	24.80	3	3.36	48.03
SEG		---	1.20	2	2.80	40.02

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.

Table C-15. Merge Symbol Sign, Recognition Distance, Urban Environment

Sheeting Type [a]	EG	SEG	HI
MRD, ft [b]	470.50	512.90	491.70

a) EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 Type III-A) sheeting materials
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG	2 HI	3 SEG	p	$q_{0.05,p,116}$	$q_{0.05,p,116}\sqrt{\frac{MSE}{r}}$
EG	---	21.20	42.40	3	3.36	48.03
HI		---	21.20	2	2.80	40.02

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG is not significantly different from that of HI.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI is not significantly different from that of EG.

Table C-16. Exit & Rest Area Signs, Detection Distance, Rural Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1469	1438	1373	1396	1322	1260

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 EG/EG	2 SEG/EG	3 HI/EG	4 SEG/SEG	5 HI/SEG	6 HI/HI	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r\,a}}$
EG/EG	---	62	113	136	178	209	6	4.03	83.72
SEG/EG		---	51	74	116	147	5	3.86	80.18
HI/EG			---	23	65	96	4	3.63	75.41
SEG/SEG				---	42	73	3	3.31	68.76
HI/SEG					---	31	2	2.77	57.54

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of SEG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of HI/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of SEG/SEG.

Table C-16 (continued). Exit & Rest Area Signs, Detection Distance, Rural Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of EG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of SEG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of EG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of SEG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of HI/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/EG is significantly larger than that of EG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/EG is significantly larger than that of EG/EG.

Table C-17. Exit Sign, Detection Distance, Rural Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1640	1553	1487	1555	1462	1402

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG/EG	2 SEG/EG	3 HI/EG	4 HI/SEG	5 SEG/SEG	6 HI/HI	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
EG/EG	---	60	85	151	153	238	6	4.03	147.65
SEG/EG		---	25	91	93	178	5	3.86	141.42
HI/EG			---	66	68	153	4	3.63	132.99
HI/SEG				---	2	87	3	3.31	121.27
SEG/SEG					---	85	2	2.77	101.49

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of SEG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of HI/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/SEG.

Table C-17 (continued). Exit Sign, Detection Distance, Rural Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of EG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of HI/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of HI/SEG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of EG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/EG is not significantly different from that of EG/EG.

Table C-18. Rest Area Sign, Detection Distance, Rural Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1298	1323	1258	1237	1182	1117

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 EG/EG	2 SEG/EG	3 SEG/SEG	4 HI/EG	5 HI/HI	6 HI/SEG	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
EG/EG	---	65	120	141	181	206	6	4.03	147.65
SEG/EG		---	55	76	116	141	5	3.86	141.42
SEG/SEG			---	21	61	86	4	3.63	132.99
HI/EG				---	40	65	3	3.31	121.27
HI/HI					---	25	2	2.77	101.49

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/EG.

Table C-18 (continued). Rest Area Sign, Detection Distance, Rural Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of EG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/EG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/EG is significantly larger than that of EG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of EG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/EG is not significantly different from that of EG/EG.

Table C-19. Exit Sign, Recognition Distance, Rural Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MRD, ft [b]	740	753	754	653	759	714

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean recognition distance
1 ft = 0.3048 meter

Order	1	2	3	4	5	6			
Sheeting Type	SEG/SEG	EG/EG	HI/HI	HI/SEG	HI/EG	SEG/EG	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
SEG/SEG	---	62	87	100	101	106	6	4.03	63.05
EG/EG		---	26	38	39	44	5	3.86	60.39
HI/HI			---	13	14	19	4	3.63	56.79
HI/SEG				---	1	6	3	3.31	51.78
HI/EG					---	25	2	2.77	43.33

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MRD of SEG/EG is significantly larger than that of SEG/SEG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of EG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/HI.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/SEG.

Table C-19 (continued). Exit Sign, Recognition Distance, Rural Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_6 - \tau_5 \neq 0$	MRD of SEG/EG is not significantly different from that of HI/EG.
H_0: $\tau_5 - \tau_1 = 0$	Reject H_0 at the 95% level of confidence.
H_1: $\tau_5 - \tau_1 \neq 0$	MRD of HI/EG is significantly larger than that of SEG/SEG.
H_0: $\tau_5 - \tau_2 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_5 - \tau_2 \neq 0$	MRD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_5 - \tau_3 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_5 - \tau_3 \neq 0$	MRD of HI/EG is not significantly different from that of HI/HI.
H_0: $\tau_5 - \tau_4 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_5 - \tau_4 \neq 0$	MRD of HI/EG is not significantly different from that of HI/SEG.
H_0: $\tau_4 - \tau_1 = 0$	Reject H_0 at the 95% level of confidence.
H_1: $\tau_4 - \tau_1 \neq 0$	MRD of HI/SEG is significantly larger than that of SEG/SEG.
H_0: $\tau_4 - \tau_2 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_4 - \tau_2 \neq 0$	MRD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_4 - \tau_3 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_4 - \tau_3 \neq 0$	MRD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_3 - \tau_1 = 0$	Reject H_0 at the 95% level of confidence.
H_1: $\tau_3 - \tau_1 \neq 0$	MRD of HI/HI is significantly larger than that of SEG/SEG.
H_0: $\tau_3 - \tau_2 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_3 - \tau_2 \neq 0$	MRD of HI/HI is not significantly different from that of EG/EG.
H_0: $\tau_2 - \tau_1 = 0$	Reject H_0 at the 95% level of confidence.
H_1: $\tau_2 - \tau_1 \neq 0$	MRD of EG/EG is significantly larger than that of SEG/SEG.

Table C-20. Rest Area Sign, Recognition Distance, Rural Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MRD, ft [b]	398	417	441	408	423	418

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean recognition distance
1 ft = 0.3048 meter

Order Sheeting Type	1 HI/HI	2 SEG/SEG	3 HI/SEG	4 EG/EG	5 SEG/EG	6 HI/EG	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
HI/HI	---	11	19	20	25	43	6	4.03	63.05
SEG/SEG		---	9	10	15	33	5	3.86	60.39
HI/SEG			---	1	6	24	4	3.63	56.79
EG/EG				---	5	23	3	3.31	51.78
SEG/EG					---	18	2	2.77	43.33

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of HI/HI.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of HI/SEG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of EG/EG.

Table C-20 (continued). Rest Area Sign, Recognition Distance, Rural Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/HI.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/SEG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of EG/EG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of HI/HI.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of HI/SEG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/SEG is not significantly different from that of HI/HI.

Table C-21. Exit & Rest Area Signs, Detection Distance, Urban Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1273	1240	1174	1229	1120	1150

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 SEG/EG	2 EG/EG	3 HI/EG	4 SEG/SEG	5 HI/SEG	6 HI/HI	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r\,a}}$
SEG/EG	---	30	54	109	120	153	6	4.03	78.42
EG/EG		---	24	79	90	123	5	3.86	75.11
HI/EG			---	55	66	99	4	3.63	70.63
SEG/SEG				---	11	44	3	3.31	64.41
HI/SEG					---	33	2	2.77	53.90

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of SEG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of HI/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/SEG.

Table C-21 (continued). Exit & Rest Area Signs, Detection Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of SEG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of EG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of HI/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of SEG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of EG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of HI/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MDD of EG/EG is not significantly different from that of SEG/EG.

Table C-22. Exit Sign, Detection Distance, Urban Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1387	1353	1250	1369	1273	1233

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance
1 ft = 0.3048 meter

Order	1	2	3	4	5	6	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
Sheeting Type	EG/EG	HI/EG	SEG/EG	HI/SEG	SEG/SEG	HI/HI			
EG/EG	---	17	40	120	136	154	6	4.03	133.39
HI/EG		---	23	103	119	137	5	3.86	127.76
SEG/EG			---	80	96	114	4	3.63	120.15
HI/SEG				---	16	34	3	3.31	109.55
SEG/SEG					---	18	2	2.77	91.68

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of HI/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/SEG.

Table C-22 (continued). Exit Sign, Detection Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of SEG/SEG is significantly larger than that of EG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of HI/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of HI/SEG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/EG is not significantly different from that of EG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/EG is not significantly different from that of HI/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of EG/EG.

Table C-23. Rest Area Sign, Detection Distance, Urban Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MDD, ft [b]	1159	1127	1098	1089	997	1066

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean detection distance
1 ft = 0.3048 meter

Order Sheeting Type	1 SEG/EG	2 EG/EG	3 SEG/SEG	4 HI/EG	5 HI/SEG	6 HI/HI	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
SEG/EG	---	69	92	101	130	162	6	4.03	133.39
EG/EG		---	23	32	61	93	5	3.86	127.76
SEG/SEG			---	9	38	70	4	3.63	120.15
HI/EG				---	29	61	3	3.31	109.55
HI/SEG					---	32	2	2.77	91.68

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/HI is significantly larger than that of SEG/EG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of EG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of SEG/SEG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/EG.

Table C-23 (continued). Rest Area Sign, Detection Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/HI is not significantly different from that of HI/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MDD of HI/SEG is significantly larger than that of SEG/EG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/SEG is not significantly different from that of HI/EG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of HI/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of SEG/SEG is not significantly different from that of EG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MDD of EG/EG is not significantly different from that of SEG/EG.

Table C-24. Exit & Rest Area Signs, Recognition Distance, Urban Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MRD, ft [b]	509	527	564	503	517	515

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean recognition distance for a particular sheeting considering all signs
1 ft = 0.3048 meter

Order Sheeting Type	1 SEG/SEG	2 HI/HI	3 EG/EG	4 SEG/EG	5 HI/SEG	6 HI/EG	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r\ a}}$
SEG/SEG	---	6	12	14	24	61	6	4.03	42.06
HI/HI		---	6	8	18	55	5	3.86	40.29
EG/EG			---	2	12	49	4	3.63	37.89
SEG/EG				---	10	47	3	3.31	34.55
HI/SEG					---	37	2	2.77	28.91

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of SEG/SEG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of HI/HI.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of EG/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of SEG/EG.

Table C-24 (continued). Exit & Rest Area Signs, Recognition Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	All signs considered, reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of HI/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/HI.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of EG/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of HI/HI.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	All signs considered, accept H_0 at the 95% level of confidence. MRD of HI/HI is not significantly different from that of SEG/SEG.

Table C-25. Exit Sign, Recognition Distance, Urban Environment

Sheeting Type [a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MRD, ft [b]	674	675	706	620	673	667

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean recognition distance
1 ft = 0.3048 meter

Order	1	2	3	4	5	6	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
Sheeting Type	SEG/SEG	EG/EG	SEG/EG	HI/HI	HI/SEG	HI/EG			
SEG/SEG	---	47	52	54	55	86	6	4.03	78.66
EG/EG		---	5	7	8	39	5	3.86	75.34
SEG/EG			---	2	2	33	4	3.63	70.85
HI/HI				---	1	32	3	3.31	64.60
HI/SEG					---	31	2	2.77	54.07

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$ H_1: $\tau_6 - \tau_1 \neq 0$	Reject H_0 at the 95% level of confidence. MRD of HI/EG is significantly larger than that of SEG/SEG.
H_0: $\tau_6 - \tau_2 = 0$ H_1: $\tau_6 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_6 - \tau_3 = 0$ H_1: $\tau_6 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_6 - \tau_4 = 0$ H_1: $\tau_6 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of HI/HI.

Table C-25 (continued). Exit Sign, Recognition Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of HI/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/HI is not significantly different from that of SEG/SEG.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/HI is not significantly different from that of EG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/HI is not significantly different from that of SEG/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of EG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of SEG/SEG.

Table C-26. Rest Area Sign, Recognition Distance, Urban Environment

Sheeting Type[a]	HI/HI	HI/SEG	HI/EG	SEG/SEG	SEG/EG	EG/EG
MRD, ft[b]	344	378	422	386	362	362

a) Legend/Background, EG = Engineering Grade, SEG = Super Engineering Grade, HI = High Intensity (FP-85 type III-A)
b) Mean recognition distance
1 ft = 0.3048 meter

Order	1	2	3	4	5	6	p	$q_{0.05,p,145}$	$q_{0.05,p,145}\sqrt{\frac{MSRT}{r}}$
Sheeting Type	HI/HI	SEG/EG	EG/EG	HI/SEG	SEG/SEG	HI/EG			
HI/HI	---	18	18	34	42	78	6	4.03	78.66
SEG/EG		---	0	16	24	60	5	3.86	75.34
EG/EG			---	16	24	60	4	3.63	70.85
HI/SEG				---	8	44	3	3.31	64.60
SEG/SEG					---	36	2	2.77	54.07

Hypothesis Testing:

Model: $x_{ijk} = \mu + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \varepsilon_{ijk}$

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_1 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_6 - \tau_1 \neq 0$	MRD of HI/EG is not significantly different from that of HI/HI.
H_0: $\tau_6 - \tau_2 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_6 - \tau_2 \neq 0$	MRD of HI/EG is not significantly different from that of SEG/EG.
H_0: $\tau_6 - \tau_3 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_6 - \tau_3 \neq 0$	MRD of HI/EG is not significantly different from that of EG/EG.
H_0: $\tau_6 - \tau_4 = 0$	Accept H_0 at the 95% level of confidence.
H_1: $\tau_6 - \tau_4 \neq 0$	MRD of HI/EG is not significantly different from that of HI/SEG.

Table C-26 (continued). Rest Area Sign, Recognition Distance, Urban Environment

Hypothesis	Conclusion
H_0: $\tau_6 - \tau_5 = 0$ H_1: $\tau_6 - \tau_5 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/EG is not significantly different from that of SEG/SEG.
H_0: $\tau_5 - \tau_1 = 0$ H_1: $\tau_5 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/SEG is not significantly different from that of HI/HI.
H_0: $\tau_5 - \tau_2 = 0$ H_1: $\tau_5 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_5 - \tau_3 = 0$ H_1: $\tau_5 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/SEG is not significantly different from that of EG/EG.
H_0: $\tau_5 - \tau_4 = 0$ H_1: $\tau_5 - \tau_4 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/SEG is not significantly different from that of HI/SEG.
H_0: $\tau_4 - \tau_1 = 0$ H_1: $\tau_4 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of HI/HI.
H_0: $\tau_4 - \tau_2 = 0$ H_1: $\tau_4 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of SEG/EG.
H_0: $\tau_4 - \tau_3 = 0$ H_1: $\tau_4 - \tau_3 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of HI/SEG is not significantly different from that of EG/EG.
H_0: $\tau_3 - \tau_1 = 0$ H_1: $\tau_3 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of HI/HI.
H_0: $\tau_3 - \tau_2 = 0$ H_1: $\tau_3 - \tau_2 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of EG/EG is not significantly different from that of SEG/EG.
H_0: $\tau_2 - \tau_1 = 0$ H_1: $\tau_2 - \tau_1 \neq 0$	Accept H_0 at the 95% level of confidence. MRD of SEG/EG is not significantly different from that of HI/HI.

APPENDIX D

MINIMUM REQUIRED VISIBILITY DISTANCES

Table D-1. Minimum Required Visibility Distances, Stop Sign

Assumed Conditions

Sign:
MUTCD code: R1-1
Dimensions: 30″ × 30″
Mounting height: 7′
Lateral offset: 12′ (rural)
2′ (urban)

Driver:
Age: 67 years
Vision percentile: 90%
Snellen acuity: 20/30

Other:
Number of lanes: 2
Driver's lane: shoulder lane
Deceleration rate: 8 ft/sec^2

Minimum Required Visibility Distances, ft [a]

Speed Limit, mph	Traffic Volume	Visual Complexity: Low DD	Low RD	Medium DD	Medium RD	High DD	High RD
40	Medium	463	362	528	362	658	362
40	High	580	479	645	479	775	479
45	Medium	551	437	624	437	771	437
45	High	683	569	756	569	903	570
50	Medium	646	519	727	519	890	519
50	High	792	666	873	666	1036	666
55	Medium	747	608	837	608	1016	608
55	High	908	770	998	770	1177	770

a) 1 ft = 0.3048 meter
1 mph = 1.6 km/hr
DD = detection distance, RD = recognition distance

Table D-2. Minimum Required Visibility Distances, Speed Limit Sign

Assumed Conditions

Sign:	Driver:	Other:
MUTCD code: R2-1	Age: 67 years	Number of lanes: 2
Dimensions: 24″ × 30″	Vision percentile: 90%	Driver's lane: shoulder lane
Mounting height: 7′	Snellen acuity: 20/30	Deceleration rate: 8 ft/sec^2
Lateral offset: 12′ (rural)		
2′ (urban)		

Minimum Required Visibility Distances, ft[a]

Speed Limit, mph[b]	Traffic Volume	Visual Complexity					
		Low		Medium		High	
		DD	RD	DD	RD	DD	RD
35	Medium	386	273	459	273	606	273
35	High	518	405	591	405	738	405
40	Medium	430	304	512	304	675	304
40	High	577	451	659	451	821	451
45	Medium	475	336	564	336	743	336
45	High	636	497	726	497	905	497
50	Medium	519	368	617	368	812	368
50	High	695	544	793	544	988	543
55	Medium	563	400	670	400	881	400
55	High	754	590	860	590	1071	590

a) 1 ft = 0.3048 meter
1 mph = 1.6 km/hr
DD = detection distance, RD = recognition distance

b) Posted speed limit -- required reduction in speed upon reaching the sign is assumed 10 mph

Table D-3. Minimum Required Visibility Distances, Merge Sign

Assumed Conditions

Sign:
MUTCD code: W4-1
Dimensions: 30″ × 30″
Mounting height: 7′
Lateral offset: 12′ (rural)
2′ (urban)

Driver:
Age: 67 years
Vision percentile: 90%
Snellen acuity: 20/30

Other:
Number of lanes: 2
Driver's lane: shoulder lane
Deceleration rate: 8 ft/sec^2

Minimum Required Visibility Distances, ft[a]

Speed Limit, mph	Traffic Volume	Visual Complexity: Low DD	Low RD	Medium DD	Medium RD	High DD	High RD
40	Medium	328	227	393	227	524	227
40	High	328	227	393	227	524	227
45	Medium	354	241	427	241	574	241
45	High	354	241	427	241	574	241
50	Medium	380	254	462	254	624	254
50	High	380	254	462	254	624	254
55	Medium	406	267	496	267	675	267
55	High	406	267	496	267	675	267

a) 1 ft = 0.3048 meter
1 mph = 1.6 km/hr
DD = detection distance, RD = recognition distance

Table D-4. Minimum Required Visibility Distances, Exit Sign

Assumed Conditions

Sign:	Driver:	Other:
MUTCD code: E5-1	Age: 67 years	Number of lanes: 2
Dimensions: 36″ × 48″	Vision percentile: 90%	Driver's lane: shoulder lane
Mounting height: 7′	Snellen acuity: 20/30	Deceleration rate: 8 ft/sec^2
Lateral offset: 12′ (rural)		
2′ (urban)		

Minimum Required Visibility Distances, ft [a]

Speed Limit, mph [b]	Traffic Volume	Visual Complexity: Low DD	Low RD	Medium DD	Medium RD	High DD	High RD
40	Medium	635	534	700	534	830	534
40	High	749	648	814	648	945	648
45	Medium	716	602	789	602	936	602
45	High	845	731	918	731	1064	731
50	Medium	794	668	875	668	1038	668
50	High	948	822	1029	822	1192	822
55	Medium	874	736	964	736	1143	736
55	High	1044	905	1134	905	1313	905

a) 1 ft = 0.3048 meter
1 mph = 1.6 km/hr
DD = detection distance, RD = recognition distance

b) Speed limit on highway upstream of exit. Exit speed is assumed 10 mph lower than highway speed

Table D-5. Minimum Required Visibility Distances, Rest Area Sign

Assumed Conditions

<u>Sign</u>:
MUTCD code: D5-2
Dimensions: 24″ × 48″
Mounting height: 7′
Lateral offset: 12′ (rural)
2′ (urban)

<u>Driver</u>:
Age: 67 years
Vision percentile: 90%
Snellen acuity: 20/30

<u>Other</u>:
Number of lanes: 2
Driver's lane: shoulder lane
Deceleration rate: 8 ft/sec^2

Minimum Required Visibility Distances, ft[a]

Speed Limit, mph	Traffic Volume	Visual Complexity					
		Low		Medium		High	
		DD	RD	DD	RD	DD	RD
40	Medium	356	255	421	255	552	255
40	High	474	373	539	373	669	373
45	Medium	386	272	459	272	606	272
45	High	518	404	591	404	738	404
50	Medium	415	289	496	289	660	289
50	High	562	436	643	436	806	436
55	Medium	445	306	535	306	714	306
55	High	606	468	695	468	875	468

a) 1 ft = 0.3048 meter
1 mph = 1.6 km/hr
DD = detection distance, RD = recognition distance

APPENDIX E

TEST SUBJECT BIOGRAPHICAL DATA

BIOGRAPHICAL DATA FORM

Subject No.: __________ Test Location: ________________

Date: ________________ Time: ______________ (a.m./p.m.)

Instructions: Please <u>Circle ONE Number</u> that best answers each of the following questions.

---

1. What is your age?

   1. 24 years and younger
   2. 25 - 34
   3. 35 - 44
   4. 45 - 54
   5. 55 - 64
   6. 65 and older

2. What is your sex?

   1. Male
   2. Female

3. How long have you been driving a vehicle?

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

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

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

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

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

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

   1. Yes
   2. No

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

   1. Grade school
   2. High school
   3. College

8. What is your occupation?

   ____

Table E-1. Age Distribution of Test Subjects

Age Category	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
≤ 24	10.0%	13.3%	13.3%	13.3%
25 - 34	23.3%	26.7%	23.3%	26.7%
35 - 44	20.0%	20.0%	26.7%	20.0%
45 - 54	20.0%	10.0%	10.0%	10.0%
55 - 64	13.3%	13.3%	13.3%	16.7%
≥ 65	13.3%	16.7%	13.3%	13.3%

Table E-2. Sex Distribution of Test Subjects

Sex	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Male	50%	50%	50%	50%
Female	50%	50%	50%	50%

Table E-3. Driving Experience of Test Subjects

No. of Years	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
< 1	0.0%	10.0%	0.0%	3.3%
1 - 2	3.3%	0.0%	3.3%	0.0%
3 - 5	0.0%	0.0%	6.7%	0.0%
> 5	96.7%	90.0%	90.0%	96.7%

Table E-4. Type of Driving Done by Test Subjects

Type	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Mostly city	3.3%	3.3%	13.3%	10.0%
Mostly highway	6.7%	23.3%	16.7%	10.0%
A little of both	26.7%	20.0%	36.7%	33.3%
A lot of both	63.3%	53.4%	33.3%	46.7%
Drive infrequently	0.0%	0.0%	0.0%	0.0%

Table E-5. Miles Driven Annualy by Test Subjects

No. of Miles	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
< 2,000	6.7%	10.0%	6.7%	10.0%
2,000 - 4,000	13.3%	6.7%	16.7%	6.6%
4,001 - 6,000	3.3%	0.0%	16.7%	6.6%
6,001 - 8,000	10.0%	3.3%	3.3%	20.0%
8,001 - 10,000	20.0%	23.3%	6.7%	13.3%
> 10,000	46.7%	56.7%	50.0%	43.3%

Table E-6. Wear of Eyeglasses/Contact Lenses by Test Subjects

Wear Eyeglasses	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Yes	76.7%	73.3%	73.3%	66.7%
No	23.3%	26.7%	26.7%	33.3%

Table E-7. Level of Education of Test Subjects

No. of Years	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Grade School	3.3%	6.6%	0.0%	6.7%
High School	46.7%	63.3%	53.3%	46.7%
College	50.0%	30.0%	46.7%	46.6%

Table E-8. Occupation of Test Subjects

Occupation	Percent of Test Subjects			
	Rural Environment		Urban Environmrnt	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Retired	6.7%	13.3%	20.0%	13.3%
Clerical	23.3%	20.0%	30.0%	16.7%
Farmer/Technician	23.3%	20.0%	10.0%	23.3%
Professional	16.7%	6.7%	10.0%	6.7%
Student	13.3%	10.0%	13.3%	13.3%
Other	16.6%	30.0%	16.7%	26.7%

APPENDIX F

SIGN ADEQUACY QUESTIONNAIRE RESULTS

(Experiment 1)

SIGN ADEQUACY QUESTIONNAIRE

Driver Number: ___________ Test Location: ___________

Date: ___________________ Time: ___________ (a.m./p.m.)

Random Code: ___________ Sign Code: ___________

Instructions: Please Circle ONE Number that best answers each of the following questions.

1. How easy were you able to recognize the legend (words or symbol) on the signs?

1st sign	1. Easy	2. Average	3. Difficult
2nd sign	1. Easy	2. Average	3. Difficult
3rd sign	1. Easy	2. Average	3. Difficult

2. How easy were you able to identify the background color of the signs?

1st sign	1. Easy	2. Average	3. Difficult
2nd sign	1. Easy	2. Average	3. Difficult
3rd sign	1. Easy	2. Average	3. Difficult

3. Please rate the overall adequacy of the signs in terms of communicating the intended message.

1st sign	1. Easy	2. Average	3. Difficult
2nd sign	1. Easy	2. Average	3. Difficult
3rd sign	1. Easy	2. Average	3. Difficult

4. What changes do you want to see made to the size of the signs?

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

5. What changes do you want to see made to the brightness of the signs?

1st sign	1. Too bright	2. Not bright enough	3. OK as is
2nd sign	1. Too bright	2. Not bright enough	3. OK as is
3rd sign	1. Too bright	2. Not bright enough	3. OK as is

6. Do you have any comments that you like to share with us concerning the signs which you have seen?

____

____

____

Table F-1. Test Subjects Response to Question 1

How easy were you able to recognize the legend (words or symbol) on the signs?

1. Easy 2. Average 3. Difficult

Test Site	Response	Stop Sign II	Stop Sign IIA	Stop Sign IIIA	Speed Limit Sign II	Speed Limit Sign IIA	Speed Limit Sign IIIA	Merge Symbol Sign II	Merge Symbol Sign IIA	Merge Symbol Sign IIIA
		Sheeting Type[a]			Sheeting Type[a]			Sheeting Type[a]		
Rural	1	63%	77%	83%	57%	70%	83%	33%	37%	47%
	2	37%	23%	17%	43%	30%	17%	37%	40%	33%
	3	0%	0%	0%	0%	0%	0%	30%	23%	20%
Urban	1	57%	63%	77%	50%	63%	77%	43%	43%	53%
	2	43%	37%	23%	47%	37%	23%	37%	37%	30%
	3	0%	0%	0%	3%	0%	0%	20%	20%	17%

a) FP-85 retroreflective sheeting typology

Table F-2. Test Subjects Response to Question 2

How easy were you able to identify the background color of the signs?

1. Easy 2. Average 3. Difficult

Test Site	Response	Stop Sign II	Stop Sign IIA	Stop Sign IIIA	Speed Limit Sign II	Speed Limit Sign IIA	Speed Limit Sign IIIA	Merge Symbol Sign II	Merge Symbol Sign IIA	Merge Symbol Sign IIIA
		Sheeting Type[a]			Sheeting Type[a]			Sheeting Type[a]		
Rural	1	77%	80%	90%	70%	83%	90%	73%	73%	77%
	2	20%	20%	10%	30%	17%	10%	27%	27%	23%
	3	3%	0%	0%	0%	0%	0%	0%	0%	0%
Urban	1	77%	83%	87%	77%	77%	83%	70%	77%	83%
	2	13%	17%	13%	23%	23%	17%	30%	23%	17%
	3	10%	0%	0%	0%	0%	0%	0%	0%	0%

a) FP-85 retroreflective sheeting typology

Table F-3. Test Subjects Response to Question 3

Please rate the overall adequacy of the signs in terms of communicating the intended message.

1. Good 2. Average 3. Poor

Test Site	Response	Stop Sign Sheeting Type[a]			Speed Limit Sign Sheeting Type[a]			Merge Symbol Sign Sheeting Type[a]		
		II	IIA	IIIA	II	IIA	IIIA	II	IIA	IIIA
Rural	1	67%	73%	80%	47%	57%	70%	40%	47%	57%
	2	23%	20%	17%	30%	30%	20%	33%	30%	23%
	3	10%	7%	3%	23%	13%	10%	27%	23%	20%
Urban	1	63%	80%	90%	57%	50%	77%	50%	53%	67%
	2	27%	13%	10%	27%	47%	20%	30%	27%	13%
	3	10%	7%	0%	16%	3%	3%	20%	20%	20%

a) FP-85 retroreflective sheeting typology

Table F-4. Test Subjects Response to Question 4

What changes do you want to see made to the size of the signs?

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

Legend Size 1. Larger 2. Smaller 3. OK as is

Test Site	Response	Stop Sign Overall Size	Stop Sign Legend Size	Speed Limit Sign Overall Size	Speed Limit Sign Legend Size	Merge Symbol Sign Overall Size	Merge Symbol Sign Legend Size
Rural	1	57%	57%	50%	57%	57%	73%
	2	0%	0%	0%	0%	0%	0%
	3	43%	43%	50%	43%	43%	27%
Urban	1	50%	57%	60%	60%	53%	73%
	2	0%	0%	0%	0%	0%	0%
	3	50%	43%	40%	40%	47%	27%

a) FP-85 retroreflective sheeting typology

Table F-5. Test Subjects Response to Question 5

What changes do you want to see made to the brightness of the signs?

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

		Stop Sign			Speed Limit Sign			Merge Symbol Sign		
		Sheeting Type[a]			Sheeting Type[a]			Sheeting Type[a]		
Test Site	Response	II	IIA	IIIA	II	IIA	IIIA	II	IIA	IIIA
	1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rural	2	67%	33%	10%	57%	43%	10%	57%	33%	7%
	3	33%	67%	90%	43%	57%	90%	43%	67%	93%
	1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Urban	2	50%	37%	17%	60%	50%	20%	50%	33%	13%
	3	50%	63%	83%	40%	50%	80%	50%	67%	87%

a) FP-85 retroreflective sheeting typology

APPENDIX G

SIGN ADEQUACY QUESTIONNAIRE RESULTS

(Experiment 2)

SIGN ADEQUACY QUESTIONNAIRE

Driver Number: __________ Test Location: ______________

Date: __________________ Time: ___________ (a.m./p.m.)

Random Code: __________ Sign Code: ______________

Instructions: Please <u>Circle ONE Number</u> that best answers each of the following questions.

---

1. How easy were you able to recognize the legend (words or symbol) on the signs?

1st sign	1. Easy	2. Average	3. Difficult
2nd sign	1. Easy	2. Average	3. Difficult
3rd sign	1. Easy	2. Average	3. Difficult
4th sign	1. Easy	2. Average	3. Difficult
5th sign	1. Easy	2. Average	3. Difficult
6th sign	1. Easy	2. Average	3. Difficult

2. How easy were you able to identify the background color of the signs?

1st sign	1. Easy	2. Average	3. Difficult
2nd sign	1. Easy	2. Average	3. Difficult
3rd sign	1. Easy	2. Average	3. Difficult
4th sign	1. Easy	2. Average	3. Difficult
5th sign	1. Easy	2. Average	3. Difficult
6th sign	1. Easy	2. Average	3. Difficult

3. Please rate the overall adequacy of the signs in terms of communicating the intended message.

1st sign	1. Good	2. Average	3. Poor
2nd sign	1. Good	2. Average	3. Poor
3rd sign	1. Good	2. Average	3. Poor
4th sign	1. Good	2. Average	3. Poor
5th sign	1. Good	2. Average	3. Poor
6th sign	1. Good	2. Average	3. Poor

4. What changes do you want to see made to the <u>size</u> of the signs?

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

5. What changes do you want to see made to the <u>brightness of the sign background</u>?

1st sign	1. Too bright	2. Not bright enough	3. OK as is
2nd sign	1. Too bright	2. Not bright enough	3. OK as is
3rd sign	1. Too bright	2. Not bright enough	3. OK as is
4th sign	1. Too bright	2. Not bright enough	3. OK as is
5th sign	1. Too bright	2. Not bright enough	3. OK as is
6th sign	1. Too bright	2. Not bright enough	3. OK as is

6. What changes do you want to see made to the brightness of the sign legend?

1st sign	1. Too bright	2. Not bright enough	3. OK as is
2nd sign	1. Too bright	2. Not bright enough	3. OK as is
3rd sign	1. Too bright	2. Not bright enough	3. OK as is
4th sign	1. Too bright	2. Not bright enough	3. OK as is
5th sign	1. Too bright	2. Not bright enough	3. OK as is
6th sign	1. Too bright	2. Not bright enough	3. OK as is

7. **Do you have any comments that you like to share with us concerning the signs which you have seen?**

____

____

____

Table G-1. Test Subjects Response to Question 1

How easy were you able to recognize the legend (words or symbol) on the signs?

1. Easy 2. Average 3. Difficult

Test Site	Response	Sheeting Type (Legend/Background)[a]					
		IIIA / IIIA	IIIA / IIA	IIIA / II	IIA / IIA	IIA / II	II / II
EXIT SIGN							
Rural	1	50%	57%	60%	47%	53%	50%
	2	37%	30%	30%	40%	30%	37%
	3	13%	13%	10%	13%	17%	13%
Urban	1	53%	53%	50%	40%	50%	40%
	2	27%	37%	13%	37%	27%	23%
	3	20%	10%	37%	23%	23%	37%
REST AREA SIGN							
Rural	1	40%	43%	53%	33%	33%	33%
	2	33%	27%	30%	40%	40%	37%
	3	27%	30%	17%	27%	27%	30%
Urban	1	37%	40%	43%	40%	40%	33%
	2	23%	30%	27%	40%	37%	20%
	3	40%	30%	30%	20%	23%	47%

a) FP-85 retroreflective sheeting typology

Table G-2. Test Subjects Response to Question 2

How easy were you able to identify the background color of the signs?

1. Easy 2. Average 3. Difficult

Test Site	Response	Sheeting Type (Legend/Background)[a]					
		IIIA / IIIA	IIIA / IIA	IIIA / II	IIA / IIA	IIA / II	II / II
EXIT SIGN							
Rural	1	80%	73%	67%	70%	63%	67%
	2	10%	20%	20%	17%	17%	20%
	3	10%	7%	13%	13%	20%	13%
Urban	1	80%	77%	73%	77%	73%	67%
	2	17%	13%	7%	10%	10%	10%
	3	3%	10%	20%	13%	17%	23%
REST AREA SIGN							
Rural	1	53%	57%	57%	53%	40%	43%
	2	30%	20%	23%	27%	40%	30%
	3	17%	23%	20%	20%	20%	27%
Urban	1	50%	50%	50%	50%	50%	50%
	2	33%	33%	27%	30%	27%	27%
	3	17%	17%	23%	20%	23%	23%

a) FP-85 retroreflective sheeting typology

Table G-3. Test Subjects Response to Question 3

Please rate the overall adequacy of the signs in terms of communicating the intended message.

1. Good 2. Average 3. Poor

Test Site	Response	Sheeting Type (Legend/Background)[a]					
		IIIA / IIIA	IIIA / IIA	IIIA / II	IIA / IIA	IIA / II	II / II
		EXIT SIGN					
	1	67%	63%	60%	57%	63%	63%
Rural	2	23%	30%	27%	20%	20%	27%
	3	10%	7%	13%	23%	17%	10%
	1	73%	70%	70%	67%	67%	67%
Urban	2	27%	30%	27%	30%	23%	20%
	3	0%	0%	3%	3%	10%	13%
		REST AREA SIGN					
	1	53%	50%	53%	47%	43%	43%
Rural	2	27%	33%	37%	30%	30%	37%
	3	20%	17%	10%	23%	27%	20%
	1	60%	57%	60%	47%	47%	43%
Urban	2	27%	23%	23%	27%	30%	33%
	3	13%	20%	17%	26%	23%	24%

a) FP-85 retroreflective sheeting typology

Table G-4. Test Subjects Response to Question 4

What changes do you want to see made to the size of the signs?

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

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

Test Site	Response	Exit Sign		Rest Area Sign	
		Overall Size	Legend Size	Overall Size	Legend Size
	1	53%	67%	73%	83%
Rural	2	0%	0%	0%	0%
	3	47%	33%	27%	17%
	1	50%	63%	67%	80%
Urban	2	0%	0%	0%	0%
	3	50%	37%	33%	20%

a) FP-85 retroreflective sheeting typology

Table G-5. Test Subjects Response to Question 5

What changes do you want to see made to the brightness of the sign background?

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

Test Site	Response	Sheeting Type (Legend/Background)[a]					
		IIIA / IIIA	IIIA / IIA	IIIA / II	IIA / IIA	IIA / II	II / II
		EXIT SIGN					
Rural	1	0%	0%	0%	0%	0%	0%
	2	10%	13%	40%	23%	43%	37%
	3	90%	87%	60%	77%	57%	63%
Urban	1	0%	0%	0%	0%	0%	0%
	2	23%	30%	37%	27%	43%	43%
	3	77%	70%	63%	73%	57%	57%
		REST AREA SIGN					
Rural	1	0%	0%	0%	0%	0%	0%
	2	23%	33%	43%	37%	40%	43%
	3	77%	67%	57%	63%	60%	57%
Urban	1	0%	0%	0%	0%	0%	0%
	2	30%	30%	43%	33%	33%	33%
	3	70%	70%	57%	67%	67%	67%

a) FP-85 retroreflective sheeting typology

Table G-6. Test Subjects Response to Question 6

What changes do you want to see made to the brightness of the sign legend?

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

Test Site	Response	Sheeting Type (Legend/Background)[a]					
		IIIA / IIIA	IIIA / IIA	IIIA / II	IIA / IIA	IIA / II	II / II
		EXIT SIGN					
Rural	1	0%	0%	0%	0%	0%	0%
	2	20%	20%	20%	27%	40%	40%
	3	80%	80%	80%	73%	60%	60%
Urban	1	0%	0%	0%	0%	0%	0%
	2	27%	27%	23%	33%	33%	40%
	3	73%	73%	77%	67%	67%	60%
		REST AREA SIGN					
Rural	1	0%	0%	0%	0%	0%	0%
	2	33%	47%	33%	50%	50%	50%
	3	67%	53%	67%	50%	50%	50%
Urban	1	0%	0%	0%	0%	0%	0%
	2	37%	33%	33%	47%	43%	47%
	3	63%	67%	67%	53%	57%	53%

a) FP-85 retroreflective sheeting typology