National Cooperative Highway Research Program

NCHRP Report 346

NCHRP - 346
SIGNS

Implementation Strategies for Sign Retroreflectivity Standards

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Report 346

Implementation Strategies for Sign Retroreflectivity Standards

K. L. BLACK, H. W. McGEE and S. F. HUSSAIN
Bellomo-McGee, Inc.
Vienna, Virginia

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD
National Research Council
Washington, D. C.
April 1992

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

Note: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers names appear herein solely because they are considered essential to the object of this report.

NCHRP REPORT 346

Project 5-11 FY'89

ISSN 0077-5614

ISBN 0-309-04869-9

L. C. Catalog Card No. 92-80551

Price $9.00

Areas of Interests
Operations and traffic control

Mode
Highway Transportation

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

This report will be of interest to transportation officials concerned with the nighttime visibility of highway traffic signs and the cost for the replacement of signs to maintain a minimum standard of nighttime visibility. The report will be of particular interest to traffic engineers responsible for the management and maintenance of traffic signs. The focus of the report is retroreflectivity—the property of traffic signs that makes them visible at night. The key issue is the national cost to provide a given level of retroreflectivity as a function of the length of time over which the standard would be phased in.

In 1985, the Federal Highway Administration published an Advance Notice of Proposed Amendment to the *Manual on Uniform Traffic Control Devices* as the initial step in developing performance standards for in-service, retroreflective, traffic-control devices. Since then, research has been conducted to determine minimum visibility requirements for traffic signs that will satisfy the need of the nighttime driving population. In addition, research has been completed to develop cost-effective, field-measurement tools to determine whether a specific in-service traffic sign meets given retroreflectivity levels. Research on the service life of retroreflective signs has also contributed to the knowledge base needed to support the proposed establishment of retroflectivity standards.

However, before retroreflectivity standards can be implemented, their potential economic impact must be assessed. Further, any adverse effects of such standards should be mitigated. The research reported here was undertaken to provide alternative strategies for economical ways to improve the effectiveness of signs within available resources.

Under NCHRP Project 5-11, "Implementation Strategies for Sign Retroreflectivity Standards," research was undertaken by Bellomo-McGee, Inc., Vienna, Virginia, with the objective of determining the economic consequences of alternative standards for retroreflective traffic signs.

To accomplish the objectives, the research agency had to address the following questions:

- What is the status of the Nation's signs regarding their level of retroreflectivity?
- How many signs exist on the Nation's roadway system by sign type, jurisdictional level, and other key factors?
- What is the cost to replace signs by the type of sign, type of retroreflective material, and by jurisdictional location?

Once this information was obtained, an economic assessment model was applied with the following specific objectives: (1) Determine the economic consequences of alternative standards for retroreflective traffic signs, i.e.: What will it cost to meet and maintain standards? (2) Develop economic-based implementation strategies and recommend options for systemwide implementation, i.e.: What are the alternative ways to have jurisdictions come into compliance, considering their resources?

The findings of the research have indicated that minimum retroreflectivity standards could cost approximately $156 million per year nationally for a 10-year implementation schedule under the higher of the two levels of standards evaluated. At the lower standards, the national cost would be no more than currently experienced for regular sign maintenance activities, assuming a 5- or 10-year implementation schedule. If a much shorter implementation schedule of one year was adopted, a one time cost of between $400 million and $2 billion would be expected, depending on the standards selected.

CONTENTS

ACKNOWLEDGMENTS

The research reported here was conducted by Bellomo-McGee, Inc. (BMI) with Hugh W. McGee and Kent L. Black as co-principal investigators. Syed F. Hussain (BMI) conducted much of the statistical analyses with the support of Margaret Rouchon (BMI). Data collection and other technical assistance were provided by Justin J. Rennilson of Advanced Retrotechnology, Inc. (ATRI) located in La Mesa, California. Westat Inc. of Gaithersburg, Maryland, provided David Mórganstein as a consultant for the development of the sampling plan followed in the collection of retroreflectivity condition of signs throughout the United States.

IMPLEMENTATION STRATEGIES FOR SIGN RETROREFLECTIVITY STANDARDS

SUMMARY

Minimum retroreflectivity standards for traffic signs are currently being considered and indications are that standards will be instituted in the near future. Prior to the establishment of retroreflectivity standards two key issues must be addressed: (1) how will the standards be implemented and (2) how much will the standards cost jurisdictions for replacement and maintenance activities. Currently, only new purchase specifications exist for permanent and temporary traffic signs. The retroreflectivity specifications measured in terms of specific intensity per unit area (SIA) are related to manufacturer's warranties and were not established based on motorist needs for sign legibility. Minimum retroreflectivity standards for traffic signs based on legibility requirements are needed.

Measurements of retroreflectivity were taken on approximately 8,000 traffic signs across the country. These samples became the basis for evaluating the general condition of the nation's traffic signs. A signing questionnaire was developed and distributed to state, county, and city jurisdictions. Estimates of sign inventory, replacement, and maintenance costs were derived from the survey responses. The Federal Highway Administration (FHWA) supplied ranges of minimum retroreflectivity values for this project. Lower and upper sets of retroreflectivity values were selected from the FHWA data for red, yellow, green, and white sheeting. The number of signs not meeting the standard criteria was determined for each sheeting type. The economic costs associated with the necessary sign replacement and related maintenance activities were determined. Several implementation strategies and schedules were identified for instituting the minimum retroreflectivity standards. These include prioritizing sign replacement by sign type and roadway class. Implementation schedules ranged from 1 to 10 years for compliance. Because a broad economic analysis was required only basic implementation strategies were tested. These strategies assumed no prioritization of sign or roadway types, but required compliance with the standards within 1 to 10 years.

The current national population of traffic signs (not including street name and parking) is estimated to be nearly 60 million. If the higher minimum retroreflectivity standards tested in this research were applied, approximately 17 million traffic signs on the nation's roadways would require replacement today. This would amount to approximately $156 million in sign maintenance costs per year for a 10-year implementation program. If the lower standards were applied, the cost for maintenance activities should not exceed current expenditures with a 5- or 10-year implementation schedule. With the advent of retroreflectivity standards, jurisdictions will also have to consider instituting sign inventories and strict inspection programs. These items will create an additional monetary demand on signing budgets. Preliminary results of an on-going FHWA research project dealing with motorists' needs in relationship to sign legibility were used to develop the minimum retroreflectivity standards tested here.

The research found that the economic impacts of standards will be hardest felt by city jurisdictions. This is because of the relatively poor condition of traffic signs on city roadways. In addition, deficient green signs accounted for a disproportionate share of replacement costs across all jurisdiction types. Green sheeting, especially engineering

grade, has rather low retroreflective properties. One of the minimum standards tested here for green sheeting was actually higher than the delivered new specification prescribed by states and the FHWA for engineering grade sheeting. Ground-mounted guide signs also tend to be at least twice as large as standard warning and regulatory signs; therefore, the cost to replace ground-mounted guide signs is nearly double that of other traffic signs.

The research reported here tested two sets (i.e., lower and upper) of retroreflectivity standards. The lower standards should have minimal economic impacts on most jurisdictions. However, the upper standards would have an extreme impact on signing budgets. Maintenance to the upper standards could cost two to six times as much as current budgets. The establishment of retroreflectivity standards between the two sets of standards tested here would still burden some jurisdictions. However, the anticipated benefits of reduced liability and improved public safety could offset the additional maintenance costs.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROJECT BACKGROUND AND RESEARCH OBJECTIVE

Traffic signs are a very important component of streets and highways. They help motorists find their way in a safe manner by providing for the orderly and predictable movement of traffic. For signs to accomplish their intended purposes, they must be visible to the motorists. Although sign visibility is generally not a problem during daylight, signs with inadequate retroreflectivity may not be sufficiently visible at night and can contribute to accidents.

Research has been initiated to determine visibility requirements for traffic signs that will satisfy the needs of the nighttime driving population. In addition, research is under way to develop field measurement tools to determine whether a specific in-service traffic sign meets given retroreflectivity levels.

The Federal Highway Administration (FHWA) published an Advanced Notice of Proposed Amendment (*1*) to the *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*) as an initial step in developing a performance standard for in-service retroreflectance of traffic control devices. The principal behind such a standard is that signs and other devices that rely on internal retroreflectance to be visible should maintain a level of performance that relates to minimum driver visibility requirements. This objective is not without technical, logistical, and practical obstacles.

One critical technical issue to resolve is to establish driver nighttime visibility needs and translate those to sign retroreflectivity requirements. This has been the task of a FHWA project entitled, "Minimum Visibility Requirements for Traffic Control Devices." The primary objective of that project is to develop a relationship between retroreflectivity levels and driver profiles so that in developing a performance standard one can use as a criterion the percent of drivers excluded by the standard.

Another issue, which is both technical and logistical, is the field measurement of retroreflectivity for signs and other devices. If the performance standard is to be a minimum retroreflectivity value, an easy method for measuring this property of in-service signs is required. The current method is to use a portable retroreflectometer. The most prevalent apparatus used is the Model 920™ manufactured by Advanced RetroTechnology, Inc. While this is a portable unit, it is still felt too cumbersome and time consuming to be used for a wide scale inspection program. The National Cooperative Highway Research Program (NCHRP) Project 5-10, "A Mobile System for Measuring Retroreflectance of Traffic Signs" (*3*) has resulted in a prototype system that is under further evaluation and refinement by FHWA.

On the practical side, there is the issue of what will be the economic impact imposed on the various jurisdictions, and indeed the public, of establishing a performance standard. Depending on the strictness of the standard, i.e., the retroreflectivity level and how soon the jurisdictions would have to be in full compliance, there will be an initial financial impact of replacing the existing deficient signs and devices. Thereafter, there will be a continuing cost to maintain the entire system within the prescribed standard. Before establishing the performance standard, the FHWA and others faced with this decision should be aware of what these impacts would be for different standard levels. How many signs would have to be replaced, what would be the costs to do so, and what will it cost agencies to maintain the signs to the standard? These and other related issues are addressed by this project.

SCOPE OF STUDY

The performance standard has not yet been established and it was not the objective of this study to do so. Rather, it was the objective of the NCHRP Project 5-11 to assess the impacts of alternative standards and provide strategies and guidelines for implementing the standard.

Before sign retroreflectivity standards can be implemented, their potential economic impact must be assessed and any adverse effects of such standards should be mitigated. To meet the overall objective of this study, and to resolve these issues, requires certain information. The information includes: What is the status of the Nation's signs regarding their level of retroreflectivity? How many signs exist on the Nation's roadway system by sign type, jurisdictional level, and other key factors? What is the cost to replace signs by the type of sign, type of retroreflective material, and by jurisdictional location?

This information is required to meet the specific objectives of this project. The information must be analyzed within an economic model to determine what it will cost jurisdictions to replace signs that do not meet alternative standards. The specific objectives, therefore, are as follows: (1) Determine the economic consequences of alternative standards for retroreflective traffic signs, i.e., What will it cost agencies to meet and maintain standards? (2) Develop economic-based implementation strategies and recommend options for system-wide implementation, i.e., What are the alternative ways to have jurisdictions come into compliance considering their resources?

It was anticipated that the initial costs of compliance with retroreflective standards would be substantial and beyond the resources of many jurisdictions. Alternative strategies for implementing the standards need to be identified and evaluated.

RESEARCH APPROACH

To accomplish the goals and objectives of this project the following general tasks were completed:

Task 1—Evaluate Literature and Other Sources. The literature and other informational sources dealing with retroreflectivity of traffic signs were considered. The various types of sign inventory systems in use and current maintenance practices were investigated.

Task 2—Summarize Information Pertinent to Establishing Feasibility Retroreflectivity Standards. This task was accomplished by reviewing pertinent references and by considering the latest results and findings from on-going and recent research projects.

Task 3—Collect Retroreflectivity Condition and Other Sign Data. Existing data on in-service sign retroreflectivity, replacement costs (e.g., labor and material), and sign densities were collected and compiled. Data were collected on standard, ground-mounted traffic signs. Overhead and parking series signs were not included.

Task 4—Analyze Data. For different categories of signs, relationships were developed that indicate how various retroreflectivity standards would affect, nationally and at the state and local levels: (a) the number of signs to be replaced, (b) the replacement costs, (c) any other economic or management considerations. The modeling techniques used are described so they can be applied readily to any jurisdiction's sign replacement and management programs.

Task 5—Develop Economic-Based Implementation Strategies. Economic-based implementation strategies were developed for alternative sign retroreflectivity standards across different categories of signs, roadways, and jurisdictions.

Task 6—Recommended Implementation Options. Several options for system-wide implementation were developed to provide guidance for phasing the implementation of the retroreflectivity standards and to indicate the expected economic consequences of adoption of the standards.

CHAPTER TWO

FINDINGS

This chapter presents the key findings of the study in three sections. Specifically, these sections relate to the literature review, the retroreflectivity data collected from more than 8,000 sign samples across the country, and the results of the questionnaire sent to the states, counties, and cities for information, sign inventories, and maintenance. More detailed information is provided in Appendixes A, B, C, and D.

LITERATURE REVIEW SUMMARY

Principles of Retroreflection and Sheeting Materials

Nearly all signs have to be legible and color distinguishable at night as well as day. While this can be accomplished through external illumination of the signs, retroreflection is the most commonly used means of making signs visible to the driver at night.

Retroreflection occurs when light rays strike a surface and are redirected back to the source of light. Two principles followed to achieve retroreflectivity for roadway signs are prismatic and spherical lens retroreflection. Prismatic, also known as cube-corner, retroreflection is achieved through total internal reflection. Incoming light hits the first surface and reflects to the rear surface which reflects it to the last surface which reflects the light rays back to the source. In the second type, spherical lens retroreflection is achieved through a combination of a glass sphere (bead) and a reflecting (mirror type) surface placed at the focal point. The incoming ray is bent and directed inside and toward the back of the sphere, reflecting off reflective surface, and after being bent at the exterior of the sphere redirected

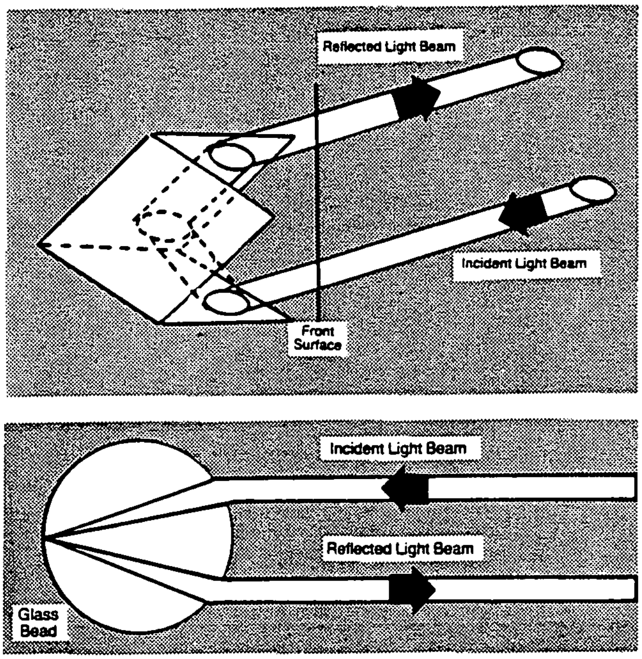


Figure 1. Two types of retroreflection, cube-corner (top) and spherical lens (bottom).

toward the light source. These two principles for achieving retroreflection are illustrated in Figure 1 and further described in Appendix A with the entire literature review. Three references (*4,5,6*) are suggested for a thorough discussion of the principles of sign retroreflectivity.

Retroreflective sheeting consists of micro cube-corners or spheres enclosed in a weather resistant, transparent plastic film. To reflect color, pigment or dye is inserted into the film or on the reflecting surface. There are three types of spherical lens (bead) retroreflective sheeting: (1) exposed glass bead, (2) enclosed glass bead, and (3) encapsulated glass bead. In the exposed lens sheeting the front half of the glass beads are exposed to the outside air. Glass beads work best when exposed to the air. However, because of the small size of the beads, a film of water can cover the beads when it rains and can greatly reduce the retroreflectivity of the beads. Hence, this type of sheeting is not recommended for traffic signs and is no longer included in state or federal specifications. Nonetheless, exposed lens sheeting is still found on traffic signs on some low-volume rural roads controlled by local jurisdictions.

Enclosed lens sheeting material consists of a layer of transparent plastic of appropriate color in which glass beads are imbedded. A metallic reflection shield is provided behind the plastic, with a layer of adhesive and with a protective liner that is removed during sign fabrication. The plastic covering enables the sheeting to be equally bright under dry and wet weather conditions.

With encapsulated lens sheeting the glass beads are also protected by a transparent material that is supported slightly above the beads by walls creating an air-filled compartment. The back of the beads are covered with a reflective surface. The resulting airspace in front of the beads makes it more retroreflective and, hence, is known as high performance sheeting.

One of the most important properties of retroreflective sheeting is the ability to return light that is commonly described by a variety of terms including brightness, retroreflectance, luminance, and candlepower. The International Commission of Illumination (CIE) uses the term coefficient of luminous intensity that is defined as the ratio of luminous intensity of reflector in the direction of the observation to the illumination at the retroreflector on a plane perpendicular to the light. In the metric system, designated as the International System of Units (SI), it is expressed as candelas, cd, per lux, lx. This definition treats the retroreflector as a point source. Because signs have a relatively large area, they are treated as an extended light source which may be thought to consist of many point sources, each with a luminance intensity of one candela. The coefficient of luminous intensity divided by the area is expressed in SI units as candelas per lux per square meter and identified as the coefficient of retroreflection. The English equivalency for coefficient of retroreflection is candelas per foot candle per square foot and is denoted as R_A. In the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-85* (*7*), the coefficient of retroreflection, R_A, is described as specific intensity per unit area (SIA). The conversion from SI to the English system is unity. CIE plans to adopt R_A as their designation in the SIA nomenclature. The SIA designation will be used throughout this report.

The retroreflectance of sheeting material is described in the context of another important property, its angularity, which is defined by the entrance (of the light) and the observation (of the motorist) angles. The entrance angle is the angle formed between a light beam striking the surface of a sign and a line coming out perpendicular from the surface. The observation angle is the angle between the incoming light beam and the reflected light beam and is a function of the height of the driver's eye with respect to the vehicle headlamps. In the FP-85 and other specifications, minimum SIA is prescribed for each different type of sheeting for two observation angles, two entrance angles, and for different colors.

The following specifications, related to retroreflectance, were a primary source of information:

1. *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-85* (*7*).
2. Federal Test Method Standard 370, Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices (*8*).
3. Four standards of the American Society for Testing and Materials (ASTM) on color and appearance measurement:

- E808-81 "Standard Practice for Describing Retroreflection"
- E809-81 "Standard Practice for Measuring Photometric Characteristics of Retroreflectors"
- E810-81 "Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting"
- E811-81 "Standard Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions"

In the FP-85, three types of retroreflective sheeting are recognized. The first type has two classes: Type II and Type II A, commonly called engineering and super-engineering grade sheeting, respectively. They are both enclosed-lens type sheeting. The minimum SIA values specified by FP-85 for Type II A are about twice those for Type II. The next type has three classes: Type III A, III B, and III C. All are encapsulated type sheeting with Type III A made of glass beads and Type III B and III C made of prismatic reflectors. All three types provide much higher brightness than both Type II and Type II A. The last type of sheeting recognized in the FP-85 is labeled as Type IV. This type is a high performance vinyl sheeting that is used for retroreflective white collars around orange cones and for "fold-up" temporary signs of the kind commonly used by utility companies.

Visibility Distance

The sight distance requirement of a sign is a function of five components: (1) sign detection, (2) sign recognition, (3) driver decision-making, (4) response, and (5) completion of maneuver. McGee et al. (*9*) developed and field tested a decision sight distance model based on detection, recognition, decision-making, response, and vehicle maneuver. The decision sight distance model elements were later reexamined by Perchonok et al. (*10*) to develop a version applicable to determining nighttime visibility requirements for retroreflective devices. The model determines minimum detection distance requirement as the summation of distances required for five phases of action. The summation process is based on the assumption that, in the worst case, the driver must accomplish each aspect of the process in order, one after the other. The model was formalized by Mace et al. (*11*) as a computerized program to evaluate luminance requirement to aid in sign maintenance decisions. This sign maintenance management program models sign visibility requirements in terms of time and distance requirements. However, it does not model the visibility requirements of signs based on human performance capabilities in terms of luminance and contrast needs.

The human visual performance model most generally accepted among highway visibility researchers is that published by the International Commission on Illumination (CIE). This model represents an analytic approach to determining the observer's detection threshold contrast when adapted to a particular surround luminance, with glare and transient adaptation requirements accounted for. An object is visible or detectable at threshold level if the object's contrast meets or exceeds the contrast required by an observer when adapted to the luminance of the object's background, also taking into account the effects of disability glare and background luminance that may change over time. This analytic approach to visibility has been incorporated by Bhise et al. (*12*) into a seeing distance model called DETECT, which is a part of the Comprehensive Headlamp Environment Systems Simulation Model (CHESS). The program calculates the threshold visibility distance (50 percent probability of detection) to targets such as delineation, pedestrians, traffic cones, etc., under a wide range of conditions with or without glare from opposing vehicles.

Sign Legibility

Drivers require a minimum amount of luminance for detection and legibility of signs. The specification of minimal luminance requirements for traffic signs has been addressed by a number of researchers. Historically, a sign was considered sufficiently bright if it provided approaching drivers with a minimum of 50 ft of legibility per inch of letter height. However, the selection of 50 ft per in. as a minimum legibility distance is quite arbitrary. Mace (*13*) suggested that older driver's visibility requirements should be based on a legibility of 40 ft per in. of letter height. Mace also reported that the typical practice in the states is to license drivers at a 20/40 high-luminance acuity. This acuity level corresponds to a legibility of approximately 30 ft per in. of letter height.

An approach that has been used is to consider a sign's level of brightness. Sign brightness is considered satisfactory if it provides a legibility distance that is greater than or equal to 85 percent of the maximum obtainable nighttime legibility distance. This criterion is too arbitrary as it does not account for the driving situation.

Other measures that have been used to develop the relationship between sign brightness and legibility have been uniformity of sign background, level of internal contrast, and luminance of legend or background. If a sign face degrades unevenly as it ages, the legibility of the sign is impaired. The Institute of Transportation Engineers (ITE) recommends a ratio of 5 : 1 as the maximum acceptable ratio of luminances for externally lighted traffic signs (*14*). Another study conducted by Allen et al. (*15*) concluded that variation in the luminance of different areas of the sign should not be more than 10 : 1. Another study (*16*) specifically designed to establish the relationship between the luminance uniformity of sign background and legibility found that for externally illuminated signs these two variables are significantly correlated only when sign luminance ranges from 9.9 to 39.7 foot-lambert (FL). These data indicated that if a reduction in maximum obtainable legibility of 50 percent is assumed to be maximum acceptable performance decrement, the maximum acceptable ratio of background luminances is 6 : 1. However, the luminance of Type II and Type III white sheeting rarely exceeds 9.9 FL. For these reasons, the luminance uniformity of background may be relevant to legibility of illuminated signs, but may not be relevant to retroreflective signs.

The contrast between the luminance of the sign legend and the luminance of the sign background is a key measure that has been related to sign brightness and legibility. A common measure of internal contrast is the luminance ratio of the legend and background of the sign, with the greater of the two values used in the numerator of the expression. For signs with a black legend on color background the legibility is determined by the luminance of the color portion of the sign. Therefore, minimum brightness standards based solely on internal contrast would have little applicability to signs having either a black legend or a black background. Also, most signs will not be taken out of service until they have lost most of their retroreflectivity, which means that the internal contrast of the sign is essentially fixed for the duration of the sign's service life by the material with which it is constructed. Therefore, internal contrast is most relevant in sign design and construction.

Another measure of sign brightness that can be related to legibility is sign luminance. Legibility as a function of sign luminance has been studied to a greater extent than any other measure of sign brightness. A 1988 study of nighttime conspicuity of highway signs by Olson (*17*) resulted in recommendation of minimum SIA values for various sign types with guidance re-

Table 1. End of service life SIA values recommended by Florida DOT.

Sheeting Color	End of Service Life SIA Values[1]	
	Type II[2]	Type II A, III A, III B[3]
White	40	140
Yellow	16	40
Green	5	5
Red	na	10

na - not available

[1] SIA values measured at 0.2° observation and -4° entrance angles.
[2] Engineering grade sheeting (Type II).
[3] Super-engineering grade (Type II A), high performance (Type III A), and prismatic (Type III B) sheeting.

Source: Florida DOT (19)

garding the selection of sheeting materials. The SIA values are based on area complexity and the required stopping sight distances for various speeds.

Another study by Morales (*18*) resulted in recommendation on required overall SIA for STOP signs for various approach speeds under ideal visibility conditions. The study suggests that legibility should not be used as a criterion for developing in-service retroreflective standards for STOP signs, and it provides mathematical relationships between STOP-sign recognition distance and its photometric characteristics. This is because the unique shape of STOP signs should be recognized and not read to be understood.

A study conducted by the Florida DOT (*19*) recommended "end of service life" SIA values for various sheeting colors and types. The study used several observers, at night, in the same vehicle. Each observer recorded when sign detection, shape recognition, color recognition, message recognition and legibility occurred. The times were converted to distances. Each sign was then screened, thereby reducing SIA, until the sign was determined to be barely adequate. Table 1 provides the recommended "end of service life" values for white, yellow, green, and red sheeting colors.

Luminance Standards

The existing federal standards for luminance of retroreflective materials for traffic signs are purchase specifications and provide no differentiation based on driver needs. The MUTCD (*2*) simply specifies that all warning and regulatory signs be reflectorized or illuminated to show the same color and shape by day or night unless specifically excepted in the standards. The MUTCD has no minimum initial or replacement requirements for retroreflective signs. FP-85 does provide minimum SIA standards for new material. These standards, however, were developed by sheeting manufacturers as a purchase specification not based on driver's needs. For work zone traffic control, FP-85 (*7*) does specify that traffic signs and devices must retain 75 percent and 50 percent of the new specification for engineering grade and high performance sheeting, respectively.

Based on the agencies surveyed, replacement is left to practices that vary between states and levels of government within states. The need for inspection of signs for retroreflectivity is typically not determined under a regimented policy or schedule, but is by casual, visual inspection. This deficiency is due to the lack of a minimum brightness standard, the competing demands on personnel's times, and the absence of a rapid and reliable reflectance measurement device. However, the development of automated sign inventories, minimum performance standards, mobile system for measuring retroreflectance, and implementation strategies will provide an opportunity for more efficient and objective solutions to the problems of sign maintenance management.

Research has been conducted which is relevant to the question of a standard, but standards have not yet been implemented that reflect fundamental driver needs. This is because specifying luminance standards for traffic signs is complex and multidimensional. Driver requirements of different signs change across situations. Also the population of signs is not uniform in purpose or function. Signs are created in different designs to serve various needs, and these differences create varying levels of luminance required for signs to function properly at night.

The FHWA project on "Minimum Visibility Requirements for Traffic Control Devices," is to determine the minimum visibility distances for signs and markings. Based on these minimum visibility requirements, it will be possible to determine the retroreflectivity necessary to make a sign or marking visible at a given distance. Another difficulty in the implementation of standards has been an absence of conclusive performance data. The final report for that project will fill this void.

The FHWA project entitled "Service Life of Retroreflective Traffic Signs" (*20*) investigated the relationship between the retroreflectivity performance of sign sheeting with respect to such factors as age, weather conditions, and the like. Based on these relationships, equations were developed to predict approximate in-service SIA of signs. The accuracy of the equations in predicting in-service SIA is limited, however, because the initial SIA values for new sheeting are quite variable.

Finally, there is no fast, practical and reliable way of measuring luminance in the field and, therefore, one cannot easily determine if the requirements are met. The study conducted under NCHRP Project 5-10, "Mobile System for Measuring Retroreflectance of Traffic Signs" (*3*), has determined the feasibility of developing instrumentation suitable to rapidly measure retroreflectivity from a moving vehicle during daylight hours. A prototype of the van-mounted system has been constructed and consists of a video camera, electronic flash gun, laser range finder, and a data acquisition/image analysis system to evaluate the video image for average legend and background retroreflectance. The results of the above three projects and the project reported here will help in development, measurement, and implementation of sign performance standards.

SUMMARY OF RETROREFLECTIVITY DATA

This section provides a summary of the retroreflectivity data collected from more than 8,000 sign samples. The 8,000 signs were samples from roadways within 28 counties in 26 states. The data collection procedures and methodologies are described in Appendix B. Table 2 presents a breakdown of total samples by sheeting color, sheeting type, and area type.

As shown in Table 2, a reasonable sample of each sheeting color and type in urban and rural areas was obtained. Not unexpected was the relatively low sample of high performance green sheeting. Apparently, few agencies currently use high performance green sheeting on their ground-mounted guide signs. Overhead signs were not included in the survey.

SIA data were collected from signs on roadways under the control of state, county, city, and town agencies. Table 3 presents the minimum, maximum, and mean SIA values for each sheeting color, sheeting type, and jurisdiction control. Except for high performance green sheeting, a reasonable sample within each jurisdiction type was obtained. As presented, differences in mean SIA values between jurisdictions do exist.

To facilitate the testing of the impacts of implementing minimum SIA standards, frequency graphs of SIA versus percent of total signs were developed. As the minimum SIA standard will be based on driver's needs and not sheeting material specifications, the sheeting types were combined by sheeting color for development of the frequency graphs. Because the intent of this project was to evaluate the economic impacts on various levels of jurisdictions, individual frequency graphs for state, county, city, and town agencies were developed. SIA values were grouped into increments of 5 SIA values and plotted versus percent of total samples. The graphs depict the percent of signs having that specific SIA value or less.

Figures 2, 3, 4, and 5 provide the frequency graphs for red, yellow, green, and white sheeting, respectively. Again, these graphs include all sheeting types combined and are provided for each of the four jurisdiction levels evaluated. Few conclusions about maintenance practices can be drawn from the frequency graphs. However, it does seem that traffic signs on city-controlled roadways tend to have lower retroreflectivity values across all sign colors.

SUMMARY OF QUESTIONNAIRE SURVEY

A survey concerning sign inventories, maintenance costs, and density factors was distributed to 790 counties, 85 cities, and 50 states. The full results of the questionnaire survey are presented in Appendix C. The major findings are presented here.

Approximately 30 percent of the states responding (48 total responses) maintain a sign inventory at the statewide or district level. Because the questionnaire survey was not inclusive of all agencies an accurate estimate of the percentage of cities and counties having sign inventories is unavailable. It is assumed, however, that few (i.e., 10 to 25 percent) of these local agencies maintain inventory systems. Table 4 provides a summary of inventory systems and data elements for city, county, and state agencies.

Of the states with sign inventories, approximately 80 percent have their systems on micro- or mainframe computers. Only 50 to 60 percent of the local jurisdictions with sign inventories maintained them on a computer system. Almost 50 percent of county agencies with inventories responded as having paper records. Nearly all inventories had the MUTCD sign type designation as a field in the system. Approximately 50 percent of the inventory systems included fields for the sheeting type. But, 75 to 85 percent of the inventory systems did include fields for the date of sign installation or replacement.

Table 5 provides a summary of sign costs and a listing of key reasons for sign replacement. Fabrication includes costs for materials, labor, and equipment. The counties responding to the survey estimated a fabrication cost of approximately $68.00 per sign, while the cities responding estimated a fabrication cost

Table 2. Total sample by area type.

Sheeting Color and Type	Urban	Rural	Combined
RED			
-EG	500	392	892
-HP	311	221	532
YELLOW			
-EG	594	635	1,229
-HP	608	511	1,119
GREEN			
-EG	209	178	387
-HP	61	23	84
WHITE			
-EG	1,293	996	2,289
-HP	798	676	1,474
TOTAL	4,374	3,632	8,006

NOTE: EG = Engineering Grade Sheeting = 60% of sample
HP = High Performance Sheeting = 40% of sample

Table 3. Description of retroreflectivity data.

Sheeting Color and Type	Criteria	Jurisdiction Type				Combined
		State	County	City	Town	
Red - EG	Min[1]	1.5	2.9	1.0	0.8	0.8
	Max[2]	55.4	59.0	55.2	55.6	59.0
	Mean[3]	19.3	19.7	15.4	18.3	17.6
	N[4]	177	222	365	128	892
Red - HP	Min	9.7	4.5	5.8	13.4	4.5
	Max	110.1	109.6	105.7	105.9	110.1
	Mean	51.1	58.2	64.5	68.3	60.1
	N	138	143	142	109	532
Yellow - EG	Min	1.5	1.1	2.2	7.9	1.1
	Max	136.5	147.1	121.0	137.6	147.1
	Mean	67.4	68.0	58.0	78.7	67.5
	N	352	488	217	172	1,229
Yellow - HP	Min	5.9	4.0	106.5	116.2	4.0
	Max	259.3	254.3	249.8	251.5	259.3
	Mean	192.1	186.8	192.7	193.7	190.4
	N	411	421	134	153	1,119
Green - EG	Min	0.6	1.0	1.9	6.1	0.6
	Max	48.6	50.2	31.6	35.5	50.2
	Mean	12.7	14.2	11.7	12.7	12.9
	N	227	85	42	33	387
Green - HP	Min	12.5	11.1	54.1	13.5	11.1
	Max	80.5	79.0	74.6	37.5	80.5
	Mean	47.2	44.2	64.5	27.4	46.1
	N	60	14	4	6	84
White - EG	Min	1.4	1.6	1.2	2.6	1.2
	Max	147.8	150.2	143.6	147.1	150.2
	Mean	89.9	92.5	75.9	98.5	88.2
	N	666	606	633	383	2,289
White - HP	Min	48.0	33.4	113.0	182.5	33.4
	Max	339.1	331.3	326.7	333.6	339.1
	Mean	271.1	271.8	272.9	281.4	273.4
	N	532	424	261	257	1,474

[1] Minimum SIA [3] Mean SIA
[2] Maximum SIA [4] Number of Samples

of approximately $54.00 per sign. The major differences were generated by the higher material and labor costs reported by county agencies. City-controlled roadways typically have much higher sign densities than county roads. Because of these differences, annual sign maintenance costs per mile on city roadways were 45 percent greater than that on county roads. However, the annual sign maintenance costs per capita were only 20 percent higher in city jurisdictions.

Concerning reasons for sign replacement, several differences between the city and county responses were found. The cities

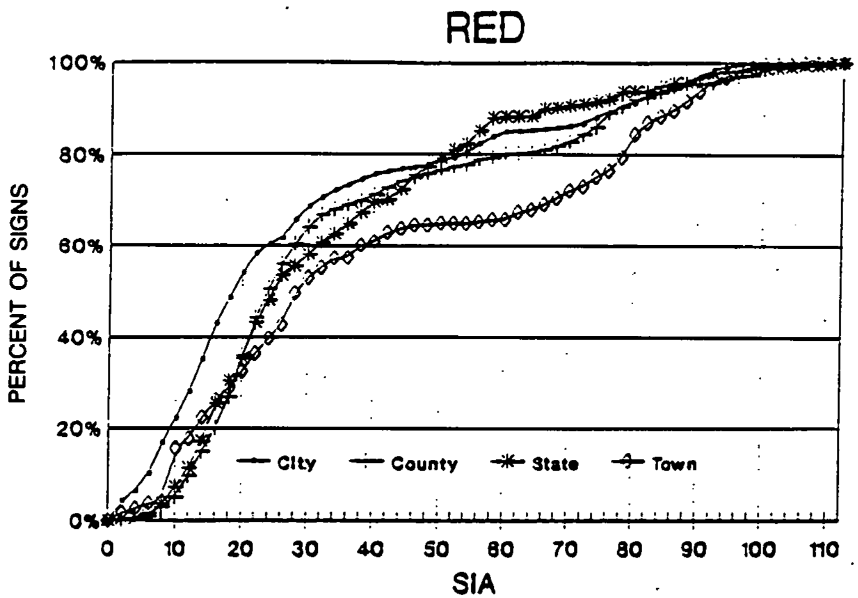


Figure 2. Frequency graph for red screened sheeting.

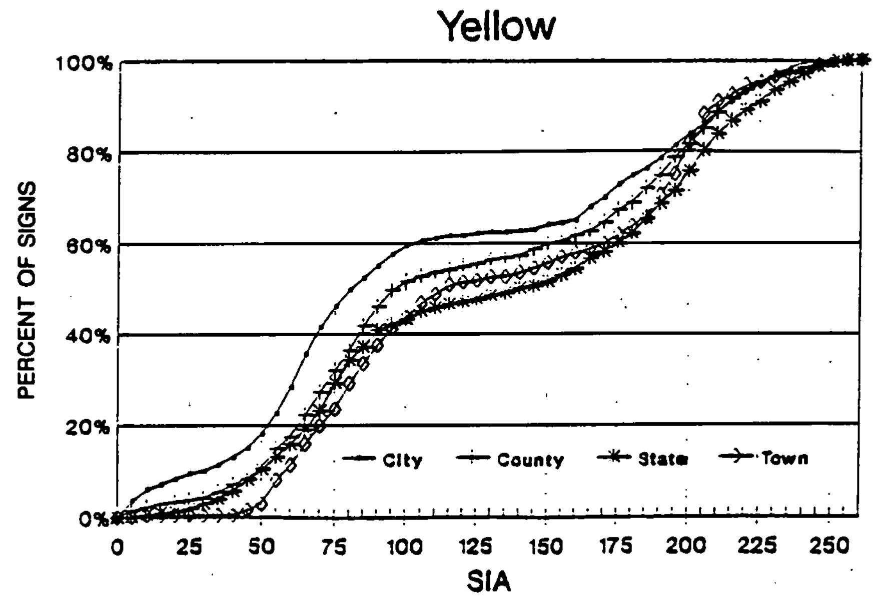


Figure 3. Frequency graph for yellow sheeting.

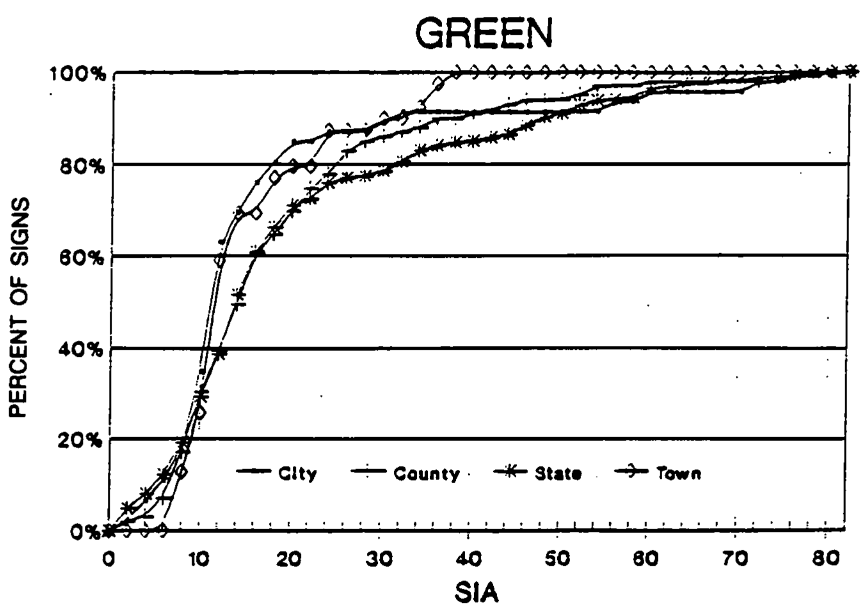


Figure 4. Frequency graph for green sheeting.

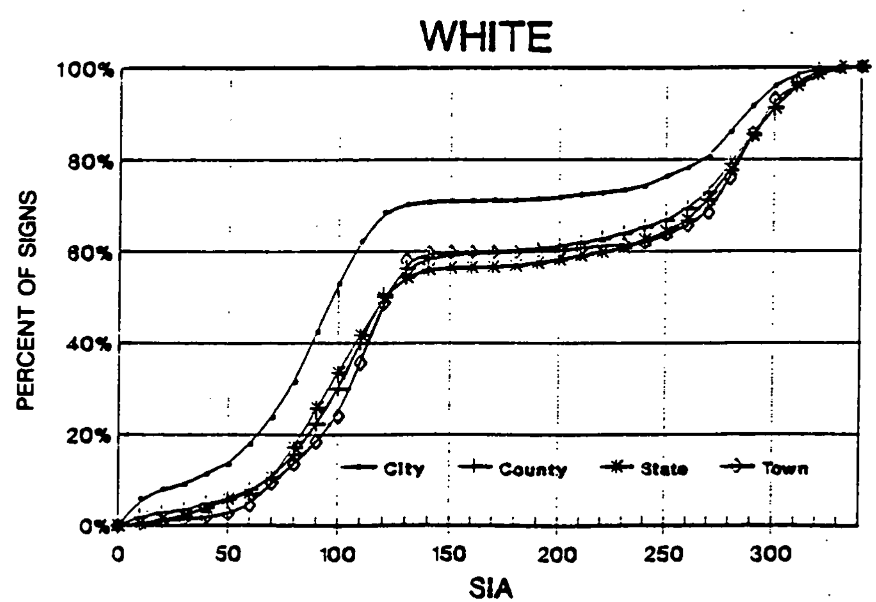


Figure 5. Frequency graph for white sheeting.

responded that 30 percent of their annual sign replacements were caused by poor retroreflectivity, while counties responded that only 16 percent of replacements were caused by this factor. Inadequate retroreflectivity was the leading cause of annual sign replacements according to the city responses. Vandalism was the leading cause of sign replacements in county jurisdictions. Nearly 40 percent of sign replacements in counties were caused by vandalism, while this factor accounted for 24 percent of the replacements in cities according to the survey responses.

The questionnaire survey also obtained sign density and sign population information for city and county agencies. Table 6 provides a summary of this information. City and county agencies have similar sign densities per capita. The cities responded as having approximately 114 total signs (not including street name and parking signs) per 1,000 persons, while counties were found to have approximately 122 total signs per 1,000 persons. The county agencies reported as having more warning and less guide signs than city agencies. Cities reported as having nearly three times the number of signs as counties on a per mile basis.

Several data files containing complete sign inventories from several small jurisdictions were obtained. Only one jurisdiction's (e.g., Kossuth County, Iowa) inventory included the date of sign installation. It is reasonable to assume that the date of installation closely reflects the age of the sheeting material. Table 7 provides the age distribution of signs from a small, rural jurisdiction. Nearly 30 percent of all signs had been installed for 5 years or more according to this database. As more jurisdictions implement a computerized sign inventory program that includes date of installation or replacement, the reliability of the distribution shown in Table 7 will be improved.

Table 4. Inventory types and data elements.

	PERCENT AND NUMBER OF JURISDICTIONS RESPONDING					
	CITY		COUNTY		State	
INVENTORY ITEM	%	N	%	N	%	N
Sign Inventory System	na	13	na	129	33	16
Inventory Type						
Main/Mini Computer	23	3	20	26	31	5
Micro Computer	38	5	32	41	50	8
Card/Paper	23	3	43	55	13	2
Other	16	2	5	7	6	1
Inventory Data Elements						
Sign Type	92	12	97	125	94	15
Installation Date	77	10	82	106	75	12
Replacement Date	77	10	83	107	75	12
Sheeting Type	54	7	50	64	56	9

na - not available

Table 5. Sign replacement and maintenance costs. Note in the table that county figures represent a weighted average value for rural and urban counties; sign fabrication and maintenance costs were not obtained from state agencies.

	CITY	COUNTY
Sign Fabrication Costs		
-Sign material cost per sign	$30	$38
-Labor cost per sign	$14	$19
-Equipment cost per sign	$10	$11
TOTAL cost per sign	$54	$68
Sign Maintenance Costs		
-Per mile costs	$135	$92
-Per capita costs	$1.20	$1.00
Reasons for Sign Replacement		
-Poor Retroreflectivity	30%	16%
-Knockdown	27%	23%
-Vandalism	24%	39%
-Other	19%	22%

Table 6. Sign population per capita and per roadway mile.

SIGN POPULATION PER CAPITA		
	CITY	COUNTY
Regulatory Signs per 1,000 persons	70	57
Warning Signs per 1,000 persons	38	63
Guide Signs per 1,000 persons	6	2
TOTAL	114	122
SIGN POPULATION PER ROADWAY MILE		
	CITY	COUNTY
Regulatory Signs per mile	18	4
Warning Signs per mile	10	4
Guide Signs per mile	1	3
TOTAL	29	11

Note: Street name and parking series signs not included.

Table 7. Age distribution of signs. (Source: Kossuth County, Iowa)

Age of Sign (years)	Number of Signs	Percent of Total Signs
12	202	4.1%
11	89	1.8%
10	165	3.3%
9	165	3.3%
8	236	4.8%
7	355	7.2%
6	260	5.3%
5	543	11.0%
4	1,561	31.6%
3	605	12.2%
2	497	10.0%
1	267	5.4%
Total	4,945	100%

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

This chapter presents the application of the findings presented in Chapter Two. The sign condition frequency graphs, sign density, and sign replacement cost information were compiled to test the economic consequences of establishing minimum retroreflectivity standards.

MINIMUM RETROREFLECTIVITY CRITERIA

In order to test the economic impacts of establishing retroreflectivity standards, actual minimum criteria needed to be identified. Selected preliminary results from the "Minimum Visibility Requirements for Traffic Control Devices" project sponsored by the Federal Highway Administration (FHWA) were obtained. These preliminary results include minimum retroreflectivity requirements for red, yellow, green, and white background signs. The minimum requirements are specified by sheeting color, roadway speed, sign placement, and sign size. Sheeting colors, roadway speeds, sign placements, and sign sizes other than those included here were evaluated in the "Minimum Visibility Requirements for Traffic Control Devices" project. The minimum SIA values tested here are preliminary and subject to change.

The following information provides a general discussion of the minimum retroreflectivity criteria provided by FHWA and selected for use in this project. Criteria for yellow sheeting signs were provided for right-mounted signs on 55-mile per hour (mph) roadways. This placement and roadway speed are appropriate for the majority of yellow warning signs. Two sign sizes—standard and standard plus 12 in.—were included. Minimum retroreflectivity values from 5 to 60 SIA for frequently used signs were recommended by FHWA. Minimum SIA criteria for red screened sheeting signs were provided for right-mounted signs on 30-mph and 55-mph roadways. The standard sign size was evaluated for the 30-mph condition and standard size plus 12 in. was assumed for the 55-mph application. The minimum standards for red sheeting ranged from 8 to 34 SIA. For green sheeting, minimum criteria were provided for freeway size signs on 65-mph roadways. Overhead and ground-mounted signs were both assumed in the minimum retroreflectivity standard. As the application of green sheeting material is limited, only a minimum standard of 10 SIA was provided. Finally, minimum SIA criteria were provided for right-mounted white sheeting signs on 10-, 30-, and 55-mph roadways. For white sheeting, sign size was limited to standard and standard plus 6 in. The range of minimum retroreflectivity values for frequently used white sheeting signs was from 10 to 100 SIA.

As ranges of SIA, instead of specific values, were provided from the FHWA research, it was appropriate to test multiple SIA values within each range. It was determined to test lower and upper SIA values within the ranges provided by FHWA for each sheeting color so that reasonable limits of the economic impact could be determined. Table 8 gives the values tested for each sheeting color. Several judgments were made to select the lower and upper SIA values for each sheeting color. The values selected for red sheeting represent the range of SIA which accommodates the driver needs for nearly all sign types and applications. For yellow sheeting, lower and upper values were selected from the FHWA recommendations. The lower standard (i.e., 20 SIA) was the reasonable limit to test because any values less than this would require little, if any, sign replacement. The upper value (i.e., 60 SIA) accommodates the driver needs for the large majority of sign types with yellow background. FHWA suggested that sign types requiring greater than 60 SIA were infrequently used or were poorly designed (i.e., unidentifiable symbol, unsatisfactory legend size, etc.). FHWA provided one value (i.e., 10 SIA) for green sheeting signs. This value was used as the upper limit because it exceeds the delivered specification of 9 SIA for new Type II sheeting provided in FP-85. A lower limit value of 8 SIA was selected in order to test a range of economic impacts. The lower value (i.e., 35 SIA) selected for testing white sheeting was not the absolute lowest SIA value provided by FHWA. However, minimum standards set at values below 35 SIA would not cause upgrades in current signing practices. The upper limit of 70 SIA for white sheeting was selected. FHWA suggested that white background signs where drivers require more than 70 SIAs are of generally poor design or they have letter sizes that are too small.

Table 8. Minimum SIA values selected for testing.

Sheeting Color	Minimum Retroreflectivity Values (SIA)	
	Lower Value	Upper Value
Red	8	21
Yellow	20	60
Green	8	10
White	35	70

The Florida DOT (*19*) reported end of service life SIA values for engineering grade sheeting as follows: yellow = 16 SIA, green = 5 SIA, and white = 40 SIA. These end of service life values are similar to the lower SIA values selected here for economic testing. Values for red, engineering grade sheeting were not available.

SIGNS REQUIRING REPLACEMENT

The percent of signs by sheeting color and jurisdiction type requiring replacement is provided in this section. The SIA frequency graphs developed and presented in Chapter Two and the minimum retroreflectivity standards described previously in this chapter were used to estimate sign replacement. Table 9 specifies the percent of signs requiring replacement today by jurisdiction control for each selected minimum SIA criteria.

The replacement percentages for yellow sheeting signs range from 2 to 29 percent across all jurisdiction types assuming that the replacement occurred today. The state, county, and town replacement percentages were similar for the two minimum SIA criteria. Yellow sheeting signs on city roadways had considerably lower retroreflectivity levels than those of other roadways. The condition of red screened signs on city roadways is considerably worse than on other roadways. The overall condition, as reflected by the high replacement percentages (i.e., 3 to 57 percent), of red screened sheeting is poor. If the upper minimum SIA standard was applied, approximately 57 percent of red screened sheeting signs on city roadways would require replacement today. Even on the other jurisdiction roadways, at least 40 percent of red-screened sheeting signs would require replacement under the upper minimum SIA standard tested here.

The sign replacement percentages are also quite high for green sheeting. The results for the four jurisdiction types were consistent at the lower and upper minimum standards. Approximately 30 percent of green sheeting signs would require replacement today under the upper retroreflectivity standard tested here.

The sign replacement percentages for white sheeting are similar to those of yellow sheeting. The percentages range from 2 to 24 percent across the two minimum SIA standards for the four jurisdiction types. The sign replacement percentages for city roadways are considerably higher than those of the other three jurisdiction types. Approximately 24 percent of white sheeting signs would require replacement under the upper minimum standard tested here.

Table 9. Sign replacement by jurisdiction type.

Sheeting Color	Sign Type	Assumed Minimum SIA Standard	Percent of Signs Requiring Replacement by Jurisdiction Type Today			
			State	County	City	Town
Red	Regulatory	8 21	4% 40%	3% 40%	17% 57%	5% 34%
Yellow	Warning	20 60	2% 16%	3% 18%	9% 29%	1% 12%
Green	Guide	8 10	20% 30%	18% 31%	18% 35%	13% 26%
White	Regulatory	35 70	3% 11%	5% 11%	11% 24%	2% 10%

Table 10. Sign density per roadway mile.

	Signs per State roadway mile	Signs per county roadway mile	Signs per city roadway mile	Signs per town roadway mile
Red[1]	3	3	12	12
Yellow[2]	4	4	10	10
Green[3]	3	3	1	1
White[4]	1	1	6	6
TOTAL	11	11	29	29

Note: Sign densities were obtained from questionnaire survey for counties and cities. Sign densities for States were assumed to be similar to that of counties and towns were assumed to be similar to cities.

[1] Based on survey results for regulatory signs reported in Chapter 2 and factored by the ratio of red to white signs found from actual sign inventories for cities and counties.
[2] Based on survey results for warning signs reported in Chapter 2.
[3] Based on survey results for guide signs reported in Chapter 2.
[4] Based on survey results for regulatory signs reported in Chapter 2 and factored by the ratio of white to red signs found from actual sign inventories for cities and counties.

SIGN DENSITIES

Sign density information per roadway mile was obtained for this study and presented in Chapter Two. The density values were applied to the total roadway mileage resulting in estimates of total traffic signs. This calculation was completed for a national estimate and estimates for states, counties, cities, and towns. Table 10 provides the density estimates per mile for yellow, red, green, and white sheeting signs by jurisdiction type. The county and city sign densities were obtained from the questionnaire survey results presented in Chapter Two. The state sign densities were assumed to be similar to those of counties, and town sign densities were assumed to be similar to those of cities. The sign densities do not include parking series and street name signs.

SIGN REPLACEMENT COSTS

Replacement cost information for traffic signs was compiled. The replacement of traffic signs includes cost for the following items: sign and substrate materials, labor for manufacturing, labor for installation, equipment and travel, and maintenance of traffic.

A model to calculate replacement costs per sign was developed. This model is described by the following equation:

$$RC = SC + TC + (L \times R)$$

where: RC = average replacement cost, SC = sign cost including materials, fabrication, and labor for a mix of engineering grade and high performance sheeting signs, TC = transportation costs, L = labor hours for sign replacement and installation, and R = labor rate including direct rate, overhead, and fringe.

For the analysis, numerous cost and time assumptions were made. The key assumptions are detailed as follows:

1. *Sign Cost (SC)*—assumes average cost for materials, labor, and fabrication of standard-size ground-mounted traffic signs with the following sheeting material: engineering grade = \$45.00 and high performance = \$65.00.
2. *Transportation Cost (TC)*—assumes 10 miles of travel at \$1.00 per mile per sign.
3. *Labor for Replacement (L)*—assumes one hour for two-person crew members or 2 man-hours for assembly and installation of a sign and the support, maintenance of traffic, and travel time. Assumes costs for traffic control devices are negligible and are available from other projects.
4. *Hourly Labor Rate (R)*—assumes \$12.50 per hour direct labor rate plus 120 percent for overhead and fringe.

These cost and hour assumptions were applied to the cost model with the following results:

$$RC = \left(\frac{\$45 + \$65}{2}\right) + (10 \text{ miles} \times \$1.00/\text{mile}) + (2 \text{ man-hours} \times \$12.50/\text{hour} \times 2.20)$$

$$RC = \$120.00 \text{ per sign}$$

The sign replacement estimate of $120.00 per sign was used for all sheeting colors and sign types except for ground-mounted green signs. The increased size and time for installation for ground-mounted green guide signs doubled the replacement cost to $240 per sign. Any or all of these assumptions can be modified using location specific values. The differences in replacement costs between jurisdiction and area types were assumed to be negligible for the broad analysis completed here.

IMPLEMENTATION STRATEGIES

Four implementation strategies of the minimum retroreflectivity standards were identified for the economic analysis. The alternative strategies are described below:

Option 1—Immediate compliance with standards (base case). This option assumes complete compliance with all minimum retroreflectivity standards *within one year.* While this is not recommended and probably not feasible, the evaluation of this option provides the basis for comparison.

Option 2—Short-term compliance with standards. This option assumes complete compliance with all minimum retroreflectivity standards for all sign, roadway, and jurisdiction types *within 3 years.* It also assumes that jurisdictions would begin sign replacement activities immediately.

Option 3—Median-term compliance with standards. This option assumes complete compliance with all minimum retroreflectivity standards for all sign, roadway, and jurisdiction types *within 5 years.* It also assumes that jurisdictions would begin sign replacement activities immediately.

Option 4—Long-term compliance with standards. This option assumes complete compliance with all minimum retroreflectivity standards for all sign, roadway, and jurisdiction types *within 10 years.* This option could accommodate the use of currently stockpiled materials within the first several years of implementation.

Strategies other than the 3, 5, and 10 year even distribution schedules tested here could be applicable. The minimum standards could be phased in over 3 to 10 years by sign priority, starting with regulatory and critical warning signs. Also, sign upgrades could be completed by roadway classification over a specified time period starting with high type (i.e., freeways, expressways, arterials, etc.) facilities. Combinations of these strategies could be instituted. However, these other strategies identified here could not be readily evaluated for economic impacts. The algorithm for assessing these strategies would be quite complex and would not provide any significant increase in accuracy.

INSPECTION PROGRAM

In addition to the sign replacement costs the implementation of minimum retroreflectivity standards will require the initiation of a sign inspection program. Jurisdictions will require the means to identify traffic signs at or near the minimum retroreflectivity standards. Several methods are available for completing the field inspection of traffic signs including: visual nighttime inspection using trained personnel, Q-beam daytime inspection using trained personnel, portable retroreflectometer to measure SIA, and mobile retroreflectometer (Traffic Sign Evaluator (TSE)) developed by NCHRP (Project No. 5-10) and FHWA to measure SIA.

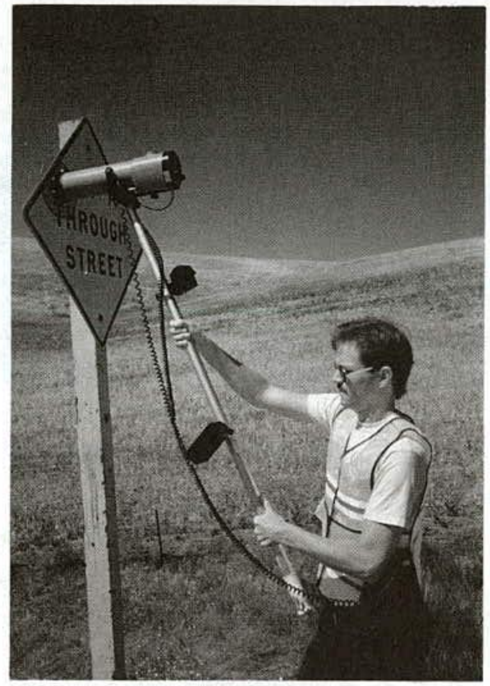


Figure 6. Operation of retroreflectometer.

The TSE provides for highway speed measurement of SIA values which should be an economical alternative for gathering retroreflectivity data as part of an inspection program. A prototype of the mobile TSE is currently being field tested at this time; therefore, it is not appropriate to consider this method for inspection here. A portable retroreflectometer can be used in the field to measure retroreflectivity. However, the instrument must be in contact with the sign face to take measurements. Figure 6 shows the field operation of a retroreflectometer. This method is time consuming when measuring a large quantity of signs.

Visual inspections conducted from moving vehicles during daytime or nighttime conditions are currently used throughout the country. A Washington State DOT study (*21*) showed that human observers can be adequately trained to perform visual inspections of traffic signs. Daytime visual inspections can be performed using a Q-beam light source. The Q-beam is used to flash a high intensity light onto a sign face and the human operator visually evaluates the retroreflective properties of the sheeting. Figure 7 shows the operation of a Q-beam light. This technique is used extensively by the Mississippi State Highway Department in its sign inspection program. With trained personnel the Q-beam inspection technique can be quickly completed. Nighttime visual inspections are performed by trained personnel using a vehicle's headlight beam to illuminate the traffic sign. The trained personnel visually evaluate the retroreflective properties of the illuminated sign face. This inspection technique can be completed economically. However, because the technique is carried out at night issues of available staff, premium pay, and union regulations must be considered.

Costs per roadway mile to perform visual inspections were calculated for the daytime and nighttime techniques. The following tabulation provides the key assumptions and cost breakdowns for the two inspection techniques.

For daytime visual inspection with Q-beam lights, crew size = 2 persons; labor rate including overhead = $27.50 per hour; vehicle and equipment = $1 per mile; actual daily inspection time = 6 hours; and data collection rate = 25 miles per hour. Inspection costs for this inspection technique = $3.93 per roadway mile.

For nighttime visual inspection with vehicle headlights, crew size = 2 persons; labor rate = $27.50 per hour (includes overhead); premium pay for overtime = 50 percent; vehicle and equipment cost = $1 per mile; actual daily inspection time = 6 hours; and data collection rate = 25 miles per hour. Inspection costs for this inspection technique = $5.40 per roadway mile.

The inspection costs presented here are rough estimates only. The subsequent analysis assumes $5.00 per mile for inspection costs. A sign inspection program will be necessary to ensure adequate compliance with the proposed minimum retroreflectivity standards.

SIGN INVENTORY PROGRAM

The application of a sign inventory system will assist agencies in maintaining the retroreflectivity of traffic signs above the established minimum criteria. The intent of the sign inventory is to track sheeting deterioration through date of installation or actual in-service SIA readings of individual signs. Tracking sheeting deterioration is critical to ensuring compliance with minimum retroreflectivity standards. Beyond the simple sign inventory database, FHWA is currently finalizing models for predicting required and available retroreflectivity. These models will be incorporated into the Sign Management System (SMS). The predictive models will use information from the sign inventory to identify when signs need to be inspected or replaced for reasons of insufficient retroreflectivity.

Considerable cost can be incurred in establishing a sign inventory system. Initial costs include the inventory of existing traffic signs within the jurisdiction. Once the signs have been initially logged the maintenance of the inventory can be accomplished through the work-order process, thus adding only minor costs. Several techniques for inventorying signs are available including manual, photolog, and videolog methods. Table 11 summarizes the data collection cost ranges for manual, photolog, and videolog inventories for cities and counties and for urban and rural areas in Minnesota.

Other methods of tracking sheeting deterioration can be established by an agency. Sign dating programs have been established in small and large jurisdictions. An effective sign dating program includes the following elements: a color-coded sticker with date of installation affixed to each sign panel; a portable retroreflectometer to periodically measure SIA from test samples and selected inservice signs; and a replacement program based on sign age, climatological, and other variables identified from test rack samples.

Figure 7. Operation of Q-Beam.

Table 11. Sign inventory data collection costs. (Source: Refs. 21, 22)

Agency	Range of Cost For Manual Data Collection		
City	$15-$27/mile		
County	$10-$15/mile		
	Range of Cost Per Inventory Method		
Area Type	Manual	Photolog	Videolog
Urban	$80-135/mile	$45-$70/mile	$30-$70/mile
Rural	$15-$45/mile	$25-$30/mile	$15-$25/mile

This method would rely on test samples and general deterioration characteristics. Sign replacement needs of deficient signs would be identified by using the color-coded sticker system.

ECONOMIC ANALYSIS METHODOLOGY AND RESULTS

This section presents the methodology and results of the economic impact analysis of the proposed minimum in-service retroreflectivity standards. To complete the analysis the following general items must be determined: (1) total signs requiring replacement, (2) cost to replace signs, and (3) implementation schedule of the minimum standards. Within each of the basic components numerous other information and data are required. Figure 8 provides a flow diagram of the assessment methodology. Although this methodology was developed specifically for this research, it is believed that the methodology could be applied to most other jurisdictions. The data needs and procedures associated with the process are presented as follows:

1. Using SIA data collected throughout the country, establish frequency graphs of sign sheeting condition.
2. Select minimum retroreflectivity standards to test.
3. Apply minimum standards to frequency graphs to determine percent of signs requiring replacement by sheeting color and by jurisdiction type.
4. Remove deficient signs from database.
5. Replace deficient signs with new signs using equal mix of engineering-grade, super-engineering-grade, and high-perform-

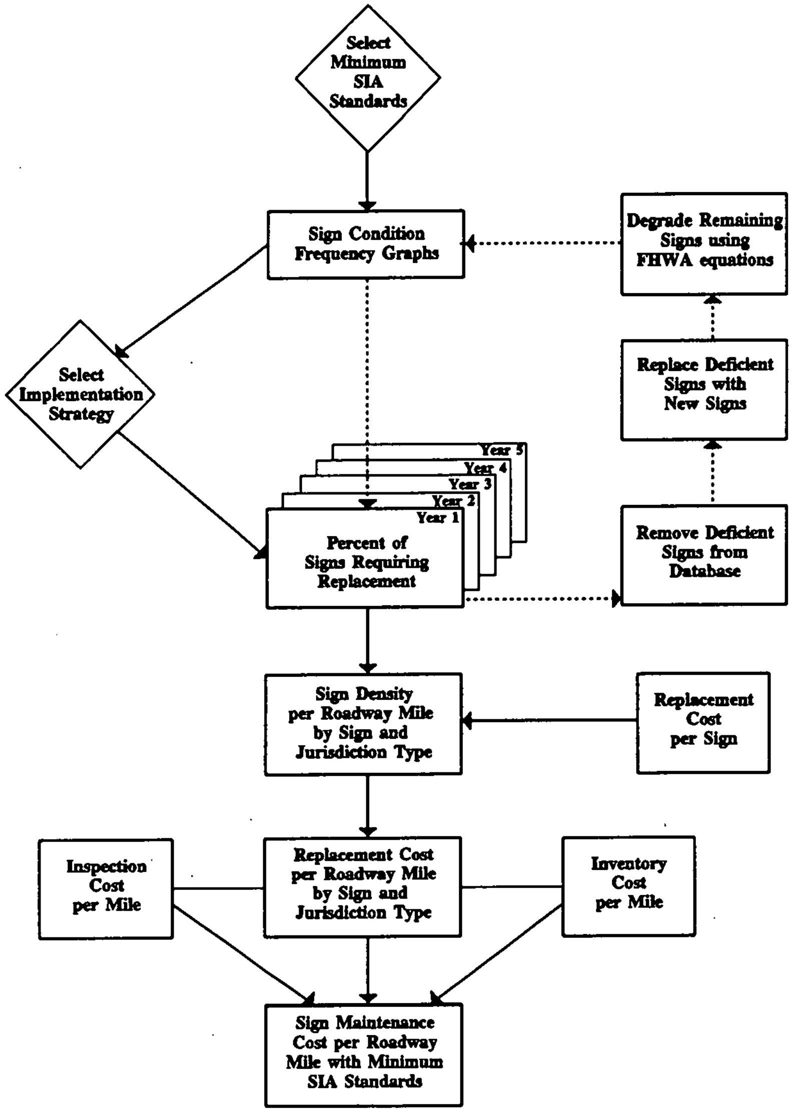


Figure 8. Process for economic assessment.

ance-grade sheeting material to represent the change in market share towards brighter materials.

6. Assign SIA values for new signs using the regression equations developed for FHWA's "Service Life of Retroreflective Traffic Signs" project for engineering-grade and high-performance-grade sheeting. Assign SIA values for super-engineering-grade sheeting material based on measurements taken on test rack samples by FHWA.

7. For non-new sheeting material in the database, reduce the SIA values using the regression equations from FHWA's "Service Life of Retroreflective Traffic Signs" report.

8. Prepare new sign condition frequency graphs for the revised database.

9. Use the minimum SIA standards to determine percent of signs requiring replacement.

10. Repeat steps 4 to 9 until implementation schedules are satisfied.

11. Use sign density data to determine the number of signs per roadway mile requiring replacement by sheeting color and jurisdiction type.

12. Use sign replacement cost data to determine the cost per roadway mile for each year of the implementation schedule and for annual maintenance thereafter.

13. Determine per mile costs for annual sign inspection by manual methods.

14. Determine per mile costs for the establishment of a sign inventory system. The development of the inventory system would coincide with the minimum standards implementation schedules.

15. Combine projected replacement, inspection, and inventory costs and compare to existing sign maintenance budgets to evaluate the economic impacts of the minimum standards.

These procedures and processes were used to complete the evaluation. The minimum SIA standards were not assumed to apply to parking series, street name and overhead guide signs. The model was run for 1-, 3-, 5-, and 10-year implementation schedules with the assumption that jurisdictions would commence upgrading their signs from the inception of the standards. The implementation schedules of 3, 5 and 10 years assumed an even distribution of replacement and inventory costs. Annual maintenance costs beyond each implementation schedule were also estimated.

For comparative purposes average annual sign maintenance budgets per roadway mile are also presented. While the economic analysis results here can be tested for reasonableness versus current sign maintenance budgets, the analysis procedures were not developed to determine costs to individual jurisdictions.

The actual or estimated sign maintenance budgets were obtained from the survey responses reported in Chapter Two. The annual maintenance budgets include sign replacement, inspections, inventory, and other related activities. Each annual sign budget was divided by the total jurisdiction controlled roadway mileage to obtain the estimated annual sign maintenance cost per roadway mile. Table 12 summarizes these costs. The high sign densities in urban areas are reflected in their per mile costs.

To test the incremental costs associated with the implementation of minimum standards, predicted sign maintenance costs per roadway mile were needed. The maintenance costs would include sign replacements, establishment of sign inventory, and sign inspection programs on a per mile basis. The costs for inventories and inspections were obtained from information received from agencies and previously presented in this chapter.

Sign replacement costs for state, county, city, and town-controlled roadways were developed for red, yellow, green, and white sheeting on the minimum SIA criteria previously presented. Each sheeting color was tested using the lower and upper minimum SIA standards. As stated previously, the economic assessment was completed for 1-, 3-, 5-, and 10-year implementation schedules. The economic model was run for a total of 11 years to obtain the annual maintenance costs for the years after the minimum standards have been implemented.

Sign replacement costs in terms of dollars per roadway mile for state, county, city, and town-controlled roadways were developed. These are presented in Appendix D. Similar to state roadways, the majority of sign replacement budgets in counties, cities, and towns would be designated for replacement of green and red sheeting signs. There is a considerable difference in replacement costs between the lower and upper standards, especially for the red, green, and white sheeting. The replacement cost for green sheeting represents 65 to 75 percent of the total replacement cost. Several reasons for this are apparent:

1. Average cost per sign to replace green guide signs is nearly twice that of standard warning and regulatory signs due to sign size.
2. Majority of green guide signs are constructed using engineering-grade sheeting, which has lower retroreflectivity characteristics than the other sheeting types.
3. Minimum retroreflectivity standards for green sheeting tested here were high and in the case of the upper value (i.e., 10 SIA) higher than the delivered new specification for green, engineering grade sheeting listed in FP-85.
4. Many of the green sheeting samples collected across the country had SIA values less than 8 SIA, which was the lower standard tested here.

On all roadways the need for replacement of red sheeting signs was quite high. The problems of color fade of this sheeting type contribute to the overall poor condition of these signs. In several instances the annual maintenance costs actually increased after the implementation schedule was completed. The population of signs for this evaluation was deteriorated, using the equations and relationships developed in FHWA's "Service Life of Retroreflective Traffic Signs" project. High annual costs after the standards implementation are the product of a large population of signs of similar age (i.e., 5 or more years old) failing to meet the minimum criteria in the years after the schedule has been fulfilled.

Table 12. Annual sign maintenance cost.

Jurisdiction Type	Annual Maintenance Cost
County - Urban	$120/mile
County - Rural	$ 80/mile
City	$135/mile

The predicted sign maintenance costs per mile per year are presented in Tables 13, 14, 15, and 16. Each table includes the costs associated with lower and upper SIA. The shaded areas highlight the annual maintenance cost (in dollars per mile) for each year of the specified implementation schedule. The unshaded areas show the annual cost per mile to maintain the minimum standards after implementation is completed. Once the programs have been established either after 1, 3, 5, or 10 years, a steady-state condition of maintenance cost occurs.

Table 17 summarizes the replacement, inspection, and inventory costs for a typical year of the implementation schedule for the 1-, 3-, 5-, and 10-year alternatives. For clarification, if the 3-year minimum standard schedule was selected, the initiation of a sign inventory would be allocated evenly across the 3-year time period. The cost for maintaining a sign inventory was neglected because it is rather minimal as compared to the other sign maintenance costs on a per mile basis.

Table 18 provides a comparison of the average sign maintenance costs per mile. The comparison is between the projected costs with the minimum standards and the current costs reported by jurisdictions. The increased cost due to the implementation of minimum retroreflectivity standards is represented by the difference between the projected and existing maintenance costs.

Projected sign costs per mile were combined using the ratios of state, county, city, and town mileage as compared to total national mileage as supplied by the Highway Performance Monitoring System (HPMS) (*25*). The difference or increment between the projected and existing per mile costs is summarized in Table 19.

Table 19 shows the estimated national economic impact in terms of yearly incremental maintenance costs of a sign retroreflectivity standard implemented over four different time periods. To arrive at these estimates, shown in the last column, the following calculations were made:

1. The projected per mile maintenance costs, shown in the second column, is a composite cost for each of the four jurisdiction types derived by obtaining an average of the sign maintenance costs given in Table 18, weighted by their respective highway mileage.
2. The existing per mile maintenance costs of $100 was selected as a composite average value on the results of questionnaire survey responses from 155 jurisdictions.

Table 13. Sign maintenance costs for state roadways.

	STATE ROADWAYS - dollars per mile per year							
	LOWER SIA STANDARDS				UPPER SIA STANDARDS			
	Implementation Schedule				Implementation Schedule			
Year	1 yr	3 yr	5 yr	10 yr	1 yr	3 yr	5 yr	10 yr
1	223	104	82	80	596	260	195	139
2	38	104	82	80	66	260	195	139
3	54	104	82	80	123	260	195	139
4	36	36	82	80	80	80	195	139
5	63	63	82	80	111	111	195	139
6	73	73	73	80	76	76	76	139
7	68	68	68	80	89	89	89	139
8	80	80	80	80	79	79	79	139
9	79	79	79	80	99	99	99	139
10	70	70	70	80	73	73	73	139
11	85	85	85	85	145	145	145	145

Table 14. Sign maintenance costs for county roadways.

	COUNTY ROADWAYS - dollars per mile per year							
	LOWER SIA STANDARDS				UPPER SIA STANDARDS			
	Implementation Schedule				Implementation Schedule			
Year	1 yr	3 yr	5 yr	10 yr	1 yr	3 yr	5 yr	10 yr
1	231	111	85	76	635	273	197	139
2	52	111	85	76	74	273	197	139
3	50	111	85	76	112	273	197	139
4	45	45	85	76	86	86	197	139
5	51	51	85	76	78	78	197	139
6	46	46	46	76	72	72	72	139
7	80	80	80	76	97	97	97	139
8	46	46	46	76	59	59	59	139
9	88	88	88	76	117	117	117	139
10	69	69	69	76	56	56	56	139
11	75	75	75	75	144	144	144	144

Table 15. Sign maintenance costs for city roadways.

	CITY ROADWAYS - dollars per mile per year							
	LOWER SIA STANDARDS				UPPER SIA STANDARDS			
	Implementation Schedule				Implementation Schedule			
Year	1 yr	3 yr	5 yr	10 yr	1 yr	3 yr	5 yr	10 yr
1	307	152	130	101	828	371	254	159
2	98	152	130	101	96	371	254	159
3	54	152	130	101	193	371	254	159
4	90	90	130	101	57	57	254	159
5	99	99	130	101	96	96	254	159
6	117	117	117	101	39	39	39	159
7	50	50	50	101	72	72	72	159
8	74	74	74	101	50	50	50	159
9	45	45	45	101	96	96	96	159
10	62	62	62	101	53	53	53	159
11	85	85	85	85	164	164	164	164

Table 16. Sign maintenance costs for town roadways.

	TOWN ROADWAYS - dollars per mile per year							
	LOWER SIA STANDARDS				UPPER SIA STANDARDS			
	Implementation Schedule				Implementation Schedule			
Year	1 yr	3 yr	5 yr	10 yr	1 yr	3 yr	5 yr	10 yr
1	202	99	99	81	582	288	206	137
2	63	99	99	81	127	288	206	137
3	32	99	99	81	153	288	206	137
4	71	71	99	81	63	63	206	137
5	128	128	99	81	105	105	206	137
6	78	78	78	81	73	73	73	137
7	68	68	68	81	55	55	55	137
8	45	45	45	81	68	68	68	137
9	78	78	78	81	62	62	62	137
10	35	35	35	81	83	83	83	137
11	79	79	79	79	170	170	170	170

Table 17. Sign maintenance costs per roadway mile.

Implementation Schedules	Annual Replacement Cost of Deficient Sheeting per mile				Annual Sign Inventory Cost per mile[1]	Annual Sign Inspection Cost per mile
	State	County	City	Town		
1 YEAR (BASE CASE)						
-lower standard	$193	$201	$277	$172	$ 25	$5
-upper standard	$491	$530	$723	$477	$100	$5
3 YEAR PROGRAM						
-lower standard	$ 91	$ 98	$139	$ 86	$ 8	$5
-upper standard	$222	$235	$333	$250	$ 33	$5
5 YEAR PROGRAM						
-lower standard	$ 72	$ 75	$120	$ 89	$ 5	$5
-upper standard	$170	$172	$229	$181	$ 20	$5
10 YEAR PROGRAM						
-lower standard	$ 72	$ 68	$ 93	$ 73	$ 3	$5
-upper standard	$124	$124	$144	$122	$ 10	$5

[1]Represents low and high range values for the specified maintenance activity. The difference in cost between the low and high values is not attributable to the lower and upper SIA standards, but reflects differences in reported and computed per mile costs.

3. The incremental increase in maintenance costs shown in the third column is simply column 2 minus column 3, with any resulting negative values limited to $0.

4. The total yearly incremental maintenance cost shown in the last column was obtained by multiplying the per mile incremental cost by the national roadway mileage of 3.8 million.

The results indicate that there would be a substantial economic impact if the standard were to be implemented within a 1-year period. The incremental cost decreases significantly as the implementation period is increased. For a 5-year or longer implementation period there would be no increase in sign maintenance cost for the lower standards. In fact, a net reduction in annual maintenance cost could be experienced. This would result from the replacement of older, engineering-grade signs with new super-engineering and high-performance sheeting which have a higher level of retroreflectivity for a longer period. Approximately 60 percent of the signs sampled for this project were constructed with engineering-grade sheeting.

The sign replacement algorithm used to evaluate economic impacts replaced deficient signs with an equal mix of engineering-grade, super-engineering-grade, and high-performance-sheeting signs. The replacement scenario vastly improves the retroreflectivity levels and effective life of the population of signs. Therefore, under certain implementation time schedules and minimum standards, a reduction in replacement costs could be realized. If the mix of sheeting remains unchanged from existing conditions, substantially higher costs than those represented here for sign replacements would be expected.

These estimates, which are presented in current (1990) dollars, are based on previously explained assumptions concerning replacement of signs using different retroreflective sheeting types, and on jurisdiction reported values for average per mile maintenance costs and sign densities. The assumptions and values used in this analysis are reasonable and sufficiently accurate to provide these order of magnitude costs. Given the methodology presented in this report, each jurisdiction can use its own cost values and sign densities to determine its specific economic impacts.

Table 18. Existing and projected sign maintenance costs.

Area Type	Existing reported sign costs per mile			
Urban Rural	$135 $ 80			
Implementation Schedule	Projected sign costs per mile with standards			
	State	County	City	Town
1 year program				
- lower standard	$223	$231	$307	$202
- upper standard	$596	$635	$828	$582
3 year program				
- lower standard	$104	$111	$152	$ 99
- upper standard	$260	$273	$371	$288
5 year program				
- lower standard	$ 82	$ 85	$130	$ 99
- upper standard	$195	$197	$254	$206
10 year program				
- lower standard	$ 80	$ 76	$101	$ 81
- upper standard	$139	$139	$159	$137

Table 19. National impact of retroreflectivity standards on sign maintenance costs.

Implementation Schedule	Projected per mile maintenance costs[1]	Existing reported per mile maintenance costs[2]	Incremental increase in maintenance costs per mile[3]	Total yearly incremental maintenance costs in millions[4]
1 year program				
- lower standard	$235	$100	$135	$513
- upper standard	$644	$100	$544	$2,067
3 year program				
- lower standard	$113	$100	$ 13	$ 49
- upper standard	$286	$100	$186	$707
5 year program				
- lower standard	$ 93	$100	$ 0	$ 0
- upper standard	$207	$100	$107	$407
10 year program				
- lower standard	$ 82	$100	$ 0	$ 0
- upper standard	$141	$100	$ 41	$156

[1] Weighted average of State, county, city, and town costs per mile.
[2] Estimate of existing maintenance costs for urban and rural areas.
[3] Difference between projected and existing maintenance costs
[4] Result of per mile maintenance costs and total national highway mileage

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The objectives of this project were to determine (1) the overall retroreflective condition of the nation's traffic signs, (2) determine sign replacement and maintenance costs, (3) estimate the number of deficient traffic signs in the field today, and (4) evaluate the economic consequences of establishing minimum retroreflectivity standards.

The condition of signs was found to vary by sheeting color, sheeting type, and jurisdiction type. Traffic signs on city roadways were in considerably poorer condition than the other jurisdiction's signs. The population of red and green signs was found to have low retroreflectivity values as compared to the minimum standards tested.

State, county, and city agencies provided sign maintenance and replacement costs. The materials, labor, travel, and equipment costs to replace a warning or regulatory sign of standard size was determined to be approximately $120. A ground-mounted guide sign costs approximately $240 to replace based on the best available information. Agencies reported that annual sign maintenance budgets require between $80 and $135 per roadway mile. Because of sign density urban areas incur higher per mile costs than do suburban and rural areas.

Once minimum standards are established agencies will need to consider implementing sign inventory and inspection programs to ensure compliance. Sign inspections conducted visually by trained personnel either during the day or at night can be adequately accomplished at costs accounting for less than 5 percent of maintenance budgets. The establishment of a sign inventory requires significant funding to initially log all signs. Once the data collection is complete the upkeep of the system can normally be accomplished through daily maintenance activities and work order processes. Sign inventories and inspection programs would be essential to maintaining signs above minimum standards.

Two levels of minimum retroreflectivity standards and three alternative implementation schedules were tested in this research. The projected annual sign maintenance costs per mile at the lower standards for the 3-, 5-, and 10-year implementation schedules were in the same range as existing sign maintenance costs and, thus, should have relatively minor economic impacts on jurisdictions. This finding suggests that current sign maintenance standards are adequately maintaining signs above the lower standards tested here. It should be emphasized however, that these conclusions derive from random national samples of existing sign retroreflectivity. Therefore, depending on any specific jurisdiction's current standards, the standards tested here could result in costs for sign replacement due to insufficient retroreflectivity that vary somewhat from the average costs reported here.

The economic impact of the higher retroreflectivity standards was found to be considerable. The annual costs for replacement, inventory, and inspection could be as much as 2 to 6 times that of current budgets. In some instances as many as 60 percent of all signs of a particular sheeting color could require replacement within city jurisdictions. The research here seems to have identified the reasonable economic impact boundaries through the testing of two sets of minimum standards.

The algorithm applied to estimate sign replacement costs assumed a shift towards the use of brighter and longer lasting sheeting material. The use of the brighter material could over time reduce the annual sign maintenance costs as reflected in Table 19 under the 5- and 10-year implementation schedules and with the lower SIA standards.

SUGGESTED RESEARCH

Through this project several other research requirements became apparent, as outlined in the following:

1. Preferred techniques for sign inspection should be identified. Detailed cost assessments for preferred inspection techniques should be completed.
2. When the Traffic Sign Evaluator (TSE) is available an economic assessment of sign inspection cost should be conducted.
3. The effects of color fade on red sheeting should be evaluated. A minimum SIA standard for red sheeting does not seem appropriate, as SIA can actually increase over time.
4. Once minimum SIA standards are selected research on specific implementation plans and schedules should be conducted. The implementation strategies must be simple and uniform in their application. This research should include identification of funding sources.
5. Research on liability costs from accidents involving inadequate signing should be included in future economic analysis.

APPENDIX A—LITERATURE REVIEW

The following three topic areas were focused on during the review of literature:

1) Principles of retroreflection and retroreflective sheeting materials.

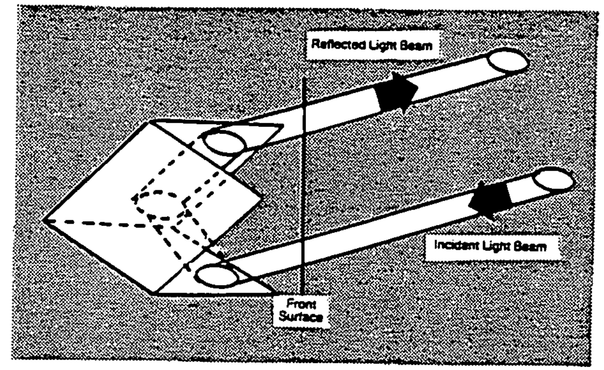
2) Specifications for retroreflective sheeting materials.

3) Sign luminance requirements, feasibility of performance standards and sign maintenance practices.

PRINCIPALS OF RETROREFLECTION

Nearly all signs have to be legible and color distinguishable at night as well as day. While this can be accomplished through external illumination of the signs, retroreflection is the most commonly used means of making signs visible to the driver at night. Three reports, "Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide" (4), "Maintenance Management of Street and Highway Signs" (5) and "Guide to the Properties and Uses of Retroreflectors at Night" (6) are the primary sources of the background information.

Retroreflection occurs when light rays strike a surface and are redirected back to the source of light. Two principles followed to achieve retroreflectivity for roadway signs are prismatic and spherical lens retroreflection. Prismatic, also known as cube-corner, retroreflection is achieved through total internal reflection. As shown in the top illustration of Figure A-1, incoming light hits the first surface and reflects to the rear surface which reflects it to the last surface which reflects the light rays back to the source. Typically, the prismatic device reflects light off these surfaces at 90 degrees to each other, i.e. the corner of the cube. In the second type, spherical lens retroreflection is achieved through a combination of a glass sphere (bead) and a reflecting (mirror type) surface placed at the focal point. As shown in the bottom illustration of Figure A-1 an incoming ray is bent and



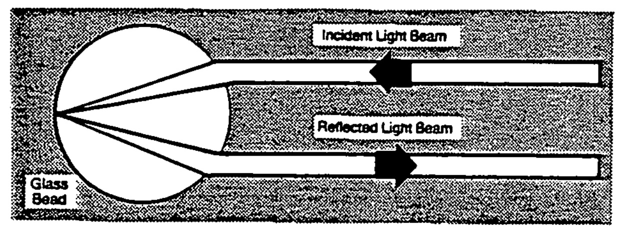


Figure A-1. Two types of retroreflection, cube-corner (top) and spherical lens (bottom).

directed inside and toward the back of the sphere, reflecting off the reflective surface, and after being bent at the exterior of the sphere redirected toward the light source.

TYPES OF RETROREFLECTIVE SHEETING

Retroreflective sheeting consists of micro cube-corners or spheres enclosed in a weather resistant transparent plastic film. To reflect color, pigment or dye is inserted into the film or on the reflecting surface. Figure A-2 shows a typical construction of cube-corner retroreflective sheeting. This type of sheeting is typically manufactured with an air cushion behind the cubes. A unique property of this sheeting is its high coefficient of retroreflection at low entrance angle, which means it appears bright at long distances if the device is not too far laterally removed from the light source.

There are three types of spherical lens (bead) retroreflective sheeting -- 1) exposed glass bead, 2) enclosed glass bead, and 3) encapsulated glass bead. These are shown in Figure A-3.

In the exposed lens sheeting the front half of the glass beads are exposed to the outside air. Glass beads work best when exposed to the air. However, because of the small size of the beads, a film of water can cover the beads when it rains and can greatly reduce the retroreflectivity of the beads. Hence, this type of sheeting is not recommended for traffic signs and generally is not included in State or federal specifications. Nonetheless, exposed lens sheeting is still found on traffic signs on some low-volume rural roads controlled by local jurisdictions.

Enclosed lens sheeting material consists of a layer of transparent plastic of appropriate color in which glass beads are imbedded. A metallic reflection shield is provided behind the plastic, with a layer of adhesive and with a protective liner that is removed during sign fabrication. The plastic covering enables the sheeting to be equally bright under dry and wet

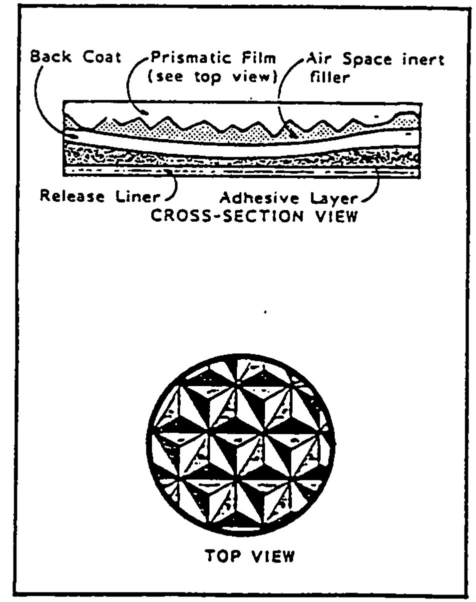


Figure A-2. Cross-section and top view of cube-corner retroreflective sheeting.

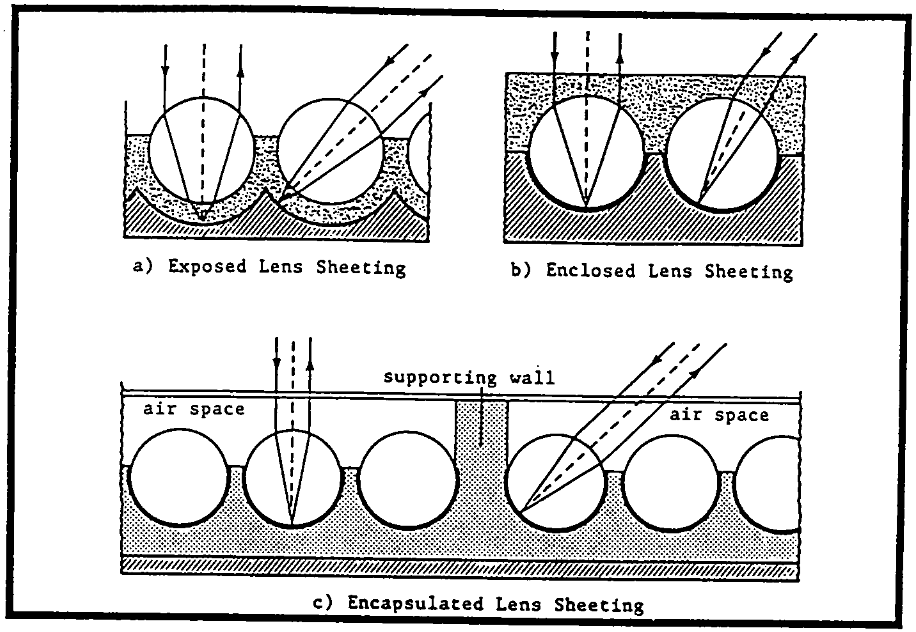


Figure A-3. Cross-section view of three types of spherical lens retroreflective sheeting.

weather conditions.

With encapsulated lens sheeting the glass beads are also protected by a transparent material that is supported slightly above the beads by walls creating an air filled compartment. The back of the beads are covered with a reflective surface. The resulting airspace in front of the beads makes it more reflective and, hence, is known as high performance sheeting.

PROPERTIES OF RETROREFLECTIVE SHEETING

One of the most important properties of retroreflective sheeting is the ability to return light which is commonly described by a variety of terms including brightness, retroreflectance, luminance or candlepower. The International Commission of Illumination (CIE) (6) uses the term coefficient of luminous intensity, which is defined as the ratio of luminous intensity of reflector in the direction of the observation to the illumination at the retroreflector on a plane perpendicular to the light. In the International System of Units (SI), i.e. the metric system, it is expressed as candelas (cd) per lux (lx). It is a measure of efficiency of the retroreflector because it describes the amount of luminance (candelas) that comes out from the retroreflector per amount of light (lux) coming in from the light source, i.e., the vehicle headlights. This definition treats the retroreflector as a point source. But because signs have a relatively large area, they are treated as an extended light source which may be thought of as consisting of many point sources each with a luminance intensity of one candela. To account for this the term coefficient (R_A) of retroreflection has been adopted by the CIE. It is merely the coefficient of luminous intensity divided by the area and expressed in SI units as candelas per lux per square meter. The English equivalency is candelas per footcandle per square foot and in the *FP-85* (7) is described as specific intensity per unit area (SIA). The conversion from English to metric (SI) is unity; hence, a value expressed in SIA terms is the same value in R_A terms.

The retroreflectance of sheeting materials is described in context of another important property, its angularity, which is defined by the entrance (of the light) and the observation (of the motorist) angles. The entrance angle is the angle formed between a light beam striking the surface of a sign and a line coming out perpendicular from the surface. The entrance angle changes with distance between the vehicle and is a function of the location of the sign and the vehicle. An entrance angle of 30 degrees is considered wide for highway signing. The observation angle is the angle between the incoming light beam and the reflected light beam and is a function of the height of the drivers eye with respect to the vehicle headlamps. Figure A-4 illustrates the entrance and observation angles.

Since a retroreflective material is supposed to reflect most of the light directly back to the source, the optimum observation angle should be zero. However, in reality this is not the case since the driver's eye is higher than the vehicle headlight and can range from 21 inches for small cars to as much as 64 inches for large trucks. A wide observation angle is anything over 2 degrees. For purchase specifications, minimum SIA is prescribed for each type of sheeting for two observation angles, two entrance angles, and the different colors.

SPECIFICATIONS FOR RETROREFLECTIVE SHEETING

There are at least four "national" specifications for reflective sheeting:

1. Federal Specification L-S-300C, a General Services Administration specification.
2. Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (*FP-85*).
3. AASHTO M268 - Retroreflective Sheeting for Traffic Control by the

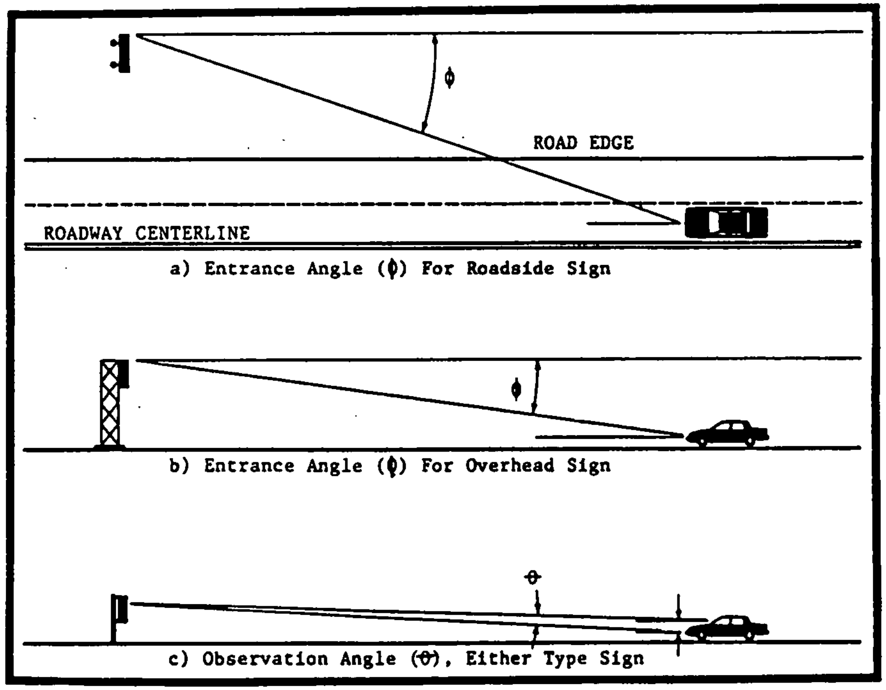


Figure A-4. Entrance and observation angles.

American Association of State Highway Officials.

4. ASTM D 4956, Reflective Sheeting Standards by the American Society for Testing Materials.

The following specifications, related to retroreflectance, were a primary source of information:

1. *FP-85*, Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects.
2. Federal Test Method Standard 370, Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices.
3. The following ASTM standards on color and appearance measurement
   - E808-81,"Standard Practice for Describing Retroreflection"
   - E809-81,"Standard Practice for Measuring Photometric Characteristics of Retroreflectors"
   - E810-81,"Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting"
   - E811-81,"Standard Practice for Measuring Colormetric Characteristics of Retroreflectors Under Nighttime Conditions"

In the *FP-85* three types of retroreflective sheeting are recognized. The first type has two classes: Type II and Type II A, commonly called engineering and super engineering grade sheeting, respectively. They are both enclosed lens type sheeting with the main distinction between the two being a higher quality glass bead in Type II A. Table A-1 shows the minimum SIA values for Type II and Type II A sheeting. As shown in Table A-1 the minimum SIA values for Type II A specified by *FP-85* are about twice those for Type II.

Table A-1 Specific Intensity Per Unit Area (SIA) for Type II sheeting.

Type II Sheeting

Observation Angle (o)	Entrance Angle (o)	White	Red	Orange	Brown	Yellow	Green	Blue
0.2	-4	70	14.5	25.0	2.0	50	9.0	4.0
0.2	+30	30	6.0	7.0	1.0	22	3.5	1.7
0.5	-4	30	7.5	13.5	1.0	25	4.5	2.0
0.5	+30	15	3.0	4.0	0.5	13	2.2	0.8

Type II-A Sheeting

Observation Angle (°)	Entrance Angle (°)	White	Red	Orange	Brown	Yellow	Green	Blue
0.2	-4	140	30	60	5	100	30	10
0.2	+30	60	12	22	2	36	10	4
0.5	-4	50	10	20	2	33	9	3
0.5	+30	20	6	12	1	20	6	2

Table A-2 Specific Intensity Per Unit Area (SIA) for Types IIIA, B and C.

A - Glass Bead Retroreflective Element Material

Observation Angle (o)	Entrance Angle (o)	White	Red	Orange	Yellow	Green	Blue
0.2	-4	250	45	100	170	45	20.0
0.2	+30	150	25	60	100	25	11.0
0.5	-4	95	15	30	62	15	7.5
0.5	+30	65	10	25	45	10	5.0

B and C - Prismatic Retroreflective Element Material

Observation Angle (0)	Entrance Angle (0)	White	Red	Orange	Yellow	Green	Blue
0.2	-4	250	45.0	100	170	45.0	20.0
0.2	+30	95	13.3	26	64	11.4	7.6
0.5	-4	200	28.0	56	136	24.0	18.0
0.5	+30	65	10.0	25	20	10.0	5.0

The next type has three classes: Type III A and III B, which are in *FP-85*, and Type III C, which was added to *FP-85* by an FHWA memorandum dated November 3, 1989. Two classes are encapsulated type sheeting with Type III A made of glass beads and Types III B and III C made of prismatic reflectors. All types provide much higher brightness than both Type II and Type II A. Their respective minimum reflectance values are shown in Table A-2.

In the *FP-85* there is reference to a "Type III Reboundable" sheeting. This is a retroreflective material intended to be applied to flexible impact resistant plastic devices such as plastic drums used as channelizing devices in work zone traffic control. It is referred to as "reboundable" because it can withstand expansion and contraction and will not crack easily when hit by a vehicle or roughly handled as is the case for standard Type III A sheeting used on permanent signs.

The last type of sheeting recognized in the *FP-85* is labeled as Type IV. This type is a high performance vinyl sheeting of low durability that is used for retroreflective white collars around orange cones, and for fold-up temporary signs of the kind commonly used by utility companies. The primary distinction between the sheeting types is their brightness, as noted in the minimum SIA specifications, and durability.

The typology presented in *FP-85* is simply a method for grouping products available when the specification was made. Other organizations, notably the American Society for Testing Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO), and the General Services Administration (GSA) have different typologies and SIA specifications. Table A-3 compares the typologies for the four most common specifications mentioned previously. Table A-4 compares the SIA specifications from the four agencies for their different types the 0.2° angle and the -4° entrance angle. Table A-5 lists by type the known manufacturers of retroreflective highway sign sheeting.

Table A-3. Comparison of retroreflective sheeting typology classifications.

Specification	TYPOLOGY CLASSIFICATIONS		
	Engineering Grade (EG)	Super Engineering Grade (SEG)	High Performance Grade (HP)
L-S-300C	Reflectivity 1	ns	Reflectivities 2, 4
AASHTO M-268	Class II	ns	Classes IIA, B
FP-85	Type II	Type IIA	Types IIIA, B, C
ASTM D-4956	Type I	Type II	Types III, IV, V

ns - not specified

Table A-4. Comparison of retroreflective sheeting SIA specifications.

Sheeting Color	L-S-300C EG	L-S-300C SEG	L-S-300C HP	AASHTO EG	AASHTO SEG	AASHTO HP[1]	FP-85 EG	FP-85 SEG	FP-85 HP[2]	ASTM EG	ASTM SEG	ASTM HP III	ASTM HP IV
White	80	ns	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

Notes: ns - not specified
[1] applies to both Type III A & B
[2] applies to Types III A,B,C

Table A-5. Known manufactures of various sheeting types.

Sheeting Type (as per FP-85)				
Type II	Type II A	Type III A	Type III B	Type III C
Avery/Fasson	Seibulite	Seibulite	Stimsonite	Stimsonite
Seibulite	Kiwalite (Sakai Trading)	3M	Reflexite*	
3M				
Kiwalite (Sakai Trading)				
American Decal (Adcolite)				

Note:

Type II = Engineering Grade
Type II A = Super Engineering Grade
Type III A = High Performance Grade
Type III B = High Performance Grade (Prismatic)
Type III C = High Performance Grade (Prismatic)
*Construction Work Zone Devices Only

The procedure for testing the SIA of retroreflective sheeting is specified in "Federal Test Method Standard 370, Photometric Measurements of Retroreflective Materials and Retroreflective Devices".(8) Because of the elaborate instrumentation and laboratory set-up this test is not within the capabilities of most small highway agencies. There are however, portable reflectometers which can be used for a quick check of SIA in a sign shop or in the field. Two such devices are the Model 920 and 930 retroreflectometers manufactured by Advanced Retrotechnology Inc. (ARTI) of La Mesa, California.

The ASTM standard E808-81 "Standard Practice for Describing Retroreflection" provides terminology, a geometrical coordinate system, and procedures for designating angles in descriptions of retroreflectors, specification of retroreflector performance and measurements of retroreflection. It is stated in the specification that the geometrical system described is complete and non-redundant and should be used in specifying and testing retroreflectors.

The ASTM Standard E809-81 "Standard Practice for Measuring Photometric Characteristics of Retroreflectors" describes procedures used to measure photometric quantities that relate to the visual perception of retroreflected light. It essentially involves the measurement of normal illuminance at the face of the sample by substituting the photoreceptor for the sample.

The ASTM standard E810-81 "Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting" describes the method for instrument measurement of the retroreflective performance of retroreflective sheeting. Measurements made by this test method are related to visual observations of retroreflective sheeting as seen by the human eye when illuminated by tungsten filament light sources. This method is intended as a laboratory test and requires a facility that can be darkened sufficiently so that stray light does not affect the test results.

The ASTM Standard E811-81 "Standard Practice for Measuring Calorimetric Characteristics of Retroreflectors Under Nighttime Conditions" describes a procedure for measuring the color appearance of retroreflectors as seen under nighttime conditions of illumination and viewing. The procedure involves spectral measurements of the incident light and of the retroreflected light under the test-geometry required with either a telecolorimeter or telespectroradiometer.

MOTORISTS NEEDS

The current SIA standards provided in *FP-85* merely reflect the available products and are purchase specifications not necessarily related to driver visibility requirements and environmental conditions.

In order for a traffic sign to be effective it must deliver its information to the driver soon enough to react appropriately and safely. The sight distance requirement of a sign is a function of five components: 1) sign detection, 2) sign recognition, 3) driver decision making, 4) response and 5) completion of maneuver. McGee et al. (9) developed and field tested a decision sight distance model based on detection, recognition, decision making, response and vehicle maneuver. The time requirements for each step were initially estimated based on an extensive literature review, then adjusted according to the findings of an empirical field study. The decision sight distance model elements were later reexamined by Perchonok et al. (10) to develop a version applicable to determining nighttime visibility requirements for retroreflective devices. The model determines minimum detection distance requirement as the summation of distances required for five phases of action. The summation process is based on the assumption that, in the worst case the driver must accomplish each aspect of the process in order, one after the other. This model was formalized by Mace et al. (11) as a computerized program to evaluate luminance requirement to aid in sign maintenance decisions. This sign maintenance management program models sign visibility requirements in terms of time and distance requirements. However, it does not model the visibility requirements of signs based on human performance capabilities in terms of luminance and contrast needs.

The human visual performance model most generally accepted among highway visibility researchers is that published by the International Commission on Illumination. This model represents an analytic approach to determining detection threshold contrast for a observer adapted to particular surround luminance, with glare and transient adaption requirements accounted for. An object is visible or detectable at threshold level if the objects contrast meets or exceeds the contrast required by an observer when adopted to the luminance of the objects background, also taking into account the effects of disability glare and background luminance that may change over time. This analytic approach to visibility has been incorporated by Bhise (12) into a seeing distance model called DETECT which is a part of the Comprehensive Headlamp Environment Systems Simulation Model (CHESS). The program calculates the threshold visibility distance (50 percent probability of detection) to targets such as delineation, pedestrians, traffic cones, etc. under a wide range of conditions with or without glare from opposing vehicles.

The intent of the FHWA study "Minimum Visibility Requirements for Traffic Control Devices" has been to research the various parts of the information processing model such as detection distance, consipicuity distance, legibility distance, response latency and maneuver time. This minimum visibility study has addressed the issues of individual differences relating to contrast sensitivity and traffic control device differences during the laboratory studies of conspicuity and legibility. After the comparisons between the laboratory and field control

studies, the field validation study, and the minimum visibility model, the minimum visibility requirement for each traffic control device class will be studied.

PERFORMANCE STANDARDS

Drivers require a minimum amount of luminance for both detection and legibility of signs. The specification of minimal luminance requirements for traffic signs has been addressed by a number of researchers. Historically, a sign was considered sufficiently bright if it provided approaching drivers with a minimum of 50 feet of legibility per inch of letter height. However, the selection of 50 ft/in as a minimum legibility distance is quite arbitrary.

Mace (13) suggested that older driver's visibility requirements should be based on a legibility of 40 feet per inch of letter height. Mace also reported that the typical practice in States is to license drivers at 20/40 high-luminance acuity. This acuity level corresponds to a legibility of approximately 30 feet per inch of letter height.

Another approach that has been used is to consider a sign's level of brightness. Sign brightness is considered satisfactory if it provides a legibility distance that is greater than or equal to 85 percent of the maximum obtainable nighttime legibility distance. Like the first approach, the criterion is also too arbitrary as it does not account for the driving situation.

The other measures that have been used to develop the relationship between sign brightness and legibility have been uniformity of sign background, level of internal contrast, and luminance of legend or background. If a sign face degrades unevenly as it ages, then the legibility of the sign is impaired. The Institute of Transportation Engineers recommends a ratio of 5:1 as the maximum acceptable ratio of luminances for externally lighted traffic signs. (14) Another study conducted by Allen et al., (15) concluded that variation in the luminance of different areas of the sign should not be more than 10:1. Another study (16) specifically designed to establish the relationship between the luminance uniformity of sign background and legibility found that for externally illuminated signs these two variables are significantly correlated only when sign luminance ranges form 9.9 to 39.7 FL. These data indicated that if a reduction in maximum obtainable legibility of 50 percent is assumed to be the maximum acceptable performance decrement, then the maximum acceptable ratio of background luminances is 6:1. However, the luminance of Type II and Type III white sheeting rarely exceed 9.9 FL. For these reasons, the luminance uniformity of background may be relevant to the legibility of illuminated signs but may not be relevant to retroreflective signs.

The contrast between the luminance of the sign legend and the luminance of the sign background is the second measure that has been related to sign brightness and legibility. A common measure of internal contrast is the luminance ratio of the legend and background of the sign, with the greater of the two values used in the numerator of the expression. For signs with a black legend on color background the legibility is determined by the luminance or the color portion of the sign. Therefore, a minimum brightness standard based solely on internal contrast would have little applicability to signs having either a black legend or a black background. Also, most signs will not be taken out of service until there is a complete loss of retroreflectivity, which means that the internal contrast of the sign is essentially fixed for the duration of the sign's service life by the material with which it is constructed. Therefore, internal contrast is most relevant in sign design and construction.

The third measure of sign brightness that can be related to legibility is sign luminance. Legibility as a function of sign luminance has been studied to a greater extent than any other measure of sign brightness. A 1988 study of nighttime conspicuity of highway signs by Olson (17) resulted in recommendations for minimum SIA values for various sign types and in guidance regarding the type of materials to use. The SIA values are based on area

complexity and the required stopping distance for various speeds. The area complexity refers to the ambient light levels in the immediate vicinity of the signing location. The complexity is typically described as low, medium and high corresponding to rural, suburban and urban areas. Table A-6 shows the SIA values of 30" x 30" red STOP signs. Based on those values, engineering grade sheeting would be sufficient for low speed and low complexity areas and high performance sheeting would be required for most situations. For high speed and high complexity areas, supplemental warning signs are warranted. Table A-7 shows the minimum SIA values for warning signs by speed and area complexity derived from the same study. Here, the engineering grade sheeting is sufficient in low-complexity areas. This finding is consistent with the guidelines for warning signs presented by Mace et al. (24). Mace found that engineering grade sheeting degraded to an SIA value of approximately 18 was adequate in low complexity areas. Table A-8 shows the minimum SIA values for overhead guide signs as derived by Olson in the same study. The research by Olson and Mace isolated by speed and area complexity, these signing situations where engineering grade and high performance sheeting are appropriate for roadway signs.

Another study by Morales (18) resulted in recommendation on required overall SIA for STOP signs for various approach speeds under ideal visibility conditions. This study suggests that legibility should not be used as a criteria for developing inservice retroreflective standards for STOP signs and provides mathematical relationships between STOP sign recognition distance and its photometric characteristics. This is based on the fact that due to the unique shape of STOP signs they are recognized and not read to be understood.

A study conducted by the Florida DOT (19) recommended "end of service life" SIA values for various sheeting colors and types. The study used several observers at night in the same vehicle. Each observer recorded when sign detection, shape recognition, color recognition,

Table A-6. Stop sign minimum SIA values.

Recommended Minimum SIA Values for a STOP Sign

Speed (mph)	Stopping Distance (feet)	Area Complexity High	Area Complexity Medium	Area Complexity Low
65	569	*	*	150
60	484	*	*	71
55	407	*	155	30
50	337	170	63	14
45	272	70	25	8
40	215	30	11	4
35	164	16	5	3
30	121	8	3	2

* Supplemental Warning Required

Source: Olson (17)

Table A-7. Warning signs minimum SIA values.

Recommended Minimum SIA Values for Warning Signs (Yellow)

Speed (mph)	Area Complexity: Low — Number of Choices 0-3	Low — 3 or more	Medium — Number of Choices 0-1	Medium — 2-3	Medium — 3 or more	High — Number of Choices 0-1	High — 2 or more
65	15	31	15	86	630	230	*
60	15	25	15	63	414	173	1115
55	15	21	15	52	276	144	750
50	15	17	15	38	180	110	520
45	15	15	15	29	126	80	345
40	15	15	15	23	80	63	230
35	15	15	15	17	52	52	150
30	15	15	15	15	35	38	100

*Supplementary devices required.

Source: Olson (17)

Table A-8. Overhead guide signs minimum SIA values.

Recommended Minimum SIA Values for Overhead Guide Signs (Green)

Speed (mph)	Area Complexity: Low, Words on Sign: 3	6	9	Medium, Words on Sign: 3	6	9	High, Words on Sign: 3	6	9
70	8	15	27	13	31	70	35	82	200
60	8	13	22	12	25	54	32	70	150
50	7	11	17	11	20	37	28	54	100
40	7	9	13	10	15	25	25	40	68
30	6	8	10	8	12	17	22	33	46

Sign placement is 20 feet high over a 24 foot roadway.

Source: Olson (17)

message recognition, and legibility occurred. The times were converted to distances. Each sign was then screened, thereby reducing SIA, until the sign was determined to be barely adequate. Table A-9 provides the recommended "end of service life" values for white, yellow, green, and red sheeting colors.

The Oregon DOT provides a specification for retroreflection at 7 and 10 years of inservice performance. Under this specification the manufacturer is responsible for all cost in restoring sign panels to the original effectiveness if the retroreflection falls below the values specified in Table A-10. For years 7 and 10 of inservice placement the manufacturer is obligated to replace the sheeting to its original effectiveness if the retroreflectivity falls below the standards listed on the right column of Table A-10. In addition, sign agencies are responsible for dating all signs at the time of installation.

Research has been conducted which is relevant to the question of standards, but standards have not yet been implemented which reflect fundamental driver needs. This is because the problem of specifying luminance standards for traffic signs is complex and multidimensional. Driver requirements of different signs change across situations. Also the population of signs is not uniform in purpose or function. Signs are created in different designs to serve various needs, and these differences create varying levels of luminance requirements for signs to function properly at night.

The ongoing Federal Highway Administration (FHWA) project entitled "Minimum Visibility Requirements for Traffic Control Devices" is to determine the minimum visibility requirements for signs and markings. Based on these minimum visibility requirements, it will be possible to determine the retroreflectivity needed to make a sign visible at a given distance.

Table A-9. End of service life SIA values

Sheeting Color	End of Service Life SIA Values[1]	
	Type II[2]	Type II A, III A, III B[3]
White	40	140
Yellow	16	40
Green	5	5
Red	na	10

na - not available

[1] SIA values measured at 0.2° observation and -4° angles.
[2] Engineering grade sheeting (Type II).
[3] Super-engineering grade (Type II A), high performance (Type III A), and prismatic (Type III B) sheeting.

Source: Florida DOT (19)

Table A-10. Minimum warranties for retroreflective sheeting as specified by Oregon DOT.

Sheeting Color	Minimum Coefficient of Retroreflection (Seven Years)	Minimum Coefficient of Retroreflection (Ten Years)
White	212	200
Yellow	144	136
Green	38	36
Red	38	36
Blue	17	16
Brown	10	9

Another difficulty in the implementation of standards has been an absence of conclusive performance data. The FHWA project entitled "Service Life of Retroreflective Traffic Signs" (20) investigated the relationship between the retroreflectivity performance of sign sheeting with respect to such factors as sheeting age, weather conditions, ground elevation, etc. Based on these relationships, equations were developed to predict approximate inservice SIA of signs. The accuracy of the equations in predicting inservice SIA is limited since the initial SIA values of new sheeting are quite variable.

Finally, there is no fast, practical, and reliable way of measuring luminance in the field, and therefore one cannot easily determine if the requirements are met. The National Cooperative Highway Research Program (NCHRP) study 5-10 "Mobile System for Measuring Retroreflectance of Traffic Signs" (3) has determined the feasibility of developing instrumentation suitable to rapidly measure retroreflectivity from a moving vehicle during daylight hours. A prototype of the system has been constructed and consists of a video camera, electronic flash gun, laser range finder and a data acquisition image analysis system to evaluate the video image for average legend and background retroreflectance. Figure A-5 is a schematic illustration of the system components which are housed in the van shown in Figure A-6. The results of the above three projects and this project will help in development, measurement and implementation of sign performance standards.

SIGN MAINTENANCE PRACTICES

The existing federal standards for luminance of retroreflective materials for traffic signs are purchase specifications and provide no differentiation based upon driver needs. The *Manual on Uniform Traffic Control Devices* (2) simply specifies that all traffic signs be retroreflectorized or illuminated to show the same color and shape by day and night unless

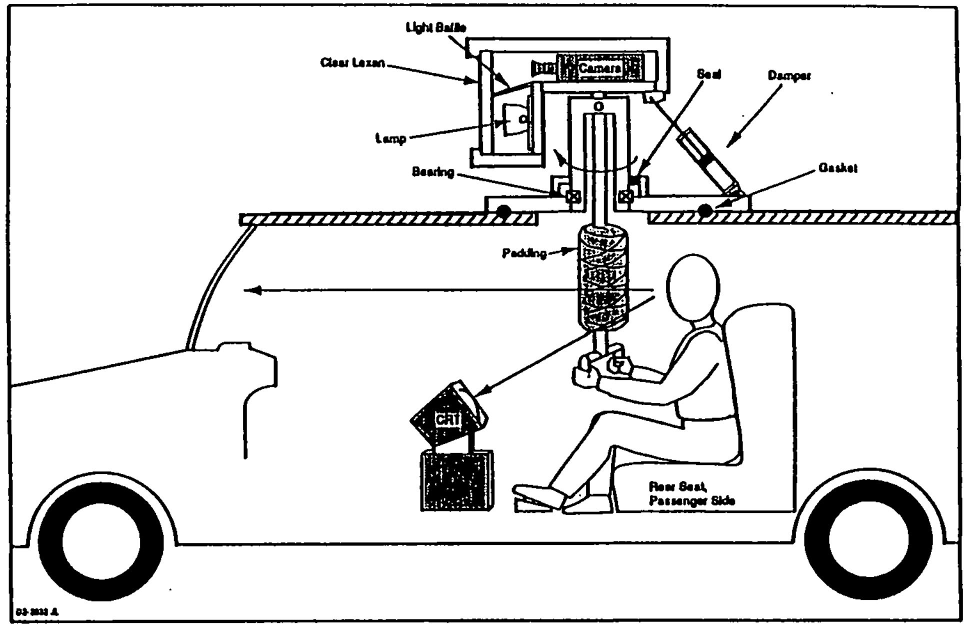


Figure A-5. Schematic illustration of system components.

Figure A-6. Prototype mobile retro-reflectivity measurement system.

specifically excepted in the standards. There are no minimum initial or replacement requirements for retroreflective signs. Based on the agencies surveyed, replacement is left to practices which vary between States, counties and cities. The need for inspection of signs for retroreflectivity is typically not determined under a regimented policy but scheduled by casual, visual inspection. This deficiency is due to the lack of a minimum legibility standards, the competing demands on personnel's times, and the absence of a rapid and reliable retroreflectance measurement device. However, the development of automated sign inventories, minimum performance standards, mobile system for measuring retroreflectance and implementation strategies will provide an opportunity for more efficient and objective solutions to the problems of sign maintenance management.

APPENDIX B—COLLECTION OF RETROREFLECTIVITY DATA

The objective of the national data collection effort was to obtain estimates of sign retroreflectivity conditions across several subgroups including: sign type, sheeting type, and jurisdiction control. To achieve this goal a intensive data collection plan was developed and initiated. The data collection plan addressed the following:

- Identification of key variables
- Determination of sample size
- Selection of study locations
- Development of effective data collection methodology

Each of these data collection plan elements are discussed in the following subsections.

VARIABLES OF INTEREST

Initially, the dependent and independent variables were identified. The dependent variable, the object of effort, was the measure (i.e., SIA value) of retroreflective condition of traffic signs. The independent variables were segregated into four main categories.

1. Geographic Area -- Weather conditions presumably influence the retroreflectivity and service life of sign sheeting. However, as found in the FHWA "Service Life of Retroreflective Traffic Signs" project (20) the effects of climate are difficult to isolate as the climatic influences are very interrelated and tend to disguise the impacts of any specific element. Due to the interrelationship of climatic variables and the influences of highly variable SIA values of new sheeting, the geographic zone system derived for the FHWA project was removed from the final service life models. However, prior to the results of the FHWA project an eight geographic zone system was developed for the data collection effort

described here. It is still reasonable to expect climatic/geographic influences on sheeting deterioration but quantifying these influences remains difficult. The zone system encompassed the continental United States as the goal of this project was to conclude with national estimates of sheeting retroreflectivity conditions.

2. Jurisdiction Levels -- Adopting retroreflectivity standards could have different economic implications depending upon the type and size of jurisdiction. Data was collected across various jurisdiction types to assess the economic impacts of a retroreflectivity standard. The jurisdiction levels identified for sampling were State, county, city, and town/township. The jurisdiction levels generally follow the levels delineated in the Highway Performance Monitoring System (HPMS) from which total roadway mileage was obtained. No data was collected on Federally controlled roadways.

3. Sign Type -- Traffic signs are made of different colors and vary in criticality; therefore, they require different retroreflectivity levels. To accommodate these differences it was necessary to develop the retroreflectivity condition estimates by sign type and color. The MUTCD classifies signs into the following categories:

- Regulatory - black and white, red and white
- Warning - yellow and black
- Guide - green and white, blue and white, brown and white

Data was collected for the following four sign colors by sign type:

- White (Regulatory)
- Red (Regulatory)
- Yellow (Warning)

- Green (Guide)

Parking series regulatory signs and blue, brown, and all street name guide signs were excluded from the sampling effort.

4. Sheeting Type -- Differences exist in retroreflective properties, service life, and per unit cost among sheeting types. Therefore, it was desirable to sample the various types of sheeting. However, from a visual inspection of inservice signs it is possible to distinguish only two types -- enclosed lens sheeting (Types II and II A from *FP-85*) and encapsulated lens sheeting (Type III A). Type II and II A material appear the same during daytime inspection, although in recent years the major manufacturer of Type II A has a symbol on its sheeting that may be distinguishable on some signs. Hence, all signs were identified as either Type II (Engineering Grade) or Type III (High Performance Grade). In the presentation of the results of the condition of signs, this classification was eliminated and all signs of the same color were grouped. Theoretically, the randomness of the data collected resulted in a mix of sheeting types representative of the Nation's population of signs.

SAMPLE SIZE DETERMINATION AND SITE SELECTION

The overall objective of the data collection was to obtain a representative sample of signs for statistically valid estimates of retroreflective condition and of sign density by roadway jurisdiction control. In order to meet the stated objective a sample of different area types, sign types, sign materials, roadway categories, and jurisdiction level of responsibility was needed.

A cluster sampling approach was selected for developing the data collection plan. It involved dividing the population, the entire country, into heterogeneous subgroups or

clusters. States were used to form clusters because they have well defined boundaries. Weather conditions influence the retroreflectivity and service life of signs and, therefore, it was believed that grouping the States by similar weather conditions would be an effective strategy to define the study areas from which to sample. The eight geographic zones developed for the FHWA "Service Life of Retroreflective Traffic Signs" project were modified slightly to maintain state boundary lines. This zone system considers general climatic conditions and solar radiation levels.

Within each zone a minimum of two primary sampling units (PSU) were selected. Each PSU needed at least three different jurisdictions (city, county, State or town). Individual counties were selected as the most appropriate PSU. Using FHWA's HPMS data, counties with three or more different jurisdictions were segregated. The counties were further segregated by urban and rural designations based on population density.

Establishing the sample size usually involves trading off statistical requirements against time and funds available. Using cost and variance models alternate combinations of total PSUs and roadway segments were selected. The cost model is described as follows:

$$\text{Total Budget} = (C_{psu})(M) + (C_{seg})(M)(N)$$

where:

Cpsu	=	Cost per sampled PSU
M	=	Number of PSUs
Cseg	=	Cost per sampled segment
N	=	Number of segments within each PSU

Judgement was used to select the following reasonable alternatives:

- 10 PSUs and 40 segments
- 25 PSUs and 12 segments
- 40 PSUs and 5 segments

Each of these alternatives satisfied the budget constraints.

A variance model was developed to evaluate the variance in SIA conditions between PSUs and within PSUs. The goal of the model was to establish if the between or within variance is greater and then optimize the sample of PSUs and segments. The variance model had the following form:

$$V^2(x) = B^2/m + W^2/mn$$

where:

$V^2(x)$ = Total variance

B^2 = Between PSU variance

W^2 = Within PSU variance

m = Number of PSUs

n = Number of segments

B^2 and W^2 were estimated from data obtained from the FHWA "Service Life of Retroreflective Traffic Signs" project. B^2 and W^2 vary by sheeting color and type. B^2 was found greater than W^2; therefore, it was concluded to increase the number of PSUs rather than increase the number of segments within each PSU. Table B-1 provides the variance estimates for several alternate design options. It was determined to sample 25 PSUs with 12 segments in each PSU, as minimal improvement in variance was afforded beyond 25 PSUs.

Table B-1. Estimated variance for three sample designs.

	Estimated Variance		
	Number PSUs Number of segments		
Sheeting Color and Type	10 40	25 12	40 5
Red			
-EG	3.0	1.7	1.6
-HP	7.8	4.0	3.5
White			
-EG	19.8	10.8	10.4
-HP	30.6	17.2	17.0
Yellow			
-EG	13.5	12.0	14.0
-HP	17.0	2.0	2.6
Green			
-EG	2.3	2.0	2.6
-HP	7.0	3.1	2.2

Note: EG = engineering grade sheeting
HP = high performance sheeting

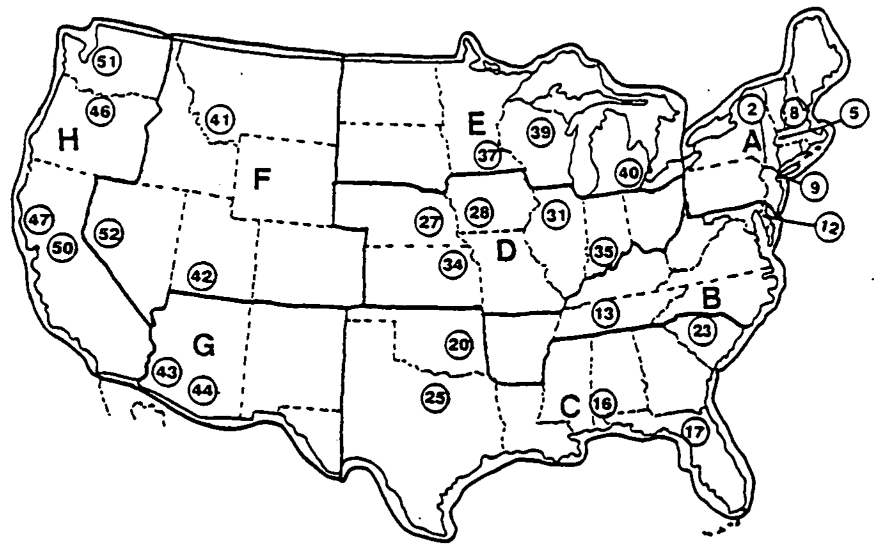
Also, as the number of PSUs increases the total signs to sample greatly decreases.

The 25 PSUs were allocated to the eight zones based on that zone's proportion of total national roadway mileage. Depending on the number of different jurisdiction roadways (i.e. State, county, city or town/township) within a county, four or five segments were selected for each jurisdiction type. The roadway segments under each jurisdiction within a county were identified on county mapping. Approximately 15 traffic signs per segment were measured. Given a starting point on a segment the first 15 traffic signs were selected and measured to insure randomness.

The candidate counties were screened for three or more different jurisdictions roadways and for urban and rural population densities. From the screened list, counties were then randomly selected using the HPMS numbering system. At least one rural and one urban county were selected in each zone. Again, the total number of PSUs per zone was determined by the total roadway mileage. Certain manual selections were necessary for travel and logistical considerations. Figure B-1 provides the geographic location of the data collection sites with the zone system boundaries. As shown 28 sites, or 3 more than the original plan, were actually sampled. This was attributed to the efficiency of the data collection crews.

DATA COLLECTION METHOD

Two teams of two technicians each were used to collect the retroreflectivity data throughout the country. The Advanced Retrotechnology model 920 retroreflectometer with extension pole and remote display was used to collect the measurements. The traffic signs were not cleaned prior to measurement because it was desirable to measure the



Data Collection Sites (County)

Delaware, NY (2)
Berkshire, MA (5)
Hillsborough, NH (8)
Westchester, NY (9)
Calvert, MD (12)
Montgomery, TN (13)
Washington, AL (16)
Levy, FL (17)
Pittsburg, OK (20)
Greensville, SC (23)
Dallas, TX (25)
Butler, NE (27)
Adair, IA (28)
Bureau, IL (31)
Shawnee, KS (34)
Vanderburgh, IN (35)
Fillmore, MN (37)
Oneida, WI (39)
Wayne, MI (40)
Madison, MT (41)
Iron, UT (42)
Yuma, AZ (43)
Pima, AZ (44)
Wasco (46)
Mendocino, CA (47)
Sacramento, CA (50)
King, WA (51)
Clark, NV (52)

Figure B-1. Location of data collection sites.

retroreflectivity as the drivers view the sign. (The FHWA "Service Life of Retroreflective Traffic Signs" project found that sign washing increased SIA by 12% and 8% for Type II and Type III A sheeting signs, respectively). The retroreflectivity readings, segment and county coding, sheeting color, and sheeting type were manually recorded in the field and transferred to computer database in the office. Four readings per sign were taken and later averaged.

APPENDIX C—QUESTIONNAIRE SURVEY RESULTS

Questionnaire surveys were used to obtain data including: sign population, existence of sign inventory, sign replacement costs, sign maintenance costs, inventory inputs, etc. The surveys were distributed to 50 state, 790 county and 85 city agencies. Responses were received from 48 states, 170 counties, and 20 cities.

The following paragraphs provide a summary of the responses to key questions. The summary of responses is grouped into two areas -- 1) sign inventory and 2) replacement and maintenance.

SIGN INVENTORY

Question A. Does your agency have a sign inventory?

Agency	Yes	No
State	14	33
County	129*	41
City	13*	7

* This is not the result of a random sample of jurisdictions. Those agencies with computer inventories were more likely to respond to the questionnaire survey.

Only 30 percent of state agencies were found to maintain statewide sign inventories. For counties and cities, generalizations cannot be made from the survey because this was not a random sample of these agencies. However, from the considerable contact with local jurisdictions it can be stated that few of these agencies maintain inventory systems.

Question B. What is your inventory format?

Format	State	Agency County	City
Card/Paper	11%	43%	24%
Main/Mini Computer	37%	20%	23%
Micro Computer	48%	32%	30%
Other (photolog,maps,etc.)	4%	5%	15%

Approximately 85 percent of statewide inventories are computerized. Only approximately 50 to 60 percent of the counties and cities responding with inventories had computerized systems. Over 40 percent of the counties responding as having inventories maintained card or paper records. The majority of the "other" responses were inventories on aerial photography and other mapping materials. The percentage of county and city agencies having micro-computer format is likely to increase as these programs are becoming readily available.

Question C. Does your inventory include the following elements?

Data Element	State	Agency County	City
Sign Type	93%	97%	92%
Installation Date	78%	82%	77%
Replacement Date	74%	83%	77%
Sheeting Type	56%	50%	54%

SIGN REPLACEMENT AND MAINTENANCE

Question D. Approximately how many signs do you replace per year due to vandalism, knockdown, poor retroreflectivity and other causes?

Reason for Replacement	Percent of All Replacement Agency County	City
Vandalism and Theft	39%	24%
Knockdown	23%	27%
Poor Retroreflectivity	16%	30%
Other	22%	19%

Question E. What is your total annual cost for sign maintenance and replacement?

Item	County Average Cost	County No. of Responses	City Average Cost	City No. of Responses
Total Cost	$96,000	148	$277,000	16
Per Mile Cost	$92.00	141	$132.30	10
Per Capita Cost	$1.00	72	$1.20	16

Question F. What is your average cost to replace a sign?

Item	County Average Cost	County No. of Responses	City Average Cost	City No. of Responses
Materials Cost/SF	$ 5.17	7	NA	0
Labor Cost/Hour	$14.97	19	NA	0
Equipment Cost/Hour	$10.35	16	NA	0
Material Cost/Sign	$38.24	117	$29.56	17
Labor Cost/Sign	$18.92	103	$14.49	14
Equipment Cost/Sign	$10.81	98	$ 9.84	13
Total Cost/Sign	$65.72	168	$54.66	13

NA - Not Available

Question G. How many traffic signs are under the control of your agency?

ITEM	TOTAL SIGNS PER CAPITA AND PER MILE[1]							
	COUNTY				CITY			
	Signs Per 100 Persons	No. of Responses	Signs Per Mile	No. of Responses	Signs Per 100 Persons	No. of Responses	Signs Per Mile	No. of Responses
Regulatory Signs[2]	7.1	35	3.7	39	7.0	13	18.2	12
Warning Signs	6.3	35	4.3	39	3.8	12	9.8	11
Guide Signs[3]	2.0	32	2.6	36	0.6	11	1.2	11
Total Signs	17.6	42	11.9	45	22.6	17	63.9	16

[1]Includes actual and estimated sign totals
[2]Does not include parking series signs
[3]Does not include street name signs

The replacement cost and sign density information obtained here became the basis for the economic analysis and the development of the implementation strategies.

APPENDIX D—SIGN REPLACEMENT COSTS

Sign replacement cost for State, county, city, and town controlled roadways were developed for red, yellow, green, and white sheeting based on the minimum SIA criteria identified in Chapter 3. Each sheeting color was tested using the lower and upper minimum SIA standards. The economic model was run for a total of 11 years to obtain the annual replacement costs for the years after implementation of the minimum standards.

Tables D-1, D-2, D-3, and D-4 provide the sign replacement cost in terms of dollars per roadway mile for State, county, city, and town controlled roadways, respectively. The shaded boxes in the tables highlight the annual replacement costs for each year of the implementation schedule. The unshaded boxes show the annual cost to maintain the minimum standards after implementation is completed.

There is a considerable difference in replacement costs between the lower and upper standards, especially for the red, green, and white sheeting. The replacement cost for green sheeting represents 65 to 75 percent of the total replacement cost. Several reasons for this are apparent:

1. Average cost per sign to replace green guide signs is nearly twice the of standard warning and regulatory signs due to sign size.
2. Majority of green guide signs are constructed using engineering grade sheeting which has lower retroreflectivity characteristics than the other sheeting types.
3. Minimum retroreflectivity standards for green sheeting tested here were high and in the case of the upper value (i.e. 10 SIA) higher than the delivered new specification for green, engineering grade sheeting listed in *FP-85*.
4. Many of the green sheeting samples collected across the country had SIA values less than 8 SIA which was the lower minimum standard tested here.

Table D-1 Sign replacement costs for state roadways.

		RED				YELLOW				GREEN				WHITE			
	State	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile
Lower Standards	Year 1	22	14	17	21	9	5	5	8	136	69	48	39	6	3	2	4
	Year 2	10	14	17	21	2	5	5	8	20	69	48	39	1	3	2	4
	Year 3	11	14	17	21	4	5	5	8	33	69	48	39	1	3	2	4
	Year 4	16	16	17	21	4	4	5	8	10	10	48	39	1	1	2	4
	Year 5	27	27	17	21	8	8	5	8	20	20	48	39	3	3	2	4
	Year 6	26	26	26	21	8	8	8	8	30	30	30	39	4	4	4	4
	Year 7	21	21	21	21	10	10	10	8	28	28	28	39	4	4	4	4
	Year 8	16	16	16	21	11	11	11	8	43	43	43	39	5	5	5	4
	Year 9	31	31	31	21	8	8	8	8	30	30	30	39	5	5	5	4
	Year 10	25	25	25	21	13	13	13	8	20	20	20	39	7	7	7	4
	Year 11	30	30	30	30	6	6	6	6	40	40	40	40	4	4	4	4
Upper Standards	Year 1	167	83	62	48	85	48	32	24	221	90	68	45	18	9	8	7
	Year 2	17	83	62	48	20	48	32	24	20	90	68	45	4	9	8	7
	Year 3	66	83	62	48	16	48	32	24	30	90	68	45	6	9	8	7
	Year 4	23	23	62	48	21	21	32	24	25	25	68	45	6	6	8	7
	Year 5	39	39	62	48	19	19	32	24	43	43	68	45	5	5	8	7
	Year 6	23	23	23	48	13	13	13	24	30	30	30	45	5	5	5	7
	Year 7	35	35	35	48	14	14	14	24	30	30	30	45	5	5	5	7
	Year 8	32	32	32	48	9	9	9	24	28	28	28	45	5	5	5	7
	Year 9	40	40	40	48	33	33	33	24	15	15	15	45	6	6	6	7
	Year 10	38	38	38	48	11	11	11	24	10	10	10	45	9	9	9	7
	Year 11	30	30	30	30	13	13	13	13	93	93	93	93	4	4	4	4

Table D-2 Sign replacement costs for county roadways.

		RED				YELLOW				GREEN				WHITE			
	County	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile
Lower Standards	Year 1	17	12	14	19	18	8	7	8	160	75	52	38	6	3	2	3
	Year 2	9	12	14	19	1	8	7	8	36	75	52	38	1	3	2	3
	Year 3	10	12	14	19	4	8	7	8	29	75	52	38	2	3	2	3
	Year 4	20	20	14	19	4	4	7	8	15	15	52	38	1	1	2	3
	Year 5	16	16	14	19	6	6	7	8	22	22	52	38	2	2	2	3
	Year 6	20	20	20	19	4	4	4	8	15	15	15	38	2	2	2	3
	Year 7	27	27	27	19	8	8	8	8	36	36	36	38	4	4	4	3
	Year 8	21	21	21	19	10	10	10	8	7	7	7	38	3	3	3	3
	Year 9	25	25	25	19	17	17	17	8	36	36	36	38	5	5	5	3
	Year 10	27	27	27	19	11	11	11	8	22	22	22	38	4	4	4	3
	Year 11	27	27	27	27	15	15	15	15	22	22	22	22	6	6	6	6
Upper Standards	Year 1	166	89	66	45	101	46	34	28	247	92	65	44	16	8	7	7
	Year 2	26	89	66	45	17	46	34	28	22	92	65	44	4	8	7	7
	Year 3	75	89	66	45	21	46	34	28	7	92	65	44	4	8	7	7
	Year 4	23	23	66	45	18	18	34	28	36	36	65	44	4	4	7	7
	Year 5	39	39	66	45	15	15	34	28	15	15	65	44	4	4	7	7
	Year 6	18	18	18	45	21	21	21	28	22	22	22	44	6	6	6	7
	Year 7	35	35	35	45	21	21	21	28	29	29	29	44	7	7	7	7
	Year 8	19	19	19	45	13	13	13	28	15	15	15	44	7	7	7	7
	Year 9	24	24	24	45	45	45	45	28	36	36	36	44	7	7	7	7
	Year 10	23	23	23	45	11	11	11	28	7	7	7	44	10	10	10	7
	Year 11	18	18	18	18	14	14	14	14	102	102	102	102	5	5	5	5

Table D-3 Sign replacement costs for city roadways.

		RED				YELLOW				GREEN				WHITE			
	City	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile
Lower Standards	Year 1	75	34	27	22	45	16	13	13	141	83	75	52	16	6	5	6
	Year 2	14	34	27	22	0	16	13	13	78	83	75	52	1	6	5	6
	Year 3	13	34	27	22	3	16	13	13	31	83	75	52	2	6	5	6
	Year 4	11	11	27	22	8	8	13	13	63	63	75	52	3	3	5	6
	Year 5	20	20	27	22	7	7	13	13	63	63	75	52	4	4	5	6
	Year 6	21	21	21	22	8	8	8	13	78	78	78	52	5	5	5	6
	Year 7	17	17	17	22	7	7	7	13	16	16	16	52	5	5	5	6
	Year 8	15	15	15	22	16	16	16	13	31	31	31	52	7	7	7	6
	Year 9	19	19	19	22	15	15	15	13	0	0	0	52	6	6	6	6
	Year 10	14	14	14	22	19	19	19	13	16	16	16	52	8	8	8	6
	Year 11	11	11	11	11	31	31	31	31	31	31	31	31	7	7	7	7
Upper Standards	Year 1	213	99	69	44	164	68	48	35	313	151	100	55	33	15	12	10
	Year 2	4	99	69	44	18	68	48	35	63	151	100	55	6	15	12	10
	Year 3	80	99	69	44	23	68	48	35	78	151	100	55	7	15	12	10
	Year 4	8	8	69	44	21	21	48	35	16	16	100	55	7	7	12	10
	Year 5	39	39	69	44	14	14	48	35	31	31	100	55	7	7	12	10
	Year 6	16	16	16	44	12	12	12	35	0	0	0	55	6	6	6	10
	Year 7	22	22	22	44	8	8	8	35	31	31	31	55	6	6	6	10
	Year 8	15	15	15	44	8	8	8	35	16	16	16	55	6	6	6	10
	Year 9	21	21	21	44	64	64	64	35	0	0	0	55	6	6	6	10
	Year 10	20	20	20	44	15	15	15	35	0	0	0	55	13	13	13	10
	Year 11	19	19	19	19	12	12	12	12	125	125	125	125	3	3	3	3

Table D-4 Sign replacement costs for town roadways.

		RED				YELLOW				GREEN				WHITE			
	Town	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile	One Yr $/Mile	3 Yrs $/Mile	5 Yrs $/Mile	10 Yrs $/Mile
Lower Standards	Year 1	39	23	17	15	1	0	0	5	129	62	70	50	3	1	2	3
	Year 2	21	23	17	15	0	0	0	5	37	62	70	50	0	1	2	3
	Year 3	8	23	17	15	0	0	0	5	18	62	70	50	1	1	2	3
	Year 4	9	9	17	15	0	0	0	5	55	55	70	50	2	2	2	3
	Year 5	9	9	17	15	0	0	0	5	111	111	70	50	3	3	2	3
	Year 6	12	12	12	15	3	3	3	5	55	55	55	50	3	3	3	3
	Year 7	18	18	18	15	6	6	6	5	37	37	37	50	2	2	2	3
	Year 8	9	9	9	15	9	9	9	5	18	18	18	50	4	4	4	3
	Year 9	15	15	15	15	19	19	19	5	37	37	37	50	2	2	2	3
	Year 10	14	14	14	15	12	12	12	5	0	0	0	50	4	4	4	3
	Year 11	14	14	14	14	19	19	19	19	37	37	37	37	4	4	4	4
Upper Standards	Year 1	134	68	52	36	71	33	28	24	258	142	96	55	14	7	5	7
	Year 2	12	68	52	36	16	33	28	24	92	142	96	55	2	7	5	7
	Year 3	58	68	52	36	12	33	28	24	74	142	96	55	4	7	5	7
	Year 4	18	18	52	36	19	19	28	24	18	18	96	55	3	3	5	7
	Year 5	38	38	52	36	21	21	28	24	37	37	96	55	4	4	5	7
	Year 6	32	32	32	36	13	13	13	24	18	18	18	55	5	5	5	7
	Year 7	24	24	24	36	18	18	18	24	0	0	0	55	8	8	8	7
	Year 8	17	17	17	36	18	18	18	24	18	18	18	55	10	10	10	7
	Year 9	14	14	14	36	34	34	34	24	0	0	0	55	9	9	9	7
	Year 10	14	14	14	36	16	16	16	24	37	37	37	55	11	11	11	7
	Year 11	15	15	15	15	15	15	15	15	129	129	129	129	6	6	6	6

On all roadways the need for replacement of red sheeting signs was quite high. The problems of color fade of this sheeting type contributes to the overall poor condition of these signs. In several instances the annual maintenance cost actually increased after the implementation schedule was completed. The population of signs for this evaluation was deteriorated using the equations and relationships developed in FHWA's "Service Life of Retroreflective Traffic Signs". High annual costs after the standards implementation are the product of a large population of signs of similar age (i.e., 5 or more years) failing to meet the minimum in the years after the schedule has been fulfilled.

REFERENCES

1. Advanced Notice of Proposed Amendment to Manual on Uniform Traffic Control Devices. Federal Highway Administration, Federal Register.
2. *Manual on Uniform Traffic Control Devices for Streets and Highways.* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (1988).
3. LUMIA, J.J., "A Mobile System for Measuring Retroreflectance of Traffic Signs." NCHRP Project 5-10 (Feb. 1989).
4. MCGEE, H.W. and MACE, D.L., "Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide." *Report No. FHWA/DF-88/001,* Federal Highway Administration, Office of Direct Federal Programs (Nov. 1987).
5. CUNARD, R.A., "Maintenance Management of Street and Highway Signs." *NCHRP Synthesis of Highway Practice 157.* Transportation Research Board, National Research Council, Washington, D.C. (Sept. 1990).
6. *Guide to the Properties and Uses of Retroreflectors at Night., Publication CIE No. 72.,* International Commission on Illumination, Vienna, Austria (1987).
7. *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-85.* U.S. Department of Transportation, Federal Highway Administration (1985).
8. Federal Test Method Standard, "Instrumental Photometric Measurements of Retroreflective Material and Retroreflective Devices" (Mar. 1977).
9. MCGEE, H.W., MOORE, W., KNAPP, B.G., and SONDERS, J.H., "Decision Sight Distance for Highway Design and Traffic Control Requirements." *Report No. FHWA/RD-78/78,* Federal Highway Administration, Washington, D.C. (Feb. 1978).
10. PERCHONOK, K., and POLLACK, L., "Luminous Requirements for Traffic Signs." Interim Report, Institute for Research, State College, Pennsylvania (Dec. 1981).
11. MACE, D.J. ET AL., "Traffic Signs in Complex Visual Environments." *Report No. FHWA/RD-82/102* (Nov. 1982).
12. BHISE, V.D., ET AL., "Modeling Vision with Headlights in a System Context." *Society of Automobile Engineers, No. 770238* (Mar. 1977).
13. MACE, D.J., "Sign Legibility and Conspicuity." *Transportation Research Board, Special Report 218,* Vol. 2 (1988) pp. 270–293.
14. Institute of Transportation Engineers, Technical Committee 7-C, "Traffic Sign Illumination with External Fluorescent Fixtures." *Traffic Engineering 30,* No. 6 (Mar. 1960).
15. ALLEN, T.M., ET AL., "Luminance Requirements for Illuminated Signs." *Highway Research Record 179* (1967).
16. DAHLSEDT, S., "Luminance Uniformity and Legibility of Traffic Signs." *Lighting Research and Technology 6,* No. 4 (1974).
17. OLSON, P.L., "Minimum Requirements for Adequate Nightline Conspicuity of Highway Signs." The University of Michigan Transportation Research Institute, Ann Arbor, Michigan, *UNTRI-88-8* (1988).
18. MORALES, J.M., "Retroreflective Requirements for Traffic Signs — A Stop Sign Case Study." *Report No. FHWA/RD-87-017* (Jan. 1987).
19. WAGNER, J.A., "Investigation of the Legibility of Sign Letter and Background Type Combinations Under Various Conditions of Weather and Viewing and Durability of Reflective Sheeting." Florida Department of Transportation, *FL/DOT/SMO/357-89* (1989).
20. BLACK, K.L., ET AL., "Service Life of Retroreflective Traffic Signs." *FHWA-RD-90-101* (Mar. 1991).
21. LAGERGREN, E., "Traffic Sign Retroreflectivity Measurements Using Human Observers." Washington State Department of Transportation, *WA-RD 140.1* (1987).
22. DATTA, T.K., TSUCHIYAMA, K.H., and OPIELA, K.S., "Cost-Effective Inventory Procedures for Highway Inventory Data." *Report No. DTFH61-83-C-00043,* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (June 1985).
23. DATTA, T.K., and HERF, L., "Cost-Effectiveness Analysis for Various Inventory Procedures." *ITE J.,* Institute of Transportation Engineers, Washington, D.C. (Sept. 1986).
24. MACE, D.J., ET AL., "Sign Luminance Requirements for Various Background Complexities." Institute for Research, State College, Pennsylvania, *Report FHWA/RD-85/056* (Sept. 1985).
25. "County Road Mileage." Highway Performance Monitoring System, U.S. Department of Transportation, Transportation Computer Center (1987).

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president designate of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 8970

000015M018
TRAFFIC SUPERVISOR

IDAHO TRANS DEPT DIV OF HWYS
P O BOX 7129
ID 83707