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16. Abstract

In 1993, the FHWA proposed minimum levels of retroreflectivity for traffic signs. The minimum values are organized into four tables according to the color of the sign. Each table defines the minimum values as a function of different variables, such as type of sheeting, size of sign, and/or speed of road. This research study was conducted to evaluate various methods that the TxDOT could use to implement the minimum retroreflectivity values. The three basic methods evaluated in the research are: total replacement of all signs, sign inspection and replacement, and sign replacement based on a sign management system. The actual replacement of signs for each method could be done with state or contract forces. Research tasks included surveys of state traffic engineers, TxDOT districts, and TxDOT sign crews; investigations and measurements of sign retroreflectivity and service life; information gathering on sign management systems; an economic analysis of the relative cost-effectiveness of the methods; and an assessment of non-economic factors. The analysis found that the sign inspection and sign management methods have essentially the same costs, but that the sign management method can be implemented with fewer personnel. The sign management method also offers many other benefits that reach beyond those immediately concerned with sign replacement. The research recommends that TxDOT adopt a sign management system in order to implement the minimum retroreflectivity values.

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IMPACT OF MINIMUM RETROREFLECTIVITY VALUES ON SIGN REPLACEMENT PRACTICES

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IMPLEMENTATION STATEMENT

The Federal Highway Administration is expected to initiate rulemaking in the near future on minimum retroreflectivity values for traffic signs. The final rule is expected to have a significant impact on the sign replacement activities of all transportation agencies. This report summarizes the findings of a one-year research project evaluating various methods that the Texas Department of Transportation (TxDOT) could use to replace signs in order to meet the minimum retroreflectivity values. Based on the results of the economic analysis, the sign management system method would be the most cost-effective replacement strategy. In this method, a computerized sign inventory system would be used to manage signing operations and predict when signs should be replaced. However, there are other, non-economic factors which also impact the implementation of a replacement method. These factors are described in the Findings and Recommendations chapter. Implementation of the recommendations should be instituted through changes in TxDOT practices.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was H. Gene Hawkins, Jr., P.E. #61509.

NOTICE

The United States Government and the state of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

At the initiation of this project, TxDOT formed a panel of Project Advisors to provide guidance in the development and conduct of the research activities and review project deliverables. The Project Advisors were able to provide the researchers with valuable insights related to many different aspects of current sign replacement practices and potential impacts of proposed methods. They also served as a valuable resource for obtaining information related to the research activities. The research team met with the Project Advisors on several occasions and their assistance and comments were instrumental in conducting the project activities. The researchers would like to acknowledge the following Project Advisors for their time, efforts, and contributions:

Project Director

- Mr. Lewis Rhodes, Traffic Operations Division, Texas Department of Transportation

Project Advisors

- Rodney Cox, Abilene District, Texas Department of Transportation
- Art Barrow, Materials and Tests Division, Texas Department of Transportation
- Herbert Bickley, Lufkin District, Texas Department of Transportation
- Thomas Ortmann, San Antonio District, Texas Department of Transportation
- Michael Reagan, Tyler District, Texas Department of Transportation

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The researchers would also like to acknowledge the Materials and Testing Division of TxDOT for loaning a retroreflectometer to the researchers to investigate sheeting service life issues.

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SUMMARY

For several years, the Federal Highway Administration (FHWA) has been developing and evaluating the benefits of adopting minimum levels of retroreflectivity for traffic signs. Part of the reason for this effort was 1992 Congressional legislation requiring the FHWA to develop "*a standard for a minimum level of retroreflectivity that must be maintained for ... signs ...*" In a 1993 research report, the FHWA proposed a framework containing the minimum levels of retroreflectivity. These values are presented in Appendix A. Rulemaking on the minimum values is expected to begin in the near future. Appendix A also contains the minimum retroreflectivity values that are expected to be proposed in the rulemaking.

The Texas Department of Transportation (TxDOT) is one of the country's largest state transportation agencies. Because of its size, TxDOT expects the impacts of minimum retroreflectivity for signs to be significant; therefore, TxDOT sponsored a research project to evaluate various methods of implementing the minimum values. The goal of the research was to determine the most effective method that will best allow TxDOT to comply with the minimum retroreflectivity values and to identify the key issues that affect implementation of alternative sign replacement methods. Key issues addressed by the research included relative costs of the various methods, required increases in personnel, sign service life, and features of sign management systems. Research tasks included surveys of state traffic engineers, TxDOT districts, and TxDOT sign crews; investigations and measurements of sign retroreflectivity and service life; information gathering on sign management systems; an economic analysis of the relative cost-effectiveness of the methods; and an assessment of non-economic factors.

The three basic methods evaluated in the research are: total replacement of all signs, sign inspection and replacement, and sign replacement based on a sign management system. The actual replacement of signs for each method could be done with state or contract forces. These methods are described in more detail in Appendix F.

Table S-1 summarizes a portion of the results of the economic analysis for the parameters that the researchers believe best represent TxDOT conditions. The equivalent annual payment represents the estimate of the total TxDOT sign maintenance budget over a period equal to the service life of signs (in this case, 9 years). The results of the economic analysis indicate that the sign inspection and sign management methods have essentially the same costs, but that the sign management method can be implemented with fewer personnel. The sign management method also offers many other benefits that reach beyond those immediately concerned with sign replacement. The greatest of these benefits is that it provides a record of all signing activities. As a result, the information that can be obtained from a sign management system can be used to evaluate and improve overall signing operations by increasing efficiency in a number of areas. These records can also be used by an agency to assist in defending tort claims. The system is also paperless, improving efficiency at all levels and improving the ability to keep the database up to date. The research recommends that TxDOT adopt a sign management system in order to implement the minimum retroreflectivity values.

Table S-1. Summary of Economic Analysis for Best Estimate of Signing Parameters[1]

Method	Equivalent Annual Payment (1 cycle)	Percent Increase over Current Practice	Increase in Full Time Equivalents
Current Sign Maintenance Budget	30.7	---	---
Total Replacement - State Forces	47.3	54	100
Sign Inspection - State Forces	37.7	22	103
Sign Management - State Forces	37.7	22	66
Total Replacement - Contract Forces	87.8	185	17
Sign Inspection - Contract Forces	56.6	84	74
Sign Management - Contract Forces	59.7	94	37

Note: [1]Numbers taken from the best sign estimate in Table VI-5.

CHAPTER I
INTRODUCTION AND BACKGROUND

Traffic signs are a vital element of the highway transportation system in that they provide road users with a variety of information that is essential to the efficient and safe movement of vehicles. The most common types of information provided by signs include notice of traffic laws and regulations, warnings of unusual or unexpected conditions in or near the roadway, and directions or guidance to specific destinations. Motorists expect and depend on traffic control devices that are easy to recognize and comprehend. Based on estimates developed as part of this project, the researchers estimate that the Texas Department of Transportation (TxDOT) is responsible for approximately 2.3 million signs on the state highway system, with a conservatively estimated value of about 125 million dollars. TxDOT spends approximately 27 million dollars annually on sign maintenance.

In order to function properly, these signs must be visible in both daytime and nighttime conditions. This performance requirement is specified in the *Texas Manual on Uniform Traffic Control Devices* (Tx MUTCD) (1), which requires that signs be reflectorized or illuminated to show the same shape and color during both daytime and nighttime conditions. To meet this requirement, TxDOT fabricates its signs from retroreflective sheeting. Although TxDOT has a purchase specification for this sheeting, an annual nighttime visual inspection is the only method used to ensure that signs have adequate levels of retroreflectivity. Consequently, there are no objective measures which indicate when a sign has reached the end of its service life.

The issue of nighttime visibility is a significant one. For instance, in 1995 over 40,000 fatalities occurred on our nation's roads, with 54 percent of these occurring at nighttime. However, the hours of darkness constitute about 40 percent of an average day, and only 25 percent of all travel occurs at nighttime. Consequently, nighttime accidents are overrepresented. In fact, the fatality rate at night is approximately three times greater than that of day. Of course, sign retroreflectivity is not the only safety issue related to nighttime driving. Actually, no single causal factor can be attributed to nighttime accidents. Many variables are working against the driver at night, some inherent to nighttime driving conditions and others self induced. However, improving the nighttime visibility of traffic signs across the United States could lead to a reduction in accidents.

FHWA DEVELOPMENT OF MINIMUM RETROREFLECTIVITY VALUES

For many years, the Federal Highway Administration (FHWA) has been evaluating the retroreflective performance of traffic signs, including the potential impacts of adopting minimum levels of retroreflectivity for signs. The objective of these evaluations was to ensure that traffic signs are sufficiently bright to meet the needs of drivers, particularly older drivers. The percentage of older drivers continues to increase, and nighttime conditions are among the more challenging environments for older drivers due to the degradation of their vision.

Formal activity toward the development of minimum retroreflectivity values for traffic signs began in a 1985 *Federal Register* advance notice of proposed amendments and request for comments (2). In this notice, the FHWA asked several questions, among the most significant of which were:

- *"Are standards needed for minimum maintained retroreflective performance requirements for traffic control devices, including those devices used in work zones?"*
- *"Are maximum initial and maintained retroreflective performance requirements needed for any specific colors or applications?"*
- *"Should standards be based on retroreflective measurements or on minimum distances at which traffic control devices need to be visible and comprehensible to a motorist under a wide range of driving environment and conditions?"*
- *"Have any highway agencies established retroreflective performance standards for their traffic control devices?"*
- *"What instruments and procedures for measuring retroreflective of traffic control devices should be specified, are being used, or are available for use?"*
- *"Would comprehensive standards be cost-effective?"*

Congress also took action on this issue with the Department of Transportation and Related Agencies Appropriations Act of 1992. In this legislation, Congress required the *Manual on Uniform Traffic Control Devices* (MUTCD) (3) to be revised to include "*a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs which apply to all roads open to public travel*" (4). Because of previous research activities in this area, the FHWA was able to develop suggested minimum values of retroreflectivity in a relatively short time period. FHWA published the suggested minimum values in technical and summary reports in October 1993 (5, 6). These proposed values are provided in Appendix A.

Once the proposed minimum values had been published, the FHWA began evaluating the impacts of those values. They identified approximately sixty state and local agencies which were willing to measure the retroreflectivity of signs in their jurisdiction and provide that information to the FHWA. The FHWA is using this retroreflectivity data to assess the impacts of the proposed values on sign replacement rates and to determine whether the proposed retroreflectivity values should be modified before initiating rulemaking. The FHWA also sponsored three regional workshops (in Denver, Baltimore, and Kansas City) to solicit input from transportation agencies regarding the proposed minimum values. TxDOT was represented at the Kansas City workshop by Lewis Rhodes, the Project Director for this research project. The information obtained in these workshops has been used to evaluate the proposed values prior to rulemaking.

Rulemaking is the process used by the federal government to solicit public comment on a proposed government action before the action takes place. The minimum retroreflectivity values will be published in the *Federal Register,* and the public will be invited to comment on the values. The FHWA will review and consider the comments received. A number of outcomes can result after the comment period closes. The matter could be dropped from rulemaking, revisions could be made and reissued for comment, or a final rule could be issued. Although the outcome of the rulemaking cannot be predicted, the researchers believe that the next edition of the MUTCD will include minimum retroreflectivity values. The new MUTCD is expected to be published in 1999 or later. At the present time, there is no indication when the minimum values, if adopted through a final rule, would become effective, or the compliance period that would be provided to bring signs in compliance with the minimum values.

As a result of input received in the workshops and from other sources, FHWA is expected to make a number of changes to the original plan for minimum retroreflectivity values. Among the most significant of these is that FHWA is expected to propose the values as recommended values (guidelines) instead of as required values (standards). The originally proposed minimum values are expected to be revised for the rulemaking. The red values are expected to decrease significantly, while the white, yellow/orange, and green values will remain essentially the same. The framework for the minimum values is not expected to change. The rulemaking is expected to take place in late 1996 or early 1997.

RESEARCH APPROACH

TxDOT currently uses a subjective measure (nighttime visual inspections) to ensure that signs possess adequate retroreflectivity. Because of the potential demands that minimum measurable values of retroreflectivity could place on the Department, TxDOT determined that a research project was needed to evaluate various methods of meeting the minimum values and the impacts of each method on TxDOT. This one-year research project, conducted by the Texas Transportation Institute (TTI), had the goal and objectives listed below. In conducting the research, the researchers also considered the key issues listed below.

- **Research Goal**
  - Determine the most effective method that will best allow TxDOT to comply with the minimum retroreflectivity values and to identify the key issues that affect implementation of alternative sign replacement methods.
- **Research Objectives**
  - Identify the factors which impact the implementation of minimum retroreflectivity values for traffic signs.
  - Identify procedures currently used in TxDOT districts to determine sign replacement schedules.
  - Identify alternative sign replacement methods which can be used to meet the minimum retroreflectivity values.
  - Determine the advantages and disadvantages of each sign replacement method.
  - Evaluate the costs associated with each alternative method.
  - Determine the most effective sign replacement method for TxDOT to use.
  - Develop guidelines and/or policies to assist TxDOT in implementing the recommended sign replacement strategy.
  - Document the project activities and findings.
- **Key Issues**
  - **Budgets** - With the reduction in available funds for maintenance activities, the replacement strategy selected by TxDOT will depend in large part on its cost-effectiveness.
  - **Full-Time Equivalents** - Recent legislative reductions in full-time equivalents (FTEs), and the likelihood of more reductions in the future, necessitate the

identification of a replacement strategy that will result in increased productivity while requiring few, if any, additional personnel.

- **Training** - Some amount of training will be necessary in order to ensure that the inventory system is maintained properly, that signs are being evaluated properly, and that the minimum values are being met.
- **Final Minimum Values** - The recommended minimum values published by FHWA are still subject to revision. FHWA expects to initiate rulemaking on the final minimum values in late 1996 or early 1997, with the final rule to be issued in time to be included in the next edition of the MUTCD.
- **Measurement Procedures** - If FHWA specifies measurement procedures, TxDOT will need to establish training and guidelines in those procedures. If FHWA does not specify the measurement procedures to be used then TxDOT will need to develop its own procedures for measuring retroreflectivity in order to comply with the minimum values.
- **Sign Service Life** - There are many variables that affect the service life of a traffic sign, including its environment, orientation, color, size, vandalism, sheeting type, and manufacturer.
- **Sign Inventory/Management System Capabilities** - TxDOT officials will need to identify the capabilities they want in an inventory/management system. Some of those capabilities include bar coding/reading, video imaging, aerial photography, global positioning systems, and geographic information systems in addition to basic sign information such as type, size, color, etc. Some systems can also be expanded to include other activities such as pavement markings.

PROJECT ACTIVITIES

In order to satisfy the project goal and objectives, the researchers undertook numerous information-gathering and analysis activities. These are briefly described below. Where appropriate, these descriptions identify the portion of this report that provides the results of the activity.

- **Collect information on signing practices and operations** - Specific efforts are listed below. Activities and findings are described in Chapter III.
  - *Meetings with TxDOT personnel* - Researchers met with and interviewed district signing personnel and also met with the Project Advisors on two occasions.
  - *Survey of sign replacement practices in other states* - Researchers conducted a survey of state traffic engineers to determine sign replacement practices in other states.
  - *Survey of TxDOT district practices* - Researchers sent a survey to TxDOT districts, area offices, and maintenance sections to solicit comment on TxDOT sign replacement activities.
  - *Survey of TxDOT sign replacements* - TxDOT sign crews filled out a form each time a sign was replaced so that researchers could obtain actual data on TxDOT sign replacement activities.
- **Collect information on sign service life** - Researchers obtained and evaluated measured retroreflectivity values to determine the impact of various factors on the service life of retroreflective sheeting. Activities and findings are described in Chapter IV.

- **Collect information on available sign management systems** - Researchers gathered information on available sign management systems, their requirements, their capabilities, and their features. Activities and findings are described in Chapter V.
- **Conduct value engineering analysis of economic factors** - The researchers developed an economic model that was used to compare the cost-effectiveness of the various replacement methods. Activities and findings are described in Chapter VI.
- **Identify non-economic factors** - The researchers identified non-economic factors that might impact the implementation of a replacement method. Activities and findings are also described in Chapter VI.
- **Develop recommendations** - The researchers used the results of all research activities to develop recommendations for TxDOT concerning sign replacement activities and the implementation of the minimum retroreflectivity values. Activities and findings are described in Chapter VII.

BASIC REPLACEMENT METHODS

At the outset of the project, three basic alternative methods were identified for evaluation. These methods are described in Table I-1. Additional methods, beyond various combinations of these three, were not identified during the research. Appendix F provides more detailed descriptions of each of these methods and the procedures that would be used to implement each method.

Table I-1. Brief Description of Alternative Sign Replacement Methods

Method	Description	Options
Total Replacement Method	All signs on a predetermined section of highway are replaced at regular, predefined, time intervals. All signs are replaced, regardless of whether they meet the minimum value and how long they have been in the field.	• Replacement personnel: ▸ State forces ▸ Contract forces
Sign Inspection Method	The minimum retroreflectivity of signs is measured at predetermined intervals. Those signs that do not meet the minimum value are scheduled for replacement.	• Inspection method: ▸ Visual inspection ▸ Measured inspection • Replacement personnel: ▸ State forces ▸ Contract forces
Sign Management System Method	A sign inventory or management system is used to track key sign characteristics such as location, size, color, highway speed, exposure, and others. This information is used by the system to predict when the sign retroreflectivity will fall below the minimum value.	• Data entry method: ▸ Paper based ▸ Paperless • Replacement personnel: ▸ State forces ▸ Contract forces

USE OF METRIC UNITS IN RESEARCH

For several years, the United States has been moving toward implementation of the metric system of weights and measures. The preferred practice in research reports is to base the research on metric units, providing English units in parenthesis, if needed. This practice is not followed in this report. All of the information obtained by the researchers from TxDOT for use in the analysis were provided in English units (centerline miles of highway, cost per square foot of sign, square footage of signs replaced annually). Sign density information in the literature is provided only as signs per mile. In order to maintain the accuracy of the information obtained for the analysis, the researchers kept this information in the units provided (English). Table I-2 lists the units used in this research project affected by the metric/English unit issue and a conversion factor that can be used to convert the U.S. units to metric units.

Table I-2. Metric/English Units Used in Research Project

English Unit	Equivalent Metric Unit
1 centerline mile	0.62 kilometer
1 sign/mile	0.62 sign/kilometer
1 square foot of sign	0.093 meter squared
$1.00/square foot/mile shipping cost	$6.68/meter squared/kilometer
$1.00/mile	$0.62/kilometer
$1.00/square foot	$10.75/meter squared

CHAPTER II
SIGN RETROREFLECTIVITY ISSUES

To reflectorize an object is to provide a surface where incoming light is redirected at some angle other than the incident angle. There are three types of reflection: mirror, diffuse, and retroreflection. Retroreflection occurs when the light that strikes an object is reflected back toward the source. Traffic signs achieve their nighttime visibility through the use of retroreflection, achieved through retroreflective sign sheeting, of which there are several types. Retroreflective sheeting deteriorates over time, losing brightness, color, and contrast and leading to a reduction in detection and legibility distance. In fact, research shows that 10 to 57 percent of existing signs installed on all roadways should be replaced due to poor retroreflectivity (7).

SCIENCE OF SIGN RETROREFLECTIVITY

When a retroreflector is treated as a point source, retroreflectance is the ratio of the light reflected by a surface (luminance) to the light striking the surface (illuminance). However, signs are an extended light source because of their large area. Therefore, a coefficient of retroreflection (R_a) has been adopted for use with signs. It is the reflectance divided by the surface area of the sign. The SI (metric) measure for R_a, which has been adopted by FHWA for the minimum retroreflectivity values, uses the units candelas per lux per square meter ($cd/lx/m^2$). The English measure is called the Specific Intensity per Area (SIA) and uses the units candelas per footcandle per square foot ($cd/fc/ft^2$) or candlepower per footcandle per square foot. The SI and English units are equivalent. The retroreflectance of a reflector is not a property of the material itself, but depends on two angles. Therefore, R_a is always described in the context of angularity, defined by the entrance angle and observation angle, as shown in Figure I-1. In the FHWA minimum value framework, the entrance angle is -4.0 degrees, and the observation angle is 0.2 degrees.

Types of Retroreflective Sheeting

The amount of light reflected from a sign is not only dependent upon the intensity of the light source and the entrance and observation angles, but is also dependent upon the type of sheeting on the sign. The physics of retroreflective sheeting follows two basic principles. In spherical lens retroreflection, light is bounced back toward the source through a combination of glass spheres (beads) with reflective (mirror type) backing. Figure II-2a demonstrates how incoming light is directed by each sphere to its focal point. At the focal point, the reflective backing reflects the ray, which, after being bent again at the surface of the sphere, returns to its source. The other basic principle used to create retroreflective sheeting is prismatic or cube-corner retroreflection. Prismatic retroreflection is achieved through total internal reflection. As illustrated in Figure II-2b, incoming light, after being reflected several times off the surfaces of the prisms, is redirected 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). These two basic principles are used to manufacture three basic retroreflective materials as described below. Figure II-3 illustrates cross-sections of these three types of sheeting.

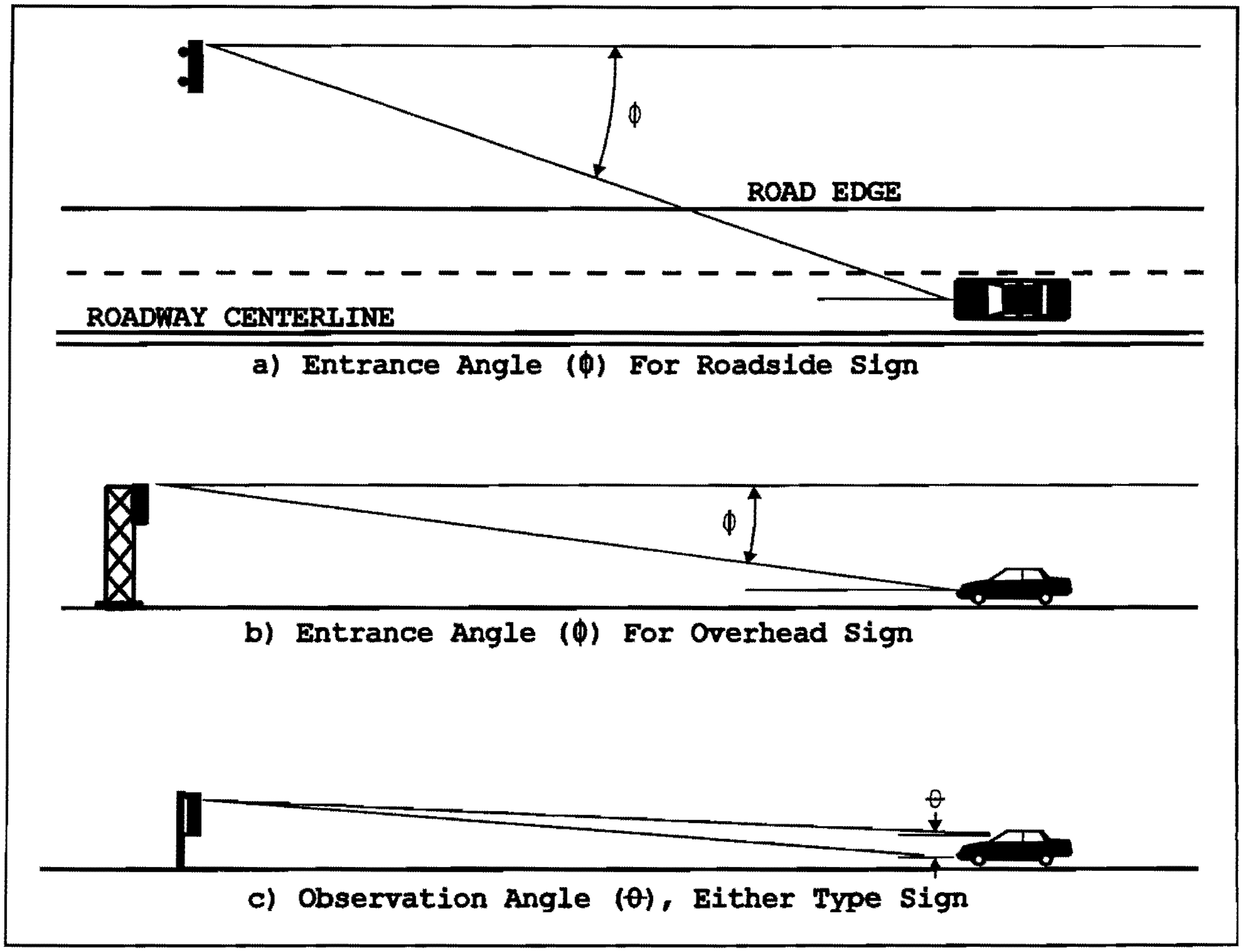

Figure II-1. Illustration of Entrance Angle (ϕ) and Observation Angle (θ)

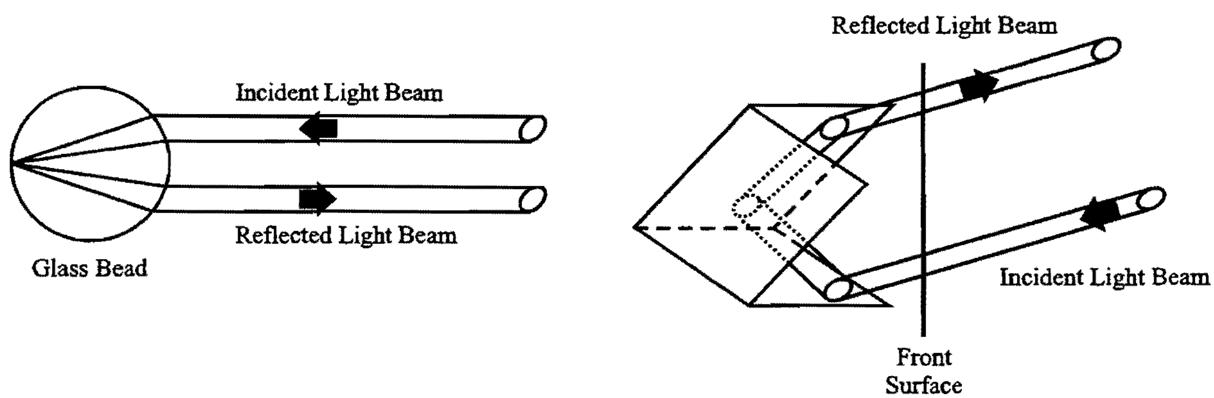

Figure II-2a. Spherical Reflector

Figure II-2b. Cube Corner Reflector

Figure II-2. Principles of Retroreflection

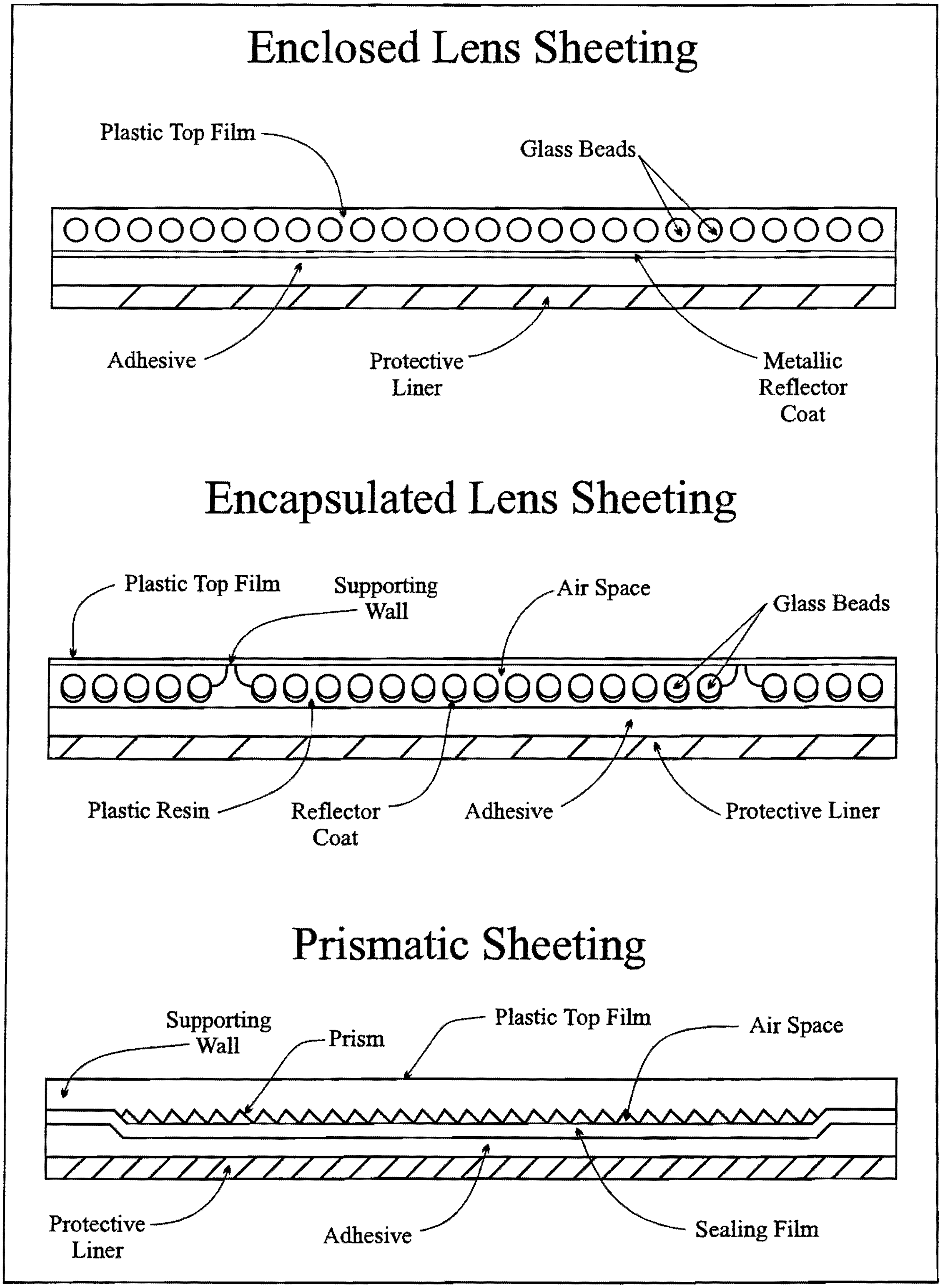

Figure II-3. Cross-Sections of Retroreflective Sheeting

- **Enclosed lens or glass beads** - The enclosed glass bead sheeting consists of small glass beads imbedded in a layer of transparent colored plastic. A metallic reflection shield is provided behind the plastic.
- **Encapsulated lens or glass beads** - Encapsulated sheeting is constructed similarly to enclosed sheeting with one exception. Between the glass beads and the outermost transparent plastic covering is a small layer of air, which improves the retroreflectivity.
- **Cube corner or prismatic** - Prismatic sheeting consists of small cube corners inserted into a transparent plastic film. To reflect color, pigment or dye is inserted into the film or on the reflecting surface.

Retroreflective sign sheeting is most commonly known by several names: engineering grade (enclosed lens), super engineering grade (enclosed lens), high intensity (encapsulated lens or prismatic), and Diamond Grade™ (prismatic). In its most recent specification for retroreflective sheeting, FP-92 (8), the FHWA has adopted the terminology used in the American Society for Testing and Materials (ASTM) specification (9) to describe the different types of materials. The ASTM specification defines the types of sheeting as Type I, Type II, Type III, Type IV, and Type V. These definitions are different from those used in the previous FHWA FP-85 specification (10). The TxDOT specification (11) defines sheeting as Type A, Type B, and Type C. Table II-1 summarizes the terminology, expected life, and performance for the different types of sheeting.

Table II-1. Comparison of Sign Sheeting

Common Description		FHWA Type (FP-85)[1]	FHWA Type (FP-92)[2]	TxDOT Type	Expected Life (yrs)	Typical Cost ($/sf)
Engineering grade		II	I	A	7-10	0.79-1.25
Super engineering grade		IIA	II	B	7-10	1.90-2.15
High intensity grade	Beaded	IIIA	III	C	10+	2.95-3.70
	Prismatic	IIIC	IV	C	10+	3.70-3.85
Diamond Grade™		---	V	C	10+	3.70-4.25

Notes: [1]Previous FHWA specification.
[2]Current FHWA specification. Same as ASTM D 4956-95 specification.

EXISTING RETROREFLECTIVITY STANDARDS/GUIDELINES

The Texas MUTCD contains no in-service retroreflective requirements for traffic signs. However, TxDOT has a purchase specification for retroreflective sheeting, Departmental Specification: D-9-8300, *Flat Surface Reflective Sheeting* (11). This standard contains information pertaining to the optical performance of reflective sheeting and reverse screened signs. But the document only refers to the material's retroreflectance before exposure or after other artificial accelerated weathering tests and contains no in-service retroreflective requirements for traffic signs.

In 1993, Flintsch (12) published a report reviewing retroreflective sign sheeting practices and policies. As part of the report, Flintsch surveyed 48 states in an attempt to identify sheeting material used and current usage policies. One particular question dealt with whether a state had minimum retroreflectivity requirements for new sheeting. Of the 36 states that responded, 17 (47 percent) indicated that they had a specification. Five states (14 percent) answered they did not have a specification, but provided one anyway. Table II-2 summarizes the results.

Table II-2. Minimum Retroreflectivity Requirements

Question: Does your state have a minimum retroreflectivity specification for new sheeting?		
Answer	**Number of States**	**Percentage**
Yes	17	47
No, but provided specification	5	14
No	13	36
No answer	1	3
Total	36	100

Of the specifications listed as used by the states, FP-85 was the most common. Other standards listed included those of the American Association of State Highway and Transportation Officials (AASHTO) and the American Society of Testing and Materials (ASTM). Florida was the only state that indicated it had end of service life retroreflectivity values for signs. These values are shown in Table II-3. Five states (Arizona, New Jersey, Pennsylvania, Texas, and Utah) reported that they used their own standards to test retroreflectivity. However, it could not be determined from the study if the states that have their own standards have requirements for minimum retroreflectivity of in-service traffic signs.

Table II-3. End of Service Life Retroreflectivity Values Used by Florida DOT

Sheeting Color	**End of Service Life SIA Values**[1]	
	Type I (TxDOT Type A)	**Type II, III, IV (TxDOT Type C)**
White	40	140
Yellow	16	40
Green	5	5
Red	not available	10

Note: [1]Measured at an entrance angle of -4.0 degrees and an observation angle of 0.2 degrees.

PROPOSED MINIMUM VALUES

In 1993, Paniati and Mace (5) published proposed minimum retroreflectivity requirements for warning, regulatory, and guide signs. These values are provided in Appendix A. The values are based on a model called Computer Analysis of the Retroreflectance of Traffic Signs (CARTS). The mathematical model accounts for such complex variables as the driver, the vehicle, the signs, and the roadway. The model's theoretical construct is based on two validated theoretical models and one submodel developed expressly for CARTS.

The basis for CARTS is the concept of minimum required visibility distance (MRVD). The MRVD is the shortest distance at which a sign must be visible to enable a driver to respond safely and appropriately. MRVD includes the distance required for a driver to detect the presence of a sign, recognize the message, decide on an appropriate action (if necessary), and make the appropriate maneuver (if necessary) before the sign moves out of the driver's vision. For a selected sign, CARTS calculates the required MRVD, determines the luminance required at the MRVD, and then converts this luminance to a minimum required retroreflectivity value. The model allows the user to vary numerous parameters, including the type, size, and location of the sign; the headlamp design and driver position; the driver age and visual characteristics; the roadway design; and the traffic volume. Details of the CARTS model are provided in the research report defining the minimum retroreflectivity (5). CARTS was used to identify the critical variables affecting sign retroreflectivity and to provide insight into the levels of retroreflectivity that are required for meeting driver needs.

As previously mentioned, the FHWA has been evaluating the impacts of the minimum values proposed in the 1993 report and is expected to revise the originally proposed minimum values for the rulemaking process. Both the originally proposed values and the values that are expected to be proposed in rulemaking are provided in Appendix A. The expected minimum retroreflectivity values in Appendix A have not been formally proposed and are subject to change before rulemaking begins. Appendix A also contains a list of the specific signs which are addressed by each table and other criteria that apply to the minimum values. As the tables in Appendix A indicate, the minimum values are defined by a framework that is based on several different parameters that affect retroreflectivity performance. Table II-4 lists these parameters and indicates those parameters that are used to define the minimum retroreflectivity value for a given color of sign. The recommended retroreflectivity values reported in the tables were developed using the CARTS 66th percentile driver although, for reasons given in the report, Paniati and Mace believe the values provide for a higher percentile driver.

Table II-4. Characteristics Used to Define Minimum Values

Characteristic			Characteristic Used to Define Minimum Value			
	Legend Color		Black and/or Red	Black	White	White
	Background Color		White	Yellow/Orange	Red	Green
Sign Size			✓	✓	✓	
Material Type			✓	✓		
Sign Legend				✓		
Sign Placement			✓			✓
Traffic Speed			✓		✓	✓
Range of minimum values (cd/lx/m²)	1993 Proposed Values	Background	15-120	15-120	6-14	5-7
		Legend	N/A	N/A	30-70	25-35
	Expected Rulemaking Values[1]	Background	20-90	15-70	5-8	5-7
		Legend	N/A	N/A	25-50	25-35
Values for Both Legend and Background					✓	✓

Note: [1]Expected values subject to change prior to rulemaking.

Also included in the minimum retroreflectivity recommendations by Paniati and Mace is a minimum contrast ratio of 4:1 for those signs that include retroreflectorized sheeting material for both the legend and background. The value was selected based on previous research cited in their report. The signs that must meet this minimum contrast ratio include red on white regulatory signs and white on green signs. The contrast ratio is determined by dividing the retroreflectivity value of the white legend material by the retroreflectivity value of the background material (red or green). If the quotient yields a value less than four, then the sign should be replaced. The contrast ratio is particularly critical for red signs made by screening because the red background color fades with time, allowing the white material to show through; thereby increasing the retroreflectivity and, in turn, decreasing the legibility distance.

The FHWA reports also include estimates of the replacement rates that would result from the suggested minimum values. These estimates are based on data collected as part of an National Cooperative Highway Research Program (NCHRP) study (7). The data are not categorized according to the structure of Tables A-1 through A-4, therefore, the estimates are based on aggregate retroreflectivity values. For a state agency, the sign replacement estimates are 7 percent per year for warning signs, 10 percent per year for red regulatory signs, 7 percent per year for white regulatory signs, and 12 percent per year for green guide signs.

Validation of the Proposed Minimum Retroreflectivity Values

To validate the proposed minimum retroreflectivity values summarized in Tables A-1 through A-4, Mercier et al. (13) conducted further research which included a simulation designed to approximate CARTS reference conditions. Analysis of data collected was directed toward the evaluation of the proposed minimum retroreflectivity requirements. They concluded that the candidate minimum retroreflectivity values are sufficient to accommodate a high percentage of drivers for all but a few of the signs tested. In general, it appears that the percent of drivers accommodated by the minimum retroreflectivity values is comfortably above the 85th percentile level. However, certain signs did not perform as well as most, especially for the older drivers. These signs included the NARROW BRIDGE (W5-2) and NO PASSING ZONE (W14-3) signs.

The study evaluated a total of 25 signs. These comprised thirteen yellow diamond warning signs (nine with symbol legends and four with word legends), three white-on-red regulatory signs, and two white-on-green guide signs. Signs were tested for two different speeds (55 and 30 mph), and five signs were tested in two different sizes.

Since only five signs were tested at different sizes, no definite conclusions could be drawn about the relation between required retroreflectivity and sign size. However, there was a fairly consistent decrease in the required retroreflectivity values for larger signs. Also, the effects of roadway speed were evident although not as consistent as sign size. Generally, the roadway speed has a small effect on the required retroreflectivity for warning signs but speed became more of a factor for regulatory and guide signs (where longer MRVDs are required at higher speeds).

Australian Study

A recent Australian report (14) also evaluated the minimum performance criterion of retroreflectivity in terms of a terminal value, below which a sign would be ineffective. The authors computed minimum values for various sheeting colors and situations but did not recommend that these values be used to implement the results of their research. Rather, they recommended the use of their computer model (which, in concept, is very similar to CARTS) to calculate appropriate retroreflectivity values for an individual sign and situation. The report also contained a recommended minimum internal contrast of ratio of 3:1 for fully retroreflectorized signs.

Interestingly, the Australians conducted a subjective nighttime field study of in-service traffic signs in order to assess the effectiveness of visual sign inspections. Experienced personnel were chosen to select those signs deemed ineffective due to poor retroreflectivity characteristics (just as TxDOT personnel conduct nighttime visual evaluations for retroreflectivity). The retroreflectivity values of the signs were recorded and compared to the minimum values derived earlier in the study. Table II-5 summarizes the findings of this task. The results indicated that the mean retroreflectivity values for signs that did not pass visual inspection were well below the recommended minimum value. The authors noted that the mean values were low because some signs selected may have been well beyond their effective life. The Australian study results indicate that personnel conducting visual inspections tend to pass a sign that has exceeded its service life.

Table II-5. Australian Nighttime Field Study

Sign Color	Application	Minimum R_a	Signs Not Passing Visual Inspection	
			Mean R_a	Maximum R_a
White (background)	Rural	75	N/A	N/A
White (background)	Urban	50	16	60
White (legend)	Stop Sign	40	10	55
White (legend)	Urban Guide	60	N/A	N/A
White (legend)	Rural Guide	100	N/A	N/A
Yellow	All	47	6	26
Red	All	5	4	14
Green	Urban Guide	8	2	12
Green	Rural Guide	13	N/A	N/A

Although the candidate minimum retroreflectivity values in Table II-5 were derived independent of the work in the U.S., the values are very similar. Therefore, a comparison of the minimum retroreflectivity data to the mean of the field study data generates suspicion as to whether the human eye is a valid measuring tool when evaluating signs for adequate retroreflectivity properties.

Washington State DOT Study

In 1986, the Washington State DOT conducted a survey to determine the policies and procedures used in maintaining retroreflective traffic signs (15). The survey found that:

- Six states maintained performance standards for retroreflective sheeting,
- Most states used their own criteria to determine how often signs should be replaced,
- Eight states used installation dates in their sign inventories as a priority to replace signs,
- Thirty-five states put either the installation date or fabrication date on their signs,
- Thirty-five states used day and night visual inspections,
- Thirty-five states used a combination of stationary and moving vehicles for conducting visual inspections,
- Retroreflectometers or patches were only used to supplement visual inspections,
- One-third of the respondents washed their signs frequently,
- Thirty-one states did not have plans to modify sign inspection practices, and
- Thirteen states intend to modify sign replacement practices.

In the second part of this study, 17 drivers were trained to conduct visual sign inspections. This was followed by several inspections of Stop and warning signs. The scale used to rate the signs was 0 (for the worst sign) to 4 (signs that seemed brand new). The scale for Stop signs differed from that of warning signs by including the internal contrast ratio as a criteria for rating the sign (rather than just rating the sign retroreflectivity). A retroreflectometer was used to measure the retroreflectivity of each sign. A decision model was then created. Results from the decision model based on the observers' ratings were then compared to the results based on the true retroreflectivity of the signs. The findings from this part of the survey include the following:

- The observers made correct decisions on 74 percent of the warning signs and 75 percent of the stop signs.
- Seventeen signs (out of 130) were replaced that should not have been.
- Ten signs were not replaced that should have been.
- Observers did not dramatically improve their ability to rate signs throughout the training. No consistency could be determined although it appeared that observers reached their optimum accuracy after 2 or 3 training sessions.
- A major caveat with the report is the failure to report the time intervals between training and field evaluations. It is likely that the observers' accuracy decreases with the increase in time between training and actual sign evaluations. There is no mention of this in the report.
- Based on this report, it seems that properly trained sign personnel can do an acceptable job of determining whether traffic signs need to be replaced due to inadequate retroreflectivity.

CHAPTER III
RESULTS OF INFORMATION GATHERING EFFORTS

The majority of the activities associated with this research project were devoted to obtaining the information needed to analyze the various aspects of the identified alternative sign replacement methods. These activities included:

- Meetings with TxDOT personnel involved in signing operations,
- A survey of sign replacement practices at other state transportation agencies,
- A survey of TxDOT district signing activities, and
- A data form on TxDOT sign replacements.

MEETINGS WITH TxDOT PERSONNEL INVOLVED IN SIGNING OPERATIONS

In one of the initial activities, the researchers met with personnel from selected TxDOT districts to assess current practices for replacing signs. Typically, the visits consisted of an interview with the district traffic engineer (or equivalent position) and the district sign shop supervisor. These interviews were conducted to gather information on district sign inspection practices, inventory, and management. The five districts that were visited are shown in Table III-1.

Table III-1. Districts Visited

District	Traffic Engineer	Sign Shop	Others
Bryan	Kirk Barnes	Tommy Moehlman	None
Lufkin	Herbert Bickley	Keith Brashier	None
San Antonio	Pat Irwin	Dee Smith	None
Tyler	Peter Eng	Kenneth Stout	Pete Martinez
Atlanta	Carlos Iberra	Joyce Machaelis	None

All of the districts were conducting two nighttime visual inspections per year. None of the inspectors are using test strips or retroreflectometers at this time; however, one district has ordered two retroreflectometers for use in daytime inspections.

All of the districts are currently involved in activities that they hope will improve their sign management process. Some of the districts have developed their own forms for requesting replacement signs from the district sign shops. These forms include information such as sign type, size, legend, color, location and support type. Sign shop personnel commented that the difficulty with the order forms is that the information is reported differently by different sign personnel. In an attempt to correct some of these problems, one district has developed a signing handbook and is in the process of repairing or replacing all the signs in the district to ensure uniformity.

Another concern is that the sign shop personnel are relying on their field crews to know the location of the signs and have no way to accurately determine the location of an individual sign. In order to alleviate this problem, some districts have developed a limited paper-based inventory on portions of the roadway system.

One district has used a computer-based inventory/management system in the past, but due to cutbacks in FTEs the data base has not been maintained for some time now. All of the districts were interested in a computer-based sign management system. The districts felt that a computer-based system would allow them to better mange their personnel's time, give them more control over the budgeting process, and would allow them to know exactly what signs were in the field and where they were located. Following are some of the comments regarding what the district personnel would like to see in a computer-based system:

- The system should be easy for the field crews to use.
- The system should not rely on handwritten information.
- The system should provide information in a uniform manner that is not subject to interpretation by office personnel who may or may not have experience in traffic signing.
- The system should be easy to maintain and update so it will remain useful.

TxDOT personnel made the following observations related to the different replacement strategies:

- Due to vandalism and knockdown, few signs actually reach their expected life.
- If replacement is not based on retroreflectivity, then how will TxDOT be sure a sign meets the minimum retroreflectivity values?
- If individual signs are replaced based on retroreflectivity, it may take more time than visual inspections currently require.
- Gang replacement may result in the replacement of signs that still meet the minimum values.
- Replacement schedules based on time may result in signs not being replaced that do not meet the minimum values.

None of the districts felt that a sign inventory system would expose them to any more tort liability than currently exists, and all the districts felt their personnel were capable of learning to use a sign inventory system.

In addition to the visits with district personnel, the researchers met with the Project Advisors on two occasions. These meetings were used to identify potential replacement methods and the key issues of concern to the Department.

As a result of one of these Project Advisor meetings, the researchers learned of a recent change in TxDOT practices regarding sign inspections. Until recently, TxDOT required two nighttime sign inspections per year to ensure retroreflectivity and legibility. A June 5, 1996 memo to districts from B.F. Templeton changed the requirement to a minimum of one nighttime inspection per year. The ability to make this change in practice was based on substantial improvements in the reliability and quality of retroreflective sign sheeting.

SURVEY OF STATE DOT SIGN REPLACEMENT PRACTICES

One of the early efforts in the project was to survey sign replacement practices used in the other 49 states (excluding Texas). This survey was one part of a survey addressing the key issues on four TxDOT/TTI research projects. The survey instrument for the sign replacement part is contained in Appendix B. The survey contained 11 different questions covering different aspects of sign replacement including sign replacement reasons, replacement methods, minimum retroreflectivity values, sign service life, and inventory systems. A total of 34 states responded to the survey (a response rate of 67 percent). Appendix C presents the raw results of the survey.

Reasons for Replacing Signs (State Survey Question 1)

The initial question of the survey asked the respondents to identify *"the approximate percentage of signs replaced for the following reasons?"* The possible responses and percentage for each response are provided in Table III-2. In responding to the question, some states based the percentage on the total number of signs replaced, while other states based the percentage on the total number of all signs in their system. The percentages in the table reflect those states that gave their responses as the percentage of the total number of signs replaced. The listed reasons are as follows: inadequate retroreflectivity, vandalism (stolen), damage (bends, dents, holes, delamination), knockdown (traffic accidents, weather, etc.), roadway maintenance activities (mowing, snow plowing, etc.), change in standard (size, legend, placement), and other (please specify).

Table III-2. Responses to State Survey Question 1

What is the approximate percentage of signs that are replaced for the following reasons?	
Response	**Percent**
Inadequate retroreflectivity	36.1%
Damage	23.6%
Vandalism	27.3%
Roadway maintenance activities	8.3%
Change in standard	6.1%
Other (please specify)	6.9%

Note: Response percentages are derived from those states the sum of replacement reasons equaled 100 percent.

This question was asked to find out the magnitude of signs replaced due to each of the listed reasons. The effectiveness of a sign replacement strategy based on retroreflectivity depends on how many of the signs are being replaced due to inadequate retroreflectivity. If very few signs last their full life based on retroreflectivity because of vandalism, knockdown, etc., the effectiveness of the sign replacement strategy is greatly reduced.

By looking at the data in Table III-2, one will see that 36.1 percent of the signs lasted their full service life and were replaced due to inadequate retroreflectivity. The other 61.4 percent of the signs were replaced for other reasons not related to retroreflective service life.

Replacement Sign Identification Procedure (State Survey Question 2)

The second question of the survey asked "*What methods does your agency currently use to identify signs that need replacing due to a lack of retroreflectivity?*" Respondents were able to check multiple responses including day and night inspection using each of the following procedures: visual inspection using the "eyeball" method, retroreflectivity predicted based on expected life, retroreflectivity measured using test patches, and retroreflectivity measured using an instrument. These results may be found in Table III-3.

Table III-3. Responses to State Survey Question 2

What types of formal procedures do you currently use to identify signs that need replacing due to retroreflectivity?

Identification Procedure	**Frequency (Percent)**		
	Daytime	**Nighttime**	**N/A**
Visual inspection using "eyeball" method	25 (64.1%)	23 (79.3%)	0 (0.0%)
Retroreflectivity predicted based on expected life	8 (20.5%)	6 (20.7%)	8 (33.3%)
Retroreflectivity measured using test patches	0 (0.0%)	0 (0.0%)	9 (37.5%)
Retroreflectivity measured using an instrument	6 (15.4%)	0 (0.0%)	7 (29.2%)
Totals	39 (100%)	29 (100%)	24 (100%)

By reviewing the comments of the survey participants, it appears that most states do not have any formal sign inspection program, and the individual districts are given the authority to inspect signs in the best manner that they see fit. Most states use the eyeball method, but as Alabama claims "*the eyeball method culls out only the worst of the bad signs.*" Some states are using more scientific methods of retroreflectivity measurement. Idaho, Iowa, and Oregon measure retroreflectivity with the Model 920L retroreflectometer by Advanced Retro Technology, Inc., while Utah uses the GAMA Scientific instrument. As can be seen in Table III-3 above, some states do replace signs based on expected life, and some states are moving in the direction of management information systems. Georgia, for example, stated that in two years they will have their management system in place to replace signs based on expected life.

Impact of Minimum Retroreflectivity Values (State Survey Question 3)

The third question of the survey asked "*What is the expected impact of the proposed minimum retroreflectivity values on signing operations in your agency?*" With new values and regulations, there are many costs that must be paid in order to gain the benefit of the new guidelines. In this case, the state transportation departments will be responsible for many new costs, including those for retroreflectivity measurement devices and the labor they require, the replacement signs, in some cases an inventory system, and possibly some tort liability claims. The vast majority of the survey set, 78.3 percent, believe that the new regulation will have a significant or very significant impact on signing practices, while the remaining 21.6 percent believe that the new guidelines will have a negligible effect. These results may be found in Table III-4.

Table III-4. Responses to State Survey Question 3

What is the expected impact of the proposed minimum retroreflectivity values on signing operations in your agency?	
Response	**Frequency (Percent)**
Very Significant	16 (43.2%)
Significant	13 (35.1%)
Little or no impact	8 (21.6%)

While respondents from many states remarked that the impact of the new values would depend on the level of retroreflectivity mandated, others believed that it will have a significant effect regardless of the level of retroreflectivity. This is because of the high cost of the labor and equipment to keep up with the level of the retroreflectivity on each sign and ensure that all signs are above minimum values. As Ohio's representative stated, "*The implementation of these minimum values will require a much closer and more precise monitoring of sign retroreflectivity to avoid potential liability.*" Utah's representative stated that they would probably need to replace approximately 20-30 percent of the present signs in the state in order to keep them above the minimum values. Other states such as Arizona and Iowa have done recent evaluations of the retroreflectivity of their signs and believe that a very low percentage of the signs would need to be replaced. Still other states such as Kansas did not believe it would effect them very significantly because they are in a ten-year campaign to upgrade all signs on the state highway system to that of high intensity sheeting. As expected, there are some states that strongly oppose the new values unless federal funding is provided

Implementation Costs (State Survey Question 4)

The fourth question asked if the respondent's agency has "*developed an estimate of the cost to implement the proposed minimum sign retroreflectivity values?*" If the agency has estimated the cost, it was asked to report it. Of the 32 respondents to this question, only five (15.6 percent) have estimates of the cost to implement the new retroreflectivity values. The other 27 (84.4 percent) have not estimated these costs. The estimated costs for the five states that provided estimates ranged from $50,000 to $50 million. Ohio broke its estimate down into the costs for inspection and the cost for replacing subgrade signs. Their total estimate was $11.1 million of which $8.7 million is attributed to inspection costs, and the remaining $2.4 million is attributed to subgrade sign replacement. Table III-5 shows the results of the states that had an implementation cost estimate.

Table III-5. Responses to State Survey Question 4

What is your state's estimate of the cost to implement the proposed minimum sign retroreflectivity values?	
State	**Estimate**
Georgia	$1,300,000
Iowa	$50,000
Kansas	$50,000,000
Ohio	$11,100,000
West Virginia	$5,000,000

Sign Replacement Method (State Survey Question 5)

The fifth question of the survey asked the respondents to identify "*What method will your state use to ensure that the minimum retroreflectivity values are met?*" The motivation behind asking this question is straightforward. The surveyor asked this question in order to find out what methods will most likely be used by the other states. The multiple choices for this method include the inventory/management system, the inspection and replacement method, the periodic mass replacement method, other, and not sure. All of these methods are currently under evaluation for use by the Texas Department of Transportation. Over a third of the respondents responded that they would use an inventory/management system. All of the results can be found in Table III-6.

Table III-6. Responses to State Survey Question 5

What method will your state use to ensure that the minimum retroreflectivity values are met?	
Responses	**Frequency (Percent)**
Inventory/management system	15 (34.1%)
Inspection and replacement of inadequate signs	13 (29.5%)
Periodic mass replacement	5 (11.4%)
Other	2 (4.5%)
Not sure	9 (20.5%)

While there are many different options on how to keep up the signs to minimum levels of retroreflectivity, the most popular method seems to be the inventory/management system. Of the twelve comments made to this question, eight stated that they were planning on using this type of system. Three of the other four will use a retroreflectometer to keep up with the retroreflectivity, while one is still doing research.

Tort Claim Lawsuits (State Survey Question 6)

Question 6 asked if the respondent's agency "*expects an increase in tort claim lawsuits as a result of the minimum retroreflectivity values?*" In a situation when a new regulation is passed, many tort liability claims will be made claiming that the cause of an accident was due to the fact that the equipment, sign sheeting in this case, was below the new minimum value. This question had a yes/no answer format with a comment blank for yes answers. Almost two-thirds (65.5 percent) of the survey set answered that their agency will expect an increase in tort claim lawsuits if these new values are passed. The other 34.5 percent responded that they do not expect an increase in lawsuits.

Respondents from most of the states believe that there will be an increase in the number of tort liability claims due to the new guidelines. The Georgia survey participant stated, "*The possibility (of tort claim lawsuits) will definitely increase since it may take one to two years to completely upgrade all of the signs statewide.*" Many respondents claim that whether the retroreflectivity contributed to an accident or not, the lawyers will be aware of the minimum values and use them against the state. Missouri reported that its tort claims have increased since the loss of sovereign immunity, and the expectation is they will escalate out of reason.

Service Life Evaluations (State Survey Question 7)

Question seven asked the survey participants if their agency has "*conducted any evaluations of the service life of retroreflective sheeting?*" This question had a yes/no answer format and asked for more information on the evaluations if any were available. With some of the sign replacement strategies, it is necessary to have an accurate value for the expected service life of the retroreflective sheeting. For example, with the inventory/management system, signs are replaced based on an expected service life. If the calculated service life is inaccurate, one of two negative consequences can and will occur. First of all, if the calculated service life is too short, good signs will be replaced. Secondly, if the calculated service life is too long, signs will be used for a period of time with inadequate retroreflectivity. Of the 34 respondents to this question, 12 (35.3 percent) of them have conducted evaluations of the service life of retroreflective sheeting. The other 22 (64.7 percent) have not conducted evaluations.

Retroreflective Measurement Training (State Survey Question 8)

The eighth question of the survey asked the respondents if their agency will "*conduct formal training in retroreflectivity measurement and sign replacement activities in order to implement the minimum retroreflectivity values? If you do, who will be the target audience for the training?*" This question had a yes/no answer format and if the respondent answered yes, they could choose among different positions of DOT employees. The survey respondent could choose multiple positions from the list below. The results of this question may be seen in Table III-7.

- Administrators,
- Engineers (headquarters level),
- Engineers (district level),
- Field personnel, and
- Maintenance supervisors.

Table III-7. Responses to State Survey Question 8

8A. Will your agency conduct formal training in retroreflective measurement and sign replacement activities in order to implement the minimum retroreflectivity values?	
Response	**Frequency (Percent)**
Yes	24 (82.8%)
No	5 (17.2%)
8B. If you do, who will be the target audience for the training?	
Target Audience	**Frequency (Percent)**
Administrators	3 (5.4%)
Engineers (headquarters level)	20 (35.7%)
Engineer (district level)	4 (7.1%)
Field personnel	17 (30.4%)
Maintenance supervisors	12 (21.4%)

There were eight respondents who added comments on this question. Of these, six said that they would train sign shop personnel and maintenance personnel. The other two commented on some other training aspect. Alabama's respondent commented that considerable training would be necessary for all components of the department, while Georgia's respondent stated that the state would add training to the Highway Safety Management System.

Sign Inventory System (State Survey Question 9)

Question nine asked if the survey respondent's agency maintains "*a sign inventory or management system, and if so, what form is it in?*" This question had a yes/no answer format with additional choices to select if they answered yes. If respondents answered yes, they could check whether their system is a paper or index card-based system, or if it is computer-based. If the system is computer-based, they could check whether it is on a mainframe computer or a microcomputer. Of the 33 states that responded to this question, 23 (69.7 percent) of them have sign inventory systems, while the remaining 10 (30.3 percent) do not. The unabridged results are displayed in Table III-8.

Table III-8. Responses to State Survey Question 9

Does your agency maintain a sign inventory or management system?		*If you do, is your system paper/index card based or computer-based?*		*Is your computer system maintained on a mainframe or a microcomputer?*	
Response	**Frequency (Percent)**	**Response**	**Frequency (Percent)**	**Response**	**Frequency (Percent)**
Yes	23 (69.7%)	Paper or index card based	4 (21.1%)	---	
		Computer-based	15 (78.9%)	Mainframe	4 (30.8%)
				Microcomputer	9 (69.2%)
No	10 (30.3%)	---			

Computer Inventory/Management System Development (State Survey Question 10)

Question ten of the survey asked the respondents who have a computer inventory system "*how was it developed or acquired?*" There were nineteen responses to this question. Of these responses, fourteen were developed by state personnel, two were developed under contract for the state, and the remaining three were "off-the-shelf" software. Table III-9 indicates the results for this question.

Table III-9. Responses to State Survey Question 10

If the inventory/management system is computerized, how was it developed or acquired?	
Response	**Frequency (Percent)**
Developed by state personnel	14 (70.0%)
Developed under contract for the state	2 (10.0%)
"Off-the-shelf" software	3 (15.0%)
"Off-the-shelf" software customized for the state	1 (5.0%)
Other	0 (0%)

Sign Inventory Data (State Survey Question 11)

The eleventh question asked the respondents to indicate "*what type data is recorded in your sign inventory?*" This question was asked to find what types of information the different states' databases contain. To use a computer-based inventory system to predict service life, all data factoring into the retroreflectivity of the signs would need to be recorded. Data such as sign orientation, color, substrate material, and sheeting material would need to be recorded for each sign and input into the database. The information that is presently kept on the computer system consists mainly of sign numbers, locations, and orientation. Multiple responses were allowed on this question. These results can be seen in Table III-10.

Table III-10. Responses to State Survey Question 11

What type data is recorded in your sign inventory?		
Rank Order	**Data Type**	**Frequency (Percent)**
1	Location	20 (11.2%)
2	Orientation	16 (9.0%)
3	MUTCD sign number	15 (8.4%)
4	Installation date	15 (8.4%)
5	Maintenance dates	14 (7.9%)
6	Unique sign number	13 (7.3%)
7	Type of sheeting	12 (6.7%)
8	Predicted retroreflectivity	12 (6.7%)
9	Type of maintenance	11 (6.2%)
10	Substrate material	11 (6.2%)
11	Date of last inspection	8 (4.5%)
12	Post condition	8 (4.5%)
13	Mounting height	7 (3.9%)
14	Date of manufacture	4 (2.2%)
15	Measured retroreflectivity	4 (2.2%)
16	Other	3 (1.7%)
17	Digitized image of sign	3 (1.7%)
18	Sign condition	2 (1.1%)

Sign Inventory System Information (State Survey Question 12)

The last question of the survey asked the respondents from states with an inventory system to provide the following information:

- Name of the system,
- Approximate cost of the system,
- Manpower requirements,
- Manufacturer's name, address, and telephone number, and
- Name and number of contact person.

While the response to this question was not very great, eight states gave information on the systems that they are using. Different systems that were listed are as follows: Traffic Sign Inventory System, a Traffic Control Device Management System, FHWA Sign Management System Version 3.4, and the Videodisc Sign Inventory System, while Georgia has developed its own system. The cost of these systems varied from free (FHWA SMS) to $463,000 for the Videodisc Sign Inventory System. As great as the system cost varied, the manpower requirement varied similarly.

SURVEY OF TxDOT DISTRICT SIGNING ACTIVITIES

One of the preliminary efforts in the project was to conduct a survey of the current sign replacement practices used by TxDOT and to analyze the sign replacement strategies under review by TTI with TxDOT personnel. This survey, which may be seen in Appendix B, contains 6 parts and 16 questions. These parts cover many different aspects affecting sign replacement including general sign information, sign inspection and replacement, service life of sign sheeting, sign inventory systems, cost information, and a description of alternative replacement strategies.

A total of 126 surveys were returned to TTI. Of those responses that indicated the place where the survey was completed, 26 came from district offices, 24 came from area offices, and 71 came from maintenance sections. Table III-11 summarizes the origins of the surveys with respect to districts and positions. Appendix D summarizes the raw results to the survey.

Table III-11. Summary of Origins of TxDOT Surveys Returned to TTI

Response Frequencies by District						Response Frequencies by Position			
Abilene	3	Corpus Christi	1	Odessa	4	Director Operations	8	Area Engr	18
Amarillo	9	Dallas	8	Paris	6	Dst Traffic Engr	5	Area Maint Engr	1
Atlanta	4	El Paso	5	Pharr	6	Dst Maint Engr	2	Rdway Maint Supvr	66
Austin	3	Fort Worth	8	San Angelo	2	Asst Dir Maint	1	Constr Inspect	1
Beaumont	3	Houston	6	San Antonio	4	Dst Support Engr	1	Area Sign Supvr	4
Brownwood	3	Laredo	2	Tyler	3	Dst Sign Supervisor	3	Sign Crew	7
Bryan	0	Lubbock	5	Waco	7				
Childress	5	Lufkin	7	Wichita Falls	11				
				Yoakum	0				

Part I - General Sign Information

TxDOT currently maintains a Maintenance Management Information System (MMIS), but it is mainly used for warehouse stock inventory purposes. For this reason, very little data are maintained on the signs that are being used in the field. The primary purpose of Part I of this survey was to obtain some concrete data on sign inventory and personnel. This proved to be a very difficult task because the majority of the respondents have very little documented data to report; therefore, most of the survey data are merely estimates.

Total Number of Signs Per District (TxDOT Survey Question 1)

The first question of the survey asked "*What is the approximate number of signs in your district?*" The responses to this question varied greatly from 1,000 to 1,000,000. This question was an attempt to find an average number of signs per district and a close number of signs in the state. The responses were provided by personnel from district offices, sign shops, area offices, and maintenance sections. Only 55 percent of the survey respondents answered this question. Of this 55 percent, 78 percent of the answers were estimates that are not based on documentation. The other 22 percent, or only 16 of the 126 survey respondents, gave estimates that were based on data or documentation. The estimates for those that stated their estimates were based on documentation are described in Table III-12. Because the responses were from a wide range of jurisdictions varying from a portion of a district to multiple districts, it is difficult to determine an average number of signs per district. It is even harder to determine a close estimate of the number of signs in the state.

Table III-12. Summary of Documented Sign Estimates (TxDOT Survey Question 1)

Jurisdiction	Number of Responses	Range of Estimates	Average Number of Signs in Jurisdiction	Average Estimate Extended to State
Maintenance Section	14	1,861 to 60,000	11,448	11,448×283 = 3,239,784
Area Office	1	N/A	15,000	15,000×124 = 1,860,000
District	1	N/A	225,000	225,000×25 = 5,625,000

Notes: N/A - information not available.
Table does not include responses that were identified as estimates.

Sign Crews and Sign Crew Personnel (TxDOT Survey Question 2)

The second question of the survey asked "*How many sign crews and individuals are there in your district or maintenance section?*" It was found that there are an average of 3.7 sign crews per district and 6.0 sign crew personnel per district. With this data, an average number of personnel per crew was found to be 1.6 persons. Many of the respondents commented that temporary sign crew personnel and some sign shop personnel are used when the work load permits.

District Sign Shop Personnel (TxDOT Survey Question 3)

The third question asked TxDOT personnel "*How many individuals are assigned to the district sign shop?*" The average number of personnel working at the sign shop of all responses was 4.3, while the responses ranged from 1 to 8. Multiple comments stated that the sign shops receive extra help during inclement weather from the field crew and during periods of high workload from temporary help.

Part II - Sign Inspection and Replacement

TxDOT has never adopted standard sign inspection or replacement procedures beyond general instructions to conduct an annual nighttime visual inspection for sign condition and retroreflectivity performance. For this reason, the procedures used are different from district to district and sometimes change within the district. The primary purpose of Part II was to find out what different methods are being used to inspect and replace signs across the state, and what major concerns need to be considered when analyzing different inspection and replacement methods.

Replacement Sign Identification Procedure (TxDOT Survey Question 4)

The fourth question of the survey asked "*What types of formal procedures do you currently use to identify signs that need replacing due to a lack of retroreflectivity?*" Respondents were able to check multiple responses including day and night inspection using each of the following procedures: visual inspection using "eyeball" method, retroreflectivity predicted based on expected life, retroreflectivity measured using test patches, and retroreflectivity measured using an instrument. These results may be found in Table III-13.

Table III-13. Responses to TxDOT Survey Question 4

What types of formal procedures do you currently use to identify signs that need replacing due to a lack of retroreflectivity?			
Identification Procedure	**Frequency (Percent)**		
	Daytime	**Nighttime**	**N/A**
Visual inspection using "eyeball" method	94 (81.0%)	112 (76.2%)	0 (0.0%)
Retroreflectivity predicted based on expected life	14 (12.1%)	11 (7.5%)	17 (32.1%)
Retroreflectivity measured using test patches	8 (6.9%)	22 (15.0%)	13 (24.5%)
Retroreflectivity measured using an instrument	0 (0.0%)	2 (1.3%)	23 (43.4%)
Totals	116 (100%)	147 (100%)	54 (100%)

Sign Replacement Reasons (TxDOT Survey Question 5)

The fifth question on the survey asked the respondents to identify "*the approximate percentage of signs replaced for the following reasons?*" The listed reasons are as follows: inadequate retroreflectivity, vandalism (stolen), damage (bends, dents, holes, delamination), knockdown (traffic accidents, weather, etc.), roadway maintenance activities (mowing, snow plowing, etc.), change in standard (size, legend, placement), and other (please specify).

This question was asked to find out the magnitude of signs replaced due to each of the listed reasons. The effectiveness of a sign replacement strategy based on retroreflectivity depends on how many of the signs are being replaced due to retroreflectivity. If very few signs last their full life based on retroreflectivity because of vandalism, knockdown, etc., the effectiveness of the sign replacement strategy is reduced greatly.

By looking at the data in Table III-14, one will see that an average of 23.4 percent of the signs lasted their full service life and were replaced due to inadequate retroreflectivity. The other 76.4 percent of the signs were replaced for other reasons not related to retroreflective service life. The 50th percentile, or median, replacement rate for inadequate retroreflectivity was 34.2 percent. The most common response, or mode, was 10 percent for inadequate retroreflectivity. It is worth noting that the responses do not add up to 100 percent because the percentages were averaged for each of the 112 responses to this question.

Table III-14. Responses to TxDOT Survey Question 5

What is the approximate percentage of signs that are replaced for the following reasons?			
Reason	**Average**	**Median**	**Mode**
Inadequate retroreflectivity	23.4%	20%	10%
Vandalism (stolen)	26.7%	20%	20%
Damage (bends, dents, holes, delamination)	14.2%	10%	10%
Knockdown (traffic accidents, weather, etc)	19.6%	11%	10%
Roadway maintenance activities (mowing, snowplowing, etc)	6.4%	5%	5%
Change in standard (size, legend, placement)	5.1%	4.5%	5%
Other (please specify)	1.7%	0%	0%
Totals	97.1%	148.1%	60%

At this point in time, TxDOT does not record data to help verify the reasons that signs are replaced. Because of this, 97 percent of the responses were estimates. In an attempt to gain concrete data, TTI asked TxDOT sign crew personnel to track sign replacements. Every time a sign was replaced, the roadway type, sign name, sign type, color, sign orientation, message type, substrate material, sheeting type, dimensions, installation and manufacture dates, and replacement reason were recorded on a data form and then sent to TTI to be analyzed. The results of the data form analysis are described later in this chapter.

Difficult Aspects of Sign Maintenance and Replacement (TxDOT Survey Question 6)

The sixth question of the survey asked respondents to identify "*the most difficult aspects of sign maintenance and replacement.*" There were 116 responses to this question, and multiple responses were allowed. This question was hard to analyze due to its open comment format. Many of the responses dealt with sign posts, footings, the weight and size of signs, problems with certain types of materials such as breakaway posts and aluminum signs, traffic volumes and keeping up with the changes in standards and regulations. While all of these issues are important to signing personnel and TxDOT, they are outside the scope of this project and as such were not included in the analysis. The comments related to the replacement of signs were analyzed, and their frequency is noted in parentheses below.

- Lack of personnel (25 times),
- Vandalism (18 times),
- Shortage of material (12 times),
- Volume of signs (10 times), and
- Insufficient funding (9 times).

Material Costs (TxDOT Survey Question 7)

The seventh question asked the respondents to "*indicate your current average material costs per square foot for sign replacement.*" They were given space to indicate how expensive each type of material is, and the percentage that material is used as compared to other commonly used materials. The results are presented in Table III-15.

Table III-15. Responses to TxDOT Survey Question 7

Please indicate your current average material costs per square foot for sign replacement.			
Material		**Cost (per sq. ft.)**	**Percent of Total Signing**
Sheeting	Engineering grade	$5.41	31.1%
	High intensity	$9.88	60.8%
Sign Blank	Plywood	$8.52	40.4%
	Steel	$9.12	16.4%
	Aluminum	$7.12	38.6%

These costs are skewed compared to the actual prices paid. This is because of the way that the TxDOT districts are billed by their central warehouse. The central warehouse bills the different districts based on the average cost of material and the production rate of the district requesting the signs. Therefore, when the districts are billed, they are billed based on the number of signs requested and the average cost per square foot. Because of this, it is very difficult for the respondents to make an educated guess at the costs for different types of substrates and sheeting.

Part III - Service Life of Sign Sheeting

When adopting a sign replacement method, one important consideration is the service life of the sheeting based on retroreflectivity. This service life represents the longest length of time that a sign will be able to be used in the field while maintaining a certain level of retroreflectivity. Many times, the sign will not last the full service life because of some sort of vandalism or a change in standards, but a sign rarely lasts longer than the service life since a level of retroreflectivity below the minimum level warrants replacement.

Sign Sheeting Service Life (TxDOT Survey Question 8)

The eighth question of the survey asked the respondents "*to indicate the average service lives you have experienced for various sign materials.*" The sign materials listed include white, yellow, red, and green colors, and engineering grade and high intensity sheeting. The results are presented in Table III-16.

Table III-16. Responses to TxDOT Survey Question 8

Please indicate the average service lives you have experienced for various sign materials.					
Sheeting Name	**TxDOT Type**	**Range of Service Lives (years)**			
		White	**Yellow**	**Red**	**Green**
Engineering grade	A	6.5	6.4	6.0	6.8
High intensity	C	6.8	6.2	5.7	6.5

Service Life Factors (TxDOT Survey Question 9)

The ninth question of the survey asked the respondents to rank the factors that have the greatest impact on retroreflective sheeting. The factors that were ranked were the manufacturer, the color, the location (urban, rural, wooded, open, etc.), direction of exposure (north, south, east, west), geographic region of Texas, and an other category was added for the respondents to write in. The overall rankings are presented in Table III-17.

Table III-17. Responses to TxDOT Survey Question 9

What factors have you found to have the greatest impact on the service life of retroreflective sheeting?	
Ranking	**Factor**
1	Direction of exposure
2	Location
3	Color
4	Geographic region of Texas
5	Manufacturer
6	Other

Part IV - Sign Inventory Systems

The fourth part of the survey was intended to help the researchers identify existing sign inventories and the information recorded in the inventory. In analyzing the results, it is apparent that there was some confusion over these questions. The researchers believe that many of the survey respondents consider the computer system used to order signs to be a sign inventory system. This fact should be considered in interpreting the results for the questions in this part of the survey.

Sign Inventory (TxDOT Survey Question 10)

The tenth question asked the respondents to indicate "*whether you maintain a sign inventory or database in the district office, area office, or any maintenance section, and if you do, the form of the inventory/database.*" The results to this question can be found in Table III-18.

Table III-18. Responses to TxDOT Survey Question 10

Please indicate whether you maintain a sign inventory or database in the district office, area office, or any maintenance section, and if you do, the form of the inventory/database.

Response	Frequency (percent)
No inventory maintained	42 (38.5%)
Paper or index card based	16 (14.7%)
Microcomputer-based	1 (0.9%)
Mainframe computer-based	47 (43.1%)
Other	3 (2.8%)

While over 60 percent of the respondents claimed to have some type of inventory system, all but a select few of them only keep inventory of signs that are in stock in the sign shop or warehouse; not of signs on the road. Three of the surveyed respondents hope to be starting an inventory soon, but were unsure of how to approach it. One comment stated that the frequency of repair and replacement prevents the use of an extensive road sign inventory system.

Sign Inventory Location (TxDOT Survey Question 11)

The eleventh question asked "*Where is the inventory/database described in the previous question maintained?*" This question allowed multiple responses. The results can be found in Table III-19.

Table III-19. Responses to TxDOT Survey Question 11

Where is the inventory/database described in the previous question maintained?

Sign Inventory Location	Frequency (percent)
District Office	28 (30.1%)
Area Office	3 (3.2%)
Maintenance Section	62 (66.7%)

Sign Inventory Update Frequency (TxDOT Survey Question 12)

The twelfth question asked "*How often is the inventory/database updated?*" The results can be found in Table III-20.

Table III-20. Responses to TxDOT Survey Question 12

How often is the inventory/database updated/maintained?	
Update Frequency	**Frequency (percent)**
Daily	24 (35.3%)
Weekly	9 (13.2%)
Monthly	14 (20.6%)
Quarterly	6 (8.8%)
Twice annually	4 (5.9%)
Annually	2 (2.9%)
Other (explain)	9 (13.2%)

Sign Inventory Data (TxDOT Survey Question 13)

The thirteenth question asked the respondents to "*indicate the data that is recorded in the inventory.*" This question was asked to find what types of information the databases contain. To use a computer inventory system to predict retroreflectivity, all data factoring into the service life of the signs would need to be recorded. Data such as sign orientation, color, substrate material, sheeting material, etc., would need to be recorded for each sign and input into the database. The information that is presently kept on the computer system consists mainly of sign numbers, locations, and post types. This can be seen in Table III-21.

Table III-21. Responses to TxDOT Survey Question 13

Please indicate the data that is recorded in the inventory.		
Rank Order	**Data Type**	**Frequency (percent)**
1	Unique sign number	38 (20.3%)
2	MUTCD sign number	26 (13.9%)
3	Location	23 (12.3%)
4	Type of post	19 (10.2%)
5	Installation date	14 (7.5%)
6	Type of sheeting	12 (6.4%)
7	Sign condition	10 (5.3%)
8	Other	10 (5.3%)
9	Substrate material	6 (3.2%)
10	Maintenance dates	6 (3.2%)
11	Mounting height	5 (2.7%)
12	Post condition	5 (2.7%)
13	Date of manufacture	4 (2.1%)
14	Type of maintenance	3 (1.6%)
15	Date of last inspection	3 (1.6%)
16	Measured retroreflectivity	2 (1.1%)
17	Predicted retroreflectivity	1 (0.5%)
18	Orientation	0 (0.0%)

Part V - Cost Information

When adopting a new sign inspection and replacement strategy, many people will be needed to implement it. Different persons of different positions will be involved in varying degrees depending on the strategy adopted. Due to this, the cost of implementing one strategy as opposed to another can vary greatly depending on the pay scale of the employees involved in each. This section of the survey attempted to obtain average pay rates that could be used when analyzing the labor costs of each strategy.

Personnel Salary & Wage (TxDOT Survey Question 14)

The fourteenth question asked the respondents to "*estimate the typical hourly wage or monthly salary of each of the following positions involved in sign replacement activities.*" While two individuals of the same position may have different pay rates, it is assumed that the higher wages will compensate for the lower wages and the differences will be negligible on the larger scale. The results appear in Table III-22.

Table III-22. Responses to TxDOT Survey Question 14

Please estimate the typical hourly wage or monthly salary of each of the following positions involved in sign replacement activities.

Employee Position	Hourly Pay Rate
Sign Crew	$10.75/hr.
Maintenance Crew	$9.47/hr.
Area Office Technician Level	$12.06/hr.
Area Office Engineer Level	$20.23/hr.
Area Office Administration	N/A
District Sign Shop Personnel	$11.23/hr.
District Technician Level	$15.05/hr.
District Engineering Level	$21.67/hr.

Note: N/A - information not available.

While the wages that pertain to hourly employees such as the sign crew, maintenance crew, etc. were reported in a dollars per hour format, most of the administration and engineering positions data were reported in a salary format. For the purpose of consistency, and ease of comparison, all salary bases responses were converted to an hourly wage format by dividing by a factor of 1920 work hours/year.

Part VI - Description of Alternative Replacement Strategies

There have been three basic methods identified for implementing the minimum retroreflectivity values. These include a sign management/inventory system method, a total replacement method, and a sign inspection method as described below.

- The sign management/inventory system method involves using a database that is set up to track key sign characteristics such as size, location, color, highway speed, exposure, etc. This information is used to predict when a sign should be replaced.
- The total replacement method involves replacing all of the signs on a predetermined section of highway at regular, predefined time intervals. In this method, all signs are replaced regardless of whether they meet the minimum value or how long they have been in the field.
- The sign inspection method involves testing the retroreflectivity on the signs in the field. Any sign not meeting the minimum retroreflectivity is scheduled for replacement. These inspections can be done on all signs or on a sample of signs that represent a larger group. If the sample does not meet the minimum value all signs in the group are replaced.

Alternative Replacement Strategies (TxDOT Survey Question 15)

The fifteenth question asked the respondents to comment on the three proposed replacement methods. The responses for each method are described below.

- **Sign Management/Inventory System Method** - Of the 95 responses to this question, only 21 were positive/supportive. The main concern that was voiced is the high cost and personnel needed to set up the system.
- **Total Replacement Method** - Of the 101 responses to this question, only 12 were positive/supportive.
- **Sign Inspection Method** - Of the 102 responses to this question, 46 were positive/supportive. It was expected that this method would have the highest amount of positive responses because it is similar to the current sign replacement method used by TxDOT.

Additional Strategies (TxDOT Survey Question 16)

The sixteenth question asked the TxDOT personnel to "*identify any other strategies that you think could be used to implement the minimum retroreflectivity values.*" While some comments to this question gave additional insight to the previously proposed methods, no new strategies were identified.

DATA FORM ON TxDOT SIGN REPLACEMENTS

The data form shown in Appendix B was primarily developed to obtain information on the service life of in-service TxDOT traffic signs. Sign replacement data forms were sent to a total of sixteen TxDOT district offices across the state. Signing personnel were asked to complete a data form for each sign they replaced. Note that the data presented here were collected under TxDOT's current sign maintenance program. Thirty-three hundred data forms were returned from the TxDOT districts. According to the returned forms, the data collection occurred between March and June of 1996. Statistical Analysis Systems (SAS) software was used to evaluate the returned data forms. Appendix E contains the raw results for the data form.

This summary is organized into four sections. The statistical results of the data collected from the complete sample (3,300 responses) are presented first. A subset of this data, for which sign age could be determined, is analyzed next with a focus on those signs replaced due to inadequate retroreflectivity. In the third section, all the signs from the original data set of 3,300 which were replaced due to inadequate retroreflectivity are used to verify the results in the previous section. Finally, conclusions about the current sign replacement activities are presented.

Complete Data Set of 3,300 Forms

This section of the summary provides an overview of all the responses to the sign replacement data request. Results of the statistical analysis, deficiencies in the data form, and conclusions regarding the statistical analysis are presented.

Description of Highway at Sign Location

The TxDOT sign crews were asked to describe the highway where the sign was being replaced. Personnel were asked to show if the location was a rural or urban setting, two lane or multilane facility, and a divided or undivided cross section. Respondents were asked to mark all of the choices that applied. The results are presented in Table III-23.

Table III-23. Description of Highway at Sign Location

Location	Frequency	Percent
Rural	1818	74.8%
Urban	612	25.2%
Two Lane	1698	74.0%
Multi-Lane	598	26.0%
Divided	270	84.6%
Undivided	49	15.4%

From the data presented above, TxDOT's sign replacement activities apparently take place most often in rural areas. The results show that 74 percent of the locations involved two lane roads and nearly 85 percent were classified as divided sections. These results suggest that some confusion existed regarding the descriptions for the number of traffic lanes. The two-lane roadway description may have been interpreted as roadways with two lanes in each direction. This description should have applied to the entire roadway such that a road with one traffic lane in each direction would be classified as a two-lane roadway. Misinterpretation of the lane descriptor may account for the conflicting results.

Name of Sign or Label / Code

Next the data form requested either the name or MUTCD code for the sign being replaced. This information was provided on 3,134 of the 3,300 returned forms. The vagueness of this question resulted in the information being provided in too many forms to analyze in detail. However, a review of the responses suggested that many replacement activities involved speed limit and route marker signs.

Type of Sign

Signing personnel were asked for the type of sign being replaced. This information was sought in an attempt to learn the percentage of signs currently being replaced that fall within each category covered by the FHWA's proposed minimum retroreflectivity values. As a result, only the data related to those sign types covered by the minimum proposed values are presented here. According to the data forms, the types of signs being replaced were represented as shown Table III-24.

Table III-24. Type of Sign Being Replaced

Sign Type	Frequency	Percent
Regulatory	850	26.1%
Warning	1058	32.5%
Guide	991	30.4%
Informational	360	11.0%

Warning signs (32.5 percent) and guide signs (30.4 percent) make up the two largest groups of signs, by type, currently being replaced. Regulatory signs, at 26.1 percent, and informational signs, at 11.0 percent, follow. The percentage of regulatory signs may be over represented due to TxDOT's efforts to replace all the traffic signs associated with the recent change in speed limit laws.

Background Color

TxDOT personnel were asked to record the color of the background sheeting. The information is presented in Table III-25. Only those background colors covered by the minimum retroreflectivity values were compiled for this analysis.

Table III-25. Background Color of Sign Being Replaced

Background Color[1]	Frequency	Percent
White	1328	44.0%
Red	629	20.8%
Yellow	779	25.8%
Green	284	9.4%

Note: [1]The current proposed minimum retroreflectivity values only apply to white, red, yellow, and green signs.

These data show that signs with a white background are being replaced most often. This category may have been inflated due to the conversion in posted speed limits from 55 mph to 70 mph. The second largest category, yellow signs at 25.8 percent, may have been influenced by the change in speed limits as well. Even with the change in the speed limit and its related impact on signing activities, the data seem to suggest those signs with white backgrounds are replaced most often.

Primary Sign Orientation

Information about the primary orientation of the signs was requested next. Black reported in 1992 that a sign's orientation may influence its service life (16). This question was included to find out if such an influence exists, and if so, its significance. The results presented in Table III-26 suggest that the service life of a sign is not influenced by its orientation.

Table III-26. Primary Orientation of Signs Being Replaced

Orientation	Frequency	Percent
North	792	26.5%
South	760	25.5%
East	702	23.5%
West	730	24.5%

Message Type

To provide background data on the signs being replaced (shown in Table III-27) the signing personnel were asked to show the type of message each sign contained. The data revealed that almost 72 percent of the signs replaced by TxDOT personnel during the survey period consisted of either word or number messages.

Table III-27. Message Type for Signs Replaced

Message Type	Frequency	Percent
Symbol	706	21.5%
Words or Numbers	2358	71.9%
Combination	214	6.5%

Type of Substrate Material

Signs crews were asked to identify the substrate material of each sign so the percentage of signs constructed of each material could be determined. The substrate material is the material on which the sign sheeting is mounted. The TxDOT currently uses plywood, aluminum, and steel substrates; however, the interviews with TxDOT district personnel indicated that the steel substrate is not being replaced as existing supplies are exhausted. Table III-28 documents the responses below.

Table III-28. Type of Substrate Material Used for Signs Replaced

Substrate Material	Frequency	Percent
Plywood	859	26.3%
Aluminum	2288	70.1%
Steel	117	3.6%

Sheeting Types

The type of sign sheeting material used on each sign was requested to learn what percentage of the replaced signs were fabricated with each type of sheeting. A response was provided on 976 of the returned forms. TxDOT uses two basic types of sheeting material: Type A sheeting, commonly called engineering grade, and Type C, high intensity sheeting. Different types of sheeting and their construction are discussed in Chapter II. The responses to this question are shown in Table III-29.

Table III-29. Type of Sheeting Material Used on Signs Replaced

Sheeting Material	Frequency	Percent
Type A: Engineering grade	859	88%
Type C: High intensity	117	12%

Sign Area

The signing personnel were also asked to provide the dimensions of each sign they replaced. This information was analyzed to find the average size of the signs being replaced. Based on the 3,260 responses to this question, the average area of a sign is approximately 7 square feet.

Original Installation and Manufacture Date

The next two questions dealt with the original installation date and the original date the sign being replaced was manufactured. According to the data recorded in response to this question, the earliest sign installation occurred in June of 1979, and the earliest date of manufacture was May of 1977. May 1996 was the most recent date given for both an original installation date and a manufacture date.

The dates of manufacture and installation should be recorded on a tag attached to the back of each traffic sign, however, of the 3,300 data forms returned, only 716 included a viable original installation date. Information regarding the date of manufacture was supplied on 1,869 of the returned surveys. Several possible explanations exist for the information not being provided. The information may not have been provided on the sign data tag, the information may have been illegible due to damage caused by exposure or vegetation, or the sign may have been stolen. However, as will be shown in the results from the next question, these explanations only account for a maximum of 1,604 signs reported. This leaves 980 forms without a viable original installation date. These forms were returned with the date the existing sign was being replaced recorded as the original installation date. The most likely explanation for this error is the apparent lack of clarity in the wording on the data forms. The lack of clarity in the data form was realized when forms from the first eleven districts began to arrive. To correct this problem, the data form was revised and distributed to five additional districts. Although the percentage of incorrect forms declined, the problem persisted.

Reason for Replacing

This final question dealt with the reason for replacing the signs. Five categories were available to choose from, including inadequate retroreflectivity, vandalism (stolen, bullet holes, graffiti, etc.), damage (bends, dents, delamination, etc.), knockdown (traffic accidents, weather, mowing, etc.), and other. A review of the returned forms revealed that a sixth category for new installations should have been included also. The responses to this question are shown in Table III-30.

Table III-30. Reason for Replacing Sign

Reason	Frequency	Percent
Inadequate Retroreflectivity	1062	32.9%
Vandalism	706	21.9%
Damage	222	6.9%
Knockdown	676	21.0%
Standards	319	9.9%
Other	240	7.4%

The results show that one-third of the sign replacement activities were needed due to a lack of retroreflectivity. Vandalism, damage, and knockdowns make up 50 percent of the sign replacements. The number of replacements due to changes in standards and the "other" category may have been increased because of the speed limit changes previously discussed.

Forms with Sign Age Data

This section describes a service life analysis for all the traffic signs reported with the required information with a focus on those signs replaced due to inadequate retroreflectivity. Fourteen of the 16 responding districts provided a combined total of 716 data forms with the original installation dates that were necessary to figure out each sign's service life. The remaining 2,584 data forms were not included in the service life analysis.

Service Life of All Traffic Signs

Based on the data form responses, the service life of each of the 716 signs was calculated. This service life value was determined by subtracting the year of the original installation from 1996. A statistical evaluation was conducted and the results are summarized in Table III-31.

Table III-31 shows that more than 50 percent of the signs were less than four years old when they were replaced, more than 75 percent were less than 8 years old, and more than 90 percent were less than 10 years old. The data presented in the table represent a total of 3,563 years of service life for a total of 716 signs. This results in an average service life of approximately 5 years.

Table III-31. Age of Traffic Signs Reported With an Original Installation Date

Sign Age (Years)	Frequency	Percent	Cumulative	
			Frequency	Percent
0	74	10.3%	74	10.3%
1	112	15.6%	186	26.0%
2	91	12.7%	277	38.7%
3	69	9.6%	346	48.3%
4	33	4.6%	379	52.9%
5	31	4.3%	410	57.3%
6	49	6.8%	459	64.1%
7	46	6.4%	505	70.5%
8	53	7.4%	558	77.9%
9	31	4.3%	589	82.3%
10	65	9.1%	654	91.3%
11	18	2.5%	672	93.9%
12	10	1.4%	682	95.3%
13	6	0.8%	688	96.1%
14	17	2.4%	705	98.5%
15	6	0.8%	711	99.3%
16	3	0.4%	714	99.7%
17	2	0.3%	716	100.0%

Service Life of Those Signs Replaced Due to Inadequate Retroreflectivity

One objective of the data form survey was to find the service life of those signs replaced due to concerns over retroreflectivity. The responses with an original installation date were filtered for replacement due to retroreflectivity. A sample of 204 traffic signs received from 11 TxDOT district offices met these criteria. The results of this evaluation are presented in Table III-32.

Table III-32 suggests that more than 50 percent of the signs were less than 9 years old when they were replaced, more than 75 percent were less than 10 years old, and more than 90 percent were less than 14 years old. The data presented in the table represent a total of 1,780 years of service life for a total of 204 signs. Based on this data, the average service life for those signs replaced due to inadequate retroreflectivity is approximately 9 years. The service lives of these signs are further analyzed in the following sections.

Table III-32. Sign Age of Traffic Signs Replaced Due to Retroreflectivity

Sign Age (Years)	Frequency	Percent	Cumulative	
			Frequency	Percent
0	2	1.0%	2	1.0%
1	3	1.5%	5	2.5%
2	0	0.0%	5	2.5%
3	8	3.9%	13	6.4%
4	8	3.9%	21	10.3%
5	9	4.4%	30	14.7%
6	19	9.3%	49	24.0%
7	17	8.3%	66	32.4%
8	30	14.7%	96	47.1%
9	15	7.4%	111	54.4%
10	49	24.0%	160	78.4%
11	10	4.9%	170	83.3%
12	6	2.9%	176	86.3%
13	5	2.5%	181	88.7%
14	16	7.8%	197	96.6%
15	6	2.9%	203	99.5%
16	0	0.0%	203	99.5%
17	1	0.5%	204	100.0%

Background Color

The influence of background color on replacement rates due to retroreflectivity was evaluated using the filters described earlier and the four background sign colors covered by the proposed minimum retroreflectivity values (white, red, yellow, and green background signs). The results of this analysis are presented in Table III-33.

Table III-33 shows nearly 58 percent of the signs being replaced due to retroreflectivity have white background sheeting. This corresponds to the findings presented elsewhere in this chapter. However, the same concern mentioned earlier related to the replacement activities associated with the change in speed limit laws applies here also. Because of these activities, the evaluation is inconclusive concerning the influence of background color on retroreflectivity levels.

Table III-33. Background Color of Signs Replaced Due to Retroreflectivity

Background Color	Frequency	Percent	Cumulative Frequency	Cumulative Percent
White	97	57.7%	97	57.7%
Red	19	11.3%	116	69.0%
Yellow	44	26.2%	160	95.2%
Green	8	4.8%	168	100.0%

The mean service life was calculated for the signs within each background color category in an attempt to clarify whether background color significantly influences the service life of traffic signs. Table III-34 documents the results of these calculations. The mean service lives shown in Table III-34 do not suggest a significant difference in the service life associated with the various background colors. However, the data do suggest those signs with yellow background sheeting have a longer service life.

Table III-34. Mean Service Life of Signs Based on Background Color

Background Color	Mean Service Life (Years)
White	8.18
Red	8.79
Yellow	9.34
Green	8.25

Primary Sign Orientation

This evaluation was done to find out if the service life of a sign is influenced by its orientation. The results of this analysis, presented in Tables III-35 and III-36, suggest that signs facing east are less likely to be replaced due to a lack of retroreflectivity. This means that an east facing sign may have a longer service life than a sign facing north, south, or west. The available information does not suggest that a sign's orientation significantly influences its service life.

Table III-35. Primary Orientation of Signs Replaced Due to Retroreflectivity

Orientation	Frequency	Percent	Cumulative Frequency	Cumulative Percent
North	57	29.8%	57	29.8%
South	56	29.3%	113	59.2%
East	26	13.6%	139	72.8%
West	52	27.2%	191	100.0%

Table III-36. Mean Service Life of Signs Based on Primary Orientation

Orientation	Mean Service Life (Years)
North	8.86
South	9.68
East	8.12
West	8.56

Type of Substrate Material

The same procedure was followed to evaluate the influence of the substrate material on the service life of signs as it relates to retroreflectivity. The responses are documented in Tables III-37 and III-38.

Table III-37. Type of Substrate Material Used for Signs Replaced Due to Retroreflectivity

Substrate Material	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Plywood	53	26.5%	53	26.5%
Aluminum	138	69.0%	191	95.5%
Steel	9	4.5%	200	100.0%

Table III-38. Mean Service Life Based on the Type of Substrate Material

Substrate Material	Mean Service Life (Years)
Plywood	9.43
Aluminum	8.29
Steel	8.56

According to Table III-37, a possible relationship exists between the service life of a sign and its substrate material. However, if this were the case, then signs with an aluminum substrate should have the shortest service life and a steel substrate should result in the longest service life. The results of the mean service lives shown in Table III-38 do not support this view. In fact, less than a 1-year difference in service life exists among the three material types.

Sheeting Type

The influence of sheeting material on service life was analyzed next. The results of this evaluation are shown in Tables III-39 and III-40.

Table III-39. Type of Sheeting Material Used on Signs Replaced Due to Retroreflectivity

Sheeting Material	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Type A: Engineering grade	157	87.2%	157	87.2
Type C: High intensity	23	12.8%	180	100.0

Table III-40. Mean Service Life of Signs Based on Type of Sheeting Material

Sheeting Material	Mean Service Life (Years)
Type A: Engineering grade	8.89
Type C: High intensity	6.09

These results suggest that signs with Type C sheeting have a shorter service life than signs with Type A sheeting. Type C sheeting, however, has only been used statewide for the past 6-7 years. The only conclusion that can be made from the Type C data is that its mean service life is at least 6 years.

Signs Replaced Due to Lack of Retroreflectivity

The following evaluation was conducted to learn if the sample of signs presented in Part II typified all the signs replaced for inadequate retroreflectivity. Table III-30 shows there were 1,062 data forms reporting inadequate retroreflectivity as the reason for replacement. A comparison between this data set (called Data Set A) and the 204 signs analyzed in Part II of this summary (called Data Set B) is shown in Table III-41. The factors evaluated include sheeting type, substrate material, orientation, and background color.

The data presented in Table III-41 show the correlation between the two data sets. This suggests that the smaller sign sample, for which service life could be evaluated, is a good representation of the data set composed of all signs replaced because of inadequate retroreflectivity.

Findings from Sign Data Form

From the analysis presented here some fundamental conclusions can be made. First, approximately 20 percent of all in-service signs are replaced each year for some reason. Second, signs replaced due to inadequate retroreflectivity (identified by visual nighttime inspections) account for approximately 30 percent of all replacements. The data suggest that the type of sheeting material, substrate material, orientation, or background color do not significantly influence either the service life of a sign or the probability that it will be replaced due to inadequate retroreflectivity.

Table III-41. Comparison of Retroreflectivity Data

Categories	Description	Percent of Total	
		Data Set A	Data Set B
Sheeting material	Type A	63.7%	87.2%
	Type C	36.3%	12.8%
Substrate material	Plywood	25.7%	26.5%
	Aluminum	70.9%	69.0%
	Steel	3.4%	4.5%
Primary orientation	North	27.8%	29.3%
	South	25.3%	29.3%
	East	21.6%	13.6%
	West	25.3%	27.2%
Background color	White	55.6%	57.5%
	Red	13.0%	11.3%
	Yellow	22.1%	26.2%
	Green	9.2%	4.7%

CHAPTER IV
SHEETING SERVICE LIFE

An essential step to implementing a sign management system is the ability to accurately predict the retroreflectivity (R_a) of traffic signs based on the amount of time the signs have been in the field. With the knowledge of minimum retroreflectivity values, and the ability to predict the in-service R_a, the service life of traffic signs can be calculated. Knowing the service life of traffic signs allows the appropriate personnel to schedule appropriate actions—whether this means a field inspection to determine a more accurate retroreflectivity value or a replacement plan. As an example of the one of many possibilities, signs nearing end of life could be highlighted in a computer inventory for field inspection in a consistent, efficient, and cost-effective manner. The system could also be used to develop future budgets by forecasting sign replacement needs.

SERVICE LIFE ISSUES

The service life of traffic signs can be defined as the age of a sign, measured in years, from the date of installation until the R_a levels of the retroreflective sheeting fail to meet the minimum retroreflectivity values proposed by the FHWA (5). The proposed minimum values are based on sign type, color, placement, roadway speed, size, internal contrast ratio, and so forth.

Although the definition of service life seems simple, the determination of an actual number of numbers to base replacement cycles on is complex. There are many factors, both natural and man-induced, which could potentially influence the retroreflectivity of sign sheeting. Geographic location, ground elevation, sign elevation, climatical conditions, airborne pollutants, sign direction, sheeting manufacturer, sheeting color, sheeting type, lateral placement from edge of roadway, vertical placement, and fabrication process are just a few of the variables that could possibly influence sign retroreflectivity. Black et al. (17) studied a comprehensive list of these factors and broke down weathering elements into the following groups:

1. The effect of solar radiation,
2. The speed of a decomposition reaction with rising temperature (i.e., heat, water/moisture effects of two kinds, that of soaking and drying out and that of chemical reaction of polymeric organic material with water, and that of freeze/thaw cycles),
3. Oxygen contribution to photo-oxidative decomposition of the surface layer of the material in combination with the solar radiation,
4. Industrial pollution largely caused by atmospheric sulfuric dioxide in combination with water and the ultraviolet radiation of the sun (acid rain), and
5. Wind erosion or abrasion in combination with sand, dirt, and salt particles.

To add to the complexity of the situation is the deterioration of signs constructed using a silk-screening process. For instance, Stop signs are typically fabricated of white retroreflective sheeting with the red background color added by silk-screening a red transparent lacquer. However, the red layer fades with time, thus allowing more of the white material to reflect light. This in turn causes the contrast of the "STOP" legend to decrease and, consequently, diminishes the legibility of the sign.

Therefore, even if one were to account for all the variables, a sign's life is rather long at an estimated 7 to 15 years (based on previous estimates and manufacturers' warranties). Within that period, any given sign could be exposed to numerous conditions that could degrade the sign faster than what would normally be expected. Therefore, even if a service life could be determined and signs were replaced on an interval based on that service life value, there would still be a certain percentage of signs that fall below the acceptable level of retroreflectivity before scheduled for replacement.

Based on previous studies (17, 18), a major hurdle in determining the service life of traffic signs is the variability in new sheeting retroreflectivity. As mentioned before, most transportation agencies' specifications regarding sheeting retroreflectivity are based exclusively on values for pre-exposed sheeting. The specifications require a minimum value but specify no maximum value. Consequently, the retroreflectivity of new sheeting can be highly variable. This creates a problem when trying to predict in-service retroreflectivity. It seems as if the most logical way to estimate the degradation of in-service retroreflectivity is with linear or curvlinear relations based on amount of exposure (i.e., how long the signs are in the field). However, using this technique requires a known starting retroreflectivity value to apply the relation to. One approach could be to base the starting retroreflectivity value(s) on the minimum retroreflectivity value for new sheeting. However, a certain percentage of signs (believed to be significant) would be replaced before their time, and thus the agency responsible would not be receiving the highest return on its investment. On the other hand, this could be one way to assure that only a minimal amount of signs are in non-compliance.

RETROREFLECTIVITY MEASUREMENTS

In an attempt to develop predictive retroreflectivity values for in-service traffic signs and to estimate the service life of traffic signs in Texas, TTI initially focused on retroreflectivity data already collected by TxDOT. After conducting an initial evaluation of the provided data, TTI deemed it valuable to collect additional data. Overall, coefficient of retroreflection readings were taken on over 850 traffic signs using a retroreflectometer (Advanced Retro Technology, Inc., Spring Valley, California, Model 920). Data that fell out of the realistic ranges of retroreflection were not included. Four sheeting colors—red, yellow, green, and white—and two sheeting types, engineering grade (Type A) and high intensity (Type C), were surveyed on signs from less than a year old to 17 years in age. Table IV-1 summarizes the data collection efforts.

Table IV-1. Total Sign Samples by Age Category

Color	Red		Yellow		White		Green		Total
Type	A (EG)	C (HI)	A (EG)	C (HI)	A (EG)	C (HI)	A (EG)	C (HI)	
0-1 yr	0	25	0	6	12	0	2	7	52
2 yr	0	15	0	15	10	2	17	0	59
3 yr	1	16	1	19	15	0	16	0	68
4 yr	3	34	1	14	14	0	7	0	73
5 yr	5	9	3	11	7	0	3	0	38
6 yr	61	1	31	3	39	0	34	0	169
7 yr	36	0	50	0	35	0	8	0	129
8 yr	18	0	36	1	16	0	5	0	76
9 yr	10	0	13	0	16	0	3	0	42
10 yr	15	0	20	0	14	0	4	0	53
11 yr	7	1	6	0	6	0	2	0	22
>12 yr	9	0	31	0	19	0	12	0	71
Total	165	101	192	69	203	2	113	7	852

Note: Type A = engineering grade (EG) sheeting and Type C = high intensity (HI) sheeting.

The results of the statistical analysis for the sample population were segregated by sheeting color and type. Table IV-2 summarizes key retroreflectivity attributes of the data. All mean values of R_a, except red and white engineering grade, exceed the minimum R_a values for new sheeting as defined in TxDOT - Departmental Materials Specification: *D-9-8300, Flat Surface Reflective Sheeting* (11).

Table IV-2. General Retroreflectivity Statistics by Sheeting Type

Sheeting	Samples	Mean R_a[1]	Standard Deviation	Minimum R_a[1]	Maximum R_a[1]
Red - Type A (EG)	165	11.38	4.21	3.1	24.0
Red - Type C (HI)	101	44.84	10.82	19.7	84.0
Yellow - Type A (EG)	192	59.20	17.93	3.0	100.0
Yellow - Type C (HI)	69	211.65	42.88	76.3	341.0
White -Type A (EG)	203	74.48	25.92	1.0	118.0
White - Type C (HI)	2	280.50	16.26	269.0	292.0
Green - Type A (EG)	113	10.62	4.00	1.0	19.0
Green - Type C (HI)	7	47.86	8.34	35.8	56.6
Total	852	58.16	56.91	1.0	341.0

Note: [1]Coefficient of retroreflectivity (R_a) expressed for 0.2° observation and -4° entrance angles.

Table IV-3 shows the key age attributes of the collected data. Note the low mean sign age for high intensity sheeting. It appears that TxDOT began implementing the use of high intensity sheeting approximately 6 years ago. Consequently, insufficient data are available to determine the end of life for high intensity sheeting. However, other states have used high intensity sheeting for many years. For instance, Pennsylvania tested 14 to 15-year-old NO PASSING ZONE signs (W14-3) made with high intensity sheeting and determined that the material (yellow high intensity sheeting) has a service life of at least 15 years. On the other hand, Pennsylvania has very different climatical and geographical characteristics compared to Texas. Therefore, Texas would benefit by conducting its own analysis of high intensity sheeting when signs made with this type of sheeting are old enough to better represent general trends.

Table IV-3. General Sign Age Statistics by Sheeting Type

Sheeting	Samples	Mean Age (years)	Standard Deviation	Minimum	Maximum
Red - Type A (EG)	165	7.49	2.09	3	14
Red - Type C (HI)	101	2.97	1.62	0	11
Yellow - Type A (EG)	192	8.63	2.73	3	17
Yellow - Type C (HI)	69	3.33	1.44	1	8
White - Type A (EG)	203	6.77	3.28	0	15
White - Type C (HI)	2	2.0	0.0	2	2
Green -Type A (EG)	113	6.16	3.84	1	17
Green - Type C (HI)	7	1.0	0.0	1	1
Total	852	6.46	3.36	0	17

SERVICE LIFE ANALYSES

The ability to predict in-service retroreflectivity values is critical to a sign management system. With this knowledge, and minimum in-service values, one can predict when traffic signs will no longer be useful to motorists due to inadequate nighttime demands set by the drivers' visual capabilities.

The analyses conducted herein include a review of the previous literature pertaining to service life values. In addition, the research team also collected in-service retroreflectivity readings, and surveyed several hierarchies involved in sign management. The surveys included a state traffic engineering survey sent to all 50 states, a district survey disseminated to all 25 TxDOT districts, and finally, a sign data form sent to several TxDOT sign maintenance crews responsible for replacing signs.

Retroreflectivity Analysis

To determine the service life of the traffic signs in Texas, TTI analyzed the retroreflectivity data using the minimum retroreflectivity values expected to be used by FHWA in rulemaking. Using cumulative distribution plots, similar to those used to calculate 85th percentile speeds, a service life can be inferred assuming a certain level of risk (i.e., given a specified service life value, there is a percentage of signs that will be below the proposed minimum retroreflectivity values, and the percentage increases with the increase in service life values). Figures IV-1 through IV-3 show the cumulative distribution plots for all signs (Type A and C combined), Type A signs, and Type C signs, respectively. Interpretation of the graphs is as follows: Figure IV-1 shows the percent of all signs (both Type A and Type C sheeting) meeting the minimum retroreflectivity requirements by age; Figure IV-2 shows the percent of Type A signs meeting the minimum retroreflectivity requirements by age; and so forth. For instance, to be sure that at least 85 percent of all red signs meet FHWA's expected minimum retroreflectivity values, the corresponding service life value would be approximately 7.5 years. In other words, if the replacement period (i.e., service life value) selected by TxDOT was 7.5 years, approximately 15 percent of the red signs would be in non-compliance with FHWA's expected minimum values. As another example: to be sure at least 95 percent of Type A white signs meet the minimum values, the corresponding service life value (from Figure IV-3) would be approximately 7 years. Note the missing trend lines for Type C (high intensity) sheeting (Figure IV-3). The reason only red and yellow signs are shown on the graph is because of lack of sufficient data to represent white and green Type C sheeting. Also, for the yellow sheeting, data were collected on signs ranging from less than a year old to 8 years old. All yellow Type C signs tested meet the proposed minimum requirements, and therefore the best fit line can be represented by y = 100. In other words, the yellow Type C sheeting service life value in Texas is at least 8 years. Further trends in the data are unavailable due to the oldest signs in service being 8 years or newer.

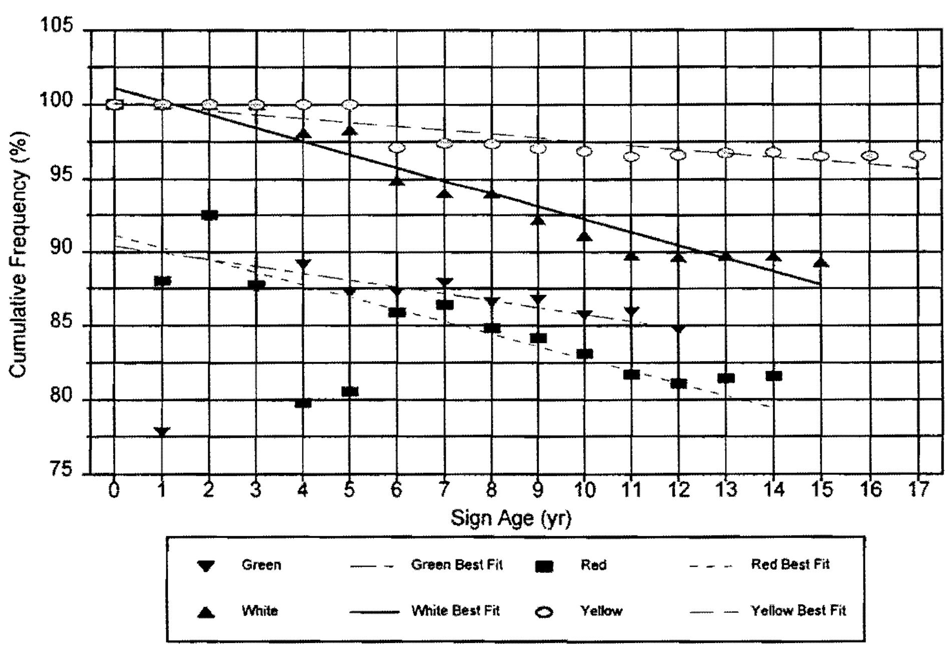

Figure IV-1. Cumulative Distribution for All Sheeting Types

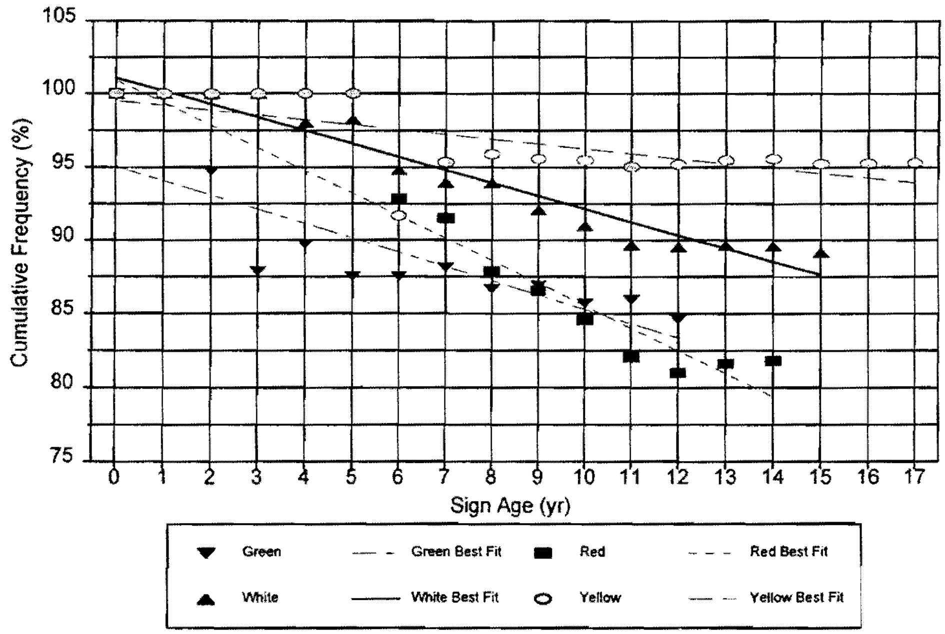

Figure IV-2. Cumulative Distribution for Type A (EG) Sheeting

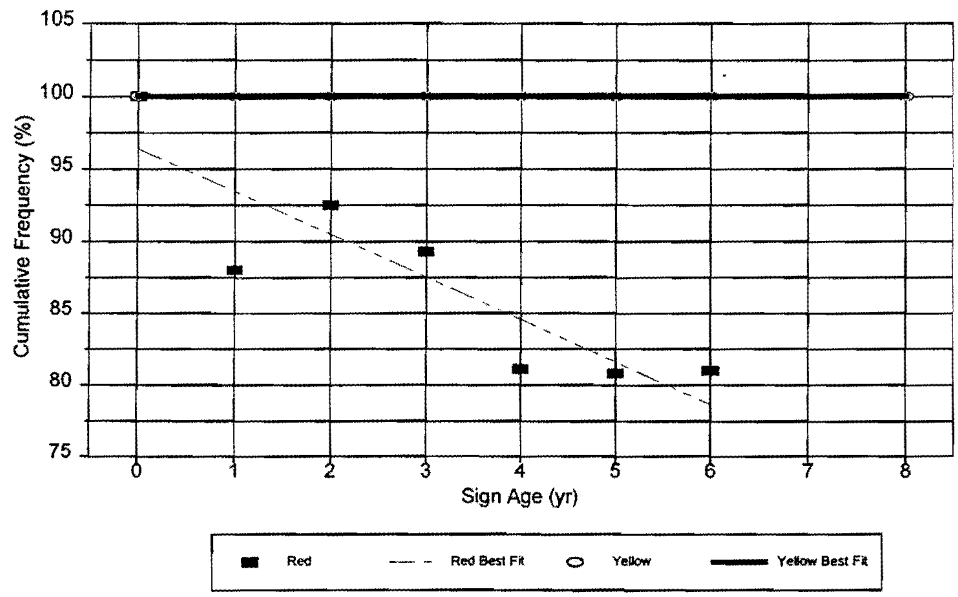

Figure IV-3. Cumulative Distribution for Type C (HI) Sheeting

Table IV-4 summarizes Figures IV-1 through IV-3 for certain cumulative frequency percentages. These percentages were selected purely as examples of how the service life values can change depending on assumed levels of risk and are in no means final recommendations to TxDOT. Also, the amount of data used to generate these values is not great enough to produce a significant statistical confidence level. The quantity of data collected and analyzed was enough to represent trends in the data, but should not be interpreted as definite.

Table IV-4. Service Life Values Based on Assumed Risk Levels

Assumed Acceptable Level	Service Life (years)											
	Red			Yellow			White			Green		
	All	Type A	Type C	All	Type A	Type C	All	Type A	Type C	All	Type A	Type C
95	N/A	4	0.5	17+	14	8+	7	7	---	N/A	0.5	---
90	1.5	7	2	17+	17+	8+	12.5	12.5	---	1	5	---
85	7.5	10.5	4	17+	17+	8+	15+	15+	---	11.5	10.5	---

Note: Type A = engineering grade sheeting and Type C = high intensity sheeting.
N/A - information not available.

Table IV-5 specifies the percent of signs requiring replacement by sign color and type if FHWA's proposed values were implemented today. Of all the measured signs, 804 had sufficient data to analyze. As mentioned previously, the total sample of retroreflectivity data was a combined effort between TxDOT and TTI. The data obtained through TxDOT (approximately 73 percent of the entire sample) could not be subdivided to match the framework required to analyze the data according to the criteria set up in *Minimum Retroreflectivity Requirements for Traffic Signs* (5). Consequently, aggregate retroreflectivity values were developed for yellow, white, red, and green sheeting materials. These aggregate values, along with the data collected by TTI personnel, were used to assess the overall impact of the proposed minimum retroreflectivity values. The following assumptions were made in developing the aggregate values:

- Standard MUTCD sign size,
- 50 percent on roads with traffic speed of 45 mph (72.4 km/h) or greater and 50 percent on roads with speeds of 40 mph (64.4 km/h) or less,
- No overhead signs, and
- Bold legend type for yellow background signs with missing legend data.

Table IV-5. Estimated Compliance with Minimum Retroreflectivity Values

Sheeting Color	Sheeting Type	Complete Sample Size	Number Failing		Percent Failing		FHWA Estimate (percent)
			Original Values	Expected Values	Original Values	Expected Values	
Red	All	266	89	49	33.5	18.4	10
	Type A (EG)	165	70	30	42.4	18.2	N/A
	Type C (HI)	101	19	19	18.8	18.8	N/A
Yellow	All	261	9	9	3.4	3.4	7
	Type A (EG)	192	9	9	4.7	4.7	N/A
	Type C (HI)	69	0	0	0.0	0.0	N/A
White	All	205	21	22	10.2	10.7	7
	Type A (EG)	203	21	22	10.3	10.8	N/A
	Type C (HI)	2	0	0	0.0	0.0	N/A
Green	All	72	11	11	15.3	15.3	12
	Type A (EG)	65	10	10	15.4	15.4	N/A
	Type C (HI)	7	1	1	14.3	14.3	N/A
Total	All	804	130	91	16.2	11.3	N/A
	Type A (EG)	625	110	71	17.6	11.4	N/A
	Type C (HI)	179	20	20	11.2	11.2	N/A

Note: N/A - information not available.

From Figures IV-1 through IV-3 and Table IV-5, it is obvious that Type A and Type C white on red signs do not perform as well as other signs. Because of the problem of red color fade, an additional evaluation of signs with red backgrounds and white legends was conducted. Contrast ratios of white legend to red backgrounds were calculated for 266 signs. Table IV-6 summarizes the average contrast ratios by sheeting type and age category with the mean retroreflectivity values of the red and white components. As shown, the contrast ratio for both types of sheeting remains fairly consistent throughout the life of the signs. This result is partially inconsistent with the findings in an FHWA report (17). The researchers found that contrast ratios of engineering grade sheeting remain consistent while contrast ratios of high intensity sheeting tend to increase as the age of the signs increase. However, limited retroreflectivity data were collected with red high intensity signs, and therefore, the results of contrast ratio analysis contained herein might not represent the actual field performance of these signs in Texas very well. On the other hand, assuming these results are representative of the in-service performance of red high intensity signs in Texas, one can conclude that the red lacquer used in the silk-screening process to fabricate these types of signs fades faster in Texas than the national average, which is what FHWA's numbers are based on.

Table IV-6. Summary of Contrast Ratios

Sign Age	Type A (EG) Sheeting				Type C (HI) Sheeting			
	Mean R_a		Mean Contrast Ratio	Samples	Mean R_a		Mean Contrast Ratio	Samples
	Red	White			Red	White		
0	N/A	N/A	N/A	0	44.6	284.3	6.4	1
1	N/A	N/A	N/A	0	37.3	233.0	6.3	24
2	N/A	N/A	N/A	0	48.1	250.3	5.3	15
3	8.0	20.0	2.5	1	41.4	229.8	5.9	16
4	7.9	76.7	11.0	3	48.3	234.9	5.3	34
5	11.6	80.9	7.0	5	53.0	253.0	4.8	9
6	12.1	73	6.2	61	49.1	267.0	5.4	1
7	14.2	89.9	6.9	36	N/A	N/A	N/A	0
8	9.4	72.1	7.9	18	N/A	N/A	N/A	0
9	11.0	66.6	7.0	10	N/A	N/A	N/A	0
10	8.1	71.2	9.9	15	N/A	N/A	N/A	0
11	8.6	45.0	6.5	7	40.0	278.0	7.0	1
12	4.7	35.1	6.6	2	N/A	N/A	N/A	0
13	8.3	77.4	9.4	5	N/A	N/A	N/A	0
14	13.5	80.0	6.2	2	N/A	N/A	N/A	0
15	N/A	N/A	N/A	0	N/A	N/A	N/A	0

Note: N/A - information not available.

A more comprehensive investigation of why the red signs seem to fail the expected FHWA guidelines more rapidly than the other signs was initiated by the previous discussion. Of all the red signs 5 years of age and newer that failed (21 signs in total) the expected guidelines, 90 percent (19) were fabricated with high intensity sheeting. Furthermore, the reason for failure for all 19 signs was due to a contrast ratio of less than 4:1. The other two signs that failed were fabricated with engineering grade sheeting, and the reasons for failure were inadequate contrast ratio and background retroreflectivity. Of the remaining red signs that failed (28), all were fabricated with engineering grade sheeting and the reasons for failure included all three possible criteria (i.e., inadequate contrast ratio, background retroreflectivity, or legend retroreflectivity). As mentioned previously, from the retroreflectivity data, it appears that TxDOT has been using high intensity sheeting on red signs for approximately 5 to 6 years. This is also where the break in sheeting types of failed red signs appears. Thus, if older high intensity red signs existed in Texas, one might expect to see even a more pronounced failure rate for these types of signs. However, a caveat in this analysis is the amount data collected. Due to time and budget constraints, the data collection efforts were limited, and therefore, the data contained herein might not represent the field performance of red signs in Texas. Further research is needed in this area to validate the results of this section of the report.

State Traffic Engineering Survey

Mail-out surveys were distributed to the 50 state transportation agencies in an attempt to identify concerns and difficulties the profession is anticipating with the implementation of FHWA's minimum retroreflectivity values. A total of 34 states responded to the survey and the following question dealing with service life.

> ***Has your agency conducted any evaluations of the service life of retroreflective sheeting? If yes, please provide citation or a copy of the evaluations.***

Of the 34 responding states, 12 replied they had evaluated service life in one form or another. Five of those 12 provided no citation or comment relating to the results of their evaluation. However, several states answering "no" to the question provided valuable insight anyway. The comments thought to be pertinent to this section of the paper are summarized in Table IV-7.

Table IV-7. Comments from State Traffic Engineering Survey

State	Comment
AZ	Ongoing tests of all types of sheeting on test decks
ID	South-facing engineering grade signs fail ±10 years
IO	Measured retroreflectivity value of 752 random traffic signs. Only four failed to meet FHWA proposed values. Of those four, three were object markers.
KS	No formal evaluations. Have used green high intensity on freeway guide signs since 1984 and have concluded service life of this type of sheeting to be at least 15 years. During summer of 1996, Kansas will start a 10 year replacement program for all high intensity signs on state system. Replacement period based on manufacturer's 10-year warranty
MS	Acceptable service life values: high intensity = 10 years, engineering grade = 7 years
ND (18)	Measured retroreflectivity on 12,709 signs. Results were similar to FHWA report (5). An exact service life value was not determined due to the oldest signs being 9 years or newer. Also concluded that for all colors except red, sign direction was not a significant factor of service life.
OH	Expected service life values: 3M high intensity = 12-15 years; 3M engineering grade = 7-10 years; Stimsonite high-performance = insufficient data
PA	Measured retroreflectivity on 14 to 15-year-old yellow high intensity signs. Concluded that this sheeting lasts at least 15 years.

Only two states (North Dakota and Pennsylvania) actually sent documentation explaining the methodology behind their attempts to determine service life values. Although useful and informative, North Dakota's study was inconclusive in that the authors did not directly identify service life values for retroreflective sheeting, although they did report that, "*Retroreflectivity readings obtained for years five to nine are fairly flat and consistent. Retroreflectivity degradation may be more pronounced for older signs (>10 years)*" (18). They did however show that retroreflectivity values in North Dakota are similar to FHWA's numbers (which were established from a national average). Pennsylvania's study is helpful in that it indicates how long yellow high intensity sheeting can last. However, it appears that they did not test their signs against the framework established by FHWA. Rather, they measured retroreflective values on 14 to 15-year-old NO PASSING ZONE signs, calculated the average, and then reported that since the average was 23 percent brighter than the minimum specification for new high intensity sheeting (and over four times as bright as the minimum brightness of new engineering grade sheeting) the material lasts as least 15 years. The origins of the other values reported are unknown, and it appears from the numbers that they could be based on manufacturers' warranties.

TxDOT Sign Data Form

TTI disseminated Sign Data Forms to each district within the state to determine how many signs were being replaced under the current sign replacement practices and why. Signs crews were issued the forms when replacing signs and used them anywhere from two to four weeks. Overall, over 3000 forms were returned. However, only 705 contained sufficient data to analyze service life values. The reasons the signs were replaced included retroreflectivity, vandalism, change in standards, knockdown, damage other than vandalism, and other. Approximately 28 percent (198 of the 705 sign forms used) of the signs being replaced were reported as caused by inadequate retroreflectivity.

A portion of the Sign Data Form requested TxDOT personnel to report the reason why the sign was replaced. Using only those signs replaced due to poor retroreflectivity, and the installation date of those signs, Table IV-8 was generated. The table summarizes the age of the signs being replaced by sheeting type.

Table IV-8. Sign Replacement Age

Sheeting Type	Sign Age (years)																Total No. Of Signs
	<1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Type A (EG)	0	2	0	7	5	8	15	12	25	13	32	6	6	5	16	5	157
Type C (HI)	2	1	0	1	3	1	4	3	3	0	5	0	0	0	0	0	23

From Table IV-8, the average age of signs being replaced that were constructed with Type A (EG) and Type C (HI) sheeting is 8.9 and 6.1 years, respectively. However, the variability in age of the signs is relatively large, therefore suggesting that a certain amount of traffic signs remain in the field past their usable age. This result is similar to what the Australians discovered in their report (14). Consequently, one can conclude that visual nighttime inspections of traffic signs is a highly subjective evaluation, at least for determining sign usefulness based on retroreflectivity. Transportation agencies responsible for signing could benefit from more detailed studies on how to evaluate traffic signs for adequate retroreflectivity. An agreed upon service life value for types and colors of sheeting would also be beneficial.

TxDOT District Survey

A survey was sent to each District within TxDOT to obtain information pertaining to TxDOT's current sign inspection and replacement practices. This part of the report focuses on the section of the TxDOT District survey which addresses service life of traffic signs in Texas.

In this survey, TxDOT engineers, sign shop personnel, and maintenance section personnel were asked to estimate the service life of traffic signs by sheeting type and color. A total of 59 individuals responded to at least part of the question. The average service life values are summarized in Table IV-9.

Table IV-9. Service Life Values

Sheeting Type	Range of Service Lives (years)			
	White	Yellow	Red	Green
Type A (EG)	6.5	6.4	6.0	6.8
Type C (HI)	6.8	6.2	5.7	6.5

Currently TxDOT maintains no statewide sign management system although several districts have reported the use of a system in various forms. Therefore, the values reported in Table IV-9 are believed to be estimates based on manufacturers' warranties rather than calculated or observed end-of-life values. Interestingly, Type C (high intensity) sheeting for yellow, red, and green sheeting colors is reported to have lower service life values than Type A (engineering grade) sheeting. This could be explained by the possibility that the reported service lives represent the length of in-use time and could therefore be interpreted as minimum service lives. However, of the 59 responses to this question, fewer estimates were submitted for Type C sheeting than Type A. This could be due to the fact that TxDOT has been using high intensity sheeting for a relatively short period (approximately 6 to 7 years).

The survey also asked the respondents to rank the factors which have the greatest impact on retroreflective sheeting. The factors that were ranked are presented in Table IV-10 with the results of the ranking. A ranking of one represents the factor thought to be most influential to sign retroreflectivity.

Table IV-10. Factors Believed to Affect Retroreflectivity

Ranking	Factor
1	Direction of exposure
2	Location
3	Color
4	Geographic region of Texas
5	Manufacturer
6	Other

In response to Table IV-10, various factors (sign direction, sheeting color, sheeting material, and sign age) were tested to determine if they were reliable predictors of retroreflectivity. The other factors in Table IV-10 were not available and therefore could not be tested. Of the four variables tested, only sign direction was determined to be insignificant. This finding is similar to others (17, 18) where a review of their scatter plots of sign orientation versus retroreflectivity for each sample by sheeting color and type revealed no distinct pattern of deterioration based on sign orientation.

MANUFACTURERS' WARRANTIES

For comparison efforts, the research team requested retroreflective sign sheeting warranties from several manufacturers. Only one sheeting manufacturer submitted warranty information. Table IV-11 summarizes the field performance warranty from that one manufacturer for a Type C (high intensity) sheeting. Table IV-12 provides similar information for Type A (engineering grade) sheeting.

Table IV-11. High Intensity Warranty for Coefficient of Retroreflection

Sheeting Color	Minimum Coefficient of Retroreflection[1]	
	Up to 7 Years	Up to 10 Years
White	212	200
Yellow	144	136
Green	38	36
Red	38	36

Note: [1]Measured in candelas per foot candle per square foot at 0.2° observation and -4° entrance angles. All measurements shall be made after sign cleaning according to sheeting manufacturer recommendations. For screen printed transparent colored areas on white sheeting, the coefficients of retroreflection shall not be less than 70 percent of the values for the corresponding color in the above table.

Table IV-12. Engineering Grade - Effective Performance Life

Sheeting Color	Average Min. Retained Brightness[1]	Years of Effective Performance Life
White	35.0	7
Yellow	25.0	7
Red	7.2	7
Green	4.5	7

Note: [1]Measured in candelas per foot candle per square foot at 0.2° observation and -4° entrance angles. All measurements shall be made after sign cleaning according to sheeting manufacturer recommendations. For screen printed transparent colored areas on white sheeting, the coefficients of retroreflection shall not be less than 70 percent of the values for the corresponding color in the above table.

CHAPTER V

SIGN MANAGEMENT AND INVENTORY SYSTEMS

Transportation agencies are increasingly coming to the realization that sign management systems can be an effective tool in sign maintenance efforts. Agencies have different needs, based on their size and budget. Luckily, there are many different types of systems available. For some agencies, a sign management system may not be necessary at all. This chapter highlights the various sign management systems available, and some of the advantages and disadvantages of each. It also explains some of the technology that is now available, and requirements for establishing and maintaining the management systems. Although this chapter may mention particular inventory system vendors by name, this does not imply that the researchers endorse this provider or their product; this information is included only to illustrate the existing state of technology and the general nature of the costs of implementing this technology.

IMPORTANCE OF SERVICE LIFE TO PROCESS

Although a sign management inventory system provides many benefits (which will be discussed later in this report), the primary concern of our research is how the sign inventory system can help to ensure that signs meet minimum values of retroreflectivity as established by the FHWA. A sign inventory system should provide advance warning to the transportation agency as to when signs need replacing. Ideally, this would be just before they drop below the minimum values for retroreflectivity.

The sign replacement predictions would be based on the expected service life of individual signs. The service life of a sign is the result of the combined effects of several variables. The predicted service life of an individual sign would be a function of the known data particular to that sign. Examples of this data might include the following variables: type of retroreflective sheeting, date of installation, geographic region, sign orientation, and distance from the roadway. A more complete listing and analysis of the variables effecting service life is provided in Chapter IV.

A sign management system should, therefore, be able to predict, or estimate, the remaining service life for every sign, based on the particular factors and data related to each individual sign. The inability to provide this essential function eliminates many sign management inventory providers.

USES AND BENEFITS

A sign management system can be used to identify and schedule replacement for those signs having retroreflectivity values which are predicted to soon fall below the minimum value. In this manner, it provides a very effective tool for scheduling sign replacement. This ability to accurately predict the service life of individual signs was the main consideration for including sign management systems in the scope of this research project. However, there are other benefits that a sign management system can offer an agency. These additional benefits are discussed below. Some benefits of developing and maintaining a computerized sign management system include:

- Allows an agency to predict service life of individual or groups of signs along a stretch of roadway.
- Reduces the likelihood of tort liability claims by increasing the likelihood that signs meet the values, by providing documentation of conditions existing at the time of an accident, and also by illustrating an agency's efforts to improve a given situation. An added benefit (at least for agencies that are not self-insured) is that some insurers recognize the value of an agency having a sign inventory system. For example, the Utah Risk Management Association reduces premiums by 3 percent for agencies that maintain a sign inventory system (19).
- Allows an agency to identify problem locations. It can help to identify repeat vandalism locations. This information can help in knowing when to use vandalism-resistant hardware or other counter-measures.
- Allows an agency to manage traffic control devices in a more efficient manner because of better planning.
- Permits an agency to respond to citizen complaints or questions more effectively.
- Allows an agency to utilize personnel more effectively.
- Allows an agency to better evaluate risks.
- Saves management time.
- Saves field personnel time.
- Allows an agency to develop contract quantities and provide descriptions and locations (including map) for contractor.
- Allows an agency to better organize and distribute project assignments to work crews.
- Allows an agency to be able to determine the correct quantity needed when purchasing materials, and possibly allows you to buy greater quantities at one time, thus allowing for additional savings.
- Allows an agency to estimate the amount of material that will be available for recycling.
- Reduces paperwork, especially if used as part of a closed-loop system.

CURRENTLY AVAILABLE SYSTEMS ("OFF-THE-SHELF")

There are a number of sign management systems that are currently available from vendors. The researchers contacted several of these vendors to obtain information about the different systems.

CartéGraph

The TTI research team contacted CartéGraph Systems for more information concerning the company's existing sign management technology services. CartéGraph, headquartered in Dubuque, Iowa, provides the necessary sign inventory software and/or hardware, including network technical support required to establish and maintain an inventory. According to James Hoeger, a CartéGraph account executive, the system is Windows based (Windows 3.1 or Windows95), and can interact with Global Positioning System (GPS) receivers, digital cameras, bar codes, and video logging. The software includes a sign library of 514 signs and has an image of each of those signs. The software will run on any computer that is capable of running Windows. However, a 486 computer with at least 8 MB of RAM is recommended. The software system does have a place for recording the retroreflectivity values. The base price for software for one computer is $1,195. The system can be expanded with additional features such as bar coding, GPS, digital imaging, etc.

State Departments of Transportation (DOTs) in Illinois, South Carolina, Vermont, Kansas and West Virginia are known to be using, or in the process of purchasing, a system from CartéGraph. In addition, the TxDOT's Laredo District purchased the CartéGraph System in early 1996, and personnel are being trained at the present time.

The CartéGraph system does not currently include the ability to predict retroreflectivity values and end-of-service life for individual signs. Company representatives indicated that this capability would be added to the system when FHWA issues the final rule containing the minimum retroreflectivity values.

Pflume, Klausmeier & Gehrun (formerly ADT)

The August 1995 edition of *3M Directions* (20) presented an article about the Louisville (Kentucky) Department of Public Works' implementation of the Sign Inventory Management System (SIMS). Advanced Data Technologies (ADT) developed SIMS, a software package with a user-friendly database. They integrated Louisville's Geographical Information System (GIS) into SIMS. This enables Louisville personnel to map data by location. There are an estimated 45,000 signs in the city, and the task of entering the initial data was expected to take about one year. According to the article, sign replacement was previously based on visual night inspections for the amount of retroreflectivity. Once the inventory is complete, the department is hoping to be able to automatically target sign replacements based on the life expectancy of the signs.

ADT is now a subsidiary of Pflume, Klausmeier & Gehrun (PKG) of Indianapolis. Todd Althaus, the founder of ADT, and Jim Klausmeier, the vice president of PKG, have both stated their ability to provide a sign management inventory system that will meet all of TxDOT's requirements. They have provided some general information about the PKG firm and are in the process of developing some estimates of costs for providing this system. The basic price for sign management system software is $2,995. The system can be expanded to utilize additional capabilities.

SIMS can be customized to meet the specific requirements of a particular agency. SIMS operates on IBM compatible personal computers and can function in single and multi-user environments. SIMS requires Microsoft Windows or DOS and a PC work station with 16 MB of RAM. SIMS is adaptable to a variety of specific interface requirements such as Oracle, MGE and Roadview.

With SIMS, several methods can be used to determine and input information about sign locations. They include the following methods:

- Distance along roadway from a known reference point (intersection, mile marker, etc.), as measured by a vehicular distance measuring instrument (DMI);
- State plane X and Y coordinates relative to the known position of a reference point, as measured by a Laser distance measuring instrument;
- State plane X and Y coordinates as determined by a GPS receiver; and
- Street address of nearby buildings (in the case of urban streets).

In each case, locations can be corrected and converted into the coordinate system used by the agency's GIS (21).

SIMS can accommodate the tracking of a sign throughout its lifetime by using a bar code. If bar codes are used, field crews can use pen computers or menu-driven data loggers to record sign information.

Advanced Data Technologies is currently developing a Windows version computerized sign management system for the Minnesota DOT. SIMS is already being used by the cities of Cincinnati, Ohio and Louisville, Kentucky. The PKG system does not currently include the ability to predict retroreflectivity values and end-of-service life for individual signs. Company representatives indicated that this capability would be added to the system when FHWA issues the final rule containing the minimum retroreflectivity values.

Hansen Technologies

Hansen has a software called IMS-Street. It operates in a Microsoft Windows environment with an NT graphical user interface, including pull-down menus, elevator bars, scroller bars, pop-up windows, and multi-media capability. It can be used with multiple SQL relational database management systems, including ORACLE, Sybase, Ingres, Informix, and DB2. The client/server architecture allows users to configure IBM compatible PCs [CLIENT] running Windows to any type of hardware [SERVER]. Bi-directional integration is possible with Intergraph Microstation, Autodesk AutoCAD, and other GIS products. This software requires a 486 processor or better, along with 16 MB RAM. This is true whether talking about a single-user or multi-user work stations.

This sign management system can, among other things, keep track of sign type, distances, location, vertical and horizontal clearance, facing, illumination, supports, material, reflective coating, and condition rating.

According to a telephone conversation with Chuck Hansen, the price of Hansen's IMS-Street inventory software would be $495 for each workstation (assuming that there are approximately 300 user locations). Again, as with the other systems, the system requires modification in order to achieve the goal of estimating retroreflectivity values and remaining service life.

Vulcan

Vulcan Traffic Management Services, located in Alabama, offers a Visual Information Maintenance Management System (VIMMS). VIMMS is a modular system that can operate on office-type PCs. It operates in a Windows environment.

Vulcan has versions of this system for agencies having as few as 10,000 traffic control devices, or for agencies with over 1,000,000 traffic control devices. The capabilities can be upgraded to accommodate growth of a system. Program pricing is discussed later in this chapter. According to Vulcan, extensive computer experience is not required to operate VIMMS, as it operates in a Windows environment, and user interface is totally driven by using the keyboard or a mouse to enter data. It provides a help/information feature. Vulcan claims that the VIMMS database can be set up to store and provide information for practically every sign attribute. Vulcan has been in the sign management system business since 1985. The Vulcan system will also require modification in order to predict retroreflectivity values and the remaining service life.

Other Vendors

There are undoubtably other sign management system providers; however, those already mentioned seem to be the most popular. Some of the other vendors we contacted (Traffic Engineering Consultants, for example) could not provide all of the functions that we thought should be available in a system. Some vendors did not reply to our requests for prices or technical information (Traffic Safety Systems, Inc., Highway Safety Software, Inc., etc.).

FHWA

A report by the FHWA appeared in the March 1987 edition of the *Public Roads* magazine (22). This article describes the framework for a sign management being developed by the FHWA to assist state and local agencies involved in sign management. The system components are outlined, ongoing research is described, possible applications of the FHWA system are described, and additional requirements necessary for the system to be fully operational are discussed.

The sign management system is a microcomputer-based system that can be accessed directly through interactive instruction or linked to an automated sign inventory. The sign management system not only develops a data base of signs, but predicts candidate signs for replacement and compares costs of various replacement strategies. The authors state that although the system will be an effective tool for state and local agencies, these agencies will first need to compile a sign inventory, including information on retroreflectivity. They acknowledge that acquiring retroreflectivity readings for every sign is a labor-intensive approach to sign replacement decisions.

An FHWA report describes retroreflectivity and ways to measure it, and briefly mentions the fact that FHWA is developing a sign management system (23). This report says that sign management system will include integrated programs for a sign inventory, a road file and four models (sight distance, aging, required luminance, and available luminance) to assess the need for replacement.

Jeff Paniati of the FHWA described the FHWA's activities in *TR News* (24). This article says that the FHWA established the High Priority National Program Area (HPNPA) to develop performance specifications for retroreflectivity of signs. HPNPA has as its goals, not only determining minimum values of retroreflectivity, but also the development of sign management programs and measurement devices to help implement these new values. It goes on to state that an IBM PC-compatible version of the database management portion of the software is already available (1989) and runs under MS-DOS. It is described as a menu-driven system that inventories and tracks the performance of signs. The ability to predict sign retroreflectivity values and remaining service life are expected to be a part of this system.

OPERATIONAL REQUIREMENTS

In order to implement a sign management system, an agency must have the necessary computer and supporting hardware in addition to the software and personnel needed to operate a system.

Hardware

Most off-the-shelf sign management inventory systems can operate on single unit or on multiple-user IBM-compatible personal computer systems which have a minimum of a 486 processor and 16 MB of RAM. Some can run with as little as 4 MB of RAM, but all of the software programs would run better with 16 MB; therefore 16 MB is suggested. Typically, a VGA monitor, Microsoft-compatible mouse, 3.5" 1.44 MB floppy drive, 30 MB of available hard drive space, and an HP Laserjet printer, or equivalent, are also required.

The systems are generally adaptable to multiple SQL relational database management systems, such as Oracle, MGE, Sybase, Ingres, Informix, and DB2.

Other hardware that would be required would include peripherals such as GPS receivers, digital cameras, bar code readers. These peripherals are described in more detail later in this chapter. Typical system requirements are shown in Table V-1.

Table V-1. Typical System Requirements

Hardware	Vendors		
	CartéGraph	Advanced Data Technologies	Hansen Technologies
Processor	386 (min.) 486 or Pentium (recmd.)	486 DX4 100 MHz or Pentium	486 (min.)
RAM	4 MB (min.) 8 MB (recmd.)	16 MB (min) 32 MB (recmd.)	16 MB (min.)
Operating environment	Win 3.11 or DOS 5.0 (min.) Win 3.11 or DOS 6.2 (recmd.)	Win 3.1, Win95, or Windows NT 3.5	Win 3.1, Windows NT
Hard Drive	20 MB (min.) 30 MB (recmd.)	60 MB	
Monitor	VGA (min.) Super VGA (recmd.)	VGA	VGA
Pointing device	Mouse or pen	mouse	mouse
Printer (for reports)	Dot Matrix (min.) Laser (recmd.)		
Server/local database engine		Microsoft Visual FoxPro 3.0 or Oracle 7	Oracle, Sybase, Ingres, Informix, DB2

Note: min. = minimum requirement and recmd. = recommended requirement

Software

Most available off-the-shelf systems are Windows based and use operating systems such as Windows 3.1 or Windows95. The ones that do not use Windows95 are in the process of changing over to, or offering, that system. Sign inventory software varies somewhat from vendor to vendor as to what tasks it can perform; however, the researchers have identified several companies that can and do provide systems that are capable of providing any desired capabilities. The software generally can allow, or can be customized to allow, for the following types of information to be stored and manipulated: sign location (entered manually, from a DMI, or by interaction with a GPS receiver); sign information such as type, horizontal and vertical distance from the roadway; orientation of sign; illumination; retroreflectivity value at the last inspection; predicted retroreflectivity value; sign material; type of reflective sheeting; condition rating; and estimated service life remaining, with options for video-logging, digital camera images, and/or bar code reading.

A typical sign inventory system similar to the one just described, and operating on a single-user/stand-alone PC, would use about 10 MB of hard drive space, assuming that office was responsible for a database of 40,000 signs.

Personnel

Sign management systems require a major commitment to the maintenance of the database. Every time a sign is handled, an entry must be made in the database. This issue seems to be a concern of many potential sign inventory system users. The number and type of personnel required depends on the type of system chosen.

If the sign crew personnel record the data manually and bring it back to the headquarters, either someone at the District office or at the Maintenance office would be required to input the data. This would necessitate a full-time person devoted to this activity at the District level, or existing personnel could probably handle this if the individual maintenance offices assume the responsibility. This would still be a significant additional workload requirement and could require shifting of duties or hiring of additional personnel.

Much of this duplication of effort can be eliminated, however, by using available technology. At least one state DOT, North Dakota, is developing a procedure where the field personnel enter the sign data on a standardized "Scantron" sheet. This reduces the time required for inputting the data at the office.

Even more technologically advanced is the use of barcoding in coordination with microcomputers (lap-top computers, pen-based notebooks, or handheld terminals). The bar code on the sign is read at a distance by a bar code reader (held by someone inside the vehicle). The microcomputer can recognize the sign, and any data existing from the last inspection are now available. The inspector can then scan the data and update them as required. This would reduce or eliminate data input at the office. It would probably be a good idea to download the data from the microcomputer into the office computer at the end of each day to prevent accidental data loss. Someone at each office would still need to have time available, at least on a part-time basis, to maintain the system hardware and peripherals, and someone would occasionally want to retrieve or manipulate the data for budgeting and scheduling. Existing personnel might be able handle these types of activities, after receiving initial training.

An economic analysis of the personnel requirements, costs, and benefits is analyzed in further detail in the chapter pertaining to value engineering.

EXPERIENCES OF OTHER AGENCIES

As part of this project, the TTI researchers sent out a questionnaire/survey to the other state's transportation agencies, asking them, among other things, questions about their sign management practices. Responses received thus far indicate that slightly less than half (13 of 30) of the agencies currently use some sort of computerized sign management inventory system. Most of these agencies' systems are microcomputer-based. Some specific agency information that was obtained from the state traffic engineer survey is described below.

Kansas

Kansas is in the process of implementing a statewide sign inventory system, using the CartéGraph system.

Washington

Washington maintains a computer-based sign inventory system developed in house by state personnel. It is a PC-based system that requires the following types of information to be entered: substrate material, date of maintenance, MUTCD sign number, location, sheeting type, orientation, date of installation, date of last inspection, and the post condition.

Missouri

Missouri's system appears to be similar, at least in capabilities, to Washington's. It was also developed in-house by department personnel, is microcomputer-based, and allows for the following information to be stored: unique sign number, substrate material, date of maintenance, digitized image of sign, MUTCD sign number, location, sign condition, date of installation, date of last inspection. The significant difference between Missouri's and Washington's appears to be that Missouri can store a digitized image of the sign.

North Dakota

North Dakota is developing a computerized sign management system that will utilize "Scantron" sheets. Their proposed sheet looks similar to the Scantron sheets commonly used by universities and testing agencies. The idea is that the field crews can quickly and easily fill in the appropriate circles on the form, and then this data will be in a format to be processed by the computer at the District or Central office. Their system is being developed in-house, by state DOT personnel.

Wyoming

Wyoming uses a microcomputer-based sign inventory system, and they purchased "off-the-shelf" software. This software cost approximately $1,000. It appears to be a fairly simple system, although the respondents indicated that it does help them to schedule replacement of signs.

New York

New York uses a microcomputer-based system developed by state personnel. It appears to be similar in capabilities to the systems used by Washington and Missouri.

Connecticut

Connecticut uses a microcomputer-based system with a FoxPro database. This system, named VSIS (Videodisc Sign Inventory System), allows users to have videodisc imaging of signs, and information about the sign such as type of support, number of posts, and location of the sign on the support. This system is more sophisticated than the in-house systems previously discussed. One of the most interesting features of this system is its videodisc image ability.

Rhode Island

The Rhode Island department has hired a consultant to develop a sign inventory system under contract. This system will be capable of handling GIS.

West Virginia

West Virginia does not currently have a computerized sign inventory system, but is in the process of purchasing a system designed by CartéGraph. It is being customized to match the state's specific needs. Some of the types of data that can be recorded will include sign number, substrate material, date of maintenance, MUTCD sign number, location, condition of sign, predicted retroreflectivity, type of sheeting, orientation, date of installation, date of last inspection, and condition of post.

Mississippi

Mississippi is in the process of hiring a consultant to design a sign inventory program. However, it may be 10 years before the state has a statewide sign inventory.

Ohio

Ohio does not have currently a system. However, a consultant is developing one for their use.

FEATURES

Data Collection

Manual Data Collection

At the current time, most agencies are still inputting data manually (if they maintain a sign inventory at all). A crew goes out and records data manually on pre-printed data forms. At the end of the day, or in some cases only after they complete their assignment, they bring the data back to the office for someone to re-enter into a computer. As you can see, this involves a duplication of effort.

With manual data collection, distances can be determined any number of ways. They can be estimated from vehicle odometers, or more likely from a vehicle-mounted DMI. Sign locations can be estimated from agency construction plans, right-of-way plans, or line-drawings. As costs become more reasonable, more agencies are using GPS receivers for establishing sign location. According to Paniati, one recent study has come to the conclusion that using GPS receivers can reduce the time required for locating signs in urban areas by up to 20 percent (19).

Video-logging Data Collection

Video-logging was in vogue just a few years ago. This usually involved filming entire sections of a highway route, in both directions. Data can be collected quicker with this method than with manual collection methods. However, it can be quite cumbersome to retrieve images for a desired location. The videotape must be advanced or reversed until the desired portion is reached; this can take several minutes, even after finding the correct tape.

Upon completion of the taping, the tape is brought back to the office, where someone views the tape on a viewing screen overlaid with a grid. This grid can allow the user to estimate the size, location, and height of the signs. If more precise measurements are desired, a return, on-the-ground visit, is required. Usually, this would be desired because the sign material, sheeting, etc., cannot be determined from the video.

Photo-logging Data Collection

Photo-logging, until very recently, meant taking photographs of each sign location, or, more usually, at pre-set distances along a highway route. For example, photographs are taken every 52.8 feet or every 26.4 feet, with a 35 mm motion picture camera modified to take individual frames. Photographs taken in this manner still present many of the same problems as the video-logging. It is time consuming to try to locate a desired image (19).

Recent advancements in technology are now allowing for photo-logging to be done with a digital camera. The images can be transferred directly to a videodisc. These discs have incredibly reduced the space required for storage of the images and other data. They also allow for much easier data retrieval, because now, by knowing either the desired location, or perhaps a sign legend, the computer can locate the desired image (19).

As discussed previously in this chapter, the Connecticut DOT uses a "Videodisc Sign Inventory System." Connecticut spent $463,200 on implementing VSIS in 1994. They spend $60,000 annually to maintain it, and this activity requires seven individuals.

As with traditional video-logging, a return visit to each sign location is usually necessary, in order to get either exact dimensions, sign material, or type of sheeting.

Pen-based Computer Data Collection

Special lap-top computers, generally measuring 10" x 12" x 1" (or even smaller) and weighing less than 5 pounds, can be used by sign crews out in the field. These computers are *pen-based.* That is, the sign data can be entered into these computers with the aid of a special pen and software. These are similar to other pen-based computers (PC notebooks, etc.). Programming is very user-friendly. It is similar to the Windows environment. Objects represent figures on the screen. Action occurs when you touch the pen to the object on the screen, or when you remove the pen. You can enter data by printing on the screen, by checking boxes, or by holding the pen down and scrolling through a list to make a selection. The data form that appears on the screen may look similar to the paper version of the form which it replaces. This familiar looking form can help facilitate the transition to using this new technology by mitigating the normal human aversion to new technological changes (25).

Besides these "lap-top" style of pen-based computers (which may look familiar to us), there are some handheld terminals in existence. These would be similar to those used by parcel delivery drivers and many others in the cargo industry.

The cost of lap-top or pen-based computers is slightly higher than most office PCs. Most are in the $2,000-$5,000 range. CartéGraph, for instance, provides the Kalidor K2100 pen computer for $4,195.

Automated Devices

Automated devices, in use now by some transportation agencies, appear to be the best method in the future. Although there are already many types of automated technology in existence (several of which are described in *Field Data Acquisition Technologies*, by E.J. Jaselskis (25), the principal method that is currently widely available is barcoding. Barcoding is described in more detail later in this chapter, in the section dealing with data storage.

Other emerging technologies such as Radio Frequency Identification (RFID), although not currently used for sign inventorying, are even more promising. RFID is also described in the section on data storage technologies.

Combination of These

Many agencies will probably use a combination of these data collection techniques. For instance (if a sign inventory management system is used), some sign data could be entered manually (handwritten on forms, or on a handheld/lap-top computer in the field), some by bar code readers, and for selected signs, a digitized image can be taken and stored. These systems are very flexible.

Data Storage

Bar Coding

Bar coding involves the use of labels with a self-contained message with information encoded in the widths of black bars and white spaces in a printed manner. Bar coding has achieved wide-spread use all over the world because of its ease of use and its cost-effectiveness. Additionally, bar coding users can expect an error rate of less than one in one million, compared to one error for every 300 characters entered using manual methods (25).

A bar code system requires equipment to read and process the bar coded information, as well as devices to print labels. (Labels can also be purchased through outside suppliers. Most of the system dealers sell the labels. This is discussed later in this report in more detail.) This includes such things as scanners/decoders, symbologies, and printers. There are scanners, or "decoders," available that are handheld, and some exist that have non-contact capabilities between the scanner and the bar code label (25).

The availability of numerous bar code devices and reduced expenses have helped the development and implementation of extensive applications. A single light pen, or wand, and decoder can cost less than $200. More sophisticated scanners can cost between $300 and $1,000. A common solution incorporates hand-held computers, which can cost between $500 and $1,500. Labels obtained from an outside supplier can cost between a few cents each for simple and rudimentary labels to several dollars each for specially designed and unique bar code labels. The most common problems encountered when using bar codes are print quality and label durability. Factors such as dirt, grease, ink spread, fading, and temperature can influence the integrity of the label. Usually, human, and not technical, problems are the most difficult obstacles to overcome. Some of this relates to the lack of knowledge associated with the benefits of using bar codes and also the hesitation towards using new technologies (25).

Radio Frequency Identification

Although not known to be used for sign management by any transportation agencies at this time, some sort of radio identification will quite possibly be the future in inventory management. RFID would have some advantages over other methods such as video-logging and bar code reading. For example, RFID technology allows information detection up to several hundred feet away, and an unblocked "line-of-sight" between the tag and the scanner is not required.

There are two types of tags: "read-only" and "read/write". The "read-only" tags have fixed information encoded that generally cannot be changed. The "read/write" tags can be reprogrammed over the radio frequency link. The "read-only" tags cost about $10 each, and are probably adequate for sign inventory. The "read/write" tags cost as much as $100 each. Portable handheld scanners cost from $1,000 to $4,000 each (25).

Vehicular-mounted Digital Camera Video-logging

A charged coupled device (CCD) records the camera's images digitally and converts to analog data. The data (image) can be stored on a disk, and edited and indexed later back at the office. The primary benefit of digital images is that it allows for much easier retrieval. The images can be indexed, and like other computer files, the specific data desired can be retrieved.

Specific software is necessary in order to index and edit the images stored on the disks. The costs associated with video-logging include $15,000 for a high-resolution camera, $20,000 for a laser disc recorder, $5,000 for an optical laser disc player, and $330 for double-sided laser discs. The cost of a vehicle is also an expense associated with this data collection method (25).

Location Referencing

Global Positioning Systems

Global Positioning System (GPS) is a type of surveying system that uses satellites orbiting the earth to help fix positions of the receiver, to within a high degree of accuracy. The GPS receiver or receivers measure the time it takes for a signal to be received from one of the orbiting satellites. Signals must be received from two or more satellites. This is generally not a problem, as there are dozens of satellites now orbiting the earth at any given time.

The cost of a GPS receiver has fallen rapidly in the last 10 years. At the same time, the accuracy has improved. Receivers start at as little as $200 now; these can fix a position accurately to within only 20 meters or so, but this may be accurate enough for locating a sign. However, the accuracy can vary significantly due to different equipment or location factors. For $15,000, very accurate receivers can be purchased that can fix positions to within a centimeter.

Geographic Information System

Geographic Information System (GIS) is a computerized database mapping system that allows spatial data to be presented in useful and varied ways. GIS can be implemented with or without GPS. GIS systems can be compared to Computer Aided Design (CAD) software, although the GIS systems normally provide much better ways to handle complex data analysis.

GIS software ranges in cost from $500 to $100,000. GIS software is sometimes developed in-house (25).

Vehicular-mounted Distance Measuring Instrument

A vehicle-installed electronic distance measuring instrument (DMI) can be configured with a lap-top computer to conduct highway inventory surveys. These DMIs are accurate to within one foot per mile.

The distance data from the DMI can be used by itself, if a simple location-referencing scheme is used that is based only on distance from a specified beginning point. A number of agencies use that type of referencing at the present time. Location data from the DMI could, however, be corrected and converted into a GIS system.

Laser Distance-measuring Instrument

Laser distance-measuring instruments have been used by some agencies to locate signs precisely. An inventory was conducted in Indianapolis by a two-person team equipped with a notebook PC and a laser distance-measuring instrument. Existing GIS maps of the city were loaded into a notebook computer. One person, equipped with the laser instrument, standing on or near a point of known position, determined the distance, azimuth, and height of the traffic control object. These data were automatically translated to X, Y, and Z coordinates and shown on the notebook computer's screen for verification by the computer operator. Other attributes of the sign can be transmitted over two-way radio to the computer operator. These attributes could be things such as sign type, orientation, condition, sheeting, etc. The cities of Louisville, Kentucky and Cincinnati, Ohio have performed inventories of traffic control devices in a similar fashion (21).

Other Information/Data

There is almost an infinite amount of types of sign information that could be collected and stored for each sign. The agency/user must weigh the usefulness of each category or type of data against the costs required to collect and maintain the data. The following is a partial listing of some of the types of data that can be included in a sign inventory:

- Sign location,
- Position,
- MUTCD sign code,
- Sign legend,
- Maintenance activity performed on sign,
- Inspection date,
- Installation date,
- Sign size,
- Sheeting type,
- Backing type,
- Post/support type,
- Post/support condition,
- Traffic speed,
- Offset (distance from pavement),
- Height,
- Orientation,
- Retroreflectivity,
- Inspector's initials, and
- Comments.

OTHER APPLICATIONS

Tort Defense

An agency with a well-organized traffic control device management program is in a position to defend itself against claims of negligence. The government agency may be able to demonstrate in court that a prioritized systematic effort has been exerted to keep roadways as safe as practical within budgeting limitations by complying with the laws, rules, and standards set forth for traffic control devices (26).

Budgeting/Scheduling

A sign management system may be worth the investment solely for its help in budgeting and scheduling. It can greatly increase the accuracy and efficiency of preparing estimates of upcoming maintenance costs, as well as make the job of ordering signs simpler.

COST ESTIMATES

Software

The basic software costs range from just under $500 to almost $3,000. However, additional software modules are required in order to be able to use bar codes, GPS, etc. Software for a more sophisticated system, then, might cost $2,000 to $4,500. Table V-2 shows a more detailed listing of software prices obtained from the vendors. The prices shown, however, are generally for one site or user. Purchasing for a large number of users should reduce the shown costs by almost half.

Table V-2. Cost Estimates for Systems

Item	CartéGraph	Advanced Data Technologies	Hansen Technologies
Software	$1,195	$2,995	$495
Bar-code software module	195	195	
Base map software module	695	595	
GPS software module	395	295	
Camera software module	195	595	
Pen computer	4,195	---	
Digital camera	1,090		
Bar-code reader	1,764		
GPS receiver	1,595		

Hardware

The hardware costs will include both the costs of the initial computer systems, PCs , etc., plus the costs of peripherals such as bar code readers, GPS receivers, etc. The costs of the peripherals are also shown in Table V-2. An agency likely will already have computer systems/PCs available that will handle the software. If not, the costs of these PCs may range from $2,000 to $3,000 per user location.

Manpower Time

Cost of Initial Inventory

The cost for collecting the initial data for the inventory will vary depending upon the number of signs, the type or categories of data desired, and on the technique used in collecting the data. Other researchers have estimated the cost of developing the initial inventory to range from $4 to $9 per sign, using manual field data collection. For collection using pen-based computers, estimates are in the $3 to $7 range, and $2 to $5 per sign for photolog-assisted data collection (19).

Cost of Maintaining the Inventory

The cost of keeping a sign inventory up to date will vary considerably from agency to agency, depending on the size of the agency, and on its ability to utilize existing personnel to assume these tasks. The ability to shift work assignments and responsibilities may be a key factor in the decision as to whether a sign management system will be implemented.

SUMMARY

The sign management system descriptions and comparisons (and general costs) are largely centered on the assumption of providing software for many (perhaps as many as 300) individual site locations on local PCs. If TxDOT has plans to implement a statewide network, linking every maintenance office and District, with Windows capabilities, this could significantly change the complexion of the sign management system descriptions and possibly the cost, if users can download and share a network version of the software. It appears that most states using a sign management system are NOT sharing a network version; however, with the fast-changing world of computer technology, that possibility should not be overlooked.

Many sign management inventory systems are available to fit the needs of any size of agency. An agency can use the information presented in this chapter to help when trying to decide what options it needs.

CHAPTER VI
ANALYSIS OF REPLACEMENT METHODS

Once the researchers had gathered sufficient data, they began to analyze the cost and other non-economic factors associated with the various sign replacement methods. Various approaches were attempted in the economic analysis. Eventually, the researchers determined that the economic costs should be calculated on a maintenance section basis and that two costs should be calculated, typical annual costs and initial start-up costs. These costs were calculated for each of the potential sign replacement methods and alternatives of each method. Table VI-1 describes the replacement methods that were analyzed in the economic model. A more detailed description of the methods is provided in Appendix F. Once the typical annual and initial start-up costs were determined, these were converted to an equivalent annual payment over two different periods. One equivalent annual payment represents the cost over the typical service life of a sign (for example, nine years). The other equivalent annual payment represents the cost over twice the typical sign service life (for example, eighteen years). The equivalent annual payments for one and two sign life cycles were compared to determine the relative cost-effectiveness of the various replacement methods and alternatives. Finally, the researchers identified the key issues associated with each method that were not quantified in the economic model.

DEVELOPMENT OF ECONOMIC ANALYSIS MODEL

The following paragraphs describe some of the specific aspects of the economic model and the methods used to calculate and compare the economic costs of the different methods. Appendix G presents the spreadsheets that represent the entire model.

Model Structure

The economic analysis model was set up in a three dimensional spreadsheet using Microsoft Excel. There are 10 sheets in the overall model. These are described in Table VI-2. The first sheet (Summary of Economic Analysis) places the calculated costs for each method on a single sheet and uses those costs to determine the equivalent annual payment for each method. The next three sheets (Economic Cost Factors, Quantitative Calculations, and Sign Replacement Rates) establish the economic and quantitative variables that were used to calculate the costs for each method. The actual costs for each method are calculated in the remaining six sheets (Total Replacement Method - Replacement by State Forces, Sign Inspection Method - Replacement by State Forces, Sign Management Method - Replacement by State Forces, Total Replacement Method - Replacement by Contract Forces, Sign Inspection Method - Replacement by Contract Forces, and Sign Management Method - Replacement by Contract Forces). The costs are calculated for a maintenance section. Statewide values are calculated by multiplying by the number of maintenance sections (283). For each method, the following costs were calculated:

- **Typical Annual Costs** - The typical annual costs, in 1996 dollars, for replacing signs based on retroreflectivity. This cost does not include the cost for normal (non-retroreflectivity replacement) sign maintenance activities.

Table VI-1. Description of Sign Replacement Methods Evaluated in Economic Analysis

Name of Method	Sign Replacement Performed by	Economic Calculations	General Description
Total Replacement Method	TxDOT forces	Page G-13	The highway system is divided into sections. All signs on a given section of highway are replaced at regular, predefined, time intervals. All signs are replaced, regardless of whether they meet the minimum value and how long they have been in the field. Sign replacement can be performed by TxDOT or contract forces.
	Contract forces	Page G-21	
Sign Inspection Method	TxDOT forces	Page G-15	The minimum retroreflectivity of signs are inspected at predetermined intervals. The initial inspection is visual, but questionable signs are measured. Those that do not meet the minimum value are scheduled for replacement. Sign replacement can be performed by TxDOT or contract forces.
	Contract forces	Page G-23	
Sign Management Method	TxDOT forces	Page G-18	A sign management/inventory system is used to track key sign characteristics. This information is used by the system to predict when the sign retroreflectivity will fall below the minimum value and schedule sign replacement. Sign replacement can be performed by TxDOT or contract forces.
	Contract forces	Page G-23	
Combination Total Replacement and Sign Management Methods	TxDOT forces	Calculations based on results from G-13 and G-18 and shown on G-4	The total replacement method is used until all signs on the system have been replaced once. As the signs are replaced, they are added to the sign management system. Once all the signs have been added to the management system, the sign management method is used to identify signs below the minimum values. Sign replacement performed by TxDOT forces.

Table VI-2. Organization of Economic Model

Sheet	Description of Content	Content	Appendix Pages
Summary of Economic Analysis	Summarizes the costs calculated for each method for a maintenance section and statewide. Costs converted to equivalent annual payment for one and two cycles for each method.	Typical Annual Costs Initial Start-Up Costs Additional FTE Needs Equivalent Annual Payment (for 1 and 2 cycles)	G-3
Economic Cost Factors	Defines the variables used in the model that have an economic value that can be assigned to the variable.	Financial Factors Personnel Costs Vehicular Costs Sign Material Costs Equipment Costs Shipping Costs Contract Costs Training Costs	G-5
Quantitative Calculations	Defines non-economic factors that are used to establish quantities for various activities.	TxDOT Organization Highway Mileage Sign Quantities Personnel and Productivity	G-8
Sign Replacement Rates	Defines the number and/or percentages of signs that are expected to be replaced with each method. Salvage/recycle factors are provided for each method.	Current TxDOT Practice Total Replacement Method Sign Inspection Method Sign Management Method	G-11
Total Replacement Method - Replacement by State Forces	Calculates the economic costs of each replacement method using the economic costs factors, quantitative calculations, and sign replacement rates established in the previous sheets.	**For Each Method:** Typical Annual Costs Initial Start-Up Costs Increased Replacement Rates Additional FTE Needs General Description	G-13
Sign Inspection Method - Replacement by State Forces			G-15
Sign Management Method - Replacement by State Forces			G-18
Total Replacement Method - Replacement by Contract Forces		**For Each Method:** Typical Annual Costs Initial Start-Up Costs Total Value of Contracts Increased Replacement Rates Additional FTE Needs General Description	G-21
Sign Inspection Method - Replacement by Contract Forces			G-23
Sign Management Method - Replacement by Contract Forces			G-25

- **Initial Start-up Costs** - This is the cost, in 1996 dollars, that would be required during the first year to meet the equipment, software, hardware, training, or other requirements needed to begin a specific replacement method.
- **Increased Replacement Rates** - This is a ratio indicating the increase in the number of total sign replacement (retroreflectivity and non-retroreflectivity replacements) over current replacement levels.
- **Additional FTE Needs** - This is an estimate of the additional number of full-time equivalents (FTE) that will be needed to implement a given sign replacement method.

Calculations

The following equations indicate how the key values of the analysis are calculated. For most of the values in the individual sheets in Appendix G, the variables that were used to calculate a number are indicated in the notes for that row.

$$\textit{Statewide Typical [Initial] Costs} = \frac{\textit{Typical [Initial] Costs}}{\textit{Maintenance Section}} \times 283 \textit{ Maintenance Sections}$$

$$\textit{Increased Sign Replacement Rate} = \frac{\textit{Current Non-Reflex Replacements} + \textit{Expected Reflex Replacements}}{\textit{Current Total Replacements}}$$

$$\textit{Additional FTEs} = \frac{\textit{Additional annual hours}}{2{,}080 \textit{ hours/year}}$$

$$\textit{Current Non-Reflex Replacement Budget} = \textit{Current Sign Maintenance Budget} \times \frac{\textit{Current Non-Reflex Sign Replacement}}{\textit{Current Total Sign Replacement}}$$

$$\textit{Annual Sign Maintenance Budget} = \textit{Current Non-Reflex Replacement Budget} + \textit{Expected Reflex Replacement Budget}$$

The Equivalent Annual Payment was calculated by adding the equivalent annual payments for the Annual Sign Maintenance Budget with an annual rate of increase and the Initial Start-Up Costs converted from a single payment. This is illustrated in Figure VI-1.

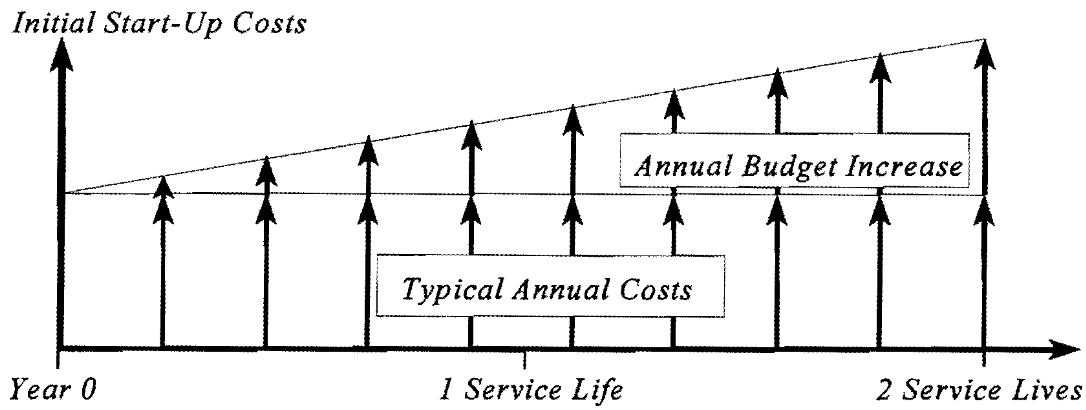

Figure VI-1. Calculation of Equivalent Annual Payment

Variables and Assumptions

As indicated earlier, the second through fourth sheets of the model defined the variables that were used to calculate the costs for each method. These variables were divided and subdivided among the three sheets as indicated in Table VI-2. The values that were used for these variables came from a variety of sources. Generally, the source of a variable is indicated in the spreadsheet in Appendix G. For several of the variables, no accurate information was available. In these cases, the researchers developed their best assumption for the variable. These assumptions are also indicated in the spreadsheet. It should be noted that not every variable was used in calculating the costs for each method. In some cases, a variable may have been initially used in costs calculations, but later dropped as the economic model was refined.

There are a few variables that were key elements in the model, but for which no reliable information could be found. The most significant of these are the number of signs on the TxDOT system and the average size of these signs. Other important, but largely elusive factors include the current replacement rate based on retroreflectivity, the service life, the accuracy of the sign management system in predicting end of service life, and a few other variables.

Number of TxDOT Signs

A key element of the analysis is the number of signs on the state highway system. TxDOT does not have any data that allow for an accurate count of the signs under its jurisdiction. For this analysis, the number of TxDOT signs was estimated to be 2,324,756. This estimate is based on urban and rural sign density information obtained from an NCHRP (7) (urban - 29 signs/centerline mile, rural - 11 signs/centerline mile) and multiplied by the urban and rural centerline mileage in Texas. The researchers believe that this is the best estimate that can be developed based on the available information.

As a point of comparison, the researchers made their own count of sign density along some highways in Brazos County and neighboring areas. This windshield count revealed an urban density of 25 signs/centerline mile and a rural density of 7 signs/centerline mile. Using these numbers, the total number of TxDOT signs would be 1,684,996.

As described in a previous chapter, the first question of the TxDOT district survey asked respondents to identify the approximate number of signs in their district. The responses varied from 1,000 to 1,000,000. Only 55 percent of the survey respondents answered this question. Of this 55 percent, 78 percent of the answers were estimates that are not based on documentation. The other 22 percent, or 16 of the 126 survey respondents, gave estimates that were based on data or documentation. These estimates are provided in Table III-11.

Based on the various numbers available to the researchers, the total number of TxDOT signs could be anywhere from 1.5 to 6 million. Given the precision of these estimates, it would not be unreasonable to expect that the total number of signs could be over 10 million. At the other extreme, is it unlikely that the total number of signs would be much less than 1.5 million. Because of the uncertainty over the number of TxDOT signs, the economic analysis was performed for the following estimates of the number of signs: 1.5 million, 2.32 million, and 6.0 million.

Average Sign Size

The researchers were not able to identify any data that indicated a value that could be used to determine the average TxDOT sign size. TxDOT has used values of 9 to 12 square feet in previous budget calculations. The Washington State DOT was the only state DOT identified that included sign size as part of its sign inventory system. The average size of the signs in its system is 15.6 square feet, although this includes freeway guide signs. Because overhead guide signs have been dropped from the minimum retroreflectivity framework, the researchers decided that 9 square feet represents the best estimate of the average sign size. However, the analysis was conducted for both 9 and 12 square feet.

Current Sign Replacement Rates

TxDOT does not maintain accurate records on the number of signs that are replaced each year and the reasons the signs are replaced. The total number of signs replaced each year and the percentage of signs that are replaced due to inadequate retroreflectivity are important for the following reasons.

- The total number of signs replaced each year is needed to determine the annual replacement rate.
- The number of signs that are replaced annually due to reasons other than retroreflectivity was needed to calculate the portion of the current sign maintenance budget that supports non-retroreflectivity signing activities.
- The number of signs that are replaced annually due to retroreflectivity reasons was needed in order to calculate the increase in retroreflectivity-based sign replacements.

In a perfect world, where signs last until the retroreflectivity falls below the minimum level, the percentage of signs replaced each year would be the inverse of the service life, that is, if the service life is 9 years, 11 percent (1/9) of the signs would be replaced each year. However, the researchers estimate that only about 8 percent of TxDOT signs are replaced each year. Three different sources of information provided information on the square footage of annual signing replacement. Bid data from the General Services Division indicate that an average of about 1.6 million square feet of sign were purchased annually over the last three years. In the previous year, the prison sign shop that provides most of TxDOT's signs produced about 1.4 million square feet. Finally, TxDOT's MMIS indicated that about 1.1 million square feet of signs were replaced last year. The sign replacement rate was determined by using 9 square feet as the average sign size to calculate the number of signs replaced, and dividing by the total number of signs on the TxDOT system (which is based on sign density and centerline miles). For the analysis, the researchers evaluated a range of replacement rates between 5 and 14 percent.

Service Life

Chapter IV describes the many issues associated with the service life of sign sheeting and the researchers' attempts to determine an accurate service life for use in the analysis. The researchers found that TxDOT does not have accurate data that allow the service life to be evaluated and that TxDOT has not generally been using high intensity signs long enough to determine the service life of this type of sheeting. For the analysis, the researchers evaluated service lives of 7, 9, and 15 years.

Accuracy of the Sign Management System

The sign inspection method is considered the most accurate because only those signs which fail the measurement are actually replaced. The sign management method was considered the next most accurate, but there are no data to indicate the precision of the predictive algorithms in the sign management systems, as they have not been widely used to date. The researchers' best estimate is that the sign management method would lead to about a 10 percent higher replacement level than the sign inspection method. However, the analysis was conducted for 0, 10, and 20 percent higher replacement levels.

Other Uncertain Items

The researchers found several other variables for which no accurate information could be provided or documentation could not be obtained. These variables are described below.

- **Annual sign maintenance budget** - The Project Director for this research project indicated that TxDOT's annual sign maintenance budget was about $27 million, but no documentation could be obtained.
- **Annual sign budget increase** - The researchers were not able to identify the annual increase that could be expected in the sign maintenance budget. A value of 4 percent per year was used for the analysis.
- **TxDOT salary/wage information** - The district survey included a question on the hourly wage of several TxDOT personnel involved in signing operations. As the model developed, however, a couple of positions were added that were not addressed in the

survey. TxDOT was not able to provide hourly rates for a Maintenance Supervisor or Administrative/Clerical position. The researchers used $17.00/hour and $11.00/hour, respectively, in the analysis.

- **Vehicle costs** - No information was provided that could be used to calculate dollar/mile costs for a sign pickup truck/car, or a sign truck. The researchers used $0.50/mile and $1.50/mile, respectively, in the analysis.
- **Costs of sign hardware** - The researchers were not able to obtain information on the cost of hardware that would be used in replacing a sign. For the analysis, the researchers used $0.25/sign.
- **Shipping costs** - The researchers were not able to obtain information on the cost of shipping signs from the regional warehouses to the districts and from the districts to the maintenance sections. The researchers used a value of $0.005/square foot of sign/mile between the warehouse and district and a value of $0.0025/square foot/mile between the district and the maintenance section.
- **Ratio of sign substrates that can be recycled** - In discussions with TxDOT personnel, the researchers determined that TxDOT does not recycle a large percentage of sign substrates, for a variety of reasons. No data could be identified or obtained that indicate the percentage of sign substrates that could be recycled. For the analysis, a value of 25 percent was used.
- **Recycle value of sign substrate** - In addition to the percentage of recycled substrates, the researchers were not able to determine the economic value of the recycled substrates. A value of $0.50/square foot was assumed.
- **Personnel productivity** - The researchers used the survey results, combined with the information obtained from discussions with TxDOT personnel, to develop the values shown in Table VI-3 for variables associated with signing personnel.

Table VI-3. Analysis Assumptions for Signing Personnel Variables

Variable	Unit	Value Used
Number of sign technicians per maintenance section	each	3.7
Number of people in district sign shop	each	4.3
Sign tech - typical daily time in field	hour/day	6
Sign tech - typical hours for nighttime inspection	hour/night	3
Making sign list - manually	signs/hour	12
Prepare sign order forms	signs/hour	12
Making sign list - pen computer	signs/hour	24
Replacing signs	signs/hour	2
Fabricating signs	sf/hour	30
Nighttime visual inspection	signs/hour	30
Measured inspection - field	signs/hour	6
Measured inspection - sign shop	signs/hour	30
Sign tech - maintaining sign database in field	minutes/sign	10
Administrative/Clerical - maintaining sign database in office	minutes/sign	5
Creating new sign database	signs/hour	6
Prepare sign replacement contract documents	signs/hour	20
Annual hours per FTE	hour	2,080

RESULTS OF ECONOMIC ANALYSIS

Once the economic model had been set up, the researchers analyzed a variety of conditions to assess the overall economic impacts of the various replacement methods. For each set of conditions, the model calculated the equivalent annual payment for one and two cycles (sheeting service life), ranked the methods from lowest to highest annual payment, calculated the percentage increase in the annual payment compared to the annual payment for current sign maintenance budget, and calculated the increase in FTEs needed to implement a replacement method.

After analyzing the replacement costs for a variety of parameters, the researchers identified three scenarios to include in this report, as described below. The differences in these scenarios are the values that are used for the most critical and unknown of the model's variables. The variables that were changed between scenarios include the total number of signs on the TxDOT system, the annual replacement rate for signs, the average sign size, the service life, and the accuracy of the sign management method. For each of the three scenarios, the researchers calculated costs for three different estimates of signs quantities: best estimate (2.32 million signs), high signs (6.00 million signs), and low signs (1.50 million signs).

- **Best Estimate** - Based on the researcher's best estimate of the key variables used in the analysis.
- **Best Case** - Based on the key variables that provide the lowest annual payment.
- **Worst Case** - Based on the key variables that provide the highest annual payment.

Tables VI-4, VI-5, and VI-6 present the results for these three scenarios and combinations of sign estimates. In almost all cases, the researchers found that the sign management and sign inspection methods were the most cost-effective of those analyzed. In these tables, the annual payments are displayed to the nearest $0.1 million. However, the rankings are based on payments to the nearest $1. Therefore, two methods can show the same cost (to the nearest $0.1 million), but one is ranked as having a lower cost.

Generally, the difference in equivalent annual payment for these two methods was less than $2 million. However, the sign management system always had a lower FTE increase, compared to the sign inspection method. The cost-effectiveness of the sign management method also increases as the total number of signs increase. Table VI-7 summarizes the single cycle annual payment, percent increase, and FTE increase for these two methods.

The single-cycle payment is used as the basis of comparison, as the researchers believe that it provides a more accurate representation of the costs. The researchers did not account for the replacing sign equipment (trucks, facilities, computers) within the model, as most equipment will last as long as the service life of sheeting. However, over the course of two service lives, it is likely that TxDOT will need to purchase equipment to support signing operations.

Table VI-4. Results for Best Estimate of Signing Parameters

Scenario	No. of Signs	Ann. Sign Repl.	Avg. Sign Size	Service Life	Mgmt. Accur.	Condition	Units	Replacement by State Forces: Total	Replacement by State Forces: Inspect	Replacement by State Forces: Mgmt	Replacement by State Forces: Combin	Replacement by Contract Forces: Total	Replacement by Contract Forces: Inspect	Replacement by Contract Forces: Mgmt
Best Estimate of All Signing Parameters Except Number of Signs Low Sign Estimate	1.50	8	9	9	10	Ann. Pymt 1 Cycle	$ million	$38.4	$32.4	$32.8	N/A	$64.6	$44.6	$47.1
						Rank	number	3	1	2	N/A	6	4	5
						% over Current[1]	percent	25%	5%	7%	N/A	110%	45%	53%
						Ann. Pymt 2 Cycles	$ million	$42.4	$34.8	$34.3	$37.4	$71.2	$46.7	$48.3
						Rank	number	4	2	1	3	7	5	6
						% over Current[2]	percent	25%	3%	1%	10%	110%	38%	42%
						FTE Increase	number	64	70	48	N/A	11	51	30
Best Estimate of All Signing Parameters	2.32	8	9	9	10	Ann. Pymt 1 Cycle	$ million	$47.3	$37.7	$37.7	N/A	$87.8	$56.6	$59.7
						Rank	number	3	1	2	N/A	6	4	5
						% over Current[1]	percent	54%	22%	22%	N/A	185%	84%	94%
						Ann. Pymt 2 Cycles	$ million	$52.1	$40.1	$39.0	$45.2	$96.8	$58.5	$60.6
						Rank	number	4	2	1	3	7	5	6
						% over Current[2]	percent	54%	18%	15%	33%	185%	72%	78%
						FTE Increase	number	100	103	66	N/A	17	74	37
Best Estimate of All Signing Parameters Except Number of Signs High Sign Estimate	6.00	8	9	9	10	Ann. Pymt 1 Cycle	$ million	$87.0	$61.1	$59.3	N/A	$191.8	$110.3	$116.3
						Rank	number	3	2	1	N/A	6	4	5
						% over Current[1]	percent	183%	99%	93%	N/A	524%	259%	278%
						Ann. Pymt 2 Cycles	$ million	$95.9	$63.8	$59.7	$79.9	$211.6	$111.7	$115.6
						Rank	number	4	2	1	3	7	5	6
						% over Current[2]	percent	183%	88%	76%	135%	524%	229%	241%
						FTE Increase	number	257	252	146	N/A	43	177	73

Notes: [1]One cycle equivalent annual payment for current practice = $30,748,977.
[2]Two cycle equivalent annual payment for current practice = $33,931,236.

Table VI-5. Results for Best Case Scenario of Signing Parameters

Scenario	No. of Signs	Ann. Sign Repl.	Avg. Sign Size	Service Life	Mgmt. Accur.	Condition	Units	Replacement by State Forces				Replacement by Contract Forces		
								Total	Inspect	Mgmt	Combin	Total	Inspect	Mgmt
Best Case Scenario of All Signing Parameters Except Number of Signs Low Sign Estimate	1.50	14	9	15	0	Ann. Pymt 1 Cycle	$ million	$34.9	$34.0	$33.6	N/A	$51.9	$45.8	$46.4
						Rank	number	3	2	1	N/A	6	4	5
						% over Current[1]	percent	6%	3%	2%	N/A	57%	39%	41%
						Ann. Pymt 2 Cycles	$ million	$38.9	$37.3	$36.3	$33.5	$57.8	$49.5	$49.6
						Rank	number	4	3	2	1	7	5	6
						% over Current[2]	percent	6%	2%	-1%	-9%	57%	35%	35%
						FTE Increase	number	39	70	53	N/A	6	51	37
Best Case Scenario of All Signing Parameters Except Number of Signs Typical Sign Estimate	2.32	14	9	15	0	Ann. Pymt 1 Cycle	$ million	$41.0	$39.3	$38.1	N/A	$67.3	$57.6	$58.0
						Rank	number	3	2	1	N/A	6	4	5
						% over Current[1]	percent	24%	19%	15%	N/A	104%	75%	76%
						Ann. Pymt 2 Cycles	$ million	$45.6	$42.9	$40.9	$39.0	$74.9	$61.8	$61.5
						Rank	number	4	3	2	1	7	6	5
						% over Current[2]	percent	24%	17%	11%	6%	104%	68%	67%
						FTE Increase	number	60	103	74	N/A	10	74	49
Best Case Scenario of All Signing Parameters Except Number of Signs High Sign Estimate	6.00	14	9	15	0	Ann. Pymt 1 Cycle	$ million	$68.3	$62.7	$58.4	N/A	$136.2	$110.4	$110.1
						Rank	number	3	2	1	N/A	6	5	4
						% over Current[1]	percent	107%	90%	77%	N/A	313%	235%	234%
						Ann. Pymt 2 Cycles	$ million	$76.0	$67.8	$61.6	$64.0	$151.7	$117.1	$115.1
						Rank	number	4	3	1	2	7	6	5
						% over Current[2]	percent	107%	85%	68%	74%	313%	219%	213%
						FTE Increase	number	154	252	169	N/A	26	177	103

Notes: [1]One cycle equivalent annual payment for current practice = $32,984,793.
[2]Two cycle equivalent annual payment for current practice = $36,734,691.

Table VI-6. Results for Worst Case Scenario of Signing Parameters

Scenario	No. of Signs	Ann. Sign Repl.	Avg. Sign Size	Service Life	Mgmt. Accur.	Condition	Units	Replacement by State Forces				Replacement by Contract Forces		
								Total	Inspect	Mgmt	Combin	Total	Inspect	Mgmt
Worst Case Scenario of All Signing Parameters Except Number of Signs Low Sign Estimate	1.50	5	12	7	20	Ann. Pymt 1 Cycle	$ million	$46.3	$34.0	$35.4	N/A	$74.3	$44.7	$48.9
						Rank	number	4	1	2	N/A	6	3	5
						% over Current[1]	percent	55%	14%	18%	N/A	148%	50%	64%
						Ann. Pymt 2 Cycles	$ million	$50.5	$35.6	$36.0	$44.6	$81.0	$45.6	$48.8
						Rank	number	6	1	2	3	7	4	5
						% over Current[2]	percent	55%	9%	10%	37%	148%	40%	49%
						FTE Increase	number	87	71	47	N/A	14	51	26
Worst Case Scenario of All Signing Parameters Except Number of Signs Typical Sign Estimate	2.32	5	12	7	20	Ann. Pymt 1 Cycle	$ million	$59.7	$40.3	$41.8	N/A	$103.1	$57.1	$62.7
						Rank	number	4	1	2	N/A	6	3	5
						% over Current[1]	percent	100%	35%	40%	N/A	245%	91%	110%
						Ann. Pymt 2 Cycles	$ million	$65.2	$41.8	$41.9	$56.2	$112.5	$57.3	$61.7
						Rank	number	6	1	2	3	7	4	5
						% over Current[2]	percent	100%	28%	28%	72%	245%	76%	89%
						FTE Increase	number	135	105	65	N/A	21	74	32
Worst Case Scenario of All Signing Parameters Except Number of Signs High Sign Estimate	6.00	5	12	7	20	Ann. Pymt 1 Cycle	$ million	$120.1	$69.0	$70.7	N/A	$232.3	$112.4	$124.6
						Rank	number	4	1	2	N/A	6	3	5
						% over Current[1]	percent	302%	131%	136%	N/A	677%	276%	317%
						Ann. Pymt 2 Cycles	$ million	$131.1	$69.6	$68.7	$108.4	$253.6	$110.1	$120.0
						Rank	number	6	2	1	3	7	4	5
						% over Current[2]	percent	301%	113%	110%	232%	677%	237%	268%
						FTE Increase	number	350	257	145	N/A	55	177	59

Notes: [1]One cycle equivalent annual payment for current practice = $29,896,320.
[2]Two cycle equivalent annual payment for current practice = $32,644,648.

Table VI-7. Comparison of Sign Inspection and Sign Management Methods

Scenario	Sign Estimate	Sign Inspection Method			Sign Management Method		
		Equivalent Annual Payment[1]	Percent over Current Method[2]	FTE Increase	Equivalent Annual Payment[1]	Percent over Current Method[2]	FTE Increase
Best Estimate	Low	32.4	5	70	32.8	7	48
	Best	37.7	22	103	37.7	22	66
	High	61.1	99	252	59.3	93	146
Best Case	Low	34.0	3	70	33.6	2	53
	Best	39.3	19	103	38.1	15	74
	High	62.7	90	252	58.4	77	169
Worst Case	Low	34.0	14	70	35.4	18	47
	Best	40.3	35	105	41.8	40	65
	High	69.0	131	257	70.7	136	145

Notes: [1]Single cycle payment (9 years for best estimate, 15 years for best case, and 7 years for worst case)
[2]Equivalent Annual Payment for current practice = $30.7 million for best estimate, $33.0 million for best case, and $29.9 million for worst case

ASSESSMENT OF NON-ECONOMIC ISSUES

The primary focus of this research project was an evaluation of the cost-effectiveness of the various sign replacement methods. However, in the course of gathering information and conducting the economic analysis, the researchers identified numerous non-economic factors associated with the each method that could affect TxDOT's implementation of that method.

There are several issues where the differences between the methods are significant. Table VI-8 provides a relative comparison of these issues. The following discussions elaborate on some of these differences and describe some of the key issues associated with each method.

Table VI-8. Relative Comparison of Sign Replacement Methods

Sign Replacement Consideration	By State Forces			By Contract Forces		
	Total Replacement	Sign Inspection	Sign Management	Total Replacement	Sign Inspection	Sign Management
Quantity of signs replaced	High	Low	Low	High	Low	Low
Probability of replacing bad signs	High	High	Moderate	High	High	High
Probability of replacing good signs	High	Low	Moderate	High	Low	Moderate
Additional FTEs required	High	Moderate	Moderate	Low	Moderate	Moderate
Amount of travel	Moderate	High	Low	Moderate	Moderate	Low
Value of contracts	Low	Low	Low	High	Moderate	Moderate
Documentation of minimum values	Low	Moderate	High	Low	Moderate	High
Ability to plan sign replacements	Low	Low	High	Low	Low	High

Total Replacement Method

The advantage of the Total Replacement Method is its simplicity. It has the lowest administrative requirements, as there is no need to keep track of individual signs or to conduct sign retroreflectivity inspections. At the beginning of the project, the thought was that this method might prove to be the most cost-effective because of the reduced administrative activities. However, the complicating factor in this method is that, to replace the signs, it is necessary to have a list of the signs to be replaced. This list is needed regardless of whether the replacements are performed by state or contract forces. In this analysis, it was assumed that this list would be developed for each replacement cycle. Therefore, there are still two trips to the field (one to make the list, another to replace the sign).

Other complicating factors for the Total Replacement Method include:

- Only one service life can be used to represent all signs.
- Replaced signs that have significant remaining life will need to be salvaged for later use. This requires an evaluation procedure and a method for warehousing the signs until they are used.
- Current visual inspections must continue to identify sign damage due to vandalism, accidents, or other factors.

In comparison to the one advantage, there are several disadvantages to this method:

- It has the highest quantity of sign replacements.
- The method does not maximize sign life to its fullest. As a result, there is significant sign wastage.
- It would be difficult to budget sign replacement activities, due to uncertainty over the number of signs in a given replacement section.

Sign Inspection Method

The biggest advantage of the Sign Inspection Method is that it has the lowest level of sign replacement and sign wastage. Only those signs whose actual measured retroreflectivity is below the minimum retroreflectivity values are replaced. Therefore, it maximizes sign life. It is also the closest to current TxDOT sign replacement activities. At the start of the project, it was believed that the inspection procedure would require a measurement of each sign. However, the FHWA has indicated that visual inspections can be used as an initial screening tool. That makes this method the most similar to current TxDOT practice, with two significant differences. Questionable signs would be measured with a retroreflectometer, and training would be needed to ensure consistency in the inspections.

The most significant of the disadvantages for this method include:

- Sign inspectors will require training to ensure that the minimum retroreflectivity values are consistently applied. This training must be conducted initially for all sign inspection personnel and at regular intervals to maintain inspection consistency. The training should address both visual and measured inspections.
- Some form of documentation is required in order to identify signs that need to be measured and those that need to be replaced.

Finally, another important disadvantage is the difficulty of using test patches for the inspections. As shown in Appendix A, the minimum retroreflectivity value for a sign of a given color is a function of several different factors. A set of test patches that represents all the possible values would have 44 different patches. Unless the minimum values are modified so that the lowest value is used for all signs of a given color, test patches have limited application.

Sign Management Method

The Sign Management Method, in which all signs are tracked in a computerized sign management/inventory system, provides the greatest number of benefits to the user. It minimizes the number of trips into the field, as the only trip needed is the sign replacement trip. It provides the capability to program sign replacement activities in advance, assisting in the budgeting process. It also provides a means of tracking various aspects of signing operation, such as common sign maintenance activities, most common maintenance problems, most common reasons for sign replacements, and compliance with criteria like mounting height. Its greatest benefit is that it provides a record of all signing activities. The information that can be obtained from a sign management system can be used to evaluate and improve overall signing operations by increasing efficiency in a number of areas. These records can also be used by an agency to assist in defending tort claims.

The paperless aspect of the system also offers many advantages. Eliminating paper improves efficiency at all levels, promotes keeping the database up to date, and makes it easier for field crews to record their actions.

As the system evolves, the accuracy of the predictive algorithm can be improved as a result of being able to track performance of signs. To maximize this capability, the retroreflectivity of a small sample of signs should be measured each year to provide benchmark data for predicting sign life. Retroreflectivity projections are only now becoming a part of sign management systems, their development being prompted by FHWA's minimum retroreflectivity values. Therefore, the accuracy of the algorithms at predicting end of service life is unknown.

There are some disadvantages to the Sign Management Method. These include:

- It requires a significant initial purchase of software and hardware to put the system in place.
- A database of signs must be created.
- The database must be maintained on a daily basis to remain accurate.

CHAPTER VII
FINDINGS AND RECOMMENDATIONS

Traffic signs are a vital element of the highway and street network because they provide an essential means of communicating information to drivers. As such, signs must be able to function effectively in both daylight and darkness. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires that signs be retroreflectorized or illuminated to show the same shape and color during both daytime and nighttime conditions. To meet this requirement, almost all signs are fabricated from retroreflective sheeting. There are several different types of retroreflective sheeting, with differences in design, brightness, angularity, cost, and service life. While modern retroreflective sheeting can last anywhere from 7 to 15 years in the field, all sheeting eventually loses its ability to reflect light back to the originating source. Although there are specifications to determine whether new sheeting is acceptable, there are not any specifications, requirements, or guidelines to determine when a sign has reached the end of its service life.

Over the last decade, the Federal Highway Administration (FHWA) has been working to develop minimum retroreflective performance requirements for signs and pavement markings. The formal process began in 1985, when the FHWA published an advance notice of proposed amendments to the MUTCD in the *Federal Register* to solicit comments on the development of minimum values of retroreflectivity for traffic signs and pavement markings. The next formal action was Congressional legislation in the 1992 U.S. DOT Appropriations Act. In this act, Congress required the MUTCD to be revised to include "*a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs which apply to all roads open to public travel*" (4). In 1993, the FHWA published proposed minimum levels of retroreflectivity for traffic signs. Since that time, the FHWA has been evaluating the impact that minimum retroreflectivity values for signs would have on the responsible agencies. The next rulemaking, which is expected to take place in late 1996 or early 1997, is expected to propose revised minimum values and request comment on those values and the proposed means of implementing the values. Appendix A presents both the originally proposed values and those values expected to be proposed in the next rulemaking. The expected values are subject to change before rulemaking begins.

The minimum values proposed in 1993 are in the form of four tables for different colors (yellow/orange background, white background, white legend on red background, and white legend on green background). For any given sign color, the minimum value is a function of several different factors such as sign size, sign material, speed of the roadway, sign placement, and/or type of legend.

National evaluations of the originally proposed values found that about 5 percent of existing signs did not meet the minimum values for all colors except red and green, which had failure rates of about 8 and 13 percent, respectively. Although specific values have not yet been proposed in rulemaking, the researchers believe that the minimum values that will be proposed in rulemaking will be essentially similar to the 1993 values, except that the white on red values will be reduced. The researchers also expect one other significant change in the upcoming rulemaking. Although the 1992 Congressional legislation required the FHWA to develop minimum standards (requirements) for retroreflective, the researchers expect that the rulemaking will propose the minimum values as recommendations (guidelines), and not a mandatory requirement.

A one-year research project, conducted for the Texas Department of Transportation (TxDOT) by the Texas Transportation Institute (TTI), was initiated to investigate the impact of minimum values of retroreflectivity on TxDOT's signing operations. The project goal was to determine the most effective method that will best allow TxDOT to comply with the minimum retroreflectivity values and to identify the key issues that affect implementation of alternative sign replacement methods. The project did not include an evaluation of the appropriateness of the values themselves. As part of this research project, TTI conducted numerous information gathering and analysis activities, including surveys of TxDOT signing operations and sign replacement practices in other states, investigation into sign services life, assessment of sign management/inventory system capabilities, and analysis of various factors expected to impact the implementation of various sign replacement methods that might be used to comply with the minimum retroreflectivity values. As a result of these activities, the researchers have developed the following findings and recommendations relative to various sign replacement methods.

RESEARCH FINDINGS

As a result of the activities conducted for this project, the researchers have developed the following findings or conclusions.

Minimum Sign Retroreflectivity Values

The FHWA proposed minimum retroreflectivity values for signs in a 1993 research report. Since that time, the FHWA has been assessing the impacts of the minimum values upon other agencies and preparing for further rulemaking on the subject.

- **Framework of minimum values.** The minimum retroreflectivity values proposed by the FHWA in 1993 were contained in a framework of four tables, each table addressing a different sign color combination (yellow/orange, white, white on red, and white on green). The minimum value for any given sign is a function of many different variables, including sign color, sign size, type of sheeting, sign placement, and road speed. As a result, there is not a single minimum value of retroreflectivity that can be applied to a large group of signs. Instead, the minimum value will vary from one sign installation to the next, depending upon the variables present in any single sign. Any given sign would fall somewhere within the framework of 71 different minimum values.
- **Measurement of sign retroreflectivity.** In past, the majority of retroreflectivity measurements were done in labs on samples of new sheeting to ensure the sheeting met the purchase specification. The minimum retroreflectivity values will require the ability to measure sign retroreflectivity in the field.
  - At the present time, there is only one instrument that is capable of measuring retroreflectivity in field conditions, although another instrument will soon become available. Both instruments require contact with the face of the sign. The FHWA has developed a prototype mobile retroreflectometer vehicle that allows measurements to be made on the fly. This vehicle is not yet available as a production unit.

- For many years, agencies and inspectors have used test patches to determine whether a sign has sufficient retroreflectivity. With the current framework, an inspector would need a test patch kit with 4 green patches, 6 red patches, 11 yellow/orange patches, and 23 white patches.
- There is no indication that the minimum retroreflectivity values will require a measured retroreflectivity for every sign. As a result, a visual inspection may be sufficient to identify signs that are obviously above the minimum values.

- **Rulemaking on minimum retroreflectivity values.** FHWA will initiate rulemaking on minimum retroreflectivity values for signs in the near future. This rulemaking will be published in the *Federal Register*. Unknown elements of the rulemaking are listed below.
  - When the *Federal Register* notice will be published. The researchers expect the notice to be published in late 1996 or early 1997.
  - The form of rulemaking (advance notice, notice, and/or request for comments). By its very nature, the rulemaking will provide an opportunity for the public to comment on the minimum values. It is uncertain whether the rulemaking will be an advance notice or notice. The 1985 *Federal Register* notice was an advance notice, which means the next rulemaking could be a notice of proposed rulemaking. This could be followed by a final rule or another notice of proposed rulemaking. However, due to the potential impacts of the subject matter, the rulemaking may be issued as another advance notice, which would need to be followed by a notice of rulemaking in the *Federal Register* before a final rule could be issued.
  - Length of comment period. The rulemaking will provide the public a period of time to submit comments on the rulemaking. This period is expected to be at least 6 months, but could be longer.
  - The actual minimum values to be proposed in rulemaking. The FHWA issued proposed values in October 1993 and have been evaluating the impacts of those values since that time. It is expected that the values for red will be reduced significantly, while the values for the other colors are expected to remain essentially the same.
  - Whether the minimum values will be proposed as standards or guidelines. It is expected that the values will be proposed as guidelines.
  - When the minimums will become effective. The final rule, if it occurs, will establish an effective date for the minimum values. The researchers do not know what date would be established.
  - Length of compliance period, if any. The compliance period is the length of time that agencies would have to bring the signs in their jurisdiction in compliance with the minimum values. The compliance period becomes more significant if the values are established as standards. The compliance period would be established in the final rule. The researchers do not have any information on the expected length of a compliance period or whether the issue will be addressed in the next rulemaking.
  - Overhead signing. It is expected that the minimum retroreflectivity values proposed in rulemaking will not include overhead signs in the framework of minimum values.

TxDOT Signing Operations

TxDOT is currently responsible for a large number of signs on its state highway system. In evaluating the impacts of minimum sign retroreflectivity values on TxDOT, the researchers developed the following findings relative to TxDOT and its signing activities.

- **TxDOT signing philosophy.** Establishment of minimum retroreflectivity values for signs is likely to lead TxDOT to increase the emphasis on sign maintenance and sign operations.
- **Number and value of TxDOT signs.** TxDOT does not have the records needed to develop an accurate count on the number of signs on the state highway system.
  - The researchers estimate that TxDOT has about 2.5 million signs. This estimate is based on urban and rural sign density (signs/mile) data contained in NCHRP Report 346 and applied to urban and rural centerline mileage in Texas. The researchers believe that the actual number of signs could be anywhere between 1.5 million and 10 million.
  - The value of these signs is somewhere between $75 million and $500 million. The researchers best estimate of the sign value is about $125 million.
- **Sign maintenance budget.** The current TxDOT annual sign maintenance budget is about $27 million.
- **TxDOT standards and guidelines for signing activities.** The following publications establish standards or provide guidance regarding various aspects of signing operations:
  - Selection and use of signs - Texas MUTCD
  - Design of signs - Texas Standard Highway Signs
  - Sign materials - Materials and Test Division specification D-9-8300 and TxDOT Standard Specifications
  - Sign design, placement, hardware, and mounting - Traffic Control Standard Sheets
  - Sign inspection - Traffic Operations Division Procedures Manual
    - This manual provides that signs should be inspected twice a year for damage and nighttime performance. This inspection frequency was recently changed to once a year.
    - There are no formal procedures on how to conduct an inspection or what constitutes an acceptable or unacceptable sign.
- **Availability of sign information.** TxDOT does not have accurate information on the following aspects of its signing operations:
  - The cost of producing signs.
  - The service life that can be expected from signs.
  - The number/percentage of signs that are being replaced for various reasons such as damage, vandalism, end of service life, etc.
- **Record keeping for sign installations.** TxDOT does not have a mechanism for recording sign information on a statewide basis.
  - The researchers found that most maintenance sections could not provide a list of signs installations in the maintenance section, including information about the following:
    - Sign location,
    - Type of sign, including MUTCD and DHT numbers,
    - Sign size,
    - Sheeting material, and
    - Installation date.

- **Recycling old sign substrates.** One of the most common assumptions associated with signing activities is that a significant proportion of old sign substrates are recycled by removing the old sheeting and applying new sheeting. In the course of information gathering, the researchers learned the following about TxDOT sign recycling activities:
  - Aluminum blanks are the only sign substrates that are recycled to any extent. Steel and plywood blanks are not generally recycled.
  - Aluminum blanks cannot be recycled if there are any holes or bends in the blank. Because the majority of sign replacements are due to damage, most sign aluminum substrates cannot be recycled.
  - The prison sign shop has found that it cannot recycle sign blanks covered with high intensity sheeting in a cost-effective manner. The high intensity sheeting gums up the sanding belts used to remove the sheeting.
  - Many districts no longer try to recycle old sign blanks. Old blanks are disposed of, donated to local charities, or sold directly to scrap/recycle dealers.
- **TxDOT sign replacement.** As mentioned, TxDOT does not have accurate information on the numbers of signs replaced annually or reasons why the signs are replaced. The researchers estimate that TxDOT replaces about 8 percent of its signs each year.
  - The district survey and sign data form indicate that 23 and 33 percent, respectively, of the signs being replaced each year are due to lack of retroreflectivity.
  - All other sign replacements are due to other reasons such as damage, vandalism, or a change in standards. The district survey and data form indicate that 66 and 50 percent, respectively, of sign replacements are due to some form of damage or vandalism. This means that many signs are being replaced before they reach the end of their service life.
- **TxDOT's ability to accommodate the proposed minimum values.** Based on the researchers' knowledge of current TxDOT sign replacement practices and the expected minimum retroreflectivity values, the researchers believe that the following actions would have to be taken by TxDOT to implement the minimum retroreflectivity values:
  - TxDOT's current retroreflectivity replacement practice is based upon an annual visual inspection. There is no formal training mechanism for those conducting the visual inspections. TxDOT will need to conduct formal sign inspection training courses to implement minimum values.
  - In general, the person conducting the visual inspection is the sign technician that is responsible for replacing the sign or the maintenance supervisor with budget responsibility for the sign. To maximize compliance with the minimum values, the sign inspector should have neither maintenance or budget responsibility for the signs being inspected.
  - TxDOT has recently begun ordering retroreflectometers to measure the retroreflectivity of signs. The Materials and Test Division has ordered one unit for each district. In order to effectively comply with the minimum values, a retroreflectometer will need to be purchased for each maintenance section.
  - TxDOT has begun to order test patches for visual inspections. However, these test patches are not related to the proposed framework of minimum retroreflectivity values proposed by FHWA, and may not be appropriate to use for inspecting signs for compliance with the minimum values.
- **Existing signs not meeting minimum values.** The researchers analyzed the sign retroreflectivity data collected by TxDOT for FHWA and, using a TxDOT retroreflectometer,

measured the retroreflectivity of numerous other signs. Based on these measurements, the researchers estimate that approximately 11 percent of TxDOT's signs do not meet the minimum retroreflectivity values expected to be proposed by FHWA in the upcoming rulemaking (this percentage could change, as the expected minimum values are subject to change).

- **Sign management systems.** Until recently, only one TxDOT district had any experience with a computerized sign management system. The Lufkin district developed a system for one county and found it very useful. The weakness in the system was that all information was entered from paper filled out by the sign crews. The Lufkin district found it difficult to maintain the system because of the personnel time needed to enter all signing activities.

Sign Service Life

The original scope of the research project did not include any specific evaluations of the service life of sign sheeting beyond reviewing the information available from the literature. However, because service life is a critical element in determining the cost-effectiveness of any sign replacement method, the researchers conducted some limited evaluations of sign retroreflectivity in order to have better information specific to Texas conditions for conducting the economic analysis.

- TxDOT does not have accurate data on the expected service life of traffic signs other than that provided in the manufacturers' warranties.
- The most significant issue associated with determining service life of sign sheeting is the variability of the coefficient of retroreflection for new sheeting. One way to overcome this problem is to measure the retroreflectance of each new sign as it is installed and store this number in a sign management system. The sign management system can then use this value (along with other factors associated with the sign such as color, sheeting manufacturer, sheeting type, etc.) in a predictive algorithm to determine when the retroreflectance of the sign falls below a predetermined value.
- From the data analyses contained in Chapter IV, it appears that, in Texas, the sheeting color of yellow can be expected to retain a sufficient retroreflectance value longer than any other color evaluated. The white colored sheeting service life expectancy closely follows the yellow colored sheeting with just a minor decrease in expected life. As expected, red colored sheeting performed the worst, with green colored sheeting performing just slightly better than red.
- Although the quantity of data collected was not sufficient enough to segregate by sheeting type and expect a statistically significantly result, general trends of the data can be observed. With that in mind, Type A (engineering grade) sheeting segregated by color of sheeting performed similarly to that of the entire data set (i.e., both Type A and Type C sheeting combined) with the exception of slightly decreased performance. It should be noted though that the sample population contained significantly more Type A sheeting signs than Type C. Therefore, findings regarding the performance of Type C segregated by color were inconclusive.
- Using the expected minimum retroreflectivity values, the analyses showed that TxDOT would have to replace 18.4 percent of its red signs, 3.4 percent of its yellow signs, 10.7 percent of its white signs, and 15.3 of its green signs to comply. Overall, TxDOT would need to replace 11.3 percent of the signs that pertain to the minimum retroreflectivity values.

- Generally, manufacturers warranty their Type C retroreflective sign sheeting for up to 10 years. The expected values are dependent on the sign colors and an understanding that signs are fabricated according the manufacturers' specifications. The same stipulations apply to Type A sheeting with the exception that the sheeting is expected to maintain 50 percent of its candlepower after 7 years. Both sets of warranties apply to signs used under normal conditions.
- From the data analyses, the Sign Data Form, the TxDOT District Survey, and the manufacturer's warranties, one could expect sign sheeting in Texas to last at least 7 years (and probably 9 years), regardless of manufacturer, type, or color. Any further breakdown of the service life would yield unreliable results.

Economic Analysis of Alternative Replacement Methods

In order to assess the economic implications of various alternative sign replacement methods, the researchers developed an economic model that calculates the costs associated with each method.

- **Replacement methods analyzed.** The economic analysis evaluated the costs associated with three basic methods and various alternatives of those methods.
    - Total replacement. All signs are replaced on a section of highway at regular intervals regardless of the length of time that a sign has been in place. Sign replacement can be performed by state or contract forces.
    - Sign inspection replacement. All signs are inspected at established intervals to identify those signs that need to be replaced because of inadequate retroreflectivity. The initial inspection would be a visual inspection, with the retroreflectivity of questionable signs being measured by an instrument. Inspections are performed by state forces and replacement can be performed by state or contract forces. This method is assumed to have the lowest retroreflectivity replacement rate as only those signs that are actually below the minimum values would be replaced.
    - Sign management system replacement. A computerized sign management or inventory system is used to track all signing activities. The system would be used to predict those signs that need replacing each year. Sign replacement can be performed by state or contract forces.
    - Combination of total and management system replacement. The total replacement approach is used until all signs have been replaced once. During this replacement period, all signs would be entered into the sign management system as they are replaced or maintained. Once the system's database is created, the sign management method is used to program all future sign replacement activities.
- **Results of the economic analysis.** The model used to estimate the costs of each method calculated the following factors for each method:
    - Typical annual costs. This is the annual costs in 1996 dollars to replace signs in order to comply with the minimum retroreflectivity values.
    - Initial start-up costs. These are the first-year costs to get a method up and running.
    - Annual non-retroreflectivity sign replacement costs. This is the portion of the current TxDOT sign maintenance budget that is used for sign replacements other than lack of retroreflectivity.

- Equivalent annual payment. This is the annualized cost in 1996 dollars calculated by converting the typical annual costs, initial start-up costs, and non-retroreflectivity annual sign replacement costs to an equivalent annual payment. The payment is calculated for one replacement cycle (sheeting service life) and two cycles.
- Additional full-time equivalents required. This is the additional personnel that will be needed to accommodate the higher numbers of signs being replaced.

- **Accuracy of key variables.** The model used to estimate the costs of the various methods is highly dependent upon two variables for which information is not available.
  - The number of TxDOT signs. This number is used to determine the actual number of signs that are replaced with each method. The researchers estimate that the actual number of signs could be from 65 to 258 percent of the researchers best estimate. The researchers accounted for the lack of accuracy by conducting the analysis for a range of sign numbers.
  - The average size of TxDOT signs. The cost of replacing signs is based on the average sign size and the number of signs replaced. The researchers accounted for the lack of accuracy by conducting the analysis for a range of sign sizes.
- **Results of economic analysis.** The economic analysis was conducted for a wide range of conditions and variables. Key results of the analysis are described below.
  - The equivalent annual payment for the current annual sign maintenance budget over a period of one sign service life (9 years) is about $30.7 million.
  - The sign inspection and sign management methods by state forces were found to have about the same equivalent annual costs. The differences between the costs for the two methods are not likely to be significant given the precision of the economic model. The sign management method appears to be slightly more cost effective and the sign management method becomes even more cost effective as the number of TxDOT signs increases.
  - For the set of variables that the researchers believe is the most accurate, the economic analysis indicates that there are four general groupings for statewide equivalent annual payment. These are:
    - $38 million - sign inspection and sign management methods, both by state forces;
    - $47 million - total replacement-state forces;
    - $57-60 million - inspection-contract forces, and management-contract forces; and
    - $88 million - total replacement-contract forces.
  - The equivalent annual payment costs for all alternative replacement methods would be higher than the current annualized sign maintenance budget. The smallest increase would be 26 percent, the largest, an increase of 186 percent.
  - All methods would require an increase in FTEs. As expected, the methods that utilize sign replacement by contract forces generally had the lowest increases in FTEs, although the sign management method by state forces had an FTE increase that was lower than the FTE increase for sign inspection with replacement by contract forces. The projected increases in FTEs ranged from 17 to 103 on a statewide basis.
  - The smallest increase in FTEs is with the total replacement by contract forces. The next smallest is the sign management with replacement by contract forces.

Non-Economic Factors Affecting Sign Replacement Methods

The sign inspection method is most similar to current TxDOT sign replacement procedures. With the present procedure, the researchers estimate that TxDOT replaces about 2.2 percent of its total signs each year due to inadequate retroreflectivity. With the inspection replacement method, the researchers estimate that the replacement rate would increase to 3.9 percent in order to bring all signs in compliance with the minimum retroreflectivity values proposed by FHWA.

- The sign management system method provides the greatest assistance in defending TxDOT in tort claims involving signs.
- It is highly likely that TxDOT will have some form of sign management system at some point in the next 15 years. The question is whether this will be developed on a district-by-district basis or with statewide guidance that could improve the compatibility between systems.
- Table VII-1 summarizes the most significant advantages and disadvantages for each of the basic sign replacement methods.

Table VII-1. Advantages and Disadvantages of Sign Replacement Methods

Method	Advantages	Disadvantages
Total Replacement	• Simplest of sign replacement methods • Minimizes administrative requirements	• Difficult to budget sign replacement activities • Not effective in using signs to their fullest potential (i.e., it has the highest level of sign waste) • Labor intensive
Sign Inspection	• Lowest level of sign waste (assuming personnel training maintained) • Most similar method to current practices while still conforming to FHWA's guidelines	• Difficult to budget sign replacement activities • Requires documentation method for measuring retroreflectivity • Test patches are not feasible for inspection use, as the minimum values for a given color vary according to several different criteria.
Sign Management	• Increases budgeting accuracy for sign maintenance • Facilitates conformance with FHWA's guidelines • Record of every sign • Minimizes paper work for field and office personnel • Direct interface with handheld retroreflectometer • GIS/GPS compatible • Increased productivity in sign maintenance activities • Can assist in defense of tort claims	• Cost of developing sign database • Highest implementation cost • Sign database must be maintained to maximize benefits

IMPLEMENTATION RECOMMENDATIONS

This research project was conducted to determine the most effective method by which TxDOT could implement the minimum retroreflectivity values for signs that FHWA is expected to propose in rulemaking in the near future. The analysis of economic and non-economic factors was able to identify one replacement method that the researchers believe will be more effective than the other methods. However, in conducting the analysis, the researchers developed numerous recommendations regarding TxDOT signing operations and the minimum retroreflectivity values. As required by TxDOT, each recommendation is numbered.

1 General Signing Recommendations

In collecting information about current TxDOT signing operations, the researchers learned that there are numerous aspects of their signing activities that TxDOT does not have accurate information on. This includes everything from sign fabrication and the associated costs, to the number of signs in the state system, to the reasons why and numbers of signs that are replaced each year. In order to become more efficient in its signing operations, TxDOT needs to conduct a detailed assessment of its signing operations. The researchers offer the following recommendations for this program:

1.1 TxDOT should create a signing task force to evaluate signing operations and identify key issues that need to be addressed.

1.1.1 Representatives from the following viewpoints should be included:

- Traffic Operations Division,
- Design Division,
- Construction and Maintenance Division,
- Materials and Test Division,
- General Services Division,
- Budget and Finance Division,
- Information Services Division,
- Occupational Safety (to address the tort claims issues),
- District Office (including personnel involved in transportation operations, maintenance, the sign shop, and administration),
- Area Office,
- Maintenance Sections (including sign technicians and maintenance supervisors), and
- Texas Department of Criminal Justice prison sign shop.

1.1.2 At a minimum, the task force should address the following issues:

- Retooling the sign maintenance program. This effort should include a thorough assessment of all aspects of signing operations and the activities of field crews.
- Potential benefits and uses of a sign management system. In particular, the task forces should address:
  - The potential use of optional components for a sign management system such as pen-based field computers, global positioning systems, bar codes, digitized photos, and other technologies.

- Uses of a sign management system to program sign replacement activities and develop replacement schedules. These schedules should be coordinated with sign fabrication activities at the district and prison sign shops.
- Any improvements in tort claim defenses that could be realized with a sign management system.
- Identification of districts that have or will soon have a sign management system and their experiences with these systems.
- System guidelines for districts to improve compatibility of systems between the districts.

- Costs of producing signs.
- Current methods of stocking and ordering signs.
- Differences between the Texas and national MUTCD's and changes to the Texas MUTCD that could benefit signing operations.
- Information needs of designers and field crews, including more useful information on sign selection, sign design, sign placement, and sign repair.
- TxDOT's ability to recycle sign substrates/blanks or salvage signs that may have some remaining life.

1.2 TxDOT should conduct or sponsor research to evaluate service life for signs in Texas. The research should evaluate various factors that are believed to affect service life, such as direction of exposure, geographical location, environmental/atmospheric impacts, color, sheeting type, and sheeting manufacturer. This research should not be initiated until sufficient numbers of high intensity signs have reached the end of their service lives to allow a statistically significant analysis.

1.3 Although the minimum values are expected to be proposed as guidelines, TxDOT should anticipate that the minimum values will become a standard at some point in the future. TxDOT should consider this factor in its evaluations of signing operations and selection of a replacement method to meet the initial minimum values.

2 Sign Replacement Methods

2.1 The research results indicate that the sign management system would be the most effective method of replacing signs to meet the minimum retroreflectivity values. This effectiveness is based on a combination of costs, FTEs, and non-economic benefits. The researchers offer the following recommendations regarding the implementation of a sign management system:

2.1.1 It should be a paperless system, where data are entered into the system by the field crew into a portable computer. The information in the computer can be downloaded into the system at the end of each day.

2.1.2 All signing activities should be tracked in the system, from the time that TxDOT receives the sign from the prison or vendor until it is scrapped or recycled.

2.1.3 Sign personnel, from the district staff to field crews, should receive training on how to use the sign management system and realize the greatest benefits from its capabilities.

2.1.4 Many TxDOT districts will adopt a sign management system in the near future, even if the Department does not adopt one on a statewide basis. If TxDOT decides not to implement the sign management replacement method on a statewide basis, then it should develop criteria for such a system to guide the districts in their purchases. This is needed to improve compatibility of the district systems and make it easier to adopt a statewide system at some point in the future.

2.2 The researchers recommend that, for those cases where an inspection is necessary, the following procedures be established for the inspections:

2.2.1 TxDOT should prepare and conduct the necessary training to ensure that sign inspections are performed in a consistent manner across the state.

2.2.2 The individual conducting the inspection should not be responsible for the maintenance of the sign or the budget covering maintenance of the sign.

The researchers recognize that the recommendations suggested by this research are extensive and many may be beyond the capabilities of TxDOT to implement within existing personnel and budgetary constraints. However, the researchers developed these recommendations without being limited by TxDOT's ability to implement any given recommendation.

CHAPTER VIII
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APPENDIX A

MINIMUM RETROREFLECTIVITY VALUES

The tables in this appendix indicate the minimum retroreflectivity values that were proposed by the FHWA in a 1993 research report (5) and those values that are expected to be proposed in the *Federal Register* rulemaking. The expected values have not been finalized and are subject to change before the rulemaking process begins.

Four tables are provided, one for each of the following color combinations:

- Black on yellow or black on orange,
- White on red,
- Black and/or red on white, and
- White on green.

The tables identify specific signs that each table applies to, if any; the parameters that establish the minimum retroreflectivity value for a specific sign; and additional requirements such as minimum contrast ratios. In the FHWA proposed minimum values, the entrance angle is -4.0 degrees, and the observation angle is 0.2 degrees.

The type of sheeting material is one of the parameters that defines the minimum retroreflectivity values for signs with yellow, orange, or white backgrounds. The following table provides a cross-reference between the terms that have been used to define material types.

Table A-1. Comparison of Terms for Sign Sheeting Types

Common Term		FHWA Type (FP-85)[1]	FHWA Type (FP-92)[2]	TxDOT Type
Engineering grade		II	I	A
Super engineering grade		IIA	II	B
High intensity	Beaded	IIIA	III	C
	Prismatic	IIIC	IV	C
Diamond Grade™		---	VII[3]	C

Notes: [1]Previous FHWA specification.
[2]Current FHWA specification.
[3]Proposed.

Table A-2. Minimum Retroreflectivity Values for Yellow and Orange Warning Signs

Legend Color		Black					
Background Color		Yellow or Orange					
Type of Legend	Material Type[2]	Minimum Retroreflectivity Values ($cd/lx/m^2$)[1]					
		Sign size ≥ 48 in		Sign size = 36 in		Sign size ≤ 30 in	
		Original[3]	Expected[4]	Original[3]	Expected[4]	Original[3]	Expected[4]
Bold Symbol[5]	ALL	15	15	20	20	25	25
Fine Symbol & Word[6]	I	20	20	30	30	45	35
	II	25	25	40	35	60	45
	III	30	30	50	45	80	55
	IV & VII[7]	40	40	70	60	120	70

Note: [1]Measured at an entrance angle of -4.0 degrees and an observation angle of 0.2 degrees.
[2]See page A-1 for definition of material types.
[3]Values originally proposed in a 1993 FHWA report (5).
[4]Values expected to be proposed in rulemaking. Values subject to change.
[5]Warning signs with bold symbols include: Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), Large Arrow (W1-6), Chevron (W1-8), Cross Road (W2-1), Side Road (W2-2), T Intersection (W2-4), Y Intersection (W2-5), Lane Reduction (W4-2), Divided Highway Begins (W6-1), Divided Highway Ends (W6-2),Two-Way Traffic (W6-3).
[6]Fine Symbol and Word Signs include all other black on yellow or orange warning signs.
[7]Proposed material type.

Table A-3. Minimum Retroreflectivity Values for Red Regulatory Signs[1]

Legend Color		White											
Background Color		Red											
Traffic Speed		45 mph or greater						40 mph or less					
Sign Size		≥ 48 in		36 in		≤ 30 in		≥ 48 in		36 in		≤ 30 in	
Portion of Sign		White	Red	White	Red	White	Red	White	Red	White	Red	White	Red
Minimum Retroreflectivity Values ($cd/lx/m^2$)[2]	Original[3]	50	10	60	12	70	14	30	6	35	7	40	8
	Expected[4]	35	8	45	8	50	8	25	5	30	5	35	5

Note: [1]White on red signs include: Stop (R1-1), Yield (R1-2), Do Not Enter (R5-1), and Wrong Way (R5-1a).
[2]Measured at an entrance angle of -4.0 degrees and an observation angle of 0.2 degrees. Since both the legend and the background of these signs are retroreflectorized, a minimum maintained contrast ratio of 4:1 has also been established. If the retroreflectivity value for either the white or red material falls below the value specified in the table or the retroreflectivity of the white material divided by the retroreflectivity of the red material is less than four, the sign should be replaced.
[3]Values originally proposed in a 1993 FHWA report (5).
[4]Values expected to be proposed in rulemaking. Values subject to change.

Table A-4. Minimum Retroreflectivity Values for White Regulatory and Guide Signs[1]

Legend Color		**Black and/or Red**											
Background Color		**White**											
Traffic Speed		45 mph or greater						40 mph or less					
Sign Size		≥ 48 in		30-36 in		≤ 24 in		≥ 48 in		30-36 in		≤ 24 in	
Mounting	**Material Type[2]**	**Minimum Retroreflectivity Values (cd/lx/m²)[3]**											
		Orig.[4]	Expt.[5]	Orig.[4]	Expt.[5]	Orig.[4]	Expt.[5]	Orig.[4]	Expt.[5]	Orig.[4]	Expt.[5]	Orig.[4]	Expt.[5]
Ground	I	20	25	35	35	50	45	15	20	20	25	35	30
	II	25	30	45	45	70	55	20	25	30	30	55	35
	III	30	40	60	55	90	70	25	30	45	40	75	45
	IV & VII[6]	40	50	80	70	120	90	35	40	60	50	100	60
Overhead	I	No values developed						40	No values[6]	50	No values[6]	100	No values[6]
	II							50		75		135	
	III							65		115		185	
	IV & VII[6]							90		150		250	

Note: [1]Parking series signs and signs intended solely for pedestrians and bicyclists are not included in this category.
[2]See page A-1 for definition of material types.
[3]Measured at an entrance angle of -4.0 degrees and an observation angle of 0.2 degrees.
[4]Values originally proposed in a 1993 FHWA report (5).
[5]Values expected to be proposed in rulemaking. Values subject to change.
[6]Proposed material type.
[7]Overhead signs have been eliminated from the expected values.

Table A-5. Minimum Retroreflectivity Guidelines for Green Guide Signs

Legend Color	**White**							
Background Color	**Green**							
Traffic Speed	45 mph or greater				40 mph or less			
Color	White		Green		White		Green	
Sign Position	**Minimum Retroreflectivity Values (cd/lx/m²)[1]**							
	Original[2]	Expected[3]	Original[2]	Expected[3]	Original[2]	Expected[3]	Original[2]	Expected[3]
Ground-Mounted	35	35	7	7	25	25	5	5
Overhead-Mounted	110	No values[4]	22	No values[4]	80	No values[4]	16	No values[4]

Note: [1]Measured at an entrance angle of -4.0 degrees and an observation angle of 0.2 degrees. Since both the legend and the background of these signs are retroreflectorized, a minimum maintained contrast ratio of 4:1 has also been established. If the retroreflectivity value for either the white or red material falls below the value specified in the table <u>or</u> the retroreflectivity of the white material divided by the retroreflectivity of the red material is less than four, the sign should be replaced.
[2]Values originally proposed in a 1993 FHWA report (5).
[3]Values expected to be proposed in rulemaking. Values subject to change.
[4]Overhead signs have been eliminated from the expected values.

APPENDIX B

INFORMATION GATHERING INSTRUMENTS

The following pages contain the instruments that were used to gather information about sign replacement activities within TxDOT and other state departments of transportation. Three different forms were used:

- Survey of State DOTs sign replacement practices,
- Survey of TxDOT district sign replacement practices, and
- Data form on TxDOT sign replacements.

SURVEY OF STATE DOTS SIGN REPLACEMENT PRACTICES

The FHWA is in the process of developing minimum values for retroreflectivity of traffic signs. These values will have a significant effect on the states' signing policy and operations. The Texas Transportation Institute is conducting research for the Texas Department of Transportation to determine the most effective method of implementing the new values. Please answer the following questions about the current sign replacement practices in your state. If you have any questions, please contact Brad McCaleb at (409) 845-6004.

Name: ____________________
Position: ____________________
State: ____________________
Phone: ____________________ Fax: ____________________

1. What is the approximate percentage of signs that are replaced annually due to the following reasons?

   Percentage
   ________ Inadequate retroreflectivity
   ________ Vandalism (stolen, graffiti, bullet holes, etc.)
   ________ Damage/knockdown (traffic accidents, bends, dents, delamination, etc.)
   ________ Roadway maintenance activities (mowing, snowplowing, etc.)
   ________ Change in standard (size, legend, placement)
   ________ Other (please specify)

   Comments: ____________________

2. What method(s) does your agency currently use to identify signs that need replacing due to lack of retroreflectivity? You may check more than one response.

Replacement Method	**Daytime**	**Nighttime**	**N/A**	**How Often**
Visual inspection using "eyeball" method	❑	❑	❑	________
Retroreflectivity predicted based on expected life	❑	❑	❑	________
Retroreflectivity measured using test patches	❑	❑	❑	________
Retroreflectivity measured using an instrument	❑	❑	❑	________

   Manufacturer and model of instrument ____________________
   Other (please specify) ____________________
   Comments: ____________________

3. What is the expected impact of the proposed minimum retroreflectivity values on signing operations in your agency?
   - ❑ Very significant ❑ Significant ❑ Little or no impact

   Comments: ______________________________

4. Has your agency developed an estimate of the cost to implement the proposed minimum sign retroreflectivity values? If yes, what is the estimated cost?
   - ❑ Yes - please provide the estimated cost ______________
   - ❑ No

   Comments: ______________________________

5. What method will your state use to ensure that the minimum retroreflectivity values are met?
   - ❑ Inventory/management system used to develop replacement schedule
   - ❑ Inspection and replacement of inadequate signs
   - ❑ Periodic mass replacement
   - ❑ Other (please describe) ______________
   - ❑ Not sure

   Comments: ______________________________

6. Does your agency expect an increase in tort claim lawsuits as a result of the minimum retroreflectivity values?
   - ❑ Yes - please comment on the nature of expected lawsuits
   - ❑ No

   Comments: ______________________________

7. Has your agency conducted any evaluations of the service life of retroreflective sheeting?
   - ❑ Yes - please provide citation or copy of the evaluations, if possible
   - ❑ No

   Comments: ____

8. Will your agency conduct formal training in retroreflectivity measurement and sign replacement activities in order to implement the minimum retroreflectivity values? If you do, who will be the target audience for the training?
   - ❑ Yes (please indicate target audience)　　❑ No
     - ❑ Administrators　❑ Engineers (headquarters level)　❑ Engineers (district level)
     - ❑ Field personnel　❑ Maintenance supervisors

   Comments: ____

9. Does your agency maintain a sign inventory or management system, and if so, what form is it in?
   - ❑ Yes (please continue below)　　❑ No
     - ❑ Paper or index card based
     - ❑ Computer-based　　Maintained on: ❑ mainframe computer
       　　　　　　　　　　　　　　　　　❑ microcomputer

   Comments: ____

10. If the inventory/management system is computerized, how was it developed or acquired?
    - ❑ Developed by state personnel
    - ❑ Developed under contract for state
    - ❑ "Off-the-shelf" software
    - ❑ "Off-the-shelf" software, but customized for the state's use.
    - ❑ Other (please describe) ____________________

    Comments: ____

11. What type data is recorded in your sign inventory? (Check all that apply)

❑ Unique sign number	❑ MUTCD sign number	❑ Type of sheeting
❑ Substrate material	❑ Location	❑ Orientation
❑ Mounting height	❑ Date of manufacture	❑ Installation date
❑ Maintenance dates	❑ Type of maintenance	❑ Date of last inspection
❑ Digitized image of sign	❑ Sign condition	❑ Post condition
❑ Measured retroreflectivity	❑ Predicted retroreflectivity	❑ Other (please list)

Comments: ______________________________

____

____

____

12. Please provide the following information regarding your state's sign inventory system.

Name of the system: ______________________________

Approximate cost of the system: ______________________________

Manpower requirements: ______________________________

Manufacturer's name, address, and telephone number: ______________________________

____

____

Name and number of contact person: ______________________________

____

Comments: ______________________________

____

____

TxDOT SURVEY OF DISTRICT SIGN REPLACEMENT PRACTICES

The Federal Highway Administration is in the process of developing minimum retroreflectivity values for traffic signs. These values will have a significant impact on TxDOT signing policy and operations. The Texas Transportation Institute is conducting a research project to determine the most effective method of replacing signs to comply with the new values. Please answer the following questions about the current signing activities in your district or maintenance section.

Please note that some of the questions may ask for information that is not available or which would require significant effort to determine. For these questions, please respond I/D (insufficient data) or provide your best estimate and indicate it as such

You may use the back of the survey or additional pages, if necessary. Please return the survey to Brad McCaleb at TTI by February 2, 1996. A mailing label is attached for your convenience. Individual responses will not be reported to TxDOT. If you have any questions, please contact Brad McCaleb or Gene Hawkins at (409) 845-6004. Thank you for your assistance.

Name: ______________________ Telephone: ______________________
Position: ______________________ Fax: ______________________
District: ____________ Area Office or Maintenance Section: ______________________

PART I - GENERAL SIGN INFORMATION

1. What is the approximate total number of signs in your district?

   ____

   Is this an estimate or based on data or documentation?
   ❑ Estimate ❑ Based on data or documentation
   Comments: ____

2. How many sign crews and individuals are there in your district or maintenance section?

Name of Maintenance Section	*Number of Sign Crews*	*Number of Sign Personnel*

Comments: ____

3. How many individuals are assigned to the district sign shop?

____

Comments: ____

____

____

PART II - SIGN INSPECTION AND REPLACEMENT

4. What types of formal procedures do you currently use to identify signs that need replacing due to a lack of retroreflectivity? You may check more than one response.

Identification Procedure	*Daytime*	*Nighttime*	*N/A*	*How Often*
Visual inspection using "eyeball" method	❑	❑	❑	________
Reflectivity predicted based on expected life	❑	❑	❑	________
Reflectivity measured using test patches	❑	❑	❑	________
Reflectivity measured using an instrument	❑	❑	❑	________

Other (please specify) ____

Comments: ____

____

____

____

5. What is the approximate percentage of signs that are replaced for the following reasons?

Percentage

________ inadequate retroreflectivity
________ vandalism (stolen, bullet holes, graffiti, etc.)
________ damage (bends, dents, delamination, etc.)
________ knockdown (traffic accidents, weather, etc.)
________ roadway maintenance activities (mowing, snowplowing, etc.)
________ change in standard (size, legend, placement, etc.)
________ other (please specify) ______________________________

Is this an estimate or based on data or documentation?

❑ Estimate ❑ Based on data or documentation

Comments: ____

____

____

____

6. What are the most difficult aspects of sign maintenance and replacement for your district or maintenance section?

____

____

____

____

____

7. Please use the table below to indicate your current average material costs per square foot for sign replacement.

Material		Cost (per sq. ft.)	Percentage of Total Signing
Sheeting	Engineering grade		
	High intensity		
Sign Blank	Plywood		
	Steel		
	Aluminum		

Are these costs an estimate or based on data or documentation?

❑ Estimate ❑ Based on data or documentation

Comments: ____

____

____

____

PART III - SERVICE LIFE OF SIGN SHEETING

8. Please use the table below to indicate the average service lives you have experienced for various sign materials. Use N/U to indicate sheeting types not used in district.

Sheeting Name	TxDOT Type	Range of Service Lives (years)			
		White	Yellow	Red	Green
Engineering grade	A				
High intensity grade	C				

Comments: ____

____

____

____

9. What factors have you found to have the greatest impact on the service life of retroreflective sheeting (please number in order of importance: 1 = most important)?

_______ manufacturer
_______ color
_______ location (urban, rural, wooded, open, etc.)
_______ direction of exposure (north, south, east, west)
_______ geographic region of Texas
_______ other (please specify) ______________________

Comments: ____

____

____

____

PART IV - SIGN INVENTORY SYSTEMS

10. Please indicate whether you maintain a sign inventory or database in the district office, area office, or any maintenance section, and if you do, the form of the inventory/database.
    - ❑ no inventory maintained
    - ❑ paper or index card based
    - ❑ microcomputer-based
    - ❑ mainframe computer-based
    - ❑ other (please describe) ______________________________

    Comments: ______________________________

11. Where is the inventory/database described in the previous question maintained? You may check more than one response.
    - ❑ in the district office
    - ❑ in the area office - please identify ____________________
    - ❑ in the maintenance section - please identify ____________________

    Comments: ______________________________

12. How often is the inventory/database updated?
    - ❑ daily ❑ weekly ❑ monthly ❑ quarterly
    - ❑ twice annually ❑ annually ❑ other (explain) ____________

    Comments: ______________________________

13. Please indicate the data that are recorded in the inventory:
    - ❑ Unique sign number ❑ MUTCD sign number ❑ Type of sheeting
    - ❑ Substrate material ❑ Location ❑ Orientation
    - ❑ Mounting height ❑ Date of manufacture ❑ Installation date
    - ❑ Maintenance dates ❑ Type of maintenance ❑ Date of last inspection
    - ❑ Sign condition ❑ Type of post ❑ Post condition
    - ❑ Measured retroreflectivity ❑ Predicted retroreflectivity
    - ❑ Other (please list)

    Comments: ______________________________

PART V - COST INFORMATION

14. Please estimate the typical hourly wage or monthly salary for each of the following positions involved in sign replacement activities.

    ________ sign crew
    ________ maintenance crew
    ________ area office technician level
    ________ area office engineer level
    ________ area office administration
    ________ district sign shop personnel
    ________ district technician level
    ________ district engineering level

    Comments: ____

    ____
    ____
    ____

PART VI - DESCRIPTION OF ALTERNATIVE REPLACEMENT STRATEGIES

Three basic methods have been identified to date for implementing the minimum retroreflectivity values. The actual method selected may be a variation of one of these methods or some combination of the methods. Please answer the following question as it relates to these methods.

15. Please comment on the replacement methods described below by addressing the ability of your district/maintenance section to implement each method, difficulties that each method would impose on your district/maintenance section, and your general opinion of each method.

    Sign Management/Inventory System Method - A sign inventory or management system is used to track key sign characteristics such as location, size, color, highway speed, exposure, and others. This information is used by the system to predict when a sign needs to be replaced.

    Comments: ____

    ____
    ____
    ____
    ____
    ____
    ____
    ____
    ____
    ____

Total Replacement Method - All signs on a predetermined section of highway are replaced at regular, predefined, time intervals. All signs are replaced, regardless of whether they meet the minimum value and how long they have been in the field. The replacements can be done by TxDOT or contract personnel.

Comments:

Sign Inspection Method - The minimum retroreflectivity of signs are measured at predetermined intervals. Those that do not meet the minimum value are scheduled for replacement. Inspections can be done on all signs or on a sample of signs that represent a larger group. If the sample sign does not meet the minimum value, then all signs in the group are also replaced.

Comments:

16. Please identify any other strategies that you think could be used to implement the minimum reflectivity values.

    Comments:

TxDOT SIGN REPLACEMENT DATA FORM

DISTRICT: ______________________ TODAY'S DATE: __________
COUNTY: ______________________
HIGHWAY NUMBER : ______________________

Please complete the following questionnaire regarding the sign being replaced.

Description of Highway At Sign Location (Check all responses that apply):

❑ rural ❑ two lane ❑ divided
❑ urban ❑ multi-lane ❑ undivided

Name of Sign or Sign Label/Code: ______________________

Type of Sign: ❑ regulatory ❑ warning ❑ guide ❑ informational ❑ construction

Background Color: ❑ white ❑ red ❑ yellow ❑ green ❑ blue ❑ brown ❑ orange

Primary Sign Orientation: ❑ north ❑ south ❑ east ❑ west

Message Type: ❑ symbol ❑ words or numbers ❑ combination
❑ other (please specify) ______________________

Type of Substrate Material: ❑ plywood ❑ aluminum ❑ steel

Sheeting Type: ❑ Engineering Grade (Type A) ❑ High Intensity (Type C)

Dimensions of Sign: ❑ 24" × 24" ❑ 30" × 30" ❑ 36" × 24" ❑ 48" × 48"
❑ 24" × 30" ❑ 30" × 36" ❑ 36" × 36" ❑ 48" × 60"
❑ 24" × 36" ❑ 30" × 42" ❑ 36" × 48" ❑ 60" × 48"
❑ other (please specify) ______________________

Original Installation Date of Sign Being Replaced: ______________________
Original Manufacture Date of Sign Being Replaced: ______________________

Reason replacing: ❑ inadequate reflectivity
❑ vandalism (stolen, bullet holes, graffiti, etc.)
❑ damage (bends, dents, delamination, etc.)
❑ knockdown (traffic accidents, weather, mowing, etc.)
❑ change in standard (size, legend, placement, etc.)
❑ other (please describe) ______________________

APPENDIX C

RESULTS OF STATE DOT SURVEY

A total of 34 states returned the portion of the state survey addressing sign replacement practices. These states are listed below.

Alaska
Arizona
Arkansas
Connecticut
Delaware
Georgia
Idaho
Indiana
Iowa
Kansas
Kentucky
Maryland
Michigan
Minnesota
Mississippi
Missouri
Nebraska
New Hampshire
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
Utah
Vermont
Virginia
Washington
West Virginia
Wyoming

It should be noted that, due to multiple responses to some questions, many of the response percentages add up to over 100 percent

1. What is the approximate percentage of signs that are replaced annually due to the following reasons? (Results based on responses that totaled 100 percent).

36.1%	*Inadequate retroreflectivity*
23.6%	*Vandalism (stolen, graffiti, bullet holes, etc.)*
27.3%	*Damage/knockdown (traffic accidents, bends, dents, delamination, etc.)*
8.3%	*Roadway maintenance activities (mowing, snowplowing, etc.)*
6.1%	*Change in standard (size, legend, placement)*
6.9%	*Other (please specify)*

Comments

- Info not readily available.
- The above figures are estimates only. Once the sign management system is in place, exact figures will be possible.
- Other-Construction
- Contract Signing on State System
- Major guide signs are replaced primarily for lack of retroreflectivity under contract, usually for a section of freeway. Related warning and regulatory signs are replaced under same contracts.
- We expect to replace everything on a 15 year life cycle.
- Interstate only. Traffic division is responsible for Interstate Sign Maintenance only. I will take the liberty of guessing for statewide off interstate (2).
- Relocation
- Other includes faded ink, lack of contract, poor chromaticity, damaged sheeting (cracking). All answers are estimates.
- Maintenance logs are not kept to the extent that this question could be answered with any accuracy.
- This information is not readily available and any percentages would be a guess.

2. What method(s) does your agency currently use to identify signs that need replacing due to lack of retroreflectivity? You may check more than one response.

Replacement Method	Daytime-Q2A	Nighttime-Q2B	N/A-Q2C
Visual inspection using "eyeball" method	25 (64.1%)	23 (79.3%)	0 (0.0%)
Retroreflectivity predicted based on expected life	8 (20.5%)	6 (20.7%)	8 (33.3)%
Retroreflectivity measured using test patches	0 (0%)	0 (0%)	9 (37.5%)
Retroreflectivity measured using an instrument	6 (15.4%)	0 (0%)	7 (29.2%)

Comments

- Eyeball culls out only worst of the bad ones.
- Maintenance supervisors on weekly road patrol report deficiencies to signs and markings sections.
- Employees of the bureau of traffic through observations made during daily field work report signs that are worn and/or old and should be scheduled for replacement.
- Will have management system in place hopefully within 2 years that will help predict sign replacement based on expectant life.

- Model 920 retroreflectometer. Advanced Retro Technology (Spring Valley, CA). South-facing EG signs fail after 10 yrs. Signs replaced as needed in additional annual/semi-annual inspection.
- Retroreflectivity based on expected life is 15 years for panel signs. 0-Beam portable spotlight - various manufacturers. The how often-yearly is done by one of our 6 districts, it varies from yearly to once in a great while.
- ART Inc. Model 920L.
- No actual measuring at this time. If it workers notice individual signing which are badly damaged the sign will be replaced. Major signing is replaced on a projected 7 yr cycle.
- Night time, Day time every other year alternating.
- Each of the 14 divisions inspect the signs differently.
- Daytime-continually, nighttime at least once a year
- Advanced Retro Technology, Inc. Model 920 Night inspection of all signs required yearly.
- GAMA Scientific. Use a Q-beam and "flash" across the sign -20%
- There is no formal inspection program. District and Traffic Shop personnel do it on a somewhat irregular basis.
- 1 daytime and 1 nighttime inspection per year.

3. What is the expected impact of the proposed minimum retroreflectivity values on signing operations in your agency?

   16 (43.2%) Very significant 13 (35.1%) Significant 8 (21.6%) Little or no impact

Comments

- Our current sign inventory and replacement policy does not take into account a physical measurement or retroreflectivity. Inventory procedure would need revision, retroreflectivity standards would have to be established, to implement action on the issue. A significant inc in labor and money.
- Data collected for FHWA on 750 signs revealed a low % of signs below min. levels of 2-3%.
- Providing proof that minimum retroreflectivity standards have been met.
- A significant number of signs that are considered marginal at best will have to be replaced.
- Districts split 50/50. Would require one man one year to test per district. Manpower and expense not available. Greatest impact to interstate signs, many of which still have button copy. Also dependent on minimum standards (Type I signs have 50% retention)
- Latest INDOT standard change involves replacing panel sign button copy legend. Contract replacement is planned.
- Recently we measured 752 random signs. Of the 752 signs, only 4 did not meet the proposed minimum values. 3/4 were object markers.
- An estimated 750,000 signs exist on a state highway system. Kansas is starting a 10-year replacement program to replace all signs with HI sheeting starting in mid-1996. Material has 10 yr warranty, and will have a 10 yr turnaround. Expense-$50M.
- Minimum retroreflectivity standards will create serious liability issues. If funding is unavailable to replace all signs not meeting, standards the state will be subject to litigation in accidents which may involve signs which do not meet minimums.
- Must determine best method to determine retroreflectivity. We need to know the standards so that we can know how often signs should be replaced.

- This standard would require the Department to establish a computerized inventory system and to purchase equipment to measure retroreflectivity. It would require additional staffing.
- I believe this is an unnecessary and burdensome regulation. I will oppose such Regulations/Mandates unless FHWA provides funding.
- Inspections would have to be increased and the replacement of signs would increase.
- The implementation of these standards will require a much closer and more precise monitoring of sign retroreflectivity to avoid potential liability.
- Standard for signs on State Highway system is High Intensity background and legend. Note: Signs off-system (City & County) are normally Engineering grade, minimum standards for retroreflectivity will have a very significant impact on these agencies.
- Maintenance engineers must ride all roads in their county at least once a year at night to review signing and marking retroreflectivity.
- Would estimate that 20-30% of our signs would have to be replaced.
- Depending on the level of retroreflectivity established.
- Little or no impact on specifications and fabrications. Significant impact on replacements for old existing signs exceeding life.
- Our program has been adequate, and I expect little change in the number of signs replaced. However, documentation may increase our cost.

4. Has your agency developed an estimate of the cost to implement the proposed minimum sign retroreflectivity values? If yes, what is the estimated cost?

   5 (15.6%) Yes - please provide the estimated cost___

   27 (84.4%) No

Comments

- $1,300,000. Since this cost estimate was established we have upgraded many signs. This estimate might be lower now because of these upgrades.
- To date standards are only a proposal with no indication of definite implementation. Cost of sheeting is a definite factor.
- $50,000
- Feel that it would be impractical to use different types of sheeting for different kinds of signs because of the records of what sheeting was to be used on the different types of signs.
- I do not know what is proposed however the NMSHTP is currently using HI, sheeting on standard signage.
- $11.1 million annually. This includes annual inspection costs of $8.7 million, and annual costs of $2.4 million to replace substandard signs.
- Will require the purchase of reflectometer for each of 5 Region offices @ $4,500.00 each.
- We expect to begin a comprehensive sampling program to evaluate what percentage of our signs will fall below the proposed minimum standards.
- $5 million

5. What method will your state use to ensure that the minimum retroreflectivity standards are met?
   - 15 (34.1%) Inventory/management system used to develop replacement schedule
   - 13 (29.5%) Inspection and replacement of inadequate signs
   - 5 (11.4%) Periodic mass replacement
   - 2 (4.5%) Other (please describe)
   - 9 (20.5%) Not sure

Comments

- Currently initiating a study to identify a sign and pavement marking management system.
- Probably will also have to implement a inventory/management system.
- Our proposed highway sign management system will do this once initiated.
- Implementation of inventory mgmt system not fully applied statewide.
- Develop a program to conduct random retroreflectivity measurements throughout the state on a regular basis.
- Model 920 Retroreflectometer. We are in the process of what the needs repairments are to establish a sign inventory/management system that will be compatible with the 10 yr signing program we are going to embark upon.
- At this time an inventory mgmt system is in the beginning stages. Most system will involve a periodic replacement of signing on certain corridors. The concept of inspection and replacement is contingent upon manpower issues.
- We are currently reviewing management software packages.
- Use of reflectometer for suspect signs.
- Much is based on the results of 3 above. Eventually, we expect to use a sign inventory management system to accomplish much of the effort to target signs falling below the minimum standards.
- If funding is available, we would like to implement an inventory system.
- Information search.

6. Does your agency expect an increase in tort claim lawsuits as a result of the minimum retroreflectivity values?
   - 19 (65.5%) Yes - please comment on the nature of expected lawsuits
   - 10 (34.5%) No

Comments

- I would expect a few test cases in court if implemented.
- We are concerned that cases could be made for claim lawsuits if an accident could be linked to not being able to see a sign that was below minimum reflectivity levels.
- When attorneys realize that there are minimum standards.
- Not sure at this time.
- The possibility will definitely increase since it may take 1-2 years to completely upgrade all signs state wide.
- Once standards are set, we have a duty to meet them. If we fail to do so, we could expect an increase in tort claims and lawsuits based on the failure to meet those minimum standards. It is impossible to estimate that on a percentage basis.
- We don't expect very many lawsuits, but inevitably they will occur.

- Answer simply based upon history that general public will be after whatever they can benefit from at the expense of the state.
- Unknown
- A recent appellate decision has given the department immunity for signing. The state supreme court considering this issue. The condition of signs has nearly been a non-existent allegation in law suits.
- Our tort claims have already risen due to the loss of sovereign immunity. The expectation is that it will escalate out of reason.
- General tort liability claims indicating lack of proper maintenance and requesting monetary compensation.
- Not sure what the outcome will be.
- Ours is a highly litigious state. I expect every lawsuit against the state for a traffic accident will "throw in" an accusation that the traffic signs did not adequately reflect.
- Substandard sign retroreflectivity will potentially be cited as a factor in lawsuits.
- No significant increase in ODOT lawsuits is expected but increase for City & County agencies is expected.
- Whether the reflectivity contributed to the accident or not the lawyers will be aware of the standard and will use it against the state in law suits.
- We believe that the establishment of either a minimum guideline or actual requirement will establish an acceptable level of service below which we may be a fair game. Currently we rely on a consistent annual effort, without an established numerical target which must be reached.
- Once values are set, proper maintenance will have to occur. If not, tort lawsuits will occur if the retroreflectivity values are an issue.
- Unknown

7. Has your agency conducted any evaluations of the service life of retroreflective sheeting?
   12 (35.3%) Yes - please provide citation or copy of the evaluations, if possible
   22 (64.7%) No

Comments

- Have ongoing test decks of all types of sheeting.
- District sign status reporting in conjunction with inventory management system. Summaries of this data is unavailable.
- Even though no formal evaluation/reports have been generated, we have used green HI freeway guide signs since 1984 and can observe that 15 yrs of life is not unrealistic.
- We accept 10 yr for HI and 7 yr for EG as a standard, more or less.
- No reports are available; evaluations were purely subjective.
- See attached sheet.
- However, it is generally expected that engineer grade sheeting will last 7-10 years, and 3M high intensity 12-15 years. Insufficient experience with Stimsonite high performance sheeting to predict service life.
- See attached.
- In the past UDOT looked at service life and cost benefits and based upon recommendation, UDOT's standards changed to require all signs to be encapsulated lens reflective sheeting.
- Information search

8. Will your agency conduct formal training in retroreflectivity measurement and sign replacement activities in order to implement the minimum retroreflectivity values?

   24 (82.8%) Yes (please indicate target audience)   5 (17.2%) No

   If you do, who will the target audience for the training?

   3 (5.4%) Administrators
   20 (35.7%) Field personnel
   4 (7.1%) Engineers (headquarters level)
   17 (30.4%) Maintenance supervisors
   12 (21.4%) Engineers (district level)

Comments

- Again, I would expect considerable training would be necessary for all components of the department.
- Will also be part of our HSMS
- It is expected that the training will mostly be the construction/maintenance personnel in the field, since this will be the level to monitor the signs. This will also be the case due to the planned sign inventory system being developed.
- Sign crews
- Ideally field personnel would be trained to inspect signing. Due to manpower issues it is possible that this function will be contracted to a private entity.
- It will be expected that engineer will provide training for field personnel.
- District sign shop foreman
- Unknown at this time.
- We are currently providing training to maintenance personnel in sign maintenance, including recognizing inadequate reflectivity.

9. Does your agency maintain a sign inventory or management system?

   23 (69.7%) Yes (please continue below)   10 (30.3%) No

   If so, what form is it in?

   4 (21.1%) Paper or index card-based
   15 (78.9%) Computer-based - Maintained on: 4 (30.8%) mainframe computer
   9 (69.2%) microcomputer

Comments

- Not complete statewide yet. No statewide program. Only in 2 of 3 regions.
- We have a sign inventory on a mainframe database.
- Foxpro database.
- This inventory is only for signs in stock. The HSMS, will also show inventory of exciting signs on the hwy.
- There is no state wide inventory system, however there is a statewide variety of localized inventories from paper to micro-computer.
- The system is truly a "features inventory" system and is kept as a record of what features within the R/W exists that requires equipment and manpower to maintain. It's sign inventory capability simply has a count of reg, warn, and guide signs within the R/W.
- Plan to develop computer-based inventory mgmt system.

- We are in the process of hiring a consultant to provide a computer program for NHS sign inventory.
- Non standard inventory system, hard copy only
- A microcomputer-based system is currently under development.
- We have a video log of all roadways
- Each District maintains paper based inventory, some districts have started computer inventories.
- Inventory is currently being taken by consultant.
- We are currently evaluating the need and how an inventory system would completed and maintained.
- Districts may choose paper or computer.
- SQL server
- We are in the process of purchasing a system designed by CarteGraph with some modifications by us.

10. If the inventory/management system is computerized, how was it developed or acquired?

14 (70.0%)	Developed by state personnel
2 (10.0%)	Developed under contract for state
3 (15.0%)	"Off-the-shelf" software
1 (5.0%)	"Off-the-shelf" software, but customized for the state's use.
0 (0%)	Other (please describe)

Comments

- Mac framework- "Filemaker Pro"
- We are currently working with a contractor in developing an inventory/sign management system.
- Datacom database, COBOL programming language
- The existing features inventory system is not a sign inventory system, because it does not contain any other data besides the fact that a certain type of sign exists at a known reference point. The system we are wanting to be developed for the inventory of signs is that briefly described in question number 4.
- Each highway district has its own system.
- Freeway-microstation non freeway-pc based.
- In process.
- See attached sheet.
- The system is being developed by consultant under contract with the state.
- Some of our maintenance division have developed a p.c. based inventory system -unique to their division.
- ODOT personnel have developed software for sign inventory.

11. What type data is recorded in your sign inventory? (Check all that apply)

13 (7.3%)	Unique sign number	12 (6.7%)	Type of sheeting
11 (6.2%)	Substrate material	11 (6.2%)	Type of maintenance
7 (3.9%)	Mounting height	2 (1.1%)	Sign condition
14 (7.9%)	Maintenance dates	12 (6.7%)	Predicted retroreflectivity
3 (1.7%)	Digitized image of sign	16 (9.0%)	Orientation
4 (2.2%)	Measured retroreflectivity	15 (8.4%)	Installation date
15 (8.4%)	MUTCD sign number	8 (4.5%)	Date of last inspection
20 (11.2%)	Location	8 (4.5%)	Post condition
4 (2.2%)	Date of manufacture	3 (1.7%)	Other (please list)

Comments

- Post condition and mounting height noted if deficiency is found. Proper size compliance is also reviewed.
- Videodisc image of sign, sign support information, such as type of support, number of posts, location of sign on the support.
- All of the data above conditions checked will be part of the data in our Highway Sign Management System.
- Removal date/time, legend, assembly no., size, speed, route, post type, no. of posts, post length, type of work, reason for work, employees performing work, remarks, sign color.
- This is the features inventory that would be replaced with a specific computerized sign inventory/mgmt system under study and development now.
- Various
- Inventory only on guide signs. No info on reg or warning.
- Support type
- Supposition in my part.
- See attached sheet
- System is not yet completed. It is anticipated that system will be capable of recording most or all of the above items.
- Inventory system has not been placed into statewide use.
- For guide signs on expressways a design layout is recorded.
- Post size and material, sign message lateral clearance.

APPENDIX D

RESULTS OF TxDOT DISTRICT SURVEY

A total of 126 surveys were returned to TTI. The districts and positions of the individuals completing the surveys are shown below. Of the surveys that provided information, 26 came from district offices, 24 came from area offices, and 71 came from maintenance sections.

Table D-1. Summary of Origins of TxDOT Surveys Returned to TTI

Response Frequencies by District						Response Frequencies by Position			
Abilene	3	Corpus Christi	1	Odessa	4	Director Operations	8	Area Engr	18
Amarillo	9	Dallas	8	Paris	6	Dst Traffic Engr	5	Area Maint Engr	1
Atlanta	4	El Paso	5	Pharr	6	Dst Maint. Engr	2	Rdway Maint Supvr	66
Austin	3	Fort Worth	8	San Angelo	2	Asst Dir Maint	1	Constr Inspect	1
Beaumont	3	Houston	6	San Antonio	4	Dst Support Engr	1	Area Sign Supvr	4
Brownwood	3	Laredo	2	Tyler	3	Dst Sign Supervisor	3	Sign Crew	7
Bryan	0	Lubbock	5	Waco	7				
Childress	5	Lufkin	7	Wichita Falls	11				
				Yoakum	0				

Part I - General Sign Information

1. What is the approximate total number of signs in your district?
   16 respondents with documented information
   Maintenance sections - 14 respondents; avg 11,448 signs; range 1,861-60,000 signs
   Area office - 1 respondent; 15,000 signs
   District - 1 respondent; 225,000 signs
   Is this an estimate or based on data or documentation?
   53 (77.9%) Estimate *16 (22.1%)* Based on data or documentation

2. How many sign crews and individuals are there in your district or maintenance section?
   Number of Sign Crews 3.7 crews
   Number of Sign Personnel 6.0 persons

3. How many individuals are assigned to the district sign shop?
   4.3 persons per sign shop

Part II - Sign Inspection and Replacement

4. What types of formal procedures do you currently use to identify signs that need replacing due to a lack of retroreflectivity? You may check more than one response.

Identification Procedure	Daytime	Nighttime	N/A
Visual inspection using "eyeball" method	*94 (81.0%)*	*112 (76.2%)*	*0 (0.0%)*
Reflectivity predicted based on expected life	*14 (12.1%)*	*11 (7.5%)*	*17 (32.1%)*
Reflectivity measured using test patches	*8 (6.9%)*	*22 (15.0%)*	*13 (24.5%)*
Reflectivity measured using an instrument	*0 (0.0%)*	*2 (1.3%)*	*23 (43.4%)*

5. What is the approximate percentage of signs that are replaced for the following reasons?

Percentage	
23.4%	inadequate retroreflectivity
26.7%	vandalism (stolen)
14.2%	damage (bends, dents, holes, delamination)
19.6%	knockdown (traffic accidents, weather, etc.)
6.4%	roadway maintenance activities (mowing, snowplowing, etc.)
5.1%	change in standard (size, legend, placement)
1.7%	other (please specify)

   Is this an estimate or based on data or documentation?
   95 (97%) Estimate *3 (3%)* Based on data or documentation

6. What are the most difficult aspects of sign maintenance and replacement for your district or maintenance section?

   Many of the responses dealt with sign posts, footings, the weight and size of signs, problems with certain types of material such as break-away posts and aluminum signs, traffic volumes, and keeping up with changes in standards. While all of these issues are important, they are outside the scope of this project and were not included in the analysis. The comments related to the replacement of signs were analyzed and their frequencies are in parentheses: lack of personnel (25), vandalism (18), shortage of equipment/material (12), volume of signs (10), and insufficient funding (9).

7. Please use the table below to indicate your current average material costs per square foot for sign replacement?

Material		Cost (per sq. ft.)	Percentage of Total Signing
Sheeting	Engineering grade	*$5.41*	*31.1%*
	High intensity	*$9.88*	*60.8%*
Sign Blank	Plywood	*$8.52*	*40.4%*
	Steel	*$9.12*	*16.4%*
	Aluminum	*$7.12*	*38.6%*

Are these costs an estimate or based on data or documentation?

28 (73.7%) Estimate *10 (26.3%)* Based on data or documentation

Part III - Service Life of Sign Sheeting

8. Please use the table below to indicate the average service lives you have experienced for various sign materials? Use N/U to indicate sheeting types not used in district.

Sheeting Name	TxDOT Type	Range of Service Lives (years)			
		White	Yellow	Red	Green
Engineering grade	A	*6.5*	*6.4*	*6.0*	*6.8*
High intensity grade	C	*6.8*	*6.2*	*5.7*	*6.5*

9. What factors have you found to have the greatest impact on the service life of retroreflective sheeting (please number in order of importance: 1 = most important)?

   5 manufacturer
   3 color
   2 location (urban, rural, wooded, open, etc.)
   1 direction of exposure (north, south, east, west)
   4 geographic region of Texas
   6 other (please specify)

Part IV - Sign Inventory Systems

10. Please indicate whether you maintain a sign inventory or database in the district office, area office, or any maintenance section, and if you do, the form of the inventory/database.
    - *42 (38.5%)* no inventory maintained
    - *16 (14.7%)* paper or index card based
    - *1 (0.9%)* microcomputer-based
    - *47 (43.1%)* mainframe computer-based
    - *3 (2.8%)* other (please describe)

11. Where is the inventory/database described in the previous question maintained? You may check more than one response.
    - *28 (30.1%)* in the district office
    - *3 (3.2%)* in the area office - please identify
    - *62 (66.7%)* in the maintenance section

12. How often is the inventory/database updated?
    - *24 (35.3%)* daily
    - *9 (13.2%)* weekly
    - *14 (20.6%)* monthly
    - *6 (8.8%)* quarterly
    - *4 (5.9%)* twice annually
    - *2 (2.9%)* annually
    - *9 (13.2%)* other (explain)

13. Please indicate the data that are recorded in the inventory:

38 (20.3%)	Unique sign number	*6 (3.2%)*	Maintenance dates
9 (13.9%)	MUTCD sign number	*3 (1.6%)*	Type of maintenance
12 (6.4%)	Type of sheeting	*3 (1.6%)*	Date of last insp.
6 (3.2%)	Substrate material	*10 (5.4%)*	Sign condition
23 (12.3%)	Location	*19 (10.2%)*	Type of post
0 (0.0%)	Orientation	*5 (2.7%)*	Post condition
5 (2.7%)	Mounting height	*2 (1.1%)*	Measured retroreflectivity
4 (2.1%)	Date of manufacture	*1 (0.5%)*	Predicted retroreflectivity
14 (7.5%)	Installation date	*10 (5.3%)*	Other (please list)

PART V - COST INFORMATION

14. Please estimate the typical hourly wage or monthly salary for each of the following positions involved in sign replacement activities.

$10.75/hr	sign crew	N/A	area office administration
$9.47/hr	maintenance crew	*$11.23/hr*	district sign shop personnel
$12.06/hr	area office technician level	*$15.05/hr*	district technician level
$20.23/hr	area office engineer level	*$21.67/hr*	district engineering level

Part VI - Description of Alternative Replacement Strategies

Three basic methods have been identified to date for implementing the minimum retroreflectivity values. The actual method selected by be a variation of one of these methods or some combination of the methods. Please answer the following question as it relates to these methods.

15. Please comment on the replacement methods described below by addressing the ability of your district/maintenance section to implement each method, difficulties that each method would impose on your district/maintenance section, and your general opinion of each method.

    Sign Management/Inventory System Method - A sign inventory or management system is used to track key sign characteristics such as location, size, color, highway speed, exposure, and others. This information is used by the system to predict when a sign needs to be replaced.

    29 of 95 responses (30.5%) were positive/supportive. The most common concern pertained to cost and personnel requirements to develop the initial database.

    Total Replacement Method - All signs on a predetermined section of highway are replaced at regular, predefined, time intervals. All signs are replaced, regardless of whether they meet the minimum value and how long they have been in the field. The replacements can be done by TxDOT or contract personnel.

    12 of 101 responses (11.9%) were positive/supportive. The most common remark concerned the use of contract labor if this alternative is implemented

    Sign Inspection Method - The minimum retroreflectivity of signs are measured at predetermined intervals. Those that do not meet the value are scheduled for replacement. Inspections can be done on all signs or on a sample of signs that represent a larger group. If the sample sign does not meet the value, then all signs in the group are also replaced.

    46 of 102 responses (45%) were positive supportive. This alternative is the closest to current practices, therefore , the higher percentage of positive responses is not unexpected.

16. Please identify any other strategies that you think could be used to implement the minimum retroreflectivity values.

    There were no new strategies identified in the responses to this question.

APPENDIX E

RESULTS OF TxDOT SIGN REPLACEMENT FORM

Sign replacement data forms were sent to a total of 16 TxDOT district offices across the state. Signing personnel were asked to complete a data form for each sign replaced under TxDOT's current sign maintenance program.

The 16 TxDOT districts returned 3,300 hundred data forms. A summary of the statistical analysis for these 3,300 responses is presented on the following page.

The information required to determine service life values was provided on only 716 of the returned data forms. Of these, 204 signs were replaced due to inadequate retroreflectivity. This set of 204 responses was analyzed separately and the results are presented on a second summary page.

DISTRICT: 16 Districts responded / 3300 data forms TODAYS DATE: ____________
COUNTY: 113 Counties
HIGHWAY NUMBER : ____________

Please complete the following questionnaire regarding the sign being replaced.

Description of Highway At Sign Location (Check all responses that apply):

1818 - rural 1698 - two lane 270 - divided
612 - urban 598 - multi-lane 49 - undivided

Name of Sign or Sign Label/Code: ____________

Type of Sign: 850 - regulatory 1058 - warning 991 - guide 360 - informational
3 - construction

Background Color: 1328 - white 629 - red 779 - yellow 284 - green 166 - blue
34 - brown 24 - orange 31 - black

Primary Sign Orientation: 792 - north 760 - south 702 - east 730 - west

Message Type: 706 - symbol 2358 - words or numbers 214 - combination 0 - other

Type of Substrate Material: 859 - plywood 2288 - aluminum 117 - steel

Sheeting Type: 1338 - Engineering Grade (Type A) 1432 - High Intensity (Type C)

Dimensions of Sign: 595 - 24" × 24" 639 - 30" × 30" 18 - 36" × 24" 231 - 48" × 48"
321 - 24" × 30" 12 - 30" × 36" 258 - 36" × 36" 51 - 48" × 60"
81 - 24" × 36" 3 - 30" × 42" 48 - 36" × 48" 15 - 60" × 48"
988 - other

Original Installation Date of Sign Being Replaced: ____________

Original Manufacture Date of Sign Being Replaced: ____________

Reason replacing: 1062 - inadequate retroreflectivity
706 - vandalism (stolen, bullet holes, graffiti, etc.)
222 - damage (bends, dents, delamination, etc.)
676 - knockdown (traffic accidents, weather, mowing, etc.)
319 - change in standard (size, legend, placement, etc.)
240 - other

DISTRICT: 11 Districts responded / 204 data forms TODAYS DATE: ____________
COUNTY: 26 Counties
HIGHWAY NUMBER : ____________

Please complete the following questionnaire regarding the sign being replaced.

Description of Highway At Sign Location (Check all responses that apply):

82 - rural	101 - two lane	27 - divided
63 - urban	47 - multi-lane	12 - undivided

Name of Sign or Sign Label/Code: ____________

Type of Sign: 30 - regulatory 55 - warning 77 - guide 40 - informational
0 - construction

Background Color: 97 - white 19 - red 44 - yellow 8 - green 28 - blue
6 - brown 1 - orange 1 - black

Primary Sign Orientation: 57 - north 56 - south 26 - east 52 - west

Message Type: 48 - symbol 143 - words or numbers 13 - combination 0 - other

Type of Substrate Material: 53 - plywood 138 - aluminum 9 - steel

Sheeting Type: 157 - Engineering Grade (Type A) 23 - High Intensity (Type C)

Dimensions of Sign:

50 - 24" × 24"	21 - 30" × 30"	0 - 36" × 24"	12 - 48" × 48"
11 - 24" × 30"	0 - 30" × 36"	12 - 36" × 36"	3 - 48" × 60"
1 - 24" × 36"	0 - 30" × 42"	2 - 36" × 48"	1 - 60" × 48"
91 - other			

Original Installation Date of Sign Being Replaced: ____________

Original Manufacture Date of Sign Being Replaced: ____________

Reason replacing:
204 - inadequate retroreflectivity
0 - vandalism (stolen, bullet holes, graffiti, etc.)
0 - damage (bends, dents, delamination, etc.)
0 - knockdown (traffic accidents, weather, mowing, etc.)
0 - change in standard (size, legend, placement, etc.)
0 - other

APPENDIX F
DESCRIPTIONS OF SIGN REPLACEMENT METHODS

Current TxDOT Practice

The current TxDOT sign replacement practice is described in the Traffic Operations Division manual (27). The current practice, as modified by a TxDOT memo on June 5, 1996, is described below.

> *"All signs, including supports, should be inspected a minimum of once per year for position, damage, legibility, obvious indications of structural distress or failure, and general condition. Only trained maintenance or traffic engineering personnel should make such inspections, especially the night inspections of retroreflectivity. Desirably, inspections should be made by two persons so notes can be taken without interfering with the driving task. All personnel who frequently travel the highways should be instructed to report any obscured or damaged signs. Maintenance personnel should be alert at all times to observe signs for legibility, position, and such minor damage for which immediate remedial action can be taken. The inspection of signs should include the checking of legibility and retroreflectivity of all signs at night, due to the high ratio of nighttime accidents."*

TOTAL REPLACEMENT METHOD

In this method, all signs on a section of highway are replaced at established intervals, regardless of how long they have been in place. The length of time between replacements is based on the service life of the sheeting. The highway system is divided up so that an approximately equal number of signs are replaced each year. Only one service life can be used to represent all signs and it must be the lowest of the service lives for all signs on the system. It is not possible to selectively replace signs with a lower service life. For example, if the lowest service life is assumed to be seven years, then the highway system would be divided into seven sections. All the signs in a given section would be replaced once every seven years.

This method requires two trips into the field: one to make a list of signs needing replacement and one to replace the signs.

All signs are replaced, regardless of the condition of the sign. As a result, many signs that have only been in place a short period of time will be replaced. Those that are in good shape can be salvaged and reused. This requires some form of evaluation and restocking the signs in the district sign shop.

Unlike with the other methods, the Total Replacement Method does not include any provisions for bringing signs in compliance with the minimum values during the first year. The researchers estimate that about 11 percent of TxDOT's signs would need to be replaced in the first year to comply with the minimum values. This was not considered feasible for the Total Replacement

Method due to the large number of signs that would need to be replaced in each year and the philosophy of this method of reducing administrative activities.

SIGN INSPECTION METHOD

In this method, a physical sign inspection is conducted on an annual basis at night. Those signs that have questionable retroreflectivity performance are identified for further evaluation with a retroreflectometer. On a second trip in the daytime, the retroreflectivity of the questionable signs is measured. Those that do not meet the minimums are identified for replacement. Since only those signs that are below the minimum values are replaced, there is no salvage value (replaced signs cannot be reused). This method requires three trips to the field: one to conduct the initial nighttime visual inspection, one to measure questionable signs, and the third to replace the signs.

This method minimizes waste, as only those signs that are below the minimum values are replaced. However, it requires a significant training effort, because sign inspectors must be trained on proper inspection procedures and to ensure consistency in the inspections.

SIGN MANAGEMENT METHOD

In this method, all signs are included in a computerized database that contains detailed information about the sign and the sign installation. The sign management system uses a predictive algorithm to calculate when a sign will reach the end of its service life. The list of signs needing replacement is then used to order/fabricate the necessary signs and perform the replacement.

In order for the system to function effectively, signing activity data must be entered as it occurs. Sign technicians will used a pen-based field computer to enter signing data as they perform their normal activities. At the end of the day, the data is downloaded to the master system. By using this type of paperless system, the accuracy of the database is improved and the opportunities to fall behind are minimized.

The key feature of the sign management system is its predictive algorithm. This algorithm can be as simple as just tracking the age of a sign, or it can incorporate other factors such as type of sheeting, color, exposure direction, manufacturer, etc. As a result, the sign management system can accommodate differences in service lives between signs. Retroreflectivity projections are only now becoming a part of sign management systems, their development being prompted by FHWA's minimum retroreflectivity values. Therefore, the accuracy of the algorithms at predicting end of service life is unknown.

APPENDIX G
VALUE ENGINEERING SPREADSHEETS

The following pages present the various sheetings in the spreadsheet that was used to calculate the economic costs associated with each of the sign replacement methods. The spreadsheet was created in Microsoft Excel. Table G-1 lists the various sheets that make up the spreadsheet.

Table G-1. Sheets That Make Up the Economic Model Spreadsheet

Sheet	Page	Description
Summary of Economic Analysis	G-3	Summarizes the costs calculated for each method for a maintenance section and statewide. Costs converted to equivalent annual payment for one and two cycles for each method.
Economic Cost Factors	G-5	Defines the variables used in the model that have an economic value that can be assigned to the variable.
Quantitative Calculations	G-8	Defines non-economic factors that are used to establish quantities for various activities.
Sign Replacement Rates	G-11	Defines the number and/or percentages of signs that are expected to be replaced with each method. Salvage/recycle factors are provided for each method.
Total Replacement Method - Replacement by State Forces	G-13	Calculates the economic costs of each replacement method using the economic costs factors, quantitative calculations, and sign replacement rates established in the previous sheets.
Sign Inspection Method - Replacement by State Forces	G-15	
Sign Management Method - Replacement by State Forces	G-18	
Total Replacement Method - Replacement by Contract Forces	G-21	
Sign Inspection Method - Replacement by Contract Forces	G-23	
Sign Management Method - Replacement by Contract Forces	G-25	

It should be noted that not all cost and number factors shown in the second through fourth sheets were used in the economic analysis. The numbers that are shown in the cells in this Appendix are those that represents the researchers best estimate of the parameters affecting the overall economic costs for the sign replacement methods.

	A	B	C	D	E	F	G	H	I
1	**SPR PROJECT 1275 - ASSESSMENT OF ALTERNATIVE SIGN REPLACEMENT STRATEGIES**								
2	**SUMMARY OF ECONOMIC ANALYSIS**								
3									
4	**Total Costs per Maintenance Section per Year in 1996 dollars**								
5			TxDOT	Using only State Forces			Using Contract Forces		
6		Units	Curr Pract	Total	Inspect	Mgmt	Total - Cont	Insp-Cont	Mgmt-Cont
7	Initial Start-Up Costs	$	$0	$2,436	$72,601	$131,572	$1,990	$199,101	$267,827
8	Typical Annual Costs	$	$95,406	$77,805	$37,929	$29,559	$203,544	$78,668	$78,444
9									
10	**Total Statewide Costs per Year in 1996 dollars**								
11			TxDOT	Using only State Forces			Using Contract Forces		
12		Units	Curr Pract	Total	Inspect	Mgmt	Total - Cont	Insp-Cont	Mgmt-Cont
13	Initial Start-Up Costs	$	$0	$689,460	$20,546,171	$37,234,816	$563,219	$56,345,722	$75,794,978
14	Typical Annual Costs	$	$27,000,000	$22,018,705	$10,733,784	$8,365,324	$57,602,977	$22,262,988	$22,199,757
15									
16	**Sign Replacement Rates and Contract Values**								
17	Signs replaced, TxDOT	ea	185,600	257,778	223,834	232,882	133,354	133,354	133,354
18	Sign repl - reflex	ea	52,246	N/A	90,480	99,528	N/A	90,480	99,528
19	Value of contracts	$	N/A	N/A	N/A	N/A	$54,001,867	$18,954,655	$20,850,121
20									
21	Incr in TxDOT repl actv	ratio	0.00	2.11	1.21	1.25	0.72	0.72	0.72
22	Curr non-reflex costs	$	19,399,500	N/A	N/A	N/A	N/A	N/A	N/A
23	Ann sign maint budget	$	$27,000,000	$41,418,205	$30,133,284	$27,764,824	$77,002,477	$41,662,488	$41,599,257
24	Add equip needed	$	N/A	N/A	$1,273,500	$7,082,469	N/A	$1,273,500	$7,789,969
25	Additional FTE	ea	0	100	103	66	17	74	37
26									
27	**Equivalent Annual Payment (existing non-reflex budget + projected reflex budget)**								
28	**For 1 replacement cycle**								
29	ann. interest rate, r %	0.08							
30	ann. budget incr, %	0.04	TxDOT	Using only State Forces			Using Contract Forces		
31	period, n, yrs	9	Curr Pract	Total	Inspect	Mgmt	Total - Cont	Insp-Cont	Mgmt-Cont
32	Annual Payment	$	30,748,977	47,281,046	37,651,442	37,662,262	87,785,743	56,590,845	59,674,953
33									
34									

	A	B	C	D	E	F	G	H	I
35	**For 2 replacement cycles**								
36	ann. interest rate, r (%)	0.08							
37	ann. budget incr, %	0.04	TxDOT	Using only State Forces			Using Contract Forces		
38	period, n, (yrs)	18	Curr Pract	Total	Inspect	Mgmt	Total - Cont	Insp-Cont	Mgmt-Cont
39	Annual Payment	$	33,931,236	52,126,027	40,111,427	38,956,470	96,831,446	58,507,736	60,551,101
40									
41	**Special Combination - Total & Mgmt**								
42	Total Replacement for first cycle, then management for 2nd and remaining cycles								
43	Database built during 1st cycle replacement - no initial costs for building database								
44	1st cycle - yrs	9							
45	2nd cycle - yrs	9							
46	item		value	Cycle A	F	P	2 Cycle A		
47	total initial		689,460	N/A	N/A	689,460	N/A		
48	mgmt initial (no database)		27,687,928	N/A	N/A	27,687,928	N/A		
49	total annual		41,418,205	47,169,164	N/A	290,674,982	N/A		
50	mgmt annual		27,764,824	31,619,997	194,854,889	94,846,057	N/A		
51	sum					413,898,426	45,175,783		
52									
53	**Best Estimate of**		No of Signs	Sign Repl %	Avg Sign Size	Service Life	Mgmt Accur		No of Inspect
54	**Signing Parameters**		2.32	8.00	9	9	10.00		1
55			Total-State	Inspect-State	Mgmt-State	Comb-Tot/Mgm	Total - Contr	Insp-Contr	Mgmt-Contr
56	Annual Pymt - 1 period	$mil	47.28	37.65	37.66	N/A	87.79	56.59	59.67
57	Rank (1 = low)		3	1	2	N/A	6	4	5
58	% over current method	%	54	22	22	N/A	185	84	94
59	Annual Pymt - 2 periods	$mil	52.13	40.11	38.96	45.18	96.83	58.51	60.55
60	Rank (1 = low)		4	2	1	3	7	5	6
61	% over current method	%	54	18	15	33	185	72	78
62	Additional FTE	ea	100	103	66	N/A	17	74	37

	A	B	C	D	E	F
1	**ECONOMIC COST FACTORS USED IN ANALYSIS**					
2	**Location**	**Position**	**Unit**	**Cost**	**Source**	**Notes**
3	**FINANCIAL FACTORS**					
4	Interest Rate, *i*		ratio	0.08	assumed	
5	Annual sign maint. budget increase		ratio	0.04	provided by Lewis Rhodes	
6						
7	**PERSONNEL COSTS**					
8	**Actual Pay Rates**					
9	Maint Section	Sign Technicial	$/hr	10.75	district survey	
10		Maint Supv	$/hr	17.00	assumed	
11		Admin/Clerical	$/hr	11.00	assumed	
12	Area Office	Engineer	$/hr	20.23	district survey	
13		Technicial	$/hr	12.06	district survey	
14		Admin/Clerical	$/hr	11.00	assumed same as maint section	
15	District Office	Engineer	$/hr	21.67	district survey	
16		Technician	$/hr	15.05	district survey	
17		Sign Shop	$/hr	11.23	district survey	
18		Admin/Clerical	$/hr	11.00	assumed same as area office	
19	Division	Engineer	$/hr	21.67	assumed same as district	
20						
21	**Personnel Costs to TxDOT**					
22	TxDOT Overhead rate		ratio	1.64	from Duane Sullivan, BFD	
23	Maint Section	Sign Technicial	$/hr	17.63	calculated from actual pay x overhead rate	
24		Maint Supv	$/hr	27.88	calculated from actual pay x overhead rate	
25		Admin/Clerical	$/hr	18.04	calculated from actual pay x overhead rate	
26	Area Office	Engineer	$/hr	33.18	calculated from actual pay x overhead rate	
27		Technicial	$/hr	19.78	calculated from actual pay x overhead rate	
28		Admin/Clerical	$/hr	18.04	calculated from actual pay x overhead rate	
29	District Office	Engineer	$/hr	35.54	calculated from actual pay x overhead rate	
30		Technician	$/hr	24.68	calculated from actual pay x overhead rate	
31		Sign Shop	$/hr	18.42	calculated from actual pay x overhead rate	
32		Admin/Clerical	$/hr	18.04	calculated from actual pay x overhead rate	
33	Division	Engineer	$/hr	35.54	calculated from actual pay x overhead rate	
34	Overtime rate		ratio	1.50	assumed	

	A	B	C	D	E	F
35	**VEHICULAR COSTS**					
36	All	Pickup/car	$/mi	0.50	assumed	
37	All	Sign truck	$/mi	1.50	assumed	
38						
39	**SIGN MATERIAL COSTS**					
40	Regional WH	HI Face signs	$/sf	6.87	avg 94 & 95 GSD bid prices	
41	Regional WH	HI Blank sign	$/sf	6.62	avg 94 & 95 GSD bid prices	
42	Regional WH	EG Face signs	$/sf	3.52	avg 94 & 95 GSD bid prices	
43	Regional WH	EG Blank signs	$/sf	3.30	avg 94 & 95 GSD bid prices	
44	Regional WH	Sign hardware	$/sign	0.25	assumed	
45	Regional WH	Avg sign cost	$/sf	5.53	calculated from costs and quantities ratios	
46	District	Salvage value	ratio	0.25	ratio of value of salvage value compared to new sign	
47	District	Salvage value	$/sf	1.38	value of remaining sign life/matl's - calc from avg sign $/sf x salvage ratio	
48	District	Recycle value	$/sf	0.50	value of sign substrate	
49						
50	**EQUIPMENT COSTS**					
51	Maint Section	Field computer	$/unit	4,195	costs of CarteGraph pen based computer - assumed representative	
52		Office computer	$/unit	2,500	Assumed	
53		SMS software	$/unit	1,390	costs of CarteGraph system - assumed representative	
54		Bar code reader	$/unit	1,764	costs of CarteGraph gun reader - assumed representative	
55		Retroreflectometer	$/unit	4,500	ART price list	
56		Bar codes	$/100	146.53	costs of CarteGraph 3 5/8 x 2 1/2 in, assumed representative	
57	District Office	SMS Software	$/unit	1,390	CarteGraph	
58						
59	**SHIPPING COSTS**					
60	Maint Section	District to maint section	$/sf/mi	.0050		
61	District Office	WH to district	$/sf/mi	.0025		
62						
63	**CONTRACT COSTS**					
64	Item	Description	unit	costs		
65	634	Plywd sign - Type A	$/sf	18.36	TxDOT 12 mo avg - installed in place, 5/8", w/ hardware, no foundation	
66	636	Alum sign - Type A	$/sf	13.63	TxDOT 12 mo avg - installed in place, w/ hardware, no foundation	
67	648	Repl/refurb rdside sign	$/ea	209.49	TxDOT 12 mo avg - replacing existing signs	
68		create sign database	$/sign	5		

	A	B	C	D	E	F
69	**TRAINING COSTS**					
70	Ann inspect trng	Sign tech	$/person	247	conducted at district - 1 day + .5 night (overtime)	
71		District technician	$/person	395	conduct training at district - 2 days	
72	Ann mgmt trng	Sign tech	$/person	141	conducted at district - 1 day	
73		Maint Supv	$/person	223	conducted at district - 1 day	
74		Admin/Clerical	$/person	144	conducted at district - 1 day	
75		District office engr	$/person	569	supervise training at district - 2 days	
76		District technician	$/person	395	conduct training at district - 2 days	
77	Initial mgmt trng	Base costs	$/person	350	costs of CarteGraph system - assumed representative	
78		Sign Tech	$/person	491	conducted by vendor at district (base costs + 1 day time)	
79		Maint Supv	$/person	573	conducted by vendor at district (base costs + 1 day time)	
80		Admin/Clerical	$/person	494	conducted by vendor at district (base costs + 1 day time)	
81		District office engr	$/person	634	conducted by vendor at district (base costs + 1 day time)	
82		District technician	$/person	547	conducted by vendor at district (base costs + 1 day time)	

	A	B	C	D
1	**QUANTITATIVE CALCULATIONS USED IN ANALYSIS**			
2				
3	**Item**	**Unit**	**Quantity**	**Source or Formula**
4	**TxDOT ORGANIZATION**			
5	No. of districts	ea	25	TxDOT
6	No. of area offices	ea	124	TxDOT
7	No. of maintenance sections	ea	283	TxDOT
8	Avg dist - warehouse to district	mi	146	from tripmaker CD-ROM
9	Avg dist - district to maint section	mi	51	from tripmaker CD-ROM
10	Avg maint section travel distance	mi	27	1-way distance to furtherest point, used to represent avg 2-way distance
11	Avg distance - district to Austin	mi	244	from state highway map
12				
13	**HIGHWAY MILEAGE**			
14	Centerline miles - statewide	mi	79,970	TxDOT TPP
15	Centerline miles/maint sect	mi	282.6	calcuated from no of maint sections
16	Centerline miles - urban	mi	15,706	calculated from TPP data
17	Centerline miles - rural	mi	64,264	calculated from TPP data
18	Ratio centerline miles - urban	ratio	0.196	calculated from urban/rural ctrln miles
19	Ratio centerline miles - rural	ratio	0.804	calculated from urban/rural ctrln miles
20	Ctrln miles/maint sect/repl sect	mi	31.4	calculated from sign service life
21				
22	**SIGN QUANTITIES**			
23	Urban sign density, signs/ctrln mi	signs/mi	29	1-direction: NCHRP 346 for cities, 1275 windshield count found 25.1
24	Rural sign density, signs/ctrln mi	signs/mi	11	1-direction: NCHRP 346 for counties, 1275 windshield count found 6.5
25	Avg sign density - statewide	sign/mi	14.54	1-direction, calculated from total signs/cl miles
26	No of signs - urban	ea	910,948	calculated from urban sign density
27	No of signs - rural	ea	1,413,808	calculated from rural sign density
28	Total no of signs - ctrln basis	ea	2,324,756	TxDOT statewide, urban + rural
29	Total no of TxDOT signs - used in calc	ea	2,320,000	cell used in all calculations
30	Total no of signs per maint section	ea	8,198	calculated from total number of signs
31	HI Face signs - annual quantity	sf	583,333	avg of GSD data for 94, 95 and projected 96
32	HI Blank signs - annual quantity	sf	460,000	avg of GSD data for 94, 95 and projected 96
33	EG Face signs - annual quantity	sf	315,000	avg of GSD data for 94, 95 and projected 96
34	EG Blank signs - annual quantity	sf	288,333	avg of GSD data for 94, 95 and projectcd 96

	A	B	C	D
35	HI face signs	ratio	0.35	calculated from annual quantities
36	HI blank signs	ratio	0.28	calculated from annual quantities
37	EG face signs	ratio	0.19	calculated from annual quantities
38	EG blank signs	ratio	0.18	calculated from annual quantities
39	Average sign size	sf	9	assumed
40	Plywood signs	ratio	0.42	from district survey
41	Aluminum signs	ratio	0.58	from district survey
42				
43	**Angelina Co Information**			
44	Red signs	ratio	0.14	from Herb Bickley sign inventory for Angelina County
45	Yellow signs	ratio	0.20	from Herb Bickley sign inventory for Angelina County
46	Green signs	ratio	0.10	from Herb Bickley sign inventory for Angelina County
47	White signs	ratio	0.56	from Herb Bickley sign inventory for Angelina County
48	total signs	ea	9,954	from Herb Bickley sign inventory for Angelina County
49	cl miles	mi	356	from 3/96 DISCOS
50	sign density	sign/mi	13.98	calculated from no of signs and cl miles
51				
52	**Urban Signs/mi by color - NCHRP**			
53	No of Red signs/urban ctrln mile	signs/mi	12	NCHRP 346, pg. 11 Tbl. 10
54	No of Yellow signs/urban mile	signs/mi	10	NCHRP 346, pg. 11 Tbl. 10
55	No of Green signs/urban ctrln mile	signs/mi	1	NCHRP 346, pg. 11 Tbl. 10
56	No of White signs/urban ctrln mile	signs/mi	6	NCHRP 346, pg. 11 Tbl. 10
57				
58	**Rural Signs/mi by color - NCHRP**			
59	No of Red signs/rural ctrln mile	signs/mi	3	NCHRP 346, pg. 11 Tbl. 10
60	No of Yellow signs/rural ctrln mile	signs/mi	4	NCHRP 346, pg. 11 Tbl. 10
61	No of Green signs/rural ctrln mile	signs/mi	3	NCHRP 346, pg. 11 Tbl. 10
62	No of White signs/rural ctrln mile	signs/mi	1	NCHRP 346, pg. 11 Tbl. 10
63				
64	**Ratio of Sign Colors - Statewide**			
65	Red signs	ratio	0.28	average of NCHRP urban, NCHRP rural, Angelian County
66	Yellow signs	ratio	0.30	average of NCHRP urban, NCHRP rural, Angelian County
67	Green signs	ratio	0.14	average of NCHRP urban, NCHRP rural, Angelian County
68	White signs	ratio	0.29	average of NCHRP urban, NCHRP rural, Angelian County

	A	B	C	D
69	Total no of Red - statewide	ea	638,666	calculated
70	Total no of Yellow - statewide	ea	702,017	calculated
71	Total no of Green - statewide	ea	315,810	calculated
72	Total no of White - statewide	ea	663,506	calculated
73				
74	**No of signs below min at end of expected life (yr) =**			9
75	Red signs below min. values	ratio	0.164	based on expected FHWA values
76	Yellow signs below min. values	ratio	0.022	based on expected FHWA values
77	Green signs below min. values	ratio	0.138	based on expected FHWA values
78	White signs below min. values	ratio	0.069	based on expected FHWA values
79	Red signs below min. values	ea	104,817	based on expected FHWA values
80	Yellow signs below min. values	ea	15,688	based on expected FHWA values
81	Green signs below min. values	ea	43,534	based on expected FHWA values
82	White signs below min. values	ea	45,808	based on expected FHWA values
83				
84	**PERSONNEL & PRODUCTIVITY**			
85	No. of sign tech per maint section	ea	3.7	from district survey
86	No of people in sign shop	ea	4.3	from district survey
87	Sign crew - typical time in field	hr/day	6	assumed
88	Making sign list - manually	signs/hr	12	assumed
89	Prepare sign order forms	signs/hr	12	assumed
90	Making sign list - pen computer	signs/hr	24	assumed
91	Replacing signs	signs/hr	2	assumed
92	Fabricating signs	sf/hr	30	assumed
93	Nighttime visual inspection	signs/hr	30	assumed
94	Measured inspection - field	signs/hr	6	assumed, reasonable based on our measurement experiences
95	Measured inspection - sign shop	signs/hr	30	assumed
96	Sign tech - nighttime inspection	hr/night	3	assumed
97	Sign tech - database maintenance	min/sign	10	assumed
98	Admin/cler - database maintenance	min/sign	5	assumed
99	Creating new sign database	#/hr	6	assumed
100	Prepare contract documents	signs/hr	20	assumed
101	Annual hours / FTE	hr	2080	calculated 40 x 52

	A	B	C	D
1	**RELATIVE REPLACEMENT RATES**			
2				
3	**SIGN LIFE**			
4	Avg service life - all sheeting types & signs	years	9	best estimate from available data
5	Def'n of good signs - max age	years	4	assumed
6				
7	**Current sign replacement practices**			
8	Current area of signs repl annually	sf	1,646,666	avg of GSD data for 94, 95 and projected 96
9	Current no of signs replaced annually	ea	182,963	calculated based on avg sf/sign
10	Current no of signs replaced annually	ea	185,600	used in calculations
11	Signs replaced annually	ratio	0.080	calculated from total no signs/current annual replacement
12	Reason replaced - lack of reflex	ratio	0.329	1275 sign crew data form (3,225 forms)
13	Reason replaced - damage/vandalism	ratio	0.498	1275 sign crew data form (3,225 forms)
14	Reason replaced - change in standards	ratio	0.099	1275 sign crew data form (3,225 forms)
15	Reason replaced - other	ratio	0.074	1275 sign crew data form (3,225 forms)
16	Reason replaced - lack of reflex	ratio	0.234	1275 district survey estimates, question 5
17	Reason replaced - damage/vandalism	ratio	0.663	1275 district survey estimates, question 5
18	Reason replaced - change in standards	ratio	0.049	1275 district survey estimates, question 5
19	Reason replaced - other	ratio	0.017	1275 district survey estimates, question 5
20	Avg replacement due to retroreflectivity	ratio	0.2815	average of data form and district survey
21	Current no of signs replaced - lack of reflex	ea	52,246	calculated from annual replacement and reflex repl rate
22	Current no of signs replaced - all other reasons	ea	133,354	calculated by annual replacement minus reflex replacement
23	Current retroreflectivity replacement rate	ratio	0.023	calculated from reflex replacement/total number of signs
24	Current non-reflex replacement rate	ratio	0.057	calculated from non-reflex/total number of signs
25	Current sign maintenance costs	$	27,000,000	provided by Lewis Rhodes
26	Current costs - non-reflex replacement	$	19,399,500	calculated from non-reflex ratio x annual budget
27				
28	**Total Replacement Method**			
29	Signs to be replaced each year - statewide	ea	257,778	calculated from total no signs/service life
30	Good signs replaced each year - statewide	ea	54,351	calculated from no of signs < or = max age
31	Signs replaced each year / maint sect	ea	911	calculated from annual replacement/no of maint sections
32	Good signs replaced / maint section	ea	192	calculated from statewide no good signs/no of maint sections
33	Good signs replaced that are reused	ratio	0.21	calculated from no of good signs/no signs replaced
34	Sign substrates that can be recycled	ratio	0.25	assumed

	A	B	C	D
35				
36	**Sign Inspection Method**			
37	Inspection Interval	#/year	1	assumed
38	Signs visually inspected / Maint Section	signs/yr	8,198	assumed that all signs in maint section are visually inspected
39	No of signs measured/no of signs replaced	ratio	2	assumed
40	No of sign refelx measured / Maint Section	signs/yr	639	calculated from replacement no and measurement ratio
41	Signs needing replacement	ratio	0.039	inspected signs below minimum values - based on data
42	No of signs replaced each year/Maint. Sect.	ea	320	calculated from replacement ratio
43	No of signs replaced each year - Statewide	ea	90,480	calculated from no of maint sections
44	1st year additional sign replacement	ratio	0.113	from Paul's measured reflex values
45	1st year sign replacement - Maint Section	ea	926	calculated from additional sign repl rate
46	1st year sign replacement - Statewide	ea	262,160	calculated from no of maint sections
47	Good signs replaced that are reused	ratio	0.00	replaced signs have no remaining service life
48	Sign substrates that can be recycled	ratio	0.25	assumed same as total method
49				
50	**Sign Management Method**			
51	Signs in Maint Section database	ea	8,198	all signs in maint section are in the database
52	Reduction in replacement accuracy	ratio	0.10	assumed
53	Signs needing replacement	ratio	0.0429	calculated from inspect rate + accuracy adjustment
54	No of signs replaced each year / maint sect	ea	352	calculated from replacement ratio
55	No of signs replaced each year - Statewide	ea	99,528	calculated from no of maint sections
56	1st year additional sign replacement	ratio	0.113	from Paul's measured reflex values
57	1st year sign replacement - Maint Section	ea	926	calculated from additional sign repl rate
58	1st year sign replacement - Statewide	ea	262,160	calculated from no of maint sections
59	Sign refelx measured / Maint Section	ratio	0.10	assumed - signs measured to maintain algorithm accuracy
60	Good signs replaced that are reused	ratio	0.00	replaced signs have no remaining service life
61	Sign substrates that can be recycled	ratio	0.25	assumed same as total method

	A	B	C	D	E	F	G
1	**TOTAL REPLACEMENT METHOD - STATE FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	**Notes**
5	**Typical Annual Costs**						
6	Sign replacement cycle		9	yr			same as service life
7	Prepare list of signs	Sign tech	76	hr	17.63	1,338	sign tech makes list, replc signs
8		Vehicle	404	mi	0.50	202	no of days used to calc no of round trips
9	Prepare sign orders	Maint Supervisor	76	hr	27.88	2,116	time to take list and convert to sign orders
10	Acquire signs	HI Face signs	2,904	sf	6.87	19,951	no of legend signs in repl section * avg size
11		HI Blank signs	2,290	sf	6.62	15,160	no of blank legend signs x avg size
12		EG Face signs	1,568	sf	3.52	5,520	
13		EG Blank signs	1,435	sf	3.30	4,737	
14	Fabricate signs	Sign shop personnel	124	hr	18.42	2,287	convert blank to legend signs in sign shop
15	Shipping signs	Warehouse to district	1,196,890	sf*mi	0.0050	5,984	calculated from sign area and distance
16		District to maint section	418,092	sf*mi	0.0025	1,045	calculated from sign area and distance
17	Replace signs	Sign tech	455	hr	17.63	8,029	calculated from no of signs and productivity
18		Vehicle	2,112	mi	1.50	3,168	no of days used to calc no of round trips
19		Attachment hardware	911	ea	0.25	228	new hardware for each installation
20	Useful life penalty	Lost value of good sign	1,728	sf	5.53	9,566	costs of lost service life of sign
21	Salvage benefit	Value of reusable signs	364	sf	1.38	-504	added value of remaining sign material
22	Recycle benefit	Value of sign substrate	2,049	sf	0.50	-1,025	added value of recycled sign substrate
23							
24	Total annual costs/maint section					$77,805	sum of typical annual costs
25	Total annual costs - statewide					$22,018,705	calculated from no of maint sections
26							
27	**Initial Start-Up Costs**						
28	Determine repl cycle	Division personnel	16	hr	35.54	569	assumes 2 days
29	Establish repl sections	District personnel	40	hr	35.54	1,422	assumes 1 week
30	Plan repl activities	Maint supervisor	16	hr	27.88	446	assumes 2 days
31	1st year sign replacement		0		0.00	0	does not apply to total replacement
32							
33	Total annual costs/maint section					$2,436	sum of initial start-up costs
34	Total annual costs - statewide					$689,460	calculated from no of maint sections
35							
36							

	A	B	C	D	E	F	G
37	**INCREASED REPLACEMENT RATES - STATEWIDE**						
38	Current replacement - all			ea/yr	185,600		from replace page for current and total replacement
39	Current replacement - reflex			ea/yr	52,246		from replace page for current and total replacement
40	Current replacement - non-reflex			ea/yr	133,354		from replace page for current and total replacement
41	Projected TxDOT additional replacement			ea/yr	257,778		from replace page for current and total replacement
42	Projected TxDOT total replacement			ea/yr	391,131		calculated from non-reflex + add. replacement
43	Increase in sign replacement activities			ratio	2.11		calculated from total repl/current repl
44	Additional time required - statewide			hr	206,996		calc from typical annual hr x no of maint sect
45	Additional FTE required - statewide			ea	100		calculated from additional time/annual hours
46							
47	**GENERAL DESCRIPTION**						
48	All signs are replaced at established intervals, regardless of the length of time they have been in the field.						
49	The cycle by which signs are replaced is the inverse of the service life.						
50	If the service life is 9 years, then 1/9 of the signs are replaced each year.						
51	The highways in each maintenance section are divided into a number of replacement sections that equal the service life.						
52	With a 9 year service life, the highways would be divided into 9 replacement sections.						
53	In any given year, all of the signs in a replacement section are replaced.						
54	FTE calculation does not include time from initial start-up						

	A	B	C	D	E	F	G
1	**INSPECTION METHOD - STATE FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	**Notes**
5	**Typical Annual Costs**						
6	Visual inspection	Sign tech	273	hr	17.63	7,226	visual inspection of every sign at night
7		Sign tech	53	hr	17.63	1,409	make list of signs requiring reflex measurement
8		Vehicle	3,222	mi	0.50	1,611	miles driven to conduct visual inspection
9	Measured inspection	Sign tech	107	hr	17.63	1,879	time req'd to measure sign reflex with instrument in day
10		Vehicle	762	mi	0.50	381	miles driven to measure sign reflex
11	Prepare sign rplcmt list	Sign tech	27	hr	17.63	470	list of signs that need to be replaced
12	Prepare sign orders	Maint. Supervisor	27	hr	27.88	743	time to take inspection results and convert to sign orders
13	Acquire signs	HI Face signs	1,019	sf	6.87	7,003	no of HI face signs in repl section x avg size
14		HI Blank signs	804	sf	6.62	5,321	no of HI blank signs in repl section x avg size
15		EG Face signs	550	sf	3.52	1,938	no of EG face signs in repl section x avg size
16		EG Blank signs	504	sf	3.30	1,663	no of EG blank signs in repl section x avg size
17	Fabricate signs	Sign shop personnel	44	hr	18.42	803	time to convert blank signs to legend signs in sign shop
18	Shipping signs	Warehouse to district	420,109	sf*mi	0.005	2,101	calculated from sign area and distance
19		District to maint section	146,750	sf*mi	0.0025	367	calculated from sign area and distance
20	Replace signs	Sign tech	160	hr	17.63	2,818	calculated from no of signs and productivity
21		Vehicle	1,002	mi	1.50	1,503	no of days used to calc no of round trips
22		Attachment hardware	320	ea	0.25	80	new hardware for each installation
23	Salvage benefit	Value of reusable signs	0	sf	0.50	0	zero salvage value assumed
24	Recycle benefit	Value of sign substrate	719	sf	0.50	-360	added value of recycled sign substrate
25	Inspection training	Sign tech	3.7	ea	246.82	913	all sign techs in maint section
26		vehicle	51	mi	0.50	26	all sign tech from maint sect in 1 vehicle
27		district technician	1	ea	394.91	35	district person training maint section staff
28	training time	for FTE calcuation	68	hr			
29							
30	Total Typical Annual Cost / Maint Section					37,929	sum of typical annual costs
31	Total Typical Annual Cost - Statewide					10,733,784	calculated from no of maint sections
32							
33							
34							
35							
36							

	A	B	C	D	E	F	G
37	**Initial Start-Up Costs Per Maintenance Section**						
38	Schedule inspections	Maint supervisor	16	hr	27.88	446	assumes 2 days
39	Retroreflectometer	Maint section	1	ea	4,500	4,500	assumes 1 per maint section
40		District office	0	ea	4,500	0	assumes districts have retroreflectometer
41	Inspection training	division engineer	400	hr	35.54	50	1 division engr training 25 district persons - 2 days/district
42		district technician	24	hr	19.78	42	district person training maint section staff
43	1st yr sign replacement						
44	Acquire signs	HI Face signs	2,953	sf	6.87	20,290	no of HI face signs in repl section x avg size
45		HI Blank signs	2,329	sf	6.62	15,418	no of HI blank signs in repl section x avg size
46		EG Face signs	1,595	sf	3.52	5,614	no of EG face signs in repl section x avg size
47		EG Blank signs	1,460	sf	3.30	4,818	no of EG blank signs in repl section x avg size
48	Fabricate signs	Sign shop personnel	126	hr	18.42	2,326	time to convert blank signs to legend signs in sign shop
49	Shipping signs	Warehouse to district	1,217,238	sf*mi	0.005	6,086	
50		District to maint section	425,199	sf*mi	0.0025	1,063	
51	Replace signs	Sign tech	463	hr	17.63	8,166	
52		Vehicle	2,367	mi	1.50	3,550	
53		Attachment hardware	926	ea	0.25	232	
54							
55	Total Initial Start-up Cost / Maintenace Section					72,601	sum of initial start-up costs
56	Total Initial Start-up Cost - Statewide					20,546,171	calculated from no of maint sections
57							
58	Initial Equipment Purchases / Maintenance Section					4,500	equipment needed for initial start-up
59	Initial Equipment Purchases - Statewide					1,273,500	calculated from no of maint sections
60							
61							
62	**INCREASED REPLACEMENT RATES FOR TYPICAL CYCLE**						
63	Current replacement - all			ea/yr	185,600		from replace page for current and total replacement
64	Current replacement - reflex			ea/yr	52,246		from replace page for current and total replacement
65	Current replacement - non-reflex			ea/yr	133,354		from replace page for current and total replacement
66	Projected TxDOT additional replacement			ea/yr	90,480		from replace page for current and total replacement
67	Projected TxDOT total replacement			ea/yr	223,834		calculated from non-reflex + add. replacement
68	Increase in sign replacement activities			ratio	1.21		calculated from total repl/current repl
69	Additional time required			hr	214,416		calculated from typical annual hr x no of maint sect
70	Additional FTE required			ea	103		calculated from additional time/annual hours
71							
72							

	A	B	C	D	E	F	G
73	**GENERAL NOTES:**						
74	All signs in a maintenance section are visually inspected each time						
75	Signs that are close to min are measured with retroreflectometer.						
76	The spreadsheet assumes that twice the number of signs that are replaced have to be measured						
77	Signs that are below the minimum values are replaced						
78	There is no salvage value at time of replacement.						
79	Sign substrates are recycled.						
80	no documentation of initial inspections for each sign - tort issue?						
81	Rcmd - visual inspector must not be responsible for the sign or the budget						
82	FTE calculation does not include time from initial start-up						
83	Test patches are not feasible for visual inspections due to the many factors that are used to define the min values for each color						

	A	B	C	D	E	F	G
1	**SIGN MANAGEMENT SYSTEM METHOD - STATE FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	**Notes**
5	**Typical Annual Costs**						
6	Add time to log signs	Sign tech	79	hr	17.63	1,385	time required to log all sign activities in system
7	Databse maint/admin	Admin/Clerical	39	hr	18.04	708	5 min/sign based on current sign replacement rates
8	Prepare sign orders	Maint. Supervisor	29	hr	27.88	817	time for maint. spvsr to make signs orders
9	Acquire signs	HI Face signs	1,121	sf	6.87	7,703	no of HI face signs in repl section x avg size
10		HI Blank signs	884	sf	6.62	5,853	no of HI blank signs in repl section x avg size
11		EG Face signs	605	sf	3.52	2,131	no of EG face signs in repl section x avg size
12		EG Blank signs	554	sf	3.30	1,829	no of EG blank signs in repl section x avg size
13	Fabricate signs	Sign shop personnel	48	hr	18.42	883	time to convert blank signs to legend signs in sign shop
14	Shipping signs	Warehouse to district	462,119	sf*mi	0.005	2,311	calculated from sign area and distance
15		District to maint section	161,425	sf*mi	0.0025	404	calculated from sign area and distance
16	Replace signs	Sign tech	176	hr	17.63	3,100	calculated from no of signs and productivity
17		Vehicle	1,074	mi	1.50	1,611	no of days used to calc no of round trips
18		Attachment hardware	352	ea	0.25	88	new hardware for each installation
19	Measure sign reflex	District sign shop	1	hr	18.42	22	measure signs to maintain predictive algorithm
20	Salvage benefit	Value of reusable signs	0	sf	0.50	0	zero salvage value assumed
21	Recycle benefit	Value of sign substrate	791	sf	0.50	-396	added value of recycled sign substrate
22	SMS training	Sign tech	3.7	ea	141.04	522	all sign techs get annual training
23		Maint. Supervisor	1.0	ea	223.04	223	maint supervisor gets annual training
24		Admin/Clerical	1.0	ea	144.32	144	maint section admin/clerical gets annual training
25		vehicle	102	mi	0.50	51	all maint sect staff travel to training in 2 vehicles
26		District office engineer	2.0	ea	568.62	100	2 district engineering level staff supervise training
27		District technician	2.0	ea	394.91	70	2 district technicians conduct training
28	training time	for FTE calcuation	110	hr			
29							
30	Total Typical Annual Cost / Maint Section					29,559	sum of typical annual costs
31	Total Typical Annual Cost - Statewide					8,365,324	calculated from no of maint sections
32							
33							
34							

	A	B	C	D	E	F	G
35	**Initial Start-Up Costs**						
36	SMS software	Maint section	1	ea	1,390	1,390	software for maintenance section
37		District office	1	ea	1,390	123	software for district office
38	Office computers	Maint section	0	ea	2,500	0	assumed computers already available.
39		District office	0	ea	2,500	0	assumed computers already available.
40	Field computer equipme	Field computer	3.7	ea	4195	15,522	each sign tech gets field computer
41		Bar code reader	3.7	ea	1764	6,527	exist. signs not equip. w/ bar codes.
42		Bar codes	10	set	146.53	1,465	bar codes to attach to signs
43	Initial SMS training	Sign tech	3.7	ea	491	1,817	all sign techs participate in training
44		Maint Supv	1	ea	573	573	participates in training
45		Admin/Clerical	1	ea	494	494	participates in training
46		District office engineer	2	ea	634	1,269	supervises training
47		District technician	2	ea	547	1,095	conducts training
48	Create sign database	Sign tech	1,366	hr	17.63	24,088	
49		Vehicle	6,431	mi	1.50	9,646	
50	1st yr sign replacement						
51	Acquire signs	HI Face signs	2,953	sf	6.87	20,290	no of HI face signs in repl section x avg size
52		HI Blank signs	2,329	sf	6.62	15,418	no of HI blank signs in repl section x avg size
53		EG Face signs	1,595	sf	3.52	5,614	no of EG face signs in repl section x avg size
54		EG Blank signs	1,460	sf	3.30	4,818	no of EG blank signs in repl section x avg size
55	Fabricate signs	Sign shop personnel	126	hr	18.42	2,326	time to convert blank signs to legend signs in sign shop
56	Shipping signs	Warehouse to district	1,217,238	sf*mi	0.005	6,086	calculated from sign area and distance
57		District to maint section	425,199	sf*mi	0.0025	1,063	calculated from sign area and distance
58	Replace signs	Sign tech	463	hr	17.63	8,166	calculated from no of signs and productivity
59		Vehicle	2,367	mi	1.50	3,550	no of days used to calc no of round trips
60		Attachment hardware	926	ea	0.25	232	new hardware for each installation
61							
62	Total Initial Start-up Cost / Maintenace Section					131,572	sum of initial start-up costs
63	Total Initial Start-up Cost - Statewide					37,234,816	calculated from no of maint sections
64							
65	Initial Equipment Purchases / Maintenance Section					25,026	equipment needed for initial start-up
66	Initial Equipment Purchases - Statewide					7,082,469	calculated from no of maint sections
67							
68							

	A	B	C	D	E	F	G
69	**INCREASED REPLACEMENT RATES**						
70	Current replacement - all			ea/yr	185,600		from replace page for current and total replacement
71	Current replacement - reflex			ea/yr	52,246		from replace page for current and total replacement
72	Current replacement - non-reflex			ea/yr	133,354		from replace page for current and total replacement
73	Projected TxDOT additional replacement			ea/yr	99,528		from replace page for current and total replacement
74	Projected TxDOT total replacement			ea/yr	232,882		calculated from non-reflex + add. replacement
75	Increase in sign replacement activities			ratio	1.25		calculated from total repl/current repl
76	Additional time required			hr	136,314		calculated from typical annual hr x no of maint sect
77	Additional FTE required			ea	66		calculated from additional time/annual hours
78							
79							
80	**GENERAL DESCRIPTION**						
81	A sign management system is used to track signing activities and identify when specific signs are expected						
82	to reach the end of their service life. Regular replacement acivities related to vandalism, knockdowns,						
83	etc. will continue						
84	At the present time, there are no commercial products that predict service life.						
85	Service life algorithms are expected to be incorporated into commercial products once rulemaking is completed.						

	A	B	C	D	E	F	G
1	**TOTAL REPLACEMENT METHOD - CONTRACT FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	Notes
5	**Typical Annual Costs**						
6	Sign replacement cycle		9	yr			
7	Prepare list of signs	Sign tech	76	hr	17.63	1,338	sign tech makes list, replc signs
8		Vehicle	404	mi	0.50	202	no of days used to calc no of round trips
9	Prepare contract specs	District office engr	46	hr	35.54	1,619	time to take list and convert to contract docs
10	Sign replacement	contract	911	ea	209.49	190,819	signs replaced by contractor
11	Useful life penalty	Lost value of good sign	1,728	sf	5.53	9,566	costs of lost service life of sign
12	Salvage benefit	Value of reusable signs	0	sf	1.38	0	contractor keeps signs with remaining life
13	Recycle benefit	Value of sign substrate	0	sf	0.50	0	contractor keeps sign blanks for recycling
14							
15	Total annual costs/maint section					$203,544	sum of typical annual costs
16	Total annual costs - statewide					$57,602,977	calculated from no of maint sections
17							
18	Value of contracts - maint section					$190,819	sum of annual contract costs
19	Value of contracts - statewide					$54,001,867	calculated from no of maint sections
20							
21	**Initial Start-Up Costs**						
22	Determine repl cycle	Division personnel	16	hr	35.54	569	assumes 2 days
23	Establish repl sections	District personnel	40	hr	35.54	1,422	assumes 1 week
24							
25	Total annual costs/maint section					$1,990	sum of initial start-up costs
26	Total annual costs - statewide					$563,219	calculated from no of maint sections
27							
28	**INCREASED REPLACEMENT RATES**						
29	Current replacement - all			ea/yr	185,600		
30	Current replacement - reflex			ea/yr	52,246		
31	Current replacement - non-reflex			ea/yr	133,354		
32	Projected TxDOT additional replacement			ea/yr	0		
33	Projected TxDOT total replacement			ea/yr	133,354		
34	Increase in TxDOT sign replacement activities			ratio	0.72		
35	Additional time required			hr	34,370		
36	Additional FTE required			ea	17		

	A	B	C	D	E	F	G
37	**GENERAL DESCRIPTION**						
38	Same as TxDOT total replacement, except that contract forces acquire and replace the signs						
39	Since contract forces remove the signs, there is no salvage or recycle value						

	A	B	C	D	E	F	G
1	**INSPECTION METHOD - CONTRACT FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	**Notes**
5	**Typical Annual Costs**						
6	Visual inspection	Sign tech	273	hr	17.63	4,818	visual inspection of every sign
7		Sign tech	53	hr	17.63	939	make list of signs requiring reflex measurement
8		Vehicle	3,222	mi	0.50	1,611	miles driven to conduct visual inspection
9	Measured inspection	Sign tech	107	hr	17.63	1,879	time req'd to measure sign reflex with handheld instrument
10		Vehicle	762	mi	0.50	381	miles driven to measure sign reflex
11	Prepare sign rplcmt list	Sign tech	27	hr	17.63	470	list of signs that need to be replaced
12	Prepare contract specs	District office engr	16	hr	35.54	568	time to take list and convert to contract docs
13	Sign replacement	contract	320	ea	209.49	66,978	signs replaced by contractor
14	Salvage benefit	Value of reusable signs	0	sf	0.50	0	contractor keeps signs with remaining life
15	Recycle benefit	Value of sign substrate	0	sf	0.50	0	contractor keeps sign blanks for recycling
16	Inspection training	Sign tech	3.7	ea	246.82	913	all sign techs in maint section
17		vehicle	51	mi	1.50	77	all sign tech from maint sect in 1 vehicle
18		district technician	1	ea	394.91	35	district person training maint section staff
19	training time	for FTE calcuation	68	hr			
20							
21	Total Typical Annual Cost / Maint Section					78,668	sum of typical annual costs
22	Total Typical Annual Cost - Statewide					22,262,988	calculated from no of maint sections
23							
24	Value of contracts - maint section					$66,978	sum of annual contract costs
25	Value of contracts - statewide					$18,954,655	calculated from no of maint sections
26							
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34							
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36							

	A	B	C	D	E	F	G
37	**Initial Start-Up Costs Per Maintenance Section**						
38	Schedule inspections	Maint supervisor	16	hr	27.88	446	Assumed alotted time.
39	Retroreflectometer	Maint section	1	ea	4,500	4,500	Assumes 1 per maint section
40		District office	0	ea	4,500	0	assumes districts have reflexometer
41	Inspection training	division engineer	400	hr	35.54	50	1 division engr training 25 district persons - 2 days/district
42		district technician	24	hr	19.78	42	district person training maint section staff
43	1st yr sign replacement	contract	926	ea	209.49	194,063	signs replaced by contractor
44							
45	Total Initial Start-up Cost / Maintenace Section					199,101	sum of initial start-up costs
46	Total Initial Start-up Cost - Statewide					56,345,722	calculated from no of maint sections
47							
48	Initial Equipment Purchases / Maintenance Section					4,500	equipment needed for initial start-up
49	Initial Equipment Purchases - Statewide					1,273,500	calculated from no of maint sections
50							
51	**INCREASED REPLACEMENT RATES**						
52	Current replacement - all			ea/yr	185,600		
53	Current replacement - reflex			ea/yr	52,246		
54	Current replacement - non-reflex			ea/yr	133,354		
55	Projected TxDOT additional replacement			ea/yr	0		
56	Projected TxDOT total replacement			ea/yr	133,354		
57	Increase in sign replacement activities			ratio	0.72		
58	Additional time required			hr	153,825		
59	Additional FTE required			ea	74		
60							
61							
62							
63	**GENERAL NOTES:**						
64	Inspections done by state						
65	Sign acquisition and replacement done by contract						

	A	B	C	D	E	F	G
1	**SIGN MANAGEMENT SYSTEM METHOD - CONTRACT FORCES**						
2	Total Cost per Maintenance Section per Year						
3							
4	**Activity**	**Costs Element**	**Quantity**	**Unit**	**Cost/unit**	**Extension**	**Notes**
5	**Typical Annual Costs**						
6	Add time to log signs	Sign tech	79	hr	17.63	1,385	time required to log all sign activities in system
7	Databse maint/admin	Admin/Clerical	39	hr	18.04	708	5 min/sign based on current sign replacement rates
8	Prepare sign orders	Maint. Supervisor	29	hr	27.88	817	time for maint. spvsr to make signs orders
9	Prepare contract specs	District office engr	18	hr	35.54	625	time to take list and convert to contract docs
10	Sign replacement	contract	352	ea	209.49	73,675	signs replaced by contractor
11	Measure sign sample	District sign shop	1	hr	18.42	22	measure signs to maintain predictive algorithm
12	Salvage benefit	Value of reusable signs	0	sf	0.50	0	contractor keeps signs with remaining life
13	Recycle benefit	Value of sign substrate	0	sf	0.50	0	contractor keeps sign blanks for recycling
14	SMS training	Sign tech	3.7	ea	141.04	522	all sign techs get annual training
15		Maint. Supervisor	1.0	ea	223.04	223	maint supervisor gets annual training
16		Admin/Clerical	1.0	ea	144.32	144	maint section admin/clerical gets annual training
17		vehicle	102	mi	1.50	153	all maint sect staff travel to training in 2 vehicles
18		District office engineer	2	ea	568.62	100	2 district engineering level staff supervise training
19		District technician	2	ea	394.91	70	2 district technicians conduct training
20	training time	for FTE calcuation	110	hr			
21							
22	Total Typical Annual Cost / Maint Section					78,444	sum of typical annual costs
23	Total Typical Annual Cost - Statewide					22,199,757	calculated from no of maint sections
24							
25	Value of contracts - maint section					$73,675	sum of annual contract costs
26	Value of contracts - statewide					$20,850,121	calculated from no of maint sections
27							
28							
29							
30							
31							
32							
33							
34							

	A	B	C	D	E	F	G
35	**Initial Start-Up Costs**						
36	SMS software	Maint section	1	ea	1,390	1,390	software for maintenance section
37		District office	1	ea	1,390	123	software for district office
38	Office computers	Maint section	1	ea	2,500	2,500	maint section gets dedicated computer for mgmt
39		District office	0	ea	2,500	0	assumed computers already available.
40	Field computer equipment	Field computer	3.7	ea	4,195	15,522	each sign tech gets field computer
41		Bar code reader	3.7	ea	1,764	6,527	exist. signs not equip. w/ bar codes.
42		Bar codes	10	set	146.53	1,465	bar codes to attach to signs
43	Initial SMS training	Sign tech	3.7	ea	491	1,817	all sign techs participate in training
44		Maint Supv	1	ea	573	573	participates in training
45		Admin/Clerical	1	ea	494	494	participates in training
46		District office engineer	2	ea	634	1,269	supervises training
47		District technician	2	ea	547	1,095	conducts training
48	Create sign database	Contract	8,198	ea	5.00	40,989	contractor creates database
49	1st yr sign replacement	contract	926	ea	209.49	194,063	signs replaced by contractor
50							
51	Total Initial Start-up Cost / Maintenace Section					267,827	sum of initial start-up costs
52	Total Initial Start-up Cost - Statewide					75,794,978	calculated from no of maint sections
53							
54	Initial Equipment Purchases / Maintenance Section					27,526	equipment needed for initial start-up
55	Initial Equipment Purchases - Statewide					7,789,969	calculated from no of maint sections
56							
57	**INCREASED REPLACEMENT RATES**						
58	Current replacement - all			ea/yr	185,600		
59	Current replacement - reflex			ea/yr	52,246		
60	Current replacement - non-reflex			ea/yr	133,354		
61	Projected TxDOT additional replacement			ea/yr	0		
62	Projected TxDOT total replacement			ea/yr	133,354		
63	Increase in sign replacement activities			ratio	0.72		
64	Additional time required			hr	77,957		
65	Additional FTE required			ea	37		
66							
67							
68							

	A	B	C	D	E	F	G
69	**GENERAL DESCRIPTION**						
70	A sign management system is used to track signing activities and identify when specific signs are expected						
71	to reach the end of their service life. Regular replacement acivities related to vandalism, knockdowns,						
72	etc. will continue						