A CONTROL SIGN FACILITY DESIGN TO MEET THE NEW FHWA MINIMUM SIGN RETROREFLECTIVITY STANDARDS

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ABSTRACT

Minimum sign retroreflectivity standards issued by the Federal Highway Administration (FHWA) on January 29, 2008 have focused the attention of administrators and sign managers on improving the nighttime performance of traffic signs. In order to predict when a sign will need replacement, an agency will need to know when the retroreflectivity of signs with similar characteristics deteriorate to the minimum level established by the FHWA. Currently in the literature, there is limited information about the long-term deterioration behavior of ASTM Type III and IX signs. One way of achieving a better understanding of long-term sign deterioration is to establish an experimental sign retroreflectivity measurement facility (ESRMF). An ESRMF is an arrangement of signs in a controlled area that have their retroreflectivity measured at regular intervals to determine how it deteriorates as a function of time. This paper shows how such a facility should look and why. A template is presented that can be used by agencies nationwide for collecting critical sign data to inform policy decisions.

Keywords: traffic signs, retroreflectivity, sign management, sign deterioration, sign testing, asset management

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* Outline is provided only for reviewers' convenience

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INTRODUCTION

Roadway signs are an essential component of the transportation system. Minimum sign retroreflectivity standards recently included in the Manual on Uniform Traffic Control Devices (MUTCD) by the Federal Highway Administration (FHWA) have focused the attention of administrators and sign managers on improving the nighttime performance of roadway signs (Carlson and Hawkins 2003). Retroreflectivity can be defined as the ratio of the light that the sign reflects to a driver (cd) to the light that illuminates the sign (lx) per unit area (m^2). In straightforward terms it is a measure of how well the sign can be seen at night.

As a result of the new minimum retroreflectivity standards, transportation agencies will need to assess whether their current sign management policies and practices will ensure compliance with the standards. Compliance with the standards will involve establishing an agency-wide sign management strategy and ensuring that there is proof of compliance to protect against lawsuits. Sign management strategies generally involve manually evaluating the retroreflectivity of all signs (or a sample of signs) in a jurisdiction or predicting when signs should be replaced based on information in a comprehensive sign inventory database. This paper directly addresses the "control sign" and other management methods described in the new standard.

To predict when a sign will need replacement, an agency will need to know how long it takes for the retroreflectivity of signs with similar characteristics to deteriorate to the minimum level established by the FHWA. The ASTM sheeting types typically used in the US for roadway signs include Type I, Type III, and Type IX. Type I sheeting is less retroreflective than Types III and IX, and is therefore no longer being used for new installations in many areas. However, the retroreflectivity deterioration behavior of Type I sheeting is the most defined because it has been in use for several decades. Currently in the literature there is limited information about the long-term deterioration behavior of ASTM Type III and IX signs because they are so new and they have not been in service for very long.

Previous Retroreflectivity Deterioration Research

Sign deterioration has been studied under controlled (where signs are separate and away from traffic) and uncontrolled outdoor conditions, as well as in indoor laboratory tests. Laboratory tests have been found to be unreliable in predicting sign durability, they have been found to be highly variable, and they are relatively expensive as compared to outdoor exposure tests (Ketola 1999).

Signs in controlled outdoor conditions are installed in a restricted outdoor area where they cannot be damaged by vandals or vehicle collisions. As a result, signs in controlled studies only deteriorate because of natural weathering (UV and weather exposure).

Signs studied in uncontrolled conditions are signs that are actually in service along the roads and are exposed to traffic and vandalism as well as to natural weathering. This section will examine both controlled and uncontrolled sign deterioration studies.

Controlled Studies

The main source for controlled sign deterioration data is the National Transportation Product Evaluation Program (NTPEP) of the American Association of State Highway and Transportation Officials (AASHTO). Manufacturers who want their new sign sheeting product to be used in the US submit it to the NTPEP for durability testing. The NTPEP's primary goal is testing for sheeting durability, not retroreflectivity deterioration. Signs tested by NTPEP generally include most sign sheetings used in permanently-installed traffic signs, including Types I, III, and IX. The NTPEP currently tests signs for three years in four states (Minnesota, Arizona, Louisiana, and Virginia) (AASHTO, 2005).

NTPEP tests two 4" x 12" sign panels for each sheeting type to be tested, and places them on southern-facing test decks angled 45° from horizontal. According to Carlson and Hawkins, placing the signs at this orientation causes the test panels to deteriorate at double the rate of a vertically mounted sign (2003). As a result, the NTPEP test panels effectively deteriorate for six years, although they are only placed outdoors for three years. One sign panel for each sheeting type remains indoors to serve as a control. As a result of the NTPEP tests being conducted in a controlled setting, there is less variability in the results than for uncontrolled tests.

Generally, R^2 values for ordinary least squares deterioration curves (of retroreflectivity versus time) generated from the NTPEP data are greater than 0.8; however, the sample size is small since there are only two weathered samples per sheeting type. The NTPEP program data are not helpful in predicting sign service life (when signs are expected to deteriorate to levels below the FHWA minimum) (Ketola 1999). There is no current source for long-term controlled sign performance data.

Uncontrolled Studies

Five uncontrolled sign deterioration studies have been conducted in the US in recent years. These studies were conducted by the FHWA (Black et al. 1991), the State of Oregon (Kirk et al. 2001), Louisiana State University (Wolshon et al. 2002), Purdue University (Bischoff and Bullock 2002), and North Carolina State University (NCSU) (Rasdorf et al. 2006). These studies measured the retroreflectivity and ages of hundreds of mostly Type I signs in the field and had some difficulty creating well-defined deterioration models from this data. Nearly all of the deterioration models had R^2 values less than 0.5, indicating that age could not explain much of the variability in the deterioration data. These studies found very few Type III signs in the field older than 15 years and could only make limited conclusions about how these signs deteriorate.

The Purdue, Louisiana, and FHWA studies investigated whether cleaning signs prior to measurement would improve retroreflectivity. Each of the studies found that although there is a slight improvement in retroreflectivity with cleaning, it is not statistically significant, and higher-intensity sheetings are less likely to show an improvement with cleaning (Bischoff and Bullock 2002; Black et al. 1991; Wolshon et al. 2002). Another cause of variability in retroreflectivity data is the damage and vandalism signs are subject to in an uncontrolled roadside environment. Further discussion and quantification of sign damage rates can be found in Immaneni et al. (2007).

There are very few Type III encapsulated lens sheeting signs in the field older than 15 years. Therefore, the studies cited above could only make limited conclusions about how these signs deteriorate to the point where they are below the FHWA minimums (Rasdorf, et. al. 2006). An evaluation of all existing models in the literature found that Type III sign retroreflectivity may fall below the FHWA minimums between 20 years (red, yellow) to 53 years (white) after installation (Immaneni et al. 2008). Type III signs (as well as Type IX signs) are also available as prismatic sheetings. These prismatic sheetings have not been studied because there are very few in the field, although many transportation agencies are currently installing or planning to install these sheeting types. It is precisely because of these shortcomings that we are recommending the facility proposed herein.

Significance

A study of 1057 signs in the field in NC found only 265 Type III signs and 10 Type IX signs (Rasdorf, et. al. 2006). The maximum ages of these signs were 15 and 5 years, respectively. While Type I signs exist in abundance (and their field age varies from new installations to typically 20 years), this is not the case for Types III and IX. In essence, while there are some Type III and IX signs installed in the field their numbers are low and, except for guide signs (which themselves are hard to measure), their locations are generally not recorded in any NCDOT database. Thus, targeted field studies of these signs are not generally feasible. However, by installing a facility like that presented herein it will be possible to begin to collect these critically-needed data that are not otherwise available and for which not other mechanism exists. These data will allow agencies to develop efficient and cost effective sign management strategies. This facility directly addresses the control sign compliance method and other management methods identified in the new MUTCD standard.

NEED FOR SIGN RETROREFLECTIVITY DATA

One way of achieving a better understanding of Type III and IX long-term sign deterioration is to establish an experimental sign retroreflectivity measurement facility (ESRMF). An ESRMF is an arrangement of signs in a controlled area that have their retroreflectivity measured at regular intervals to determine how it deteriorates as a function of time and other variables, such as sign orientation and weather conditions. Other variables are identified in the following section.

While field measurement of in-place signs affords valuable data, as demonstrated by the five previous retroreflectivity deterioration studies, there are uncontrollable factors that are faced when using only in-place signs. Vandalism (gunshots, paintballs, and eggs) can cause a sign to deteriorate prematurely as can natural deposits of tree sap and dust. Because of these uncontrollable factors, there is a need to design and build an ESRMF in which a wide range of variables of interest to traffic sign managers can be controlled.

A better understanding of sign sheeting performance will help transportation agencies to better manage their sign assets because they will be able to predict when signs will deteriorate to the point where they require replacement. Improved knowledge about the deterioration of certain sheetings will also improve sign specification and purchasing decisions. For example, the North Carolina DOT owns over one million signs with a replacement value of around $140 million; effective management of this asset can save the agency and its stakeholders millions per year. The findings from the ESRMF will also be helpful to agencies and researchers across the United States because for the first time long-term sign deterioration data will be publicly available for review and analysis.

Sign Maintenance Strategies

Besides the need of researchers and transportation agencies to better understand how sign retroreflectivity deteriorates in the long term, an ESRMF can be a key element of a transportation agency's overall traffic sign management program. The FHWA has developed several retroreflectivity maintenance strategies that DOTs can implement to comply with the standards (Chappell and Schertz 2005). These retroreflectivity maintenance strategies can be divided into two main groups--assessment methods and management methods--and are further broken down in Section 2A.09 of the MUTCD as follows (FHWA 2007):

- Assessment Methods
    - Visual Nighttime Inspection Method
    - Measured Retroreflectivity Method
- Management Methods
    - Expected Sign Life Method
    - Blanket Replacement Method
    - Control Sign Method

Assessment methods ensure compliance with the standards by evaluating all signs in place on the roadways through either qualitative visual assessment or quantitative retroreflectometer assessment. Management methods, on the other hand, do not involve evaluating every sign in place on the roadways, which can be costly. Instead, management methods predict how long signs with similar characteristics (such as sign color and sheeting type) will maintain an above-standard retroreflectivity, also known as the sign life.

The expected sign life method calculates a sign life from known sign retroreflectivity deterioration rates for combinations of sign sheeting color and sheeting type. When an individual sign's retroreflectivity is predicted to fall below the minimum it is replaced. The blanket replacement method replaces all signs along a corridor, within an area, or of the same sign and sheeting type at intervals based on the expected sign life of the signs. The control sign method uses signs either in an ESRMF or a sample of carefully identified control signs from the field to determine sign life. The control sample of signs is assumed to represent all of the signs in an agency's jurisdiction. The sampling plan should ensure that the quantity and diversity of signs sampled represents the agency's sign population and that there is monitoring of sign retroreflectivity at regular intervals. When a control sign's retroreflectivity is measured by a retroreflectometer and is found to fall below the minimum level, all similar signs in the field should be replaced.

An ESRMF can provide data in support of all the management methods suggested by FHWA. Data from several years of sign retroreflectivity measurements at an ESRMF can be analyzed to determine the sign life of various sign types. This sign life can then be used in the expected sign life or blanket replacement methods. Signs in the ESRMF could also serve as control signs for the control signs method. Thus, the proposed ESRMF addresses all three of the management methods directly.

The FHWA minimum retroreflectivity standards require that transportation agencies can prove compliance with the standards, especially to avoid lawsuits. An ESRMF that is used in conjunction with one of the maintenance strategies recommended by the FHWA will aid agencies and motorists and help prove compliance with the standards. This is especially critical for small cities, towns and municipalities who do not have the large infrastructure or resources to respond to the new standard via assessment methods. They, more than anyone, would benefit from an ESRMF, enabling them to implement one of the more cost efficient management methods for compliance because they would have the data to do so.

CASE STUDY DESIGN

A design for an experimental sign retroreflectivity measurement facility needs to ensure that the following objectives are met:

- Measure sign retroreflectivity over time in order to effectively and accurately model sign deterioration under real world conditions.
- Determine when signs will fall below the FHWA minimum retroreflectivity standards.
- Evaluate sign sheeting types and colors most used by transportation agencies, both now and in the future.
- Minimize the costs and space requirements associated with the ESRMF.

In order to illustrate how an ESRMF can be designed according to these objectives, an ESRMF design is presented as a case study. The case study design includes a base ESRMF design and suggested optional modifications to show how the design can be customized or expanded, depending on an agency's unique needs.

The ESRMF design process involves the following four steps:

- Sign Selection
- Sign and Facility Layout and Installation
- Data Collection Plan Design
- Cost Analysis

Sign selection entails determining the sign sheeting types and colors to be studied, the sign size, and the required sample size. Signs are selected based on their sheeting type, color(s), cost, and criticality to safety. Once the signs are selected, the necessary sign layout and installation parameters can be determined in order for the signs to all be subject to the appropriate exposure to the sun and weather. A data collection program, to measure sign retroreflectivity and monitor its deterioration over time, must also be designed and implemented. A cost analysis for the proposed ESRMF has been performed and is included. The ESRMF design outlined in this section can be viewed as a base configuration that can be modified depending on the unique needs and requirements of any transportation agency.

Sign Selection

One of the objectives of the ESRMF design is to evaluate the sign sheeting types and colors most commonly used in the field currently and those that will be used in the future. The “most used” criterion motivated the selection of sign sheeting types and colors as well as the actual signs chosen for the ESRMF.

Sheeting Type

Sign sheeting types were selected based on the sheeting types that agencies are currently installing or are planning to install in the near future. Major manufacturers of sign sheeting materials are Avery Dennison®, 3M™, Nippon Carbide, ATSM, Inc., Kiwalite®, and LG Lite (FHWA 2005). Our recommended sheetings are as follows:

- Type III encapsulated lens
- Type III prismatic
- Type IX prismatic

Type III encapsulated lens sheeting was selected because the NCDOT, as well as many other DOTs nationwide, is presently using it for all new sign installations on secondary and on most primary roads. Type III prismatic sheeting was selected because it has the potential to maintain its retroreflectivity longer than a more easily damaged encapsulated lens sheeting. Type IX prismatic sheeting is often used on interstate signage and important primary road guide signs. Type I sheeting was not selected for the ESRMF because most agencies across the country have discontinued new installations of Type I sheeting.

Colors

Similar to sign sheeting types, sign colors for the ESRMF were selected based on the sign colors most commonly used in permanent signage by most transportation agencies. The requirement that the signs be permanent eliminates orange signs from consideration because they are used only on a temporary basis in work zones. Brown signs were also not included in the ESRMF because they are primarily used to guide drivers to daytime attractions and therefore do not need high visibility at night. The sign colors selected for the ESRMF are as follows:

- White
- Yellow
- Red
- Green

These sign colors are most typically used for regulatory, warning, and guide signs nationally. If an agency would like to evaluate possible deterioration differences between retroreflective sign sheeting, screened ink, overlay film, and digitally printed media of the same color, signs produced using these different manufacturing techniques can be included in the ESRMF for comparison. Blue signs are not included in the basic design of the ESRMF because the FHWA has not proposed minimum retroreflectivity values for blue signs, but they could be added to the ESRMF in a more customized design, as could fluorescent colors if the facility sponsor had an interest in them.

Sample Size

To obtain 95% confidence in the analysis results, each sheeting color should have the total sample size indicated in the fifth column of Table 1. The total sample size (column 5) is equal to four times the maximum needed sample size per orientation (column 4) because the ESRMF will be testing signs facing north, south, east, and west.

The sample size per orientation was derived from the standard deviation of R_a values (column 2) with the same Type III sheeting color and age from the NCSU field study (Rasdorf et al. 2006) and an acceptable difference in the ESRMF R_a results (column 3) equivalent to 10% of the average R_a value for the same Type III sheeting color and age. A variance value from field sign data was used instead of a variance from controlled sign data because the field variance would logically be greater and lead to a more conservative (and larger) sample size. The acceptable difference was selected to be as large as 10% to account for often low repeatability of measurements and noisy variability in R_a measurements. Column 4 was calculated from columns 2 and 3 by using the standard sample size formula $[(1.96*\text{Column 2})/\text{Column 3}]^2$ and then rounding to the nearest multiple of 4.

Table 1. Determination of ESRMF Sample Size

(1) Sheeting Color	(2) Standard Deviation of R_a from Field Study	(3) Acceptable Difference in R_a Values	(4) Sample Size per Orientation	(5) Total Sample Size
White	15.6	24.4	4	16
Yellow	18.2	19.9	4	16
Red	7.2	5.2	8	32
Green	3.9	4.1	4	16

Sign Selection

Specific signs were selected for the ESRMF based on a combination of their sheeting color(s), their cost, and how critical they are in the field. Ideal signs would have one to two sheeting colors that could be measured for retroreflectivity, would be critical to driver safety, and would be a typical size. Table 2 and Figure 1 show the test signs selected as a result of these criteria for the basic ESRMF design.

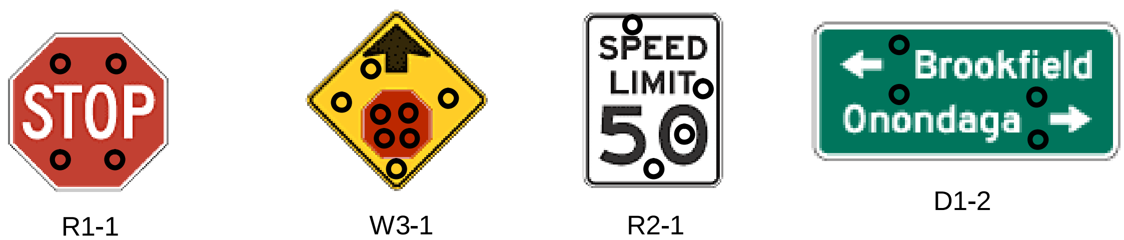
Table 2. Color and Size of Signs Selected for ESRMF

Sign Message	Sign Color Background (legend)	Sign MUTCD Code	Sign Size	Per ASTM Sheeting Type		TOTAL Number of Signs
				Number of Test Signs	Number of Extra Signs	
Stop	Red	R1-1	30"	16	5	63*
Stop Ahead	Yellow (Red)	W3-1	36" x 36"	16	5	63
Speed Limit	White	R2-1	24" x 30"	16	5	63
Destination Sign	Green	D1-2	54" x 24"	16	5	63
TOTAL				64	20	252

** Total = 16 + 5 or 21 signs per sheeting times 3 sheeting types*

The Stop (R1-1) sign was selected because it is the most critical red color sign in the field and a high priority on maintaining stop sign retroreflectivity is critical. The 30" Stop sign size is the most widely used size on secondary roads (and is less expensive than the 36" version). The Stop Ahead (W3-1) sign was selected primarily because it has large areas of both yellow and red sheeting and could be measured for both yellow and red retroreflectivity, thereby reducing the number of red Stop signs needed in the ESRMF. Together, the 16 Stop signs and 16 Stop Ahead signs will satisfy the red sign sample size of 32 signs specified in Table 1.

The Speed Limit (R2-1) sign was chosen for the ESRMF because it is the most common white background sheeting sign in the field on all road types. The Destination Sign (D1-2) was chosen because it is a green background sign that is commonly used on both secondary and primary roads. Signs with white letters on a darker background such as the Stop and Destination Signs can fail the FHWA minimum standards if there is insufficient contrast between the letters and the background. Sign contrast is quantified using the contrast ratio, which is the ratio of the retroreflectivity of the white letters to the retroreflectivity of the darker background (FHWA 2007).



Legend

¢ Retroreflectometer measurement locations on each sign (four per sign per color measured)

Figure 1. Signs Selected for Basic ESRMF Design with MUTCD Code

In addition to the 16 test signs needed per ASTM sheeting type (in order to meet sample size requirements) for each sign message and color combination, 5 extra signs should be included. Four of these signs are intended to serve as *substitute* signs. These signs should be exposed to the same environmental conditions in the ESRMF as the 16 test signs but should be placed in separate locations. A substitute sign can be used to replace a test sign that has been damaged during shipping, installation, or the testing period.

The remaining extra sign should serve as a *control* sign. The control sign should be stored indoors so it is protected from deterioration due to the outside environment. The retroreflectivity deterioration not due to environmental effects can be determined by comparing the deterioration of the control sign to that of the test signs. A total of 4 substitute signs and 1 control sign should be ordered for every sign message/color combination in the ESRMF (for a total of 16 + 4 + 1 = 21 signs for each sign/sheeting type combination).

Sign and Facility Layout and Installation

The installation of signs in the ESRMF needs to resemble as closely as possible the typical installation conditions in the field. This requires that the sign height, sign spacing, sign layout, and ESRMF location are designed to approximate the average field conditions in the region the ESRMF represents. All of the signs included in the basic ESRMF design are intended to be installed at approximately the same time to ensure that all signs have the same installation date and therefore can be compared on this basis.

<u>Sign Height</u>

The signs in the ESRMF should be installed at a height of five feet from the ground to the bottom of the sign, which is consistent with the MUTCD-specified height for rural roads.

<u>Sign Spacing</u>

In the ESRMF, the signs need to be placed far enough apart to ensure that shadows are not cast from one sign onto another. The necessary spacing between the signs to achieve this is based on the angle of the sun and the dimensions of the sign. The basic ESRMF design requires that when the angle between the sun and the ground is 15° or greater, none of the signs, except those facing west when the sun is in the east, etc., will be covered by shadow. Since the height of the largest sign (Stop Ahead) is 4.25 ft (the diagonal of a 36″ sign), sign supports need to be spaced at least 16 feet from the nearest sign that could be casting a shadow.

<u>Sign and Facility Layout</u>

In order to increase the sign support density in the ESRMF, modules of 16 signs each were designed to minimize shadows and simultaneously test four different sign orientations: north, south, east, and west. Figure 2 shows the design of a typical "module" of 16 signs. Each sign, when installed, will have a label on the front of its support with its assigned sign inventory number to aid in data collection. The signs will also be marked with their sign inventory number, the sign manufacture date, and the sign installation date on their back face.

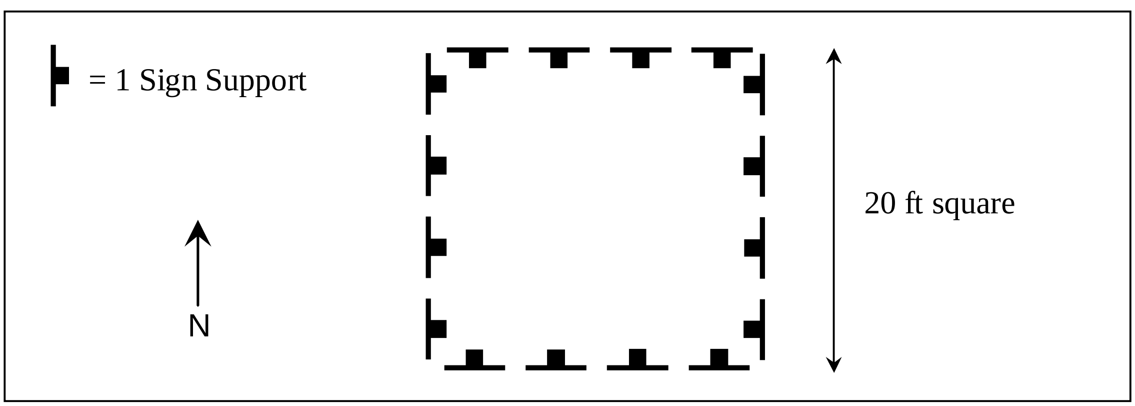


Figure 2. Layout of Sign Module

The basic facility layout, as shown in Figure 3, will consist of four modules for each sign type collected per each of the three sheeting types, for a total of 12 modules. Per Table 2 and Figure 1 the four modules per sheeting type consist of the following:

1. 16 Stop signs
2. 16 Stop Ahead signs
3. 16 Speed Limit signs
4. 16 Destination signs

A layout of the entire ESRMF is shown in Figure 4. This layout includes an area for the basic, 12-module ESRMF, for 15 additional module locations for future ESRMF expansion, and for 3 modules for "substitute" signs that can replace damaged test signs in the original 12-module section. The substitute signs would be exposed and measured along with the signs in the 12-module ESRMF, so they would be ready to be used as substitutes for a damaged test sign if needed.

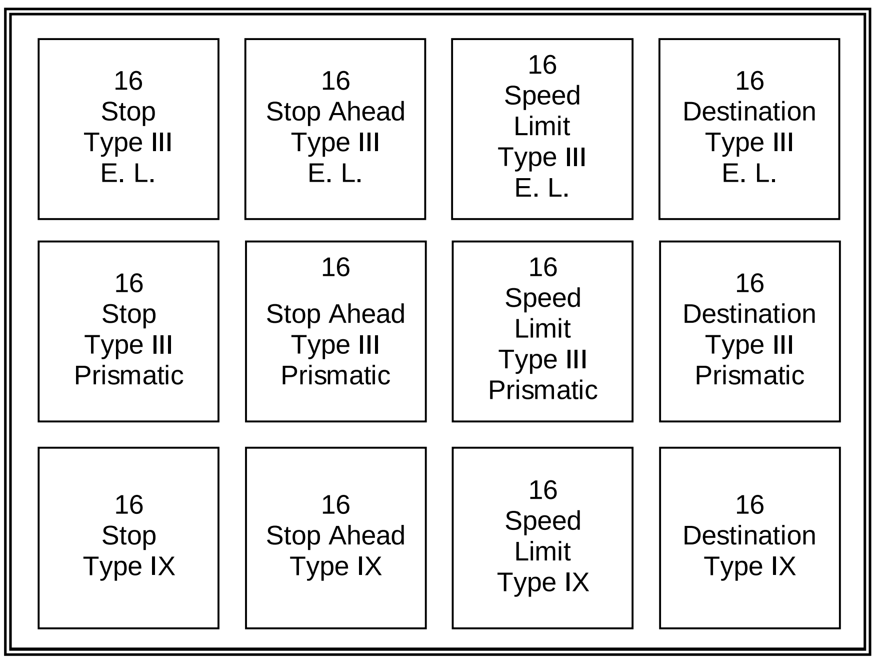


Figure 3. Basic 12-Module Sign Facility Layout

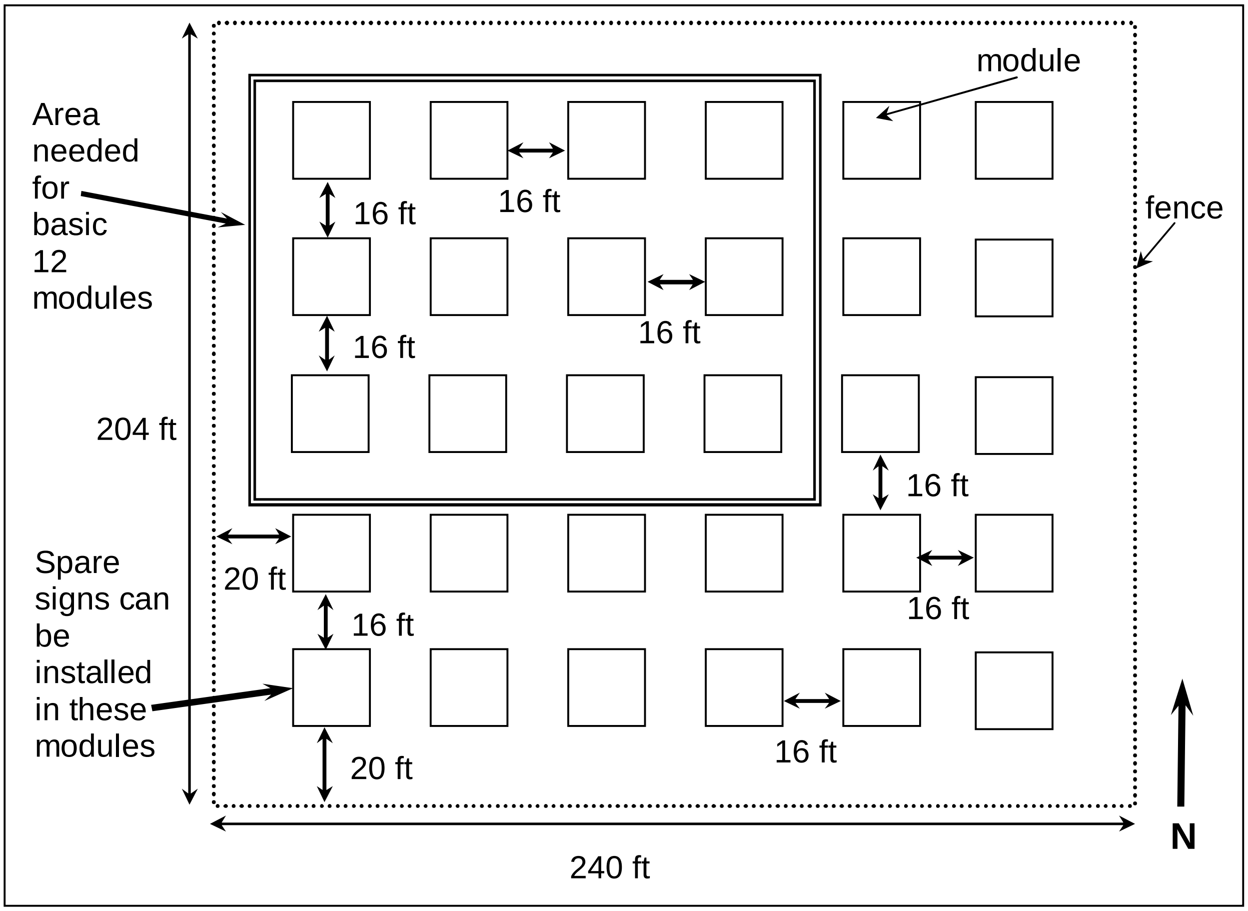


Figure 4. 30-Module ESRMF Layout

Other arrangements of the modules, such as the checkerboard design shown in Figure 5, are also possible. The checkerboard design provides 15 module locations, which would include the basic 12-module ESRMF as well as 3 substitute sign modules. The final 15 additional module locations would be used to test, for example, blue sheeting signs or for expansion. Note that the proposed facility size is quite large. It allows for a full 100% expansion, providing 30 modules while initially using only 15 (12 for test and 3 for substitute signs). If desired, an agency could reduce the facility to a 5x5 module size allowing 5 extra modules, a 50% expansion.

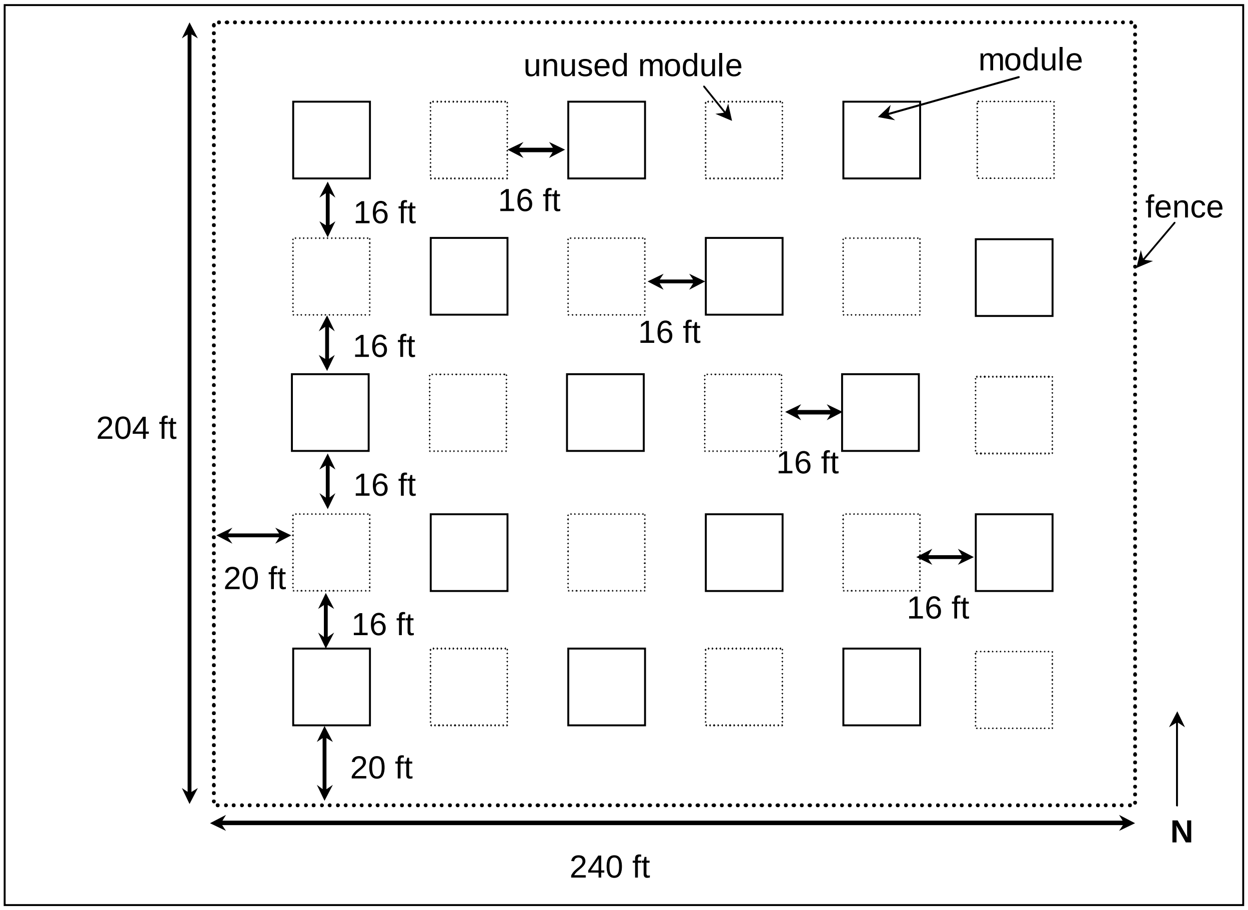


Figure 5. Checkerboard ESRMF Layout for 15 Modules

The ESRMF, with a module size of 20 ft square and a spacing of 16 ft between modules, will need a level area at least 204 ft by 240 ft, or 1.12 acres. This area should be as far as possible from surrounding trees and buildings and should have a gravel or bare dirt surface to either eliminate or limit vegetation (grass). This will reduce the cost to maintain the area and the chances of damage to the signs from maintenance operations.

Security

Protecting the signs in the ESRMF is critical. Once this facility is put into operation, any significant damage through vandalism or theft would be devastating. Therefore protection is of paramount importance. For this reason, the ESRMF should be surrounded by two enclosures. The inner enclosure will be a 9 ft. high wood fence that would be a visual barrier to prevent those outside the ESRMF from even noticing the test facility. The fence should be no taller than 9 ft. so that it does not cast shadows on the signs. The outer enclosure should be another fence located 20 feet further out from the first, acting as a physical barrier to prevent unauthorized access to the ESRMF. The outer fence may not be needed if the ESRMF can be installed within an access-controlled agency facility, such as a locked compound. Both fences should have a gate that is locked at all times. The gate can be located at any convenient location in the ESRMF layout.

ESRMF Location

The proposal in NC is to implement an ESRMF in a number of locations. The first location was chosen to be in the greater Raleigh area because of the area's typical NC climate, proximity to the NCDOT research office, proximity to research universities, ease of access, and availability of space. A second priority location would be near the Atlantic coast and the third priority location would be in the Appalachian mountains. Near the coast there is greater exposure to salty air and sun, while in the mountains the signs will be more exposed to cold temperatures, snow, and ice.

In other states, the primary factors may or may not be seaside, mountain, and plain locations, depending on the state's unique geography. More broadly, on a national basis, such facilities would ideally be located in New England, Florida or Georgia, the western mountains, the desert, along the Pacific coast, and in the plains of the northern and southern Midwest. This would provide the broadest climatic and geographic exposure possible. Differences in UV exposure and pollution levels between testing locations should also be considered. An ESRMF cannot cover all conceivable environments in which a sign might be placed. For example, signs near industrial areas may be exposed to chemicals or unusually high levels of dust that will cling to a sign. However, only a small fraction of all signs exist in these atypical environments.

Installation Procedure

Signs to be installed in the ESRMF should be selected from the usual sign supplier for the agency or region. The signs selected should not be part of a special run, although the green guide signs and some of the Type III prismatic and Type IX prismatic sheeting signs may need to be specially manufactured because they are not manufactured on a regular basis. Additional signs should be ordered so there are replacement signs in case some signs are damaged during shipping or installation.

Once the signs arrive on site, they should be examined closely for defects. The initial retroreflectivity is to be measured in the four previously identified locations (in Figure 1) and compared to the typical initial retroreflectivity value for the sheeting type and color. If the retroreflectivity at all four locations is not within the typical initial range, a replacement sign should be installed in place of the original sign. The replacement sign would need to meet the same initial retroreflectivity criterion.

All of the signs selected for the ESRMF should have a known manufacturing date and both the manufacturing and installation dates for each sign should be recorded. A regular DOT sign crew using typical materials and tools should install the test and substitute signs. Substitute signs should be installed in a module outside of the basic ESRMF installation so they could replace a vandalized or otherwise damaged sign if needed.

The control sign for each module should be stored in a known, secure indoor location and protected from sunlight, weather, and temperature extremes (NTPEP 2008). The control sign should be stored vertically and should be protected by foam packing material. This is to prevent pressure on the sign's face that can cause premature degradation. The control sign for each module should have its retroreflectivity measured at the same time the sign module in the ESRMF is initially measured.

Data Collection Plan Design

Once the ESRMF is installed, all signs should have their initial in-place retroreflectivity measured by a portable retroreflectometer point instrument in the four standard locations using an observation angle of 0.2°, an entrance angle of -4.0°, and a rotational angle of 0°. The rotation angle for the point instrument is determined by the angular position of the instrument on the sign face. Assuming the retroreflector's datum axis to be upward, the rotation angle equals 0° when the instrument is upright (ASTM 2001). This retroreflectivity measurement method is in accordance with the ASTM E1709 standard for retroreflectivity measurement. The retroreflectometer should be calibrated each time it is used, and the same retroreflectometer unit should be used to collect all readings. After the initial measurements all signs should be measured semi-annually.

As noted above, the FHWA minimum retroreflectivity standard is based on a 0.2°/-4.0° measurement geometry. However agencies can decide to measure retroreflectivity using other geometries representing different road user types. It should be noted that the FHWA has established a standard. Any agency deviating from this standard would want to justify doing so because their results would not fit within the framework of other national studies using the standard. Careful consideration should be given to any such deviations.

For each sign type (Stop, Stop Ahead, Speed Limit, and Destination Sign) a template should be created showing the precise location and order in which measurements are to be taken for signs in the ESRMF and control signs. The templates will specify measurement locations to be used over the life of the facility. This will ensure that retroreflectivity measurements are taken in the same locations on each sign over time because slight changes in the retroreflectometer location on the sign may yield different readings (ASTM 2001). The reader is referred back to Figure 1 where measurement locations are shown on the four signs selected for the basic ESRMF design. Note that the Stop Ahead sign shows eight locations while the remaining three signs show four. As mentioned previously, this permits the measurement of both the red and yellow colors. Additionally, the retroreflectivity of the Stop sign legend and Destination Sign legend (white letters) should be measured in four places so it can be used to determine the contrast ratio for these signs.

A database for the ESRMF should be implemented. This database will contain the sign inventory number, sign installation date, sign manufacture date, and sign attributes such as sign color, message, orientation, and sheeting type. All signs will have one unique inventory number, except for the Stop Ahead signs, which will have two; one for the yellow sheeting and one for the red sheeting. Each sign, when it is installed, will have a label on the front of its support with its assigned sign inventory number and a label on the back of the sign with the sign inventory number, the sign manufacture date, and the sign installation date.

A technician should record all four retroreflectivity values for each sign/color combination directly into a measurement data log using a personal data assistant (PDA). A sample of the PDA data log is shown in Table 3. The measurement date should be included in the filename of the PDA data log. The PDA data log should be uploaded to the main database where the retroreflectivity readings and the measurement date are incorporated into the database file. The main database will calculate an average retroreflectivity reading for each sign and color combination from the four readings. The entire database should be posted on a website and updated semi-annually.

Table 3. PDA Data Log Example

INVENTORY #	SIGN MESSAGE	SHEETING COLOR	READING 1	READING 2	READING 3	READING 4
1021	Stop Ahead	Red	45	46	43	45
1022	Stop Ahead	Yellow	210	212	215	208
1023	Stop	Red	50	49	48	51

A university collaboration should be established to ensure the implementation of the data collection and analysis plan and to make data readily available for research use. This would include semi-annual measurement of all signs, data compilation and reporting to the FHWA and the state agency, and posting of all data on the internet. The analysis activity would be performed on an annual and a multi-year basis.

Every variable influencing retroreflectivity degradation and overall sign health should be studied. The variables under consideration should include at least sign type and color, sheeting type, age, orientation, and weather. Deterioration models should be developed and performance results published. The literature has shown that numerous models exist to approximate degradation rates. The authors have proposed one such model (Immaneni, et. al. 2008).

Cost Analysis

The total cost for an ESRMF consists of the initial cost of the signs and their installation as well as the ongoing operation and maintenance costs for the ESRMF. The cost of signs and installation is fixed and will occur when the ESRMF is installed, while the operation and maintenance costs may vary and will be ongoing for the life of the ESRMF.

<u>Signs and Installation</u>

For the basic ESRMF design, the cost of Type III encapsulated lens, Type III prismatic, and Type IX prismatic sheeting signs was obtained from NCDOT's supplier, Correction Enterprises. The cost of sign installation (materials and labor) was obtained from NCDOT Division 6. Table 4 lists the prices for each Type III encapsulated lens, Type III prismatic, and Type IX prismatic sheeting sign and its installation. Note that the cost of Type III encapsulated lens sheeting is the same as Type III prismatic. With 21 signs purchased of each sheeting (3) and sign message type (4), the total number of signs to be purchased in the basic ESRMF design is 21 * 3 sheeting types * 4 sign message types = 252. The total cost for Stop signs, for example, would be 21*($74.00 +

$74.00 + $76.95) = $4,724, with a total cost for all four sign message types of approximately $30,000.

Table 4. Cost of Signs and Installation (S&I) for ESRMF

Sign Message	Sign Color Background (legend)	S&I Cost for Type III Encapsulated Lens Sheeting	S&I Cost for Type III Prismatic Sheeting	S&I Cost for Type IX Prismatic Sheeting	TOTAL
Stop	Red	$74.00	$74.00	$76.95	$4,724
Stop Ahead	Yellow (red)	$83.72	$83.72	$149.85	$6,739
Speed Limit	White	$76.81	$76.81	$96.78	$5,258
Destination Sign	Green	$139.05	$139.05	$194.83	$12,670
	TOTAL	$8,783	$8,783	$11,824	**$29,391**

The cost of the inner wooden fence was estimated to be $25,000 using a fence cost estimating tool with a total fence length of 888 feet, one 10 ft gate, and a fence height of 9 feet. The cost of the outer barbed-wire chain-link fence was estimated to be $35,000 using a fence cost estimating tool with a total fence length of 1048 feet, one 12 ft gate, and a fence height of 8 feet. The installation cost, including the fence, gate, signs, and supports (but excluding site preparations), is estimated to be $90,000.

Accessories

There are some fixed data collection equipment costs associated with the ESRMF. A portable point retroreflectometer, such as the RetroSign® 4500, costs approximately $12,000 including accessories. A PDA with accessories and software will add approximately $1,000 to the cost. Assuming that software to manage the ESRMF database will cost $1,000, the accessories cost will be $14,000 and the total fixed costs for the ESRMF will be $104,000. Computers and associated peripherals are assumed to be available and to result in no additional costs.

Operation and Maintenance

The operation and maintenance costs also include the annual costs associated with data collection and analysis and the costs of maintaining the ESRMF site. The annual cost of data collection will include the costs of the agency or university that is responsible for the ESRMF's data collection, analysis, and reporting. Allowing a $20,000 annual budget for data collection and analysis and $5000 for ESRMF site maintenance per year, the total annual maintenance and data collection budget is $25,000. Assuming a ESRMF lifetime of 20 years, the total costs will be approximately $500,000, excluding inflation.

SIGN TEST FACILITY CUSTOMIZATION OPTIONS

The ESRMF design aims for flexibility in order to support a broad and robust study, to make available to the research community data that have not heretofore been available, and to allow for customization and specialization in testing. Each location that sets up such a facility can do so in a way to meet its specific needs. In particular, the following are possible extensions or enhancements that could be considered depending on an agency's needs:

- Other sign colors and messages
- Additional sheeting types and other sheeting manufacturers
- Modification of module size and layout
- Data collection changes

The following sections discuss these potential facility customization and expansion options.

Sign Colors and Messages

Adding variables could change the basic sign experimental facility design outlined in the previous sections. Blue signs could be incorporated into the design by adding one additional module per each of the three sign sheeting types. One blue sign that could be used, especially because of both its commonality and its economical size, is the Rest Area sign (MUTCD code D5-2a), shown in Figure 6. Adding the D5-2a sign to the basic three sheeting type sign farm design would cost an additional $9,300.

Figure 6. Rest Area, Yield, and Keep Right Signs

A greater variety of signs can be selected for each color, such as adding a module of Yield signs (white and red color) or Keep Right signs (white) as shown in Figure 6. Because of the criticality of red signs a yield sign would be a particularly ideal addition to the basic design.

Sheeting Types and Manufacturers

Additional sheeting types could be considered in the ESRMF. Possibilities include the new Type XI sheeting (e.g. 3M™ Diamond Grade™ DG3). The basic ESRMF design could also be expanded to include sign sheetings produced by several manufacturers.

Module Size and Layout

The number of signs in each module as well as the number of modules can be modified to create a larger or smaller sample size. If an agency is not concerned about how orientation affects sign deterioration, it can place all signs facing in a direction of their choice. Agencies should check that the selected sample size meets their desired statistical confidence level.

Similarly, an agency may want to simulate accelerated weathering of the signs in the ESRMF. Accelerated weathering can be accomplished in two ways. First, ASTM G7-05 specifies that accelerated weathering can be achieved by orienting the signs to face the equator and to be installed at an angle from to the horizontal that is equal to the geographic latitude of the ESRMF site (ASTM, 2005). Second, the NTPEP achieves accelerated weathering by orienting signs to face south and installing them at an angle of 45° to the horizontal, which is also in accordance with ASTM G7-05. As noted earlier, claims have been made that the accelerated weathering method used by NTPEP effectively doubles the deterioration rate of signs (Carlson and Hawkins 2003). In other words, a sign deteriorated three years in the test facility would be representative of six years of deterioration in the field.

Differing site situations may require that an agency modify the basic ESRMF layout. The layout of the modules can be modified to accommodate an unusually shaped site or any other configuration. The checkerboard layout shown in Figure 5 can be used to further minimize any shadows on test signs as can an increased spacing between the modules.

Data Collection

An agency can change the data collection specifications to fit their data collection needs. For example, an agency may already own a portable annular retroreflectometer instead of a point retroreflectometer. Costs could also be increased or decreased by changing how often the retroreflectivity data are collected. The authors recommend that data be collected at least semi-annually. Some agencies may wish to incorporate the daily weather conditions at the ESRMF into their sign deterioration analysis to determine if weather conditions play a significant role in sign deterioration. Another variable that agencies may want to consider is change in sign color over time. Sign color measurements can be made using a portable color meter and should follow the procedure outlined by NTPEP (NTPEP 2008).

CLOSURE

An ESRMF will enable an agency to measure how signs deteriorate over time in a controlled environment that mimics field conditions. The controlled environment limits the effects of vandalism and damage on signs and results in less variability in both deterioration data and models. Better deterioration models can help agencies determine when signs in the field will deteriorate without having to initiate programs to field measure sign retroreflectivity at regular intervals.

The FHWA minimum sign retroreflectivity standards require that agencies implement a sign management and evaluation method. The deterioration models developed from the ESRMF could be used to calculate sign lifetimes that could be used in both the expected sign life or blanket replacement method. The ESRMF could also be used to implement the control sign maintenance method suggested by the FHWA where ESRMF signs can be chosen to represent similar signs in the field. When the retroreflectivity of the test signs in the ESRMF falls below the minimum, similar signs in the field should be replaced.

The ESRMF will assist agencies in determining sign sheeting selection policies, or in other words, which sign sheetings to use for different applications. Currently, there is a particularly significant need for long-term performance data on the newer sign sheetings, beyond the shortterm performance data from the NTPEP. If an agency knows how a sign sheeting type deteriorates over time relative to its cost, life-cycle cost analysis can be used to determine the most cost-effective sheeting applications. Thus, facilities such as the ESRMFs recommended here will yield important data that are not available in any other cost-effective way.

RECOMMENDATIONS

The authors recommend that ESRMFs be built in at least each of the major climatic regions in the United States to best determine how signs in the area deteriorate over time. The facilities could be located in New England, Florida or Georgia, the Rockies, the arid Southwest, the Pacific coast, and the plains of the northern and southern Midwest. ESRMFs built using this design or a variation thereof can be used, along with a sign inventory program, to ensure compliance with the FHWA minimum retroreflectivity standards on a national scale. The data collected by each ESRMF should be made available to all agencies nationwide. Federal funding could be made available for both ESRMFs and the sharing of ESRMF data.

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