Technical Report Documentation Page

1. Report No. TX-00/2962-S	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF FLUORESCENT ORANGE SIGNS		5. Report Date October 1998, Resubmitted May 2000
		6. Performing Organization Code
7. Author(s) H. Gene Hawkins, Jr., Paul J. Carlson, and Michael Elmquist		8. Performing Organization Report No. Report 2962-S
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project No. 7-2962
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Project Summary: September 1995 - August 1998
		14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with the Texas Department of Transportation.
Research Project Title: Evaluation of Fluorescent Orange Signs for Work Zone Application

16. Abstract
In recent years, fluorescent orange signs have become a viable option for increasing the visibility of traffic control devices in temporary traffic control zones due to the fact that the fluorescent properties of these signs are more stable now than when they were initially developed. This report describes research on the durability and color recognition of fluorescent orange signs. The evaluation focused on two primary activities: a comparison of the durability of fluorescent and non-fluorescent orange signs; and a comparison of the color recognition of fluorescent orange, non-fluorescent orange, and other sign colors. In the durability evaluation, damaged and undamaged products were exposed for 24 months on a weathering rack. The evaluation of the fluorescent products included measurements with a new instrument that accurately measures the fluorescent properties of fluorescent materials. Other measurements included retroreflectivity and color. In the color recognition evaluation, drivers were asked to identify the color of various stimuli as they drove on a closed course. The accuracy of color identification and the identification distance were recorded.

The results of the durability evaluations found some significant changes in material properties over the 24-month period. Several products were outside of ASTM specifications at the beginning or end of the exposure period. The fluorescence measurements found that two of the four products evaluated retained a reasonable amount of fluorescence at the end of 24 months. The results of the color recognition evaluation found that many of the older drivers had difficulty distinguishing between some colors. Several stimuli had color perception accuracies below 80 percent. The fluorescent orange products had greater recognition distances and color perception accuracy than those of non-fluorescent orange products.

The research results indicate that fluorescent orange signs may offer color recognition benefits and that some of the fluorescent products possess adequate durability characteristics to justify their use.

17. Key Words Traffic Control Devices, Signs, Fluorescent Signs, Work Zones		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 70	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EVALUATION OF FLUORESCENT ORANGE SIGNS

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Report 2962-S
Project Number 7-2962
Research Project Title: Evaluation of Fluorescent Orange Signs for Work Zone Application

Sponsored by the
Texas Department of Transportation

October 1998
Revised May 2000

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ACKNOWLEDGMENTS

The successful completion of this research project was achieved only because of a significant degree of assistance from a large number of individuals. At the initiation of this project, the Texas Department of Transportation (TxDOT) formed a panel of Project Advisors to provide guidance in the development and conduct of the research activities and review project deliverables. The researchers would like to acknowledge the following Project Advisors for their time, efforts, and contributions:

- Cathy Wood, Fort Worth District, Department of Transportation, Project Director
- Ron Bailey, Austin District, Texas Department of Transportation
- Kirk Barnes, Bryan District, Texas Department of Transportation
- Greg Brinkmeyer, Traffic Operations Division, Texas Department of Transportation
- Larry Colclasure, Waco District, Texas Department of Transportation
- Mark Olson, Federal Highway Administration
- Sam Swan, Brownwood District, Texas Department of Transportation

The researchers would also like to recognize the following companies for their donation of orange sign products for evaluation in this research effort:

- Minnesota Mining and Manufacturing (3M), Inc.
- Reflexite
- Stimsonite

This research utilized a new instrument for measuring the fluorescent properties of the fluorescent sign materials. The researchers recognize Michelle Frazier of Labsphere for her explanations and assistance in understanding the technology of the new instrument. The researchers would also like to acknowledge the cooperation of John Bassett of the TxDOT Materials and Test group for loaning instruments to make retroreflectivity and color measurements.

The preparation of the experimental setup and the sign changing during data collection required significant contributions from TTI student workers. Special recognition is given to Mike Elmquist, an undergraduate student who contributed heavily to the project and used a portion of the research activities in his TAMU Undergraduate Fellows Program. Other students who contributed to various project activities include: Mike Davis, Melanie Glees, Paul Fread, Ken Fogle, Kelly Parma, and Melissa Peoples.

Of course, this research could not have been conducted without the generosity of the 41 individuals who gave up some of their time to be test subjects. Their patience and cooperation are greatly appreciated.

Finally, the researchers would like to recognize the efforts of J. Alan Parham, who was responsible for the early activities of this project, but left TTI prior to the completion of the project.

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IMPLEMENTATION RECOMMENDATIONS

Based on the results of the evaluations, the researchers offer the following recommendations:

- Compared to standard orange signs, fluorescent orange sign materials have sufficient durability and color recognition to justify their use in work zone applications. The only exception to this finding, Classic Fluorescent, is no longer available.
- The fluorescent properties of a fluorescent orange sign offer no benefit at night. Therefore, the use of fluorescent signs should not be based on nighttime performance.
- All products have some difficulty staying within the color zone. The Federal Highway Administration (FHWA) is currently evaluating the color definitions and may establish new color zones in the future. TxDOT should wait for the results of that rulemaking effort before making any decisions regarding color of retroreflective materials.
- The researchers offer the following recommendations regarding the products evaluated in this research effort:
    - TxDOT should not allow the Reflexite Classic Fluorescent Orange product to be used. This product is no longer available.
    - If the Reflexite Classic Orange or Super Bright Orange products are used, TxDOT should implement a standard procedure for cleaning these products every six months.
    - The researchers cannot offer any insight into whether the performance of Stimsonite's new Series 6200 sheeting is any better or worse than that of the Series 4200 sheeting evaluated in this research.

CHAPTER 1
BACKGROUND

With roadway congestion and speed increases demanding more of the driver's attention, it is becoming paramount for the driver to be able to safely operate the vehicle in a more efficient manner. This is particularly true in the vicinity of construction and maintenance work zones due to the changing roadway conditions and the exposure to the work zone personnel and equipment. Work zones, or temporary traffic control zones as they are now being referred to, present unique traffic control situations because of many factors. These factors include changes in travel paths; presence of workers, equipment, and work activities; greater frequency of potential hazards; and greater consequence severity; plus other factors. Worker and driver safety is a major concern of transportation agencies throughout the United States.

One method of increasing the safety in temporary traffic control zones is to increase the visibility of the traffic control devices used in these areas. As a result, significant attention has been focused upon the use of traffic control devices in temporary traffic control zones. In 1971, the U.S. *Manual on Uniform Traffic Control Devices* (MUTCD) (1) introduced the use of orange for temporary traffic control devices to improve the visibility of these devices.

Since the introduction of the color orange for temporary traffic control zone applications, there have been several visibility-enhancing advancements in temporary traffic control devices. The retroreflective sheeting used in temporary traffic control zones today is significantly brighter than that used 25 years ago. Sign sizes have also been increased over time. A more recent advancement is the introduction of fluorescent signs. The first use of fluorescent orange in signs was in the mid-1980s with roll-up signs. In addition to the benefits provided by the orange color and retroreflective properties, fluorescent devices convert invisible ultraviolet rays to visible light. This phenomenon is most visible during low-light conditions such as dawn, dusk, or overcast days. Many transportation agencies around the U.S. have been using fluorescent orange sheeting in various temporary traffic control applications, and its use appears to be growing. However, several other agencies, including the Texas Department of Transportation (TxDOT), have not adopted the use of fluorescent orange signs in temporary traffic control applications.

Although manufacturers have been able to produce fluorescent materials for over 30 years, the early products had limited value as traffic control devices due to the short life of the fluorescent properties. Durable fluorescent orange sign products have been available only for a few years. Consequently, there is a limited amount of information on the overall effectiveness of fluorescent orange sign products, particularly with respect to comparisons between individual products.

RESEARCH APPROACH

In order to assess the potential effectiveness of using fluorescent orange, TxDOT sponsored a research project to evaluate various aspects of fluorescent orange signing. This research, conducted by the Texas Transportation Institute (TTI), was intended to address some of the key questions associated with the potential use of fluorescent orange signs. These questions include:

- How durable are fluorescent sheeting materials in comparison to materials currently in use, including the longevity of the fluorescent properties?
- To what degree does the use of fluorescent orange signs increase the visibility of the signs in comparison to standard orange signs?
- What has been the experience of other agencies that have used fluorescent orange signs in temporary traffic control applications?

The overall objective of the research was to determine the potential effectiveness of using fluorescent orange material for temporary traffic control zone applications. The research plan addressed the major issues described above. Each of these areas is addressed in a separate chapter of this report. Within each area, research activities were conducted to obtain the information needed to assess the potential effectiveness of fluorescent orange signing. These activities included:

- assessing state practices regarding fluorescent orange signs (Chapter 2),
- assessing the durability of retroreflectivity, color, and fluorescent properties of orange signs (Chapter 3), and
- evaluating the color recognition aspects of fluorescent orange signs (Chapter 4).

MEASURING SIGN PROPERTIES

This research focused upon three physical properties of sign materials: retroreflectivity, color, and fluorescence. Each of these properties can be measured and quantified.

Retroreflectivity

The basic principle of retroreflectivity is that light coming from a source is returned by a reflecting surface in a parallel direction. When this principle is applied to traffic signs, the light source is the vehicle headlights, the reflecting surface is the sign, and the receptor (driver) is located close to the light source. The light emitted from the headlights is the luminous intensity and is measured in candelas. The luminous intensity decreases with the distance traveled. The light that reaches the sign is the illuminance and is measured in lux. The light that is reflected from the surface is the luminance and is measured in candelas per meter squared (cd/m^2). The retroreflective performance of a sign material is described by the coefficient of retroreflection, R_A, with the units candela/lux/meter squared ($cd/lux/m^2$). The metric unit for sign performance ($cd/lux/m^2$) is equivalent to the English unit candle power per foot candle per square foot, which is also referred to as the specific intensity per area, or SIA.

There are two critical factors in the measurement of retroreflective properties — the observation angle and the entrance angle. The observation angle is the angle formed between the light source and the receptor. As the observation angle increases, the luminance of the retroreflector decreases. The entrance angle is the angle between the surface of the reflecting surface (sign) and the entering beam of light. The luminance is greatest when the entrance angle is 90 degrees (perpendicular to the sign face).

As applied to signs, the standard observation angles are 0.2 and 0.5 degrees. The standard entrance angles are -4 and +30 degrees. The most commonly used geometry for describing retroreflective performance is 0.2 and -4.

Color

Color is a complex property to define and quantify. The American Society for Testing and Materials (ASTM) defines color by indicating what it is not. The ASTM definition of color is the "*aspect of object appearance distinct from form, shape, size, position, or gloss that depends upon the spectral composition of the incident light, the spectral reflectance or transmittance of the object, and the spectral response of the observer, as well as the illuminating and viewing geometry*" (2). Three measurements are typically used to define the color of traffic signs: the *x* and *y* chromaticity coordinates and the Y tristimulus value.

With the use of chromaticity coordinates, all colors fall within the 1931 Commission Internationale de l'Eclairage (CIE), or the International Lighting Committee, (a Paris-based standards organization) chromaticity diagram. The 1931 CIE diagram uses a 2 degree observer, which is the most appropriate for the small observation angles associated with traffic signs, and illumination that represents daylight conditions. When the chromaticity coordinates are plotted on the 1931 CIE chromaticity diagram, they graphically illustrate the chromatic aspect of the color.

The Y tristimulus value (luminous factor) describes the lightness of the color. It ranges between 0 for perfect black and 100 for perfect white.

Fluorescence

In typical color pigments, incident light energy is partially absorbed and the portion that is not absorbed is reflected from the surface. In fluorescent materials, the properties act in a markedly different manner. Fluorescent materials absorb short wavelength ultraviolet (UV) high-energy radiation (wavelengths invisible to the human eye) and reradiate it at a longer wavelength (wavelengths visible to the human eye). This process is referred to as an energy shift. As a result, fluorescent materials emit more energy than they absorb from the incident light energy source and appear brighter than would a surface of the same color that was not fluorescent. This phenomenon is visible in low-light conditions such as dawn, dusk, and overcast days when shorter wavelength light is more prevalent. Fluorescent materials do not fluoresce at night because there is no UV radiation available.

The measurement of the color of fluorescent materials is an attempt to determine the total spectral radiance factor (β_T) under specified conditions of illumination and viewing and then to evaluate this spectrum in terms of the CIE system of colorimetry. The total spectral radiance factor at each wavelength is the sum of the reflected spectral radiance factor (β_R) and the luminescent (fluorescent) spectral radiance factor (β_F). The reflected radiance factor is actually the amount of incident light that is naturally reflected from the specimen, while the luminescent spectral radiance factor is a measure of the amount of shorter wavelength incident light that is converted to longer wavelength light. With non-fluorescent materials, β_F is zero.

TxDOT AND ASTM SPECIFICATIONS FOR ORANGE SIGNS

The results of the retroreflective and color evaluations of the various products were compared to criteria in two specifications for retroreflective sheeting: D4956 from ASTM and DMS-8300 from TxDOT. Both of these specifications classify sign sheeting materials into different types or grades. Table 1 compares the terminology from the different specifications and relates those terms to generic terminology used for sign materials. Neither of these specifications provides a separate material type for the super high intensity grade of sheeting. This proprietary product is commonly known as Diamond Grade™ sheeting. As a result, this type of material is classified as Type IV or Type C.

Table 1. Types of Sign Sheeting Materials

Common Description		ASTM Type – D4956	TxDOT Type – DMS-8300
Engineering grade		I	A
Super engineering grade		II	B
High intensity grade	Beaded	III	C
	Prismatic	IV	C

ASTM Specification D4956

ASTM specification D4956 (3) is the most widely utilized specification for retroreflective sheeting. Several other specifications, such as FP-96 from the FHWA and M-268 from the American Association of State Highway and Transportation Officials (AASHTO), are based on the ASTM D4956 specification. Table 2 lists the material properties from the ASTM specification that are pertinent to this research.

TxDOT Specification DMS-8300

The TxDOT specification for retroreflective sign sheeting is DMS-8300 (4). This specification marks a major shift from the previous TxDOT specification (5) in that it adopts most of the provisions of ASTM's D4956, including the classification of material types (i.e., Types I, II, III, or IV instead of Types A, B, or C). The new specification also adopts the ASTM *xy* color coordinate zones, which are different from those of the previous TxDOT specification. Table 2 also lists the material properties that are pertinent to this research from the current and previous TxDOT specifications.

Table 2. Material Properties from ASTM and TxDOT Specifications

<table>
<tr><th rowspan="2">Property</th><th rowspan="2">Type of Material</th><th rowspan="2">ASTM D4956</th><th colspan="2">TxDOT Specification 8300</th></tr>
<tr><th>11/92</th><th>8/98</th></tr>
<tr><td rowspan="3">Retroreflectivity R_A</td><td>ASTM Type III and TxDOT Type C, Class I</td><td>0.2 -4 100
0.2 +30 60
0.5 -4 30
0.5 +30 25</td><td>Same as ASTM</td><td>Same as ASTM</td></tr>
<tr><td>ASTM Type IV and TxDOT Type C, Class II</td><td>0.2 -4 100
0.2 +30 34
0.5 -4 64
0.5 +30 22</td><td>Same as ASTM</td><td>Same as ASTM</td></tr>
<tr><td>ASTM Type VI</td><td>0.2 -4 70
0.2 +30 26
0.5 -4 56
0.5 +30 17</td><td colspan="2">No applicable specification</td></tr>
<tr><td>Color Coordinates (x, y)</td><td>all materials</td><td>0.550 0.360
0.630 0.370
0.581 0.418
0.516 0.394</td><td>0.530 0.360
0.510 0.390
0.580 0.420
0.640 0.360</td><td>Same as ASTM</td></tr>
<tr><td rowspan="2">Luminous Factor (Y)</td><td>Type III and VI</td><td>min 14
max 30</td><td>min 12
max 30</td><td>Same as ASTM</td></tr>
<tr><td>Type IV</td><td>min 15
max 30</td><td>No applicable specification</td><td>Same as ASTM</td></tr>
<tr><td>Fluorescence</td><td colspan="4">No applicable specification</td></tr>
</table>

Note: All values for orange only.

FHWA Minimum Retroreflectivity Guidelines

For several years, the 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 pavement markings and signs which apply to all roads open to public travel*" (6). In a 1993 research report, the FHWA proposed a framework containing minimum levels of retroreflectivity (7). Those initial guidelines were extensively evaluated from an implementation perspective. As a result of the implementation evaluation, the FHWA revised the minimum retroreflectivity values (8). The most recent proposed minimum values of retroreflectivity for orange signs are presented in Table 3. These values are expected to be part of a proposed rule that will be published in the *Federal Register*. These values have not been adopted by the FHWA and are subject to change before or during the rulemaking process. Eventually, minimum values of retroreflectivity for signs are expected to be incorporated into the MUTCD.

Table 3. Minimum Retroreflectivity Values for Yellow and Orange Warning Signs

Legend Color		Black		
Background Color		**Yellow or Orange**		
Type of Legend	**ASTM Material Type**	**Minimum Retroreflectivity Values[1]**		
		Sign size ≥ 48 in	**Sign size = 36 in**	**Sign size ≤ 30 in**
Bold Symbol	ALL	15	20	25
Fine Symbol & Word	III	30	45	55
	IV	40	60	70

Notes: [1]Units are cd/lux/m^2. Measured at an observation angle of 0.2 degrees and an entrance angle of -4.0 degrees. These values are expected to be published in a *Federal Register* proposed rule. They are subject to change before publication as a proposed rule or during the rulemaking process.

DESCRIPTION OF MATERIALS EVALUATED

The field of fluorescent retroreflective materials is relatively new. Until recently, manufacturers were not able to produce a fluorescent sheeting that would maintain the fluorescent properties for a reasonable length of time in normal use. Manufacturers began to overcome this challenge in the early 1990s when fluorescent orange materials first began to appear.

All of the materials evaluated in this research project were donated by the manufacturers of the products. The materials selected for evaluation included all products that met TxDOT specifications for temporary traffic control zone signs at the time the material acquisition activities began (Fall 1995). Those specifications required that all products be ASTM Type III or IV (TxDOT Type C, high intensity or brighter) sheeting. Only three manufacturers produced a Type III/IV (high intensity or brighter) fluorescent sheeting in the Fall of 1995. For each of these fluorescent products, one or more equivalent non-fluorescent products were also acquired for evaluation. Because of the Type III/IV requirement in temporary traffic control zone applications, the research evaluations did not include any fluorescent orange products that were available in Type I (engineering grade) or Type II (super engineering grade) sheeting. Table 4 lists the eight products that were selected for evaluation as part of the research effort.

Table 4. Material Information

Type of Product	Manufacturer	Fluorescent Material	Product Name and Number		ASTM Type	Label[1]
Roll-up sign	Reflexite	No	Classic		VI	C-S
		Yes	Classic Fluorescent		VI	C-F
		Yes	Super Bright Fluorescent		VI	SB-F
Rigid sign	3M	No	High Intensity	3824	III	HI-S
		No	Long Distance Performance	3984	IV	LDP-S
		Yes	Long Distance Performance	3924	IV	LDP-F
	Stimsonite	No	High Performance	4370	IV	HP-S
		Yes	High Performance	4380	IV	HP-F

Notes: [1]The label is used throughout the report to identify specific products. The label coding is product-color. All products were orange.

In addition to one fluorescent and one non-fluorescent product from each of three manufacturers, there were two other products included in the evaluation. Reflexite provided a second fluorescent product for evaluation. Non-fluorescent 3M High Intensity sheeting was also included because it is one of the most widely used products in temporary traffic control zone applications. The Type C products most widely used in TxDOT temporary traffic control zone applications are the 3M High Intensity and the Stimsonite High Performance products. As such, they provided a means of comparing the performance of fluorescent materials to materials that are widely used in current applications.

The Reflexite materials were roll-up signs, while the 3M and Stimsonite materials were sheeting for rigid signs. Since the products were obtained for use in the research, Stimsonite has changed its product line. The Series 4200 sheeting has been replaced by the Series 6200. Both standard and fluorescent orange are available in the Series 6200 sheeting. In July 1999, Avery-Dennison purchased the Stimsonite Corporation and former Stimsonite products are now sold under the Avery-Dennison label. However, as the materials evaluated in this research are no longer marketed by Stimsonite or Avery-Dennison, they are referred to as Stimsonite products.

Reflexite has also introduced a new fluorescent material, named Marathon, that it claims has better fluorescence retention properties the previous product line. Reflexite has also discontinued its Classic Fluorescent material.

The Reflexite vinyl roll-up sheeting was provided in 200×200 mm (8×8 in) samples. The researchers mounted these samples on plywood substrates using heavy duty staples. The 3M and Stimsonite samples for rigid signs were provided by the manufacturers on 225×300 mm (9×12 in) aluminum substrates.

CHAPTER 2
SURVEY OF STATE PRACTICES

In December 1995, researchers distributed a survey to the state traffic engineer in all states except Texas. The survey was developed to determine the experiences, practices, and uses that other state transportation agencies have had with fluorescent orange signs in temporary traffic control zones. Table 5 lists the seven questions that were in the survey. Thirty-five of the 49 states responded to the survey. Appendix A presents the survey questions, responses, response percentages, and comments.

Table 5. Questions Included in Survey

Number	Question
1	Does your agency use fluorescent orange work zone signs?
2	How long has your agency been using fluorescent orange signs in work zones?
3	What type of work zones use fluorescent orange signs?
4	Do you mix fluorescent orange signs and standard orange signs in the same work zones? Also, if yes, please list any signs that are specifically designated for fluorescent orange.
5	Have you noticed any fading, dulling, or accelerated deterioration of the fluorescent orange color?
6	Do you believe the benefits of using fluorescent orange signs are worth the additional costs?
7	Have you noticed a reduction in accidents in work zones that use fluorescent orange signs? Has such a reduction been documented?

USE AND APPLICATION

The first four questions of the survey addressed whether states use fluorescent orange signs and the manner in which the signs are used. The first question asked states to indicate whether they had used fluorescent orange signs in work zones. There were 33 responses to this question. Of these, 22 (67 percent) indicated they had used fluorescent orange signs, 10 (30 percent) indicated they had not, and 1 (3 percent) indicated both. Two of the states that returned the survey did not answer this question. If one considers that the states that did not return a survey (14 states) are most likely to not use fluorescent orange signs, then the results can be interpreted that, in 1995, about half of the states used fluorescent orange signs.

The second question asked the states to indicate how long they had been using fluorescent orange signs. This question was intended to determine how much experience was available to determine the effectiveness of fluorescent orange signs. Twenty-four of the 35 states indicated that they had used fluorescent orange signs for some period of time. One of the responding states indicated that it had been using fluorescent orange signs for 6 to 12 months, but that state did not answer the first question of the survey. Table 6 summarizes these responses. It should be noted that this survey was distributed in December 1995, and the current length of experience with fluorescent orange signs is likely to be over two years greater than indicated by the survey results.

Table 6. States' Experience with Fluorescent Orange Signs

Length of Experience	Number of States	Percentage
0 to 6 months	4	17%
6 to 12 months	8	33%
1 to 2 years	3	13%
over 2 years	9	38%
no response	11	not included

Note: Data reflect state's use in late 1995.

The third question asked the states to indicate the various situations in which fluorescent orange signs are used. The question addressed the type of work zone, the time of day, and the duration of the work zone activity. Twenty-six states responded to at least one of the applications. One state did not respond to the time of day or work zone duration inquiries. Two of the 26 were states that did not respond to the first question of the survey. Table 7 summarizes the responses to this question. The results indicate that fluorescent orange signs are used in a wide variety of applications.

Table 7. Typical Applications for Fluorescent Orange Signs

Application	Use	Number of States	Percentage
Type of Work Zone	Construction only	13	50%
	Construction and maintenance	10	38%
	Maintenance only	3	12%
Time of Day	Daytime only	1	4%
	Daytime and nighttime	23	92%
	Nighttime only	1	4%
Work Zone Duration	Long duration only	3	12%
	Both long and short duration	14	56%
	Short duration only	8	32%

The fourth question asked if states mixed fluorescent and standard orange signs in the same work zone. This question was included to determine the extent to which states were limiting the use of fluorescent properties to specific signs. Twenty-eight states responded to the question, with 16 (57 percent) indicating that they use both standard and fluorescent colors in the same work zone. Many of these states indicated that they use fluorescent signs for the advance warning signs to get drivers' attention. Other states are mixing fluorescent orange signs with standard orange sheeting but only until all standard orange sheeting signs are phased out.

DURABILITY

The fifth question asked states to indicate their experiences with the durability of fluorescent orange signs. This question was asked to determine the experiences that states have had with the durability of the fluorescent materials. Of the 27 states that responded to this question, only 5 (18.5 percent) indicated that they had noticed fading, dulling, and/or accelerated deterioration of fluorescent orange signs compared to standard orange signs. However, most states commented that they had not used the material long enough to adequately answer this question. Two of those five states had noticed significant fading problems and a third state reported that fluorescent orange signs were more susceptible to cuts and tears and needed to be handled with more care than standard orange signs.

BENEFITS AND SAFETY IMPACTS

The last two questions of the survey asked states to identify the benefits and safety impacts of using fluorescent orange signs. The sixth question addressed the benefits of fluorescent orange signs compared to standard orange signs. This question was asked to determine if the states believe that the extra costs associated with the fluorescent material benefit their work zones. It appears from the survey that most states who have experience with fluorescent orange signs generally like it. Of the 23 responses, 19 (83 percent) believed that fluorescent orange signs are worth the additional cost. Most states using fluorescent orange signs commented that the signs seem to attract the attention of motorists more than standard orange signs. The same states also believe that fluorescent orange signs seem to be more conspicuous, increasing the safety in work zones. In spite of the generally positive comments concerning the conspicuity and positive safety impacts of fluorescent orange signs, a few states have reported problems. Sign crews in one state have noticed a frost and dew problem with fluorescent orange signs that they did not notice on other signs. Other states reported that fluorescent orange signs are cost-effective only if used at high accident locations and/or work zones that require advanced lane movements.

The seventh and last question asked states to indicate whether they could attribute a reduction in work zone accidents to the use of fluorescent orange signs. Only one state out of the 18 that responded indicated that a reduction in work zone accidents might be attributed to fluorescent orange signs. However, that state had also implemented several other work zone safety improvements, so the reduction in accidents could not be directly linked to the use of fluorescent orange signs.

CHAPTER 3
DURABILITY EVALUATION

Fluorescent materials have been available in various forms since the early 1960s. For about 30 years, manufacturers attempted to produce a fluorescent retroreflective material but were not able to develop a product that would retain the fluorescent properties when exposed to sunlight in normal use. It was not until the early 1990s that durable retroreflective fluorescent materials became available. However, as indicated in the previous chapter, some states believe that fluorescent orange materials do not have sufficient life to justify the cost of using fluorescent orange signs. Furthermore, there has been little published research outside of the manufacturing industry that has evaluated the durability of fluorescent orange sign products.

The durability of fluorescent materials is a major concern of TxDOT and was a significant element of the research effort. Of particular interest is the durability of fluorescent orange signs that experience the type of wear-and-tear that is typical of temporary traffic control zone applications. This chapter describes the portion of the research project that evaluated the effect of weathering on the performance of fluorescent and non-fluorescent orange sign products.

DURABILITY EVALUATION PROCEDURE

TTI researchers addressed the durability issue by exposing undamaged and damaged samples of fluorescent and non-fluorescent orange products on a weathering rack for 24 months. Samples were removed at regular intervals during the weathering evaluation. At the conclusion of the evaluation period, the retroreflectivity, color, and fluorescent properties were measured.

Exposure Procedure

Four weathering racks were constructed for testing the samples. These racks were located at the Texas A&M University Riverside Campus, approximately 10 miles from the College Station/Bryan metropolitan area. The weathering racks were oriented to a 45-degree exposure angle. All sign racks faced due south. Previous research has shown that this orientation provides a 2:1 accelerated weathering ratio, i.e., 24 months of exposure on the weathering racks is equivalent to 48 months in a real-world application (9). The racks were constructed to ensure that the lowest of the samples were approximately five feet above the ground. This was done to prevent weeds from shadowing the sheeting samples and to minimize the potential of damage from other activities. Figure 1 illustrates one of the weathering racks.

A total of 448 samples were installed on the exposure racks. The total set of samples represented four damage conditions (undamaged, cut, dent, puncture) for each of the eight products for 14 exposure durations. Another set of eight undamaged samples for the eight products was not exposed on the racks in order to represent the base condition. This resulted in a total of 456 samples that were part of the evaluation. The samples were removed at the end of months 1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24. When removed, samples were labeled and stored in a controlled dark environment until the sheeting properties were measured at the

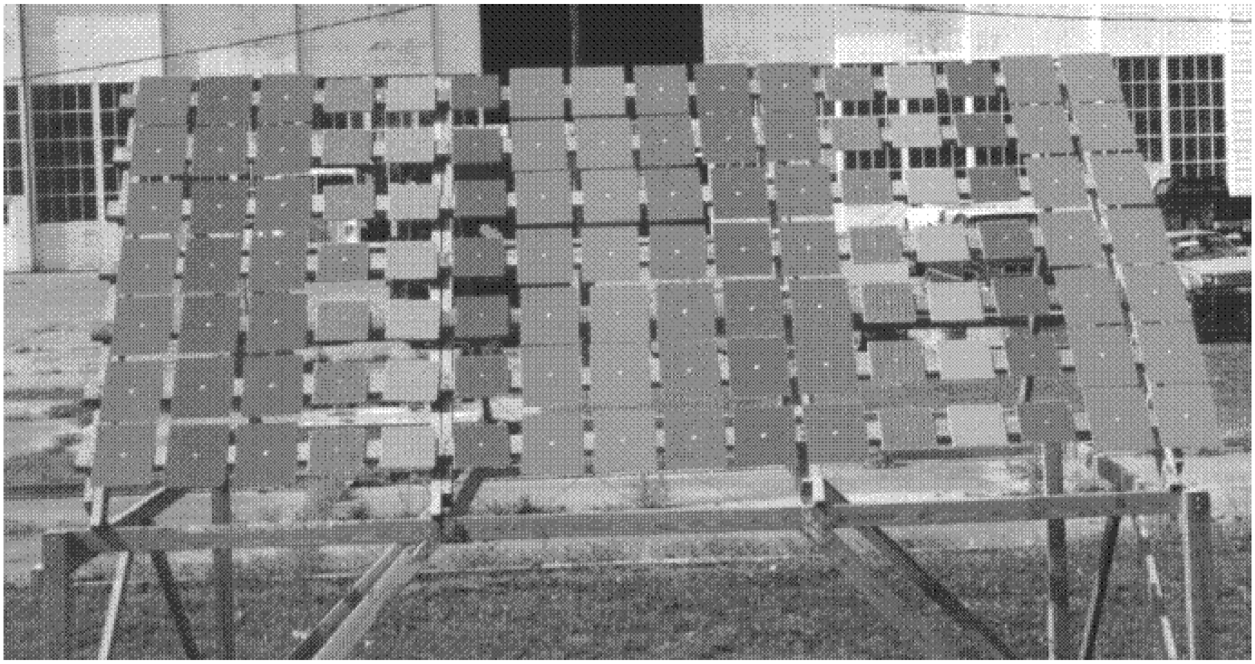

Figure 1. Weathering Rack

end of the exposure period. Various measurements of the sample properties were taken at the end of the two-year weathering period.

Sample Damage

Although the fading of fluorescence due to sunlight was a major concern of the research, a related concern was the durability of the products when subject to the typical wear-and-tear associated with temporary traffic control zone signing. Therefore, the weathering evaluation included both damaged and undamaged samples of each material. Since there is no standard test for damaging retroreflective sheeting in a manner that represents real-world wear-and-tear, the researchers developed three standard types of damage: cuts, dents, and punctures. The damage allowed water and/or sunlight to penetrate the different layers of the sheeting material and possibly cause the materials to behave differently than in a perfectly sealed environment. Each type of damage was done on a separate sample. There were no samples with multiple types of damage. Nine cuts were made on each cut sample in various arrangements of horizontal, vertical, and diagonal directions using a template developed by the researchers. Each cut was 75 mm (3 in) long. Four dents were made in the corners of each dent sample by dropping a 16 mm (⅝ in) steel ball bearing on the sample. The ball bearing was attached to a 4.36 kg (10 lb) hammer and dropped 254 mm (10 in), resulting in a force of 11.3 Newton-meter (8.3 foot-pounds) on the sample. The Reflexite products were placed on top of an aluminum substrate when the dent damage was inflicted. Four punctures were made on each puncture sample by using a 6.35 mm (¼ in) center punch that was hammered through the sample, then twisted as it was removed.

Evaluation Measurements

Once the 24-month exposure period was concluded, various properties of the samples were measured. Three different measurements were made on the samples: retroreflectivity, color, and fluorescence. Retroreflectivity was measured at four points on each sample using an ART Model 920 retroreflectometer. All retroreflectivity measurements were made with a 0.2 degree observation angle and -4 degree entrance angle. Color was measured at four points on each non-fluorescent sample using a Hunter Lab MiniScan™ XE colorimeter.

Measuring the fluorescent properties of sign materials has been a significant challenge in the past. However, in the summer of 1997, Labsphere introduced an instrument capable of accurately measuring the properties of fluorescent materials. This instrument, the BFC-450 Bispectral Fluorescence Colorimeter, was used to measure the color and fluorescent properties of the fluorescent samples. Since this instrument is relatively new, Appendix C provides more information about the instrument. All measurements of the fluorescent samples were made by Labsphere personnel at their New Hampshire laboratory using a D_{65} illuminant. Because of the expense associated with measuring the samples, only samples from three of the fluorescent products were measured: Reflexite Super Bright, 3M Long Distance Performance, and Stimsonite High Performance. The Reflexite Classic Fluorescent Orange was not measured due to the rapid fading of the color of this product (as described later in this chapter). Three measurements were made on each sample. The samples represented the 0-, 6-, 12-, and 24-month exposure durations.

EVALUATION OF UNDAMAGED SAMPLES

The properties of the undamaged samples were measured to a much greater extent than the undamaged samples. Retroreflectivity and color were measured on all the undamaged samples. The fluorescence of three of the fluorescent products was measured for four weathering durations.

Retroreflectivity

In order to obtain a measure of retroreflectivity performance for products in a real-world environment, the retroreflectivity of the samples was measured without cleaning the samples when they were removed. The accumulation of foreign matter was determined by measuring retroreflectivity for 12- and 24-month samples. Tables 8 and 9 indicate the retroreflectivity measurements on the base samples and the exposed samples at various exposure times, for samples before cleaning. Retroreflectivity was measured at four points on each sample. Table 10 provides the minimum, maximum, and standard deviation retroreflectivity measurements for the uncleaned samples at selected weathering durations. This range provides some indication of the variability in the sample measurements. Table 11 indicates the percentage change in retroreflectivity between the base (unexposed) condition and various lengths of exposure for the samples. Retroreflectivity was measured both before cleaning and after cleaning the samples. Figure 2 plots the average retroreflectivity measurements for the uncleaned samples over the 24 months of exposure. Table 12 compares the retroreflectivity measurements for the 12- and 24-month samples before and after cleaning of the samples. This comparison provides an indication of the accumulation of foreign matter that might be expected on samples that are not cleaned on a regular basis.

Table 8. Retroreflectivity of Base Condition (0 Month) Samples

Material		Average Retroreflectivity (cd/lux/m^2) for Each Sample								Total Number of Samples	Average of Samples	Standard Deviation
Manufacturer	Product	1	2	3	4	5	6	7	8			
Reflexite	C-S	213.0	203.2	183.5	205.1	228.1	209.3	215.9	224.1	8	210.3	13.9
	C-F	166.5	189.6	182.8	177.6	186.7	168.5	180.5	N/A	7	178.9	8.7
	SB-F	209.3	261.3	263.2	272.4	237.6	237.6	N/A		6	246.9	23.3
3M	HI-S	97.2	120.0	112.2	N/A					3	109.8	11.6
	LDP-S	514.1	562.4	571.2	564.5	613.2	617.4	N/A		6	573.8	38.0
	LDP-F	340.8	413.8	428.0	409.6	383.9	N/A			5	395.2	34.3
Stimsonite	HP-S	171.8	207.4	212.6	203.4	211.0	193.7	179.9	212.2	8	199.0	15.7
	HP-F	135.4	189.6	182.4	184.2	194.6	198.8	190.3	152.0	8	178.4	22.5

Notes: Measurement geometry - observation angle of 0.2 degrees and entrance angle of -4.0 degrees.
Average of four measurements per sample.

Table 9. Retroreflectivity of Exposed Samples

Material		Retroreflectivity (cd/lux/m^2) after Months of Exposure													
Manufacturer	Product	1	2	3	4	6	8	10	12	14	16	18	20	22	24
Reflexite	C-S	160.2	109.2	109.7	102.3	84.8	73.3	32.8	60.0	41.4	28.7	24.6	31.0	42.0	34.3
	C-F	231.0	230.2	232.8	177.7	158.1	119.0	151.0	108.1	85.2	43.1	44.2	42.8	39.4	29.9
	SB-F	192.9	164.0	169.8	165.5	135.2	96.9	83.2	87.0	69.8	24.4	23.8	33.8	29.7	28.7
3M	HI-S	84.4	80.7	96.2	87.0	85.4	97.4	98.2	106.3	92.6	87.7	88.5	101.0	100.5	112.1
	LDP-S	359.5	474.9	511.2	504.1	401.8	497.2	484.2	557.0	446.1	356.1	358.4	437.4	445.2	538.9
	LDP-F	372.3	350.8	364.4	396.8	331.6	375.3	291.7	347.1	306.4	253.0	328.4	369.3	337.6	331.4
Stimsonite	HP-S	139.6	179.1	180.8	174.0	159.5	165.3	180.6	204.9	172.0	136.8	155.0	176.2	180.8	210.0
	HP-F	140.4	162.8	172.9	164.1	166.8	155.6	162.8	165.8	176.7	133.7	140.6	173.6	167.0	176.8

Note: Measurement geometry - observation angle of 0.2 degrees and entrance angle of -4.0 degrees.
All measurements taken before cleaning samples. See Table 12 for data on samples after cleaning.

Table 10. Variability in Sample Retroreflectivity

Material		0 Months			6 Months			12 Months			18 Months			24 Months		
Manufacturer	**Product**	**Min**	**Max**	**SD**	**Min**	**Max**	**SD**	**Min**	**Max**	**SD**	**Min**	**Max**	**SD**	**Min**	**Max**	**SD**
Reflexite	C-S	136.8	240.1	26.3	59.8	107.3	20.9	56.4	63.5	3.1	20.3	29.1	3.6	27.3	41.1	7.7
	C-F	156.7	204.8	13.4	137.6	177.9	16.9	89.3	127.6	17.0	38.0	50.7	5.4	26.9	35.8	4.0
	SB-F	195.4	320.4	35.4	106.8	164.3	24.1	71.7	110.3	17.0	21.4	27.6	2.8	24.0	34.0	4.4
3M	HI-S	95.7	122.8	10.6	73.7	95.5	10.8	104.8	108.3	1.5	86.0	92.0	2.5	109.2	113.6	2.0
	LDP-S	464.4	626.8	41.9	329.2	449.5	52.9	516.3	595.5	37.0	326.3	380.6	23.8	489.3	578.9	46.6
	LDP-F	328.9	455.7	38.3	290.9	368.2	31.8	321.9	369.6	22.7	292.5	359.8	29.5	322.6	344.9	9.6
Stimsonite	HP-S	148.4	231.9	23.3	139.8	178.6	17.5	183.9	233.2	23.0	142.4	159.5	8.4	198.8	230.0	14.2
	HP-F	129.9	200.3	23.3	163.1	173.5	4.7	145.3	178.0	15.5	63.5	3.1	10.7	169.6	183.6	5.8

Note: Units are cd/lux/m^2.
Measurement geometry - observation angle of 0.2 degrees and entrance angle of -4.0 degrees.
Month 0 condition represents multiple samples (see Table 7). All other conditions are for one sample (see Table 8).
SD is the standard deviation.

Table 11. Change in Retroreflectivity with Exposure Duration

Material		Percent Change in Retroreflectivity Over Exposure Durations					
Manufacturer	**Product**	**Before Cleaning**				**After Cleaning**	
		0-6 mo	**0-12 mo**	**0-18 mo**	**0-24 mo**	**0-12 mo**	**0-24 mo**
Reflexite	C-S	-59.7%	-71.5%	-88.3%	-83.7%	-26.1	-25.8
	C-F	-11.6%	-39.6%	-75.3%	-83.3%	69.1	-59.9
	SB-F	-45.2%	-64.8%	-90.3%	-88.4%	-24.6	-41.2
3M	HI-S	-22.2%	-3.1%	-19.4%	2.1%	4.8	17.5
	LDP-S	-30.0%	-2.9%	-37.5%	-6.1%	6.4	7.0
	LDP-F	-16.1%	-12.2%	-16.9%	-16.1%	3.5	-8.3
Stimsonite	HP-S	-19.8%	2.9%	-22.1%	5.5%	20.7	28.0
	HP-F	-6.5%	-7.1%	-21.2%	-0.9%	4.5	12.5

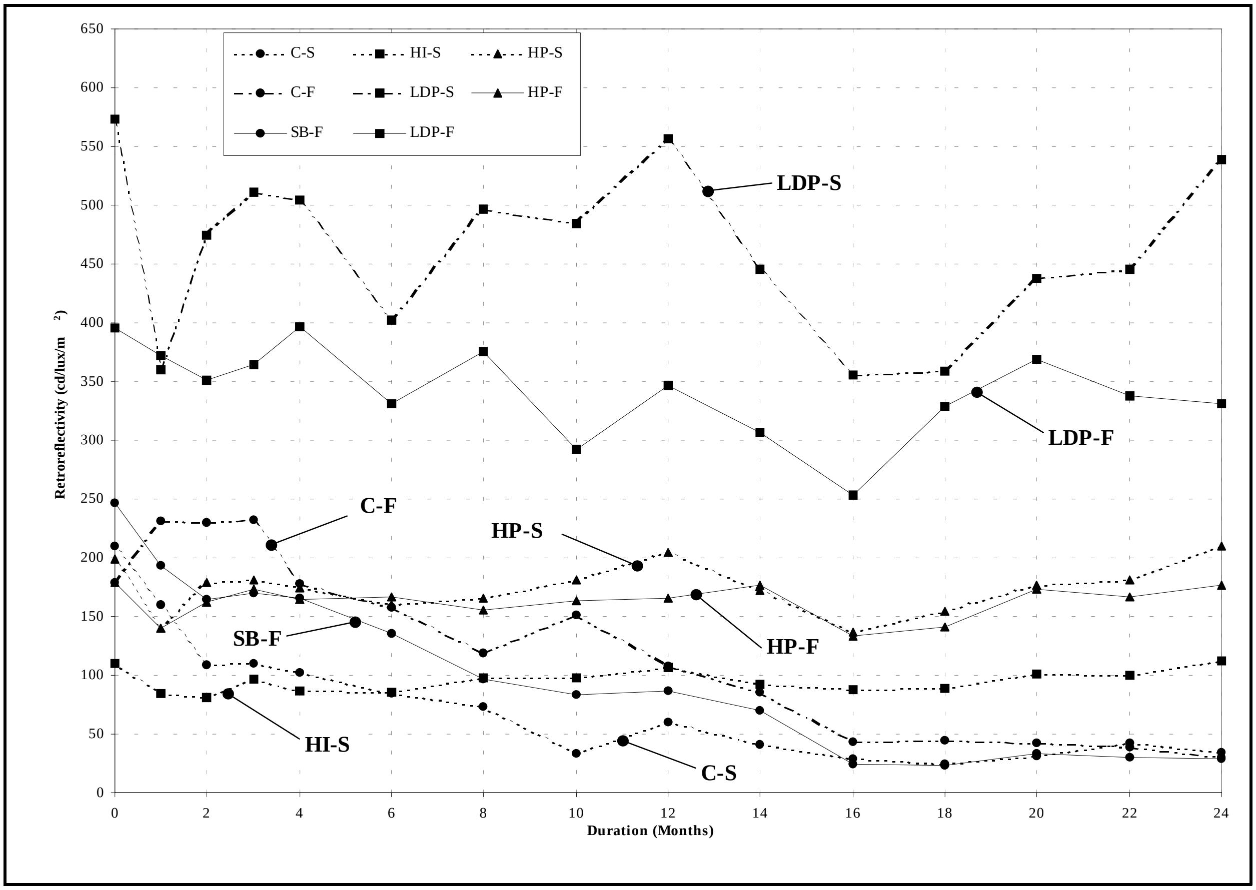

Figure 2. Results of Retroreflectivity Measurements

Table 12. Comparison of Retroreflectivity for Samples Before and After Cleaning

Material		Retroreflectivity after Months of Exposure						
Manufacturer	Product	0 Months	12 Months			24 Months		
			Before Cleaning	After Cleaning	Gain	Before Cleaning	After Cleaning	Gain
Reflexite	C-S	210.3	60.0	155.3	158.7%	34.3	156.1	355.1%
	C-F	178.9	108.1	302.5	179.8%	29.9	71.8	140.5%
	SB-F	246.9	87.0	186.2	114.0%	28.7	145.1	405.8%
3M	HI-S	109.8	106.3	115.1	8.2%	112.1	129.0	15.0%
	LDP-S	573.8	557.0	610.4	9.6%	538.9	614.2	14.0%
	LDP-F	395.2	347.1	381.4	9.9%	331.4	362.3	9.3%
Stimsonite	HP-S	199.0	204.9	240.3	17.3%	210.0	254.7	21.2%
	HP-F	178.4	165.8	186.4	12.5%	176.8	200.8	13.5%

Notes: Retroreflectivity units are cd/lux/m^2.
Measurement geometry - observation angle of 0.2 degrees and entrance angle of -4.0 degrees.
Average of four measurements per sample.

An examination of the retroreflectivity data in the preceding tables and figure indicates considerable variability in performance from one exposure duration to another. This could be attributed to variability of retroreflectivity in the individual samples before the exposure period began or differences in the degree of residue accumulations on the samples. Although not done for this effort, two actions could have provided a better understanding of the variability. One would have been to measure all samples before installing them on the weathering racks. The second would have been to remove all samples at each duration interval, measure their properties, then reinstall those with time remaining on their duration exposure.

Another potential factor that could account for the variability in the retroreflectivity measurements is the fact that all but one of the products are microprismatic materials. Prismatic materials have a directional orientation, which means that retroreflectivity measurements can vary depending upon the rotational angle between the measurement instrument and the sample. For some prismatic materials, the orientation impacts can be very significant, varying retroreflectivity by 20 percent or more.

Color

Table 13 summarizes the results of the color measurements of the undamaged samples for 0 months (base), 6 months, 12 months, and 24 months of exposure. The values shown represent the average of four color measurements per sample. Figures 3, 4, and 5 plot the *x* and *y* color coordinates for the products from each manufacturer. Figure 6 plots the Y values for each product.

Table 13. Results of Color Measurements

Material		0 months exposure			6 months exposure			12 months exposure			24 months exposure		
Manufacturer	**Product**	**x**	**y**	**Y**	**x**	**y**	**Y**	**x**	**y**	**Y**	**x**	**y**	**Y**
Reflexite	C-S	0.5959	0.3756	12.06	0.5480	0.3863	14.85	0.5345	0.3841	15.25	0.5090	0.3923	17.98
	C-F	0.5913	0.3840	47.04	0.3406	0.3629	37.61	0.3403	0.3580	40.21	0.3432	0.3619	41.94
	SB-F*	0.6287	0.3655	23.20	0.5736	0.3958	13.30	0.5433	0.4053	16.80	0.5015	0.4025	20.38
3M	HI-S	0.5548	0.3834	14.73	0.5387	0.3762	13.70	0.5335	0.3751	13.90	0.5108	0.3697	14.42
	LDP-S	0.6155	0.3783	15.59	0.5995	0.3868	17.11	0.5986	0.3859	17.34	0.5852	0.3907	19.20
	LDP-F*	0.6298	0.3659	33.93	0.6279	0.3656	28.30	0.6202	0.3690	30.98	0.5714	0.3845	34.44
Stimsonite	HP-S	0.5973	0.3826	17.81	0.5754	0.3881	19.12	0.5716	0.3889	18.93	0.5474	0.3935	21.68
	HP-F*	0.6372	0.3621	30.89	0.6286	0.3687	31.41	0.6223	0.3717	32.65	0.6045	0.3788	37.57

Notes: *Data measured with Labsphere instrument. Otherwise, measured with Hunter Lab instrument.

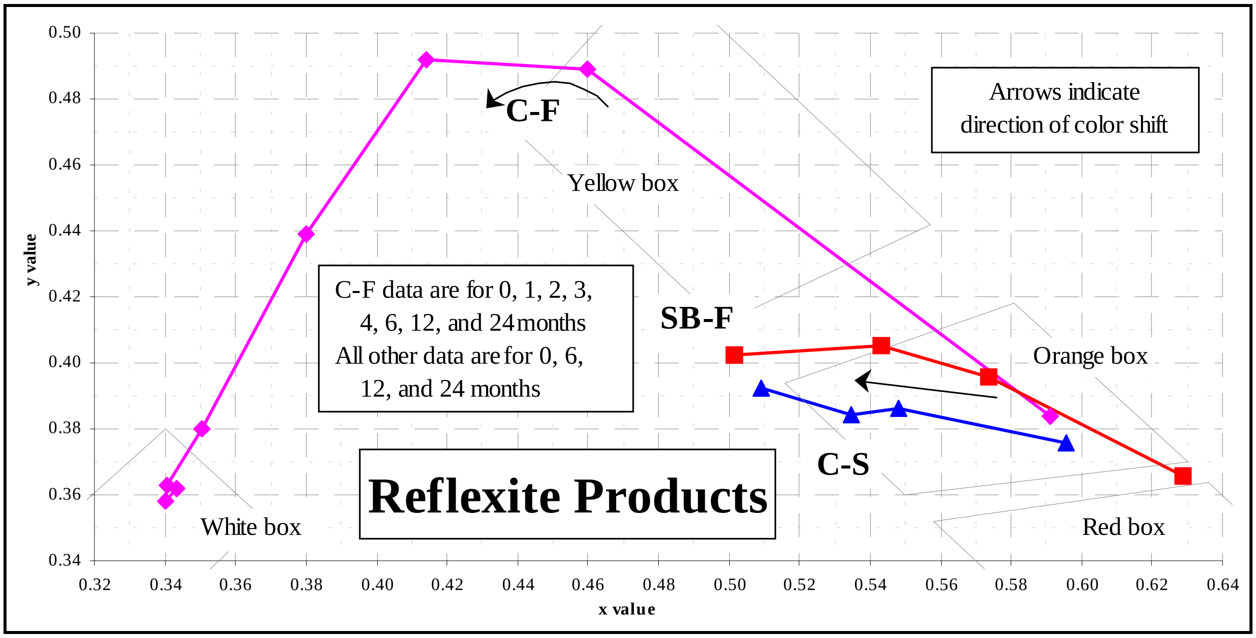

Figure 3. Color Performance of Reflexite Products

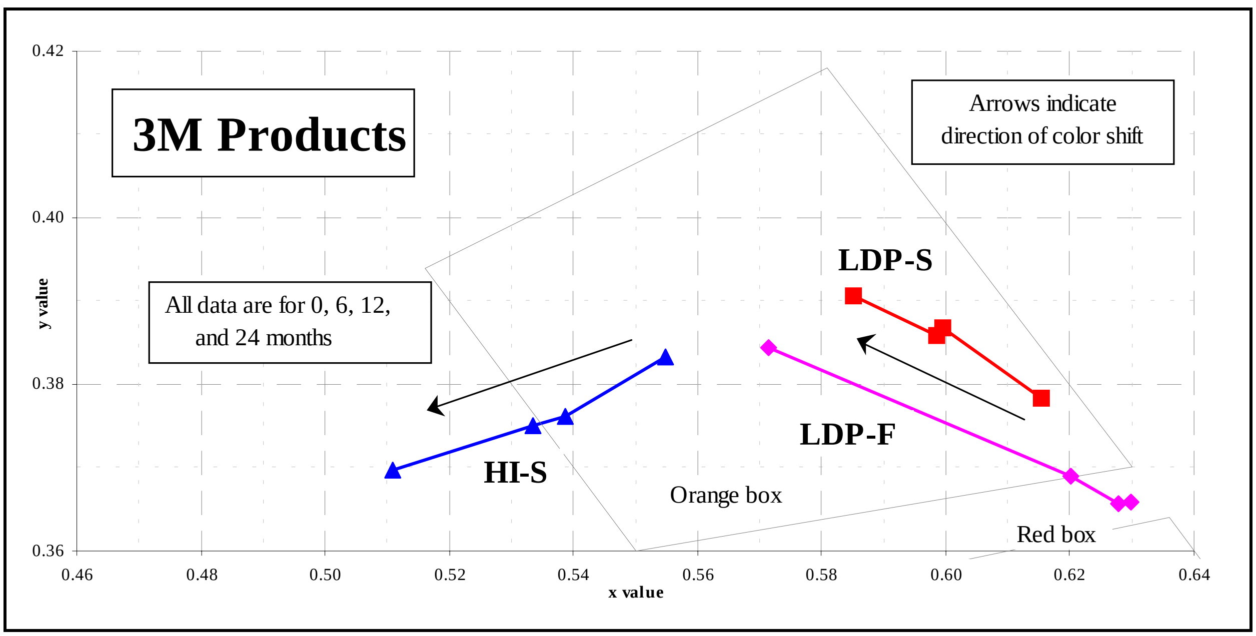

Figure 4. Color Performance of 3M Products

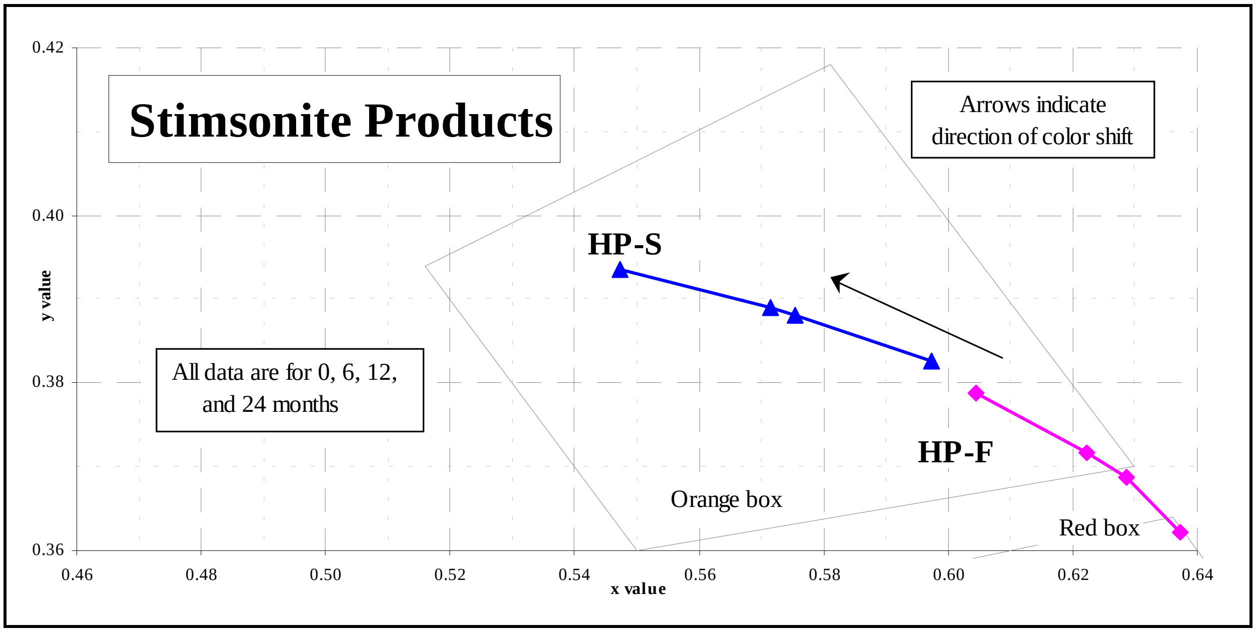

Figure 5. Color Performance of Stimsonite Products

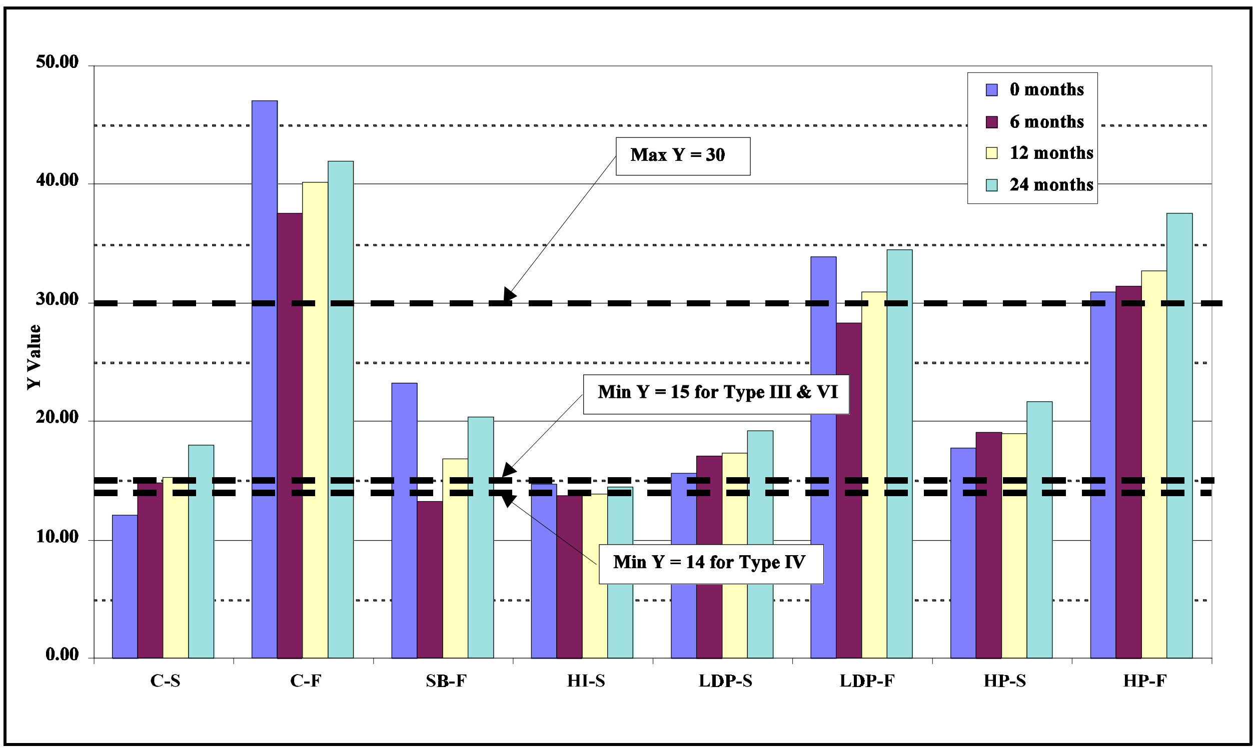

Figure 6. Y Values

Fluorescence

Due to the cost of measuring the fluorescent properties of the samples, only selected samples of fluorescent materials were measured. The Labsphere instrument was used to measure sample color due to fluorescence and reflected color at 0 (base), 6, 12, and 24 months of exposure. Table 14 provides the ***peak*** spectral radiance factors for the fluorescent and reflected portions of the total sample color, along with the total of the two. In Table 14, the reflected and fluorescence components do not add to the total because the peak values were averaged. In addition, these peaks typically occurred at different wavelengths for a given component. The spectral radiance factor due to fluorescence (β_F) is plotted for each product in Figures 7 through 9. These figures show the change in fluorescence as a function of the exposure duration.

Table 14. Results of Fluorescence Measurements

Exposure Duration	Peak Spectral Radiance Factor (β)								
	Reflexite SB-F			3M LDP-F			Stimsonite HP-F		
	β_F	β_R	β_T	β_F	β_R	β_T	β_F	β_R	β_T
Peak β at 0 months	51.84	38.58	79.73	74.66	39.48	113.94	77.45	50.76	125.69
Peak β at 6 months	4.82	30.35	33.15	54.78	40.39	90.16	70.62	49.35	117.76
Peak β at 12 months	2.02	35.50	35.74	48.93	47.50	96.43	69.20	49.66	117.67
Peak β at 24 months	0.40	37.47	63.92	40.92	44.12	80.00	67.79	51.01	120.16

Notes: β_F - peak fluorescent spectral radiance factor, β_R - peak reflected spectral radiance factor, β_T - peak total spectral radiance factor.

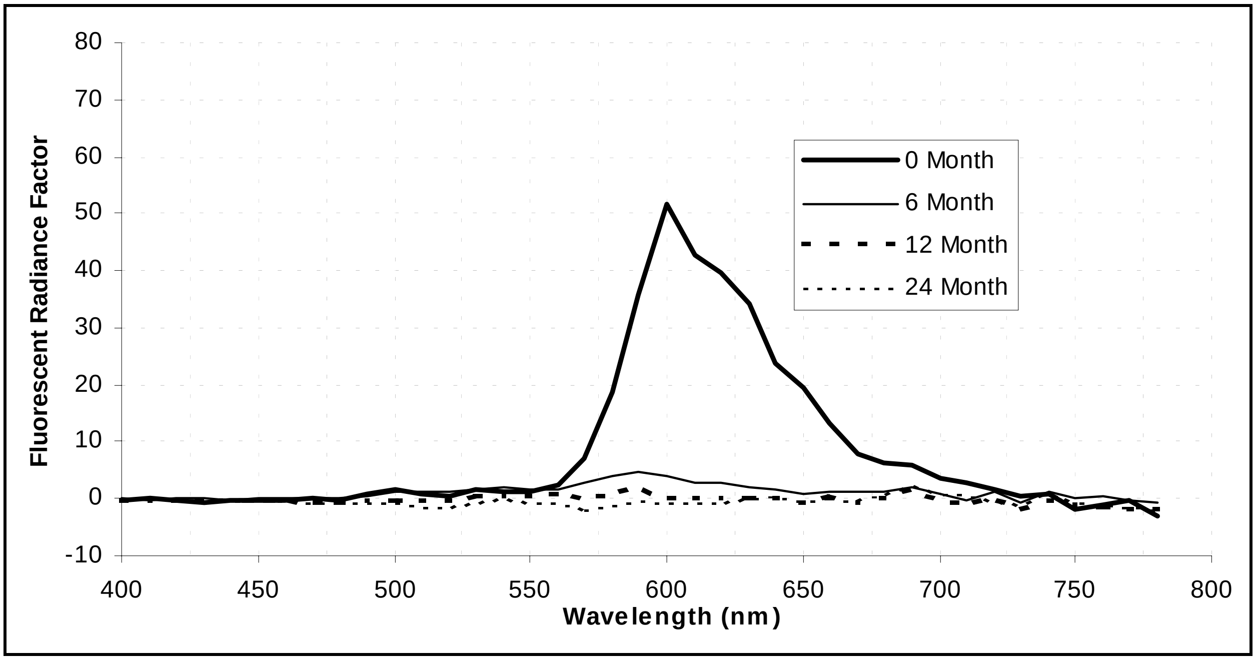

Figure 7. Change in Fluorescent Radiance Factor (β_F) for Reflexite SB-F Product

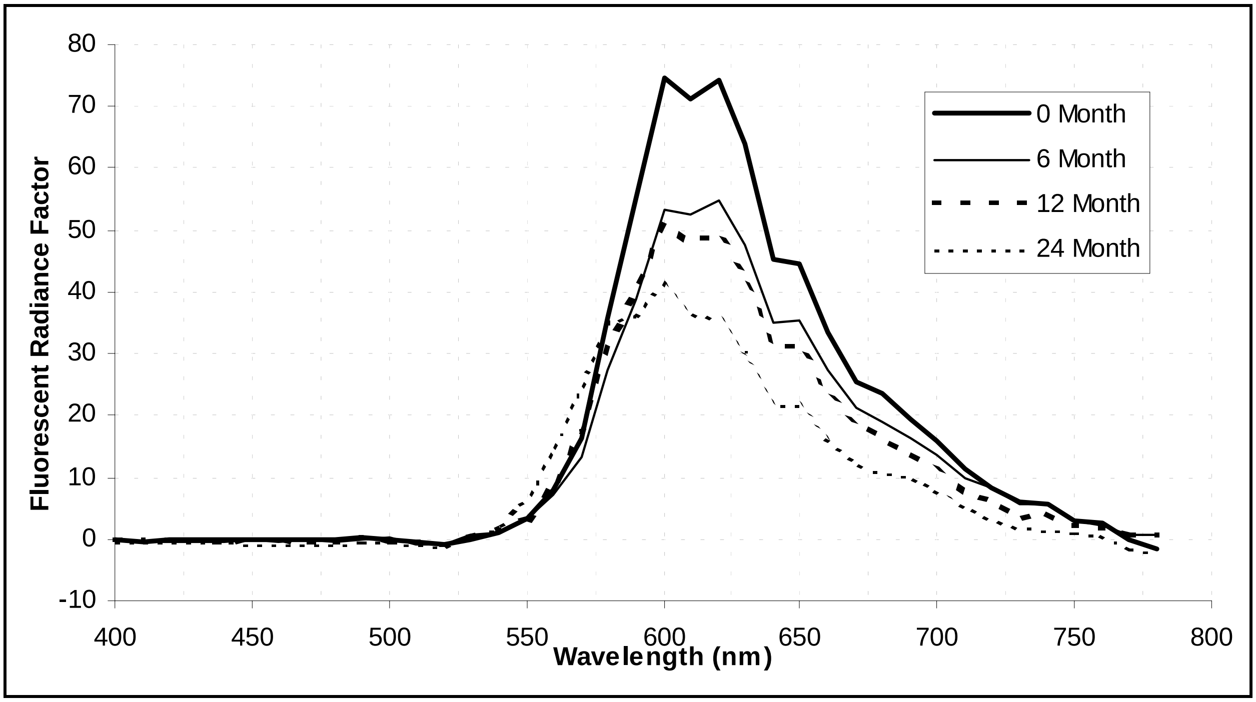

Figure 8. Change in Fluorescent Radiance Factor (β_F) for 3M LDP-F Product

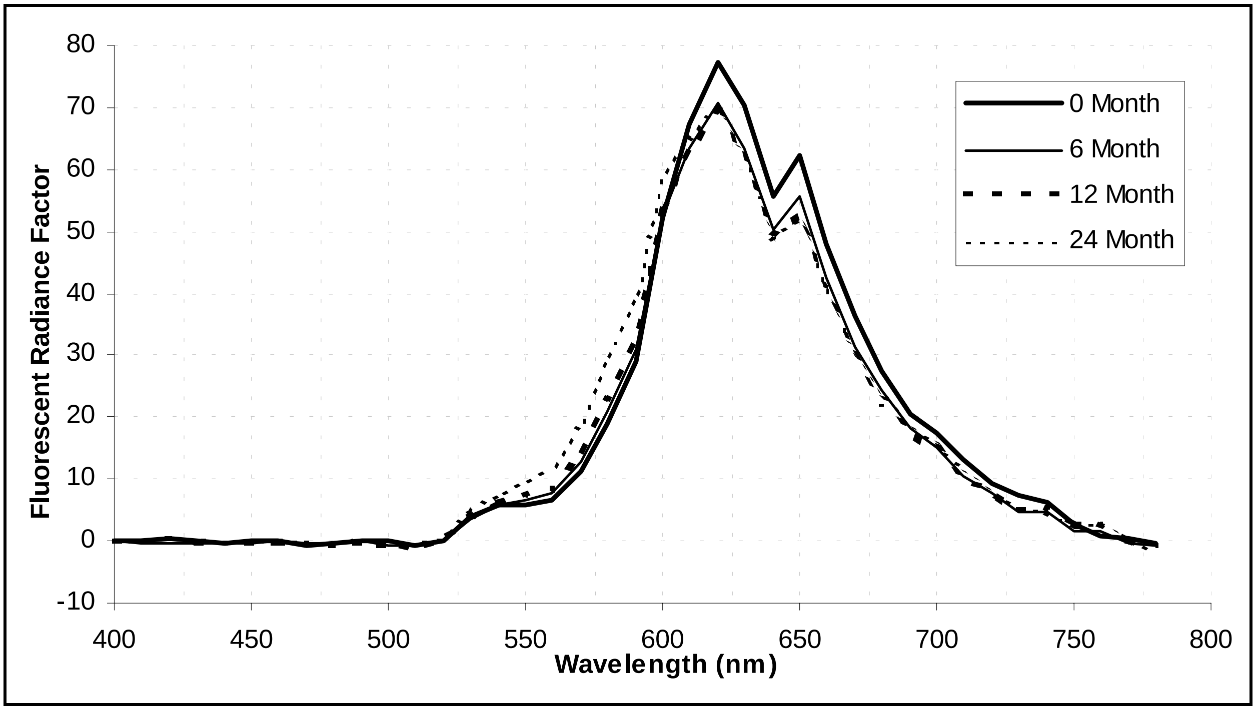

Figure 9. Change in Fluorescent Radiance Factor (β_F) for Stimsonite HP-F Product

EVALUATION OF DAMAGED SAMPLES

As described previously, some of the samples were damaged with cuts, dents, or punctures. These damaged samples were placed on the weathering racks for the same exposure durations as the undamaged samples. The samples were measured by centering the instrument on the damaged area. The following describes the impact of the damage on selected samples.

Retroreflectivity

The retroreflectivity of the damaged samples was measured for exposure durations of 12 and 24 months. The results of the measurements are indicated in Tables 15 and 16 for the 12-month samples and Tables 17 and 18 for the 24-month samples. The retroreflectivity data for these samples are presented as a percentage of the base (undamaged) sample that was exposed for the same duration as the samples being tested.

Table 15. Retroreflectivity Measurements for Unclean Damaged Samples at 12 Months

Material		12-Month Undamaged Sample	Percent of 12-Month Undamaged Sample		
Manufacturer	Product		Cut	Dent	Puncture
Reflexite	C-S	60.0	-48.6%	-13.6%	-2.2%
	C-F	108.1	-44.4%	-3.9%	-9.5%
	SB-F	87.0	-61.3%	-14.4%	-30.6%
3M	HI-S	106.3	-9.1%	-13.8%	-9.5%
	LDP-S	557.0	-22.7%	-21.8%	-32.1%
	LDP-F	347.1	-25.7%	-18.0%	-17.0%
Stimsonite	HP-S	204.9	-2.7%	-16.4%	-18.1%
	HP-F	165.8	15.5%	-15.6%	-9.3%

Note: Units for base measurements are cd/lux/m^2.

Table 16. Retroreflectivity Measurements for Clean Damaged Samples at 12 Months

Material		12-Month Undamaged Sample	Percent of 12-Month Undamaged Sample		
Manufacturer	Product		Cut	Dent	Puncture
Reflexite	C-S	155.3	-46.7%	-8.8%	-11.0%
	C-F	302.5	-54.6%	-19.6%	-37.8%
	SB-F	186.2	-7.3%	4.6%	2.6%
3M	HI-S	115.1	-10.5%	-15.7%	-8.1%
	LDP-S	610.4	-23.3%	-22.7%	-33.3%
	LDP-F	381.4	-26.1%	-19.2%	-16.4%
Stimsonite	HP-S	240.3	-24.5%	-14.1%	-20.1%
	HP-F	186.4	8.1%	-25.5%	-20.4%

Note: Units for base measurements are cd/lux/m^2.

Table 17. Retroreflectivity Measurements for Unclean Damaged Samples at 24 Months

Material		24-Month Undamaged Sample	Percent of 24-Month Undamaged Sample		
Manufacturer	**Product**		**Cut**	**Dent**	**Puncture**
Reflexite	C-S	34.3	-67.5%	2.3%	-11.3%
	C-F	29.9	-87.1%	16.8%	16.2%
	SB-F	28.7	-88.8%	30.6%	13.7%
3M	HI-S	112.1	-20.0%	-9.3%	-18.6%
	LDP-S	538.9	-18.4%	-18.2%	-26.1%
	LDP-F	331.4	-16.6%	-20.1%	-19.6%
Stimsonite	HP-S	210.0	-9.0%	-19.2%	-26.3%
	HP-F	176.8	-7.6%	-13.4%	-23.0%

Note: Units for base measurements are cd/lux/m^2.

Table 18. Retroreflectivity Measurements for Clean Damaged Samples at 24 Months

Material		24-Month Undamaged Sample	Percent of 24-Month Undamaged Sample		
Manufacturer	**Product**		**Cut**	**Dent**	**Puncture**
Reflexite	C-S	156.1	-74.0%	1.3%	-23.9%
	C-F	71.8	-85.9%	73.7%	42.2%
	SB-F	145.1	-94.0%	3.9%	-15.6%
3M	HI-S	129.0	-22.8%	-12.1%	-13.4%
	LDP-S	614.2	-20.8%	-19.9%	-19.9%
	LDP-F	362.3	-20.3%	-22.5%	-23.1%
Stimsonite	HP-S	254.7	-2.1%	-17.4%	-17.0%
	HP-F	200.8	-14.5%	-17.6%	-42.3%

Note: Units for base measurements are cd/lux/m^2.

Color

Figure 10 presents *x* and *y* color coordinate values for four of the non-fluorescent products. These values include the following for each product:

- undamaged color coordinates for 0, 6, 12, and 24 months for samples that were not cleaned (same values shown in Figures 3, 4, and 5),
- undamaged color coordinates for 12 and 24 months for samples that were cleaned,
- damaged color coordinates for 12 and 24 months that were not cleaned, and
- damaged color coordinates for 12 and 24 months that were cleaned.

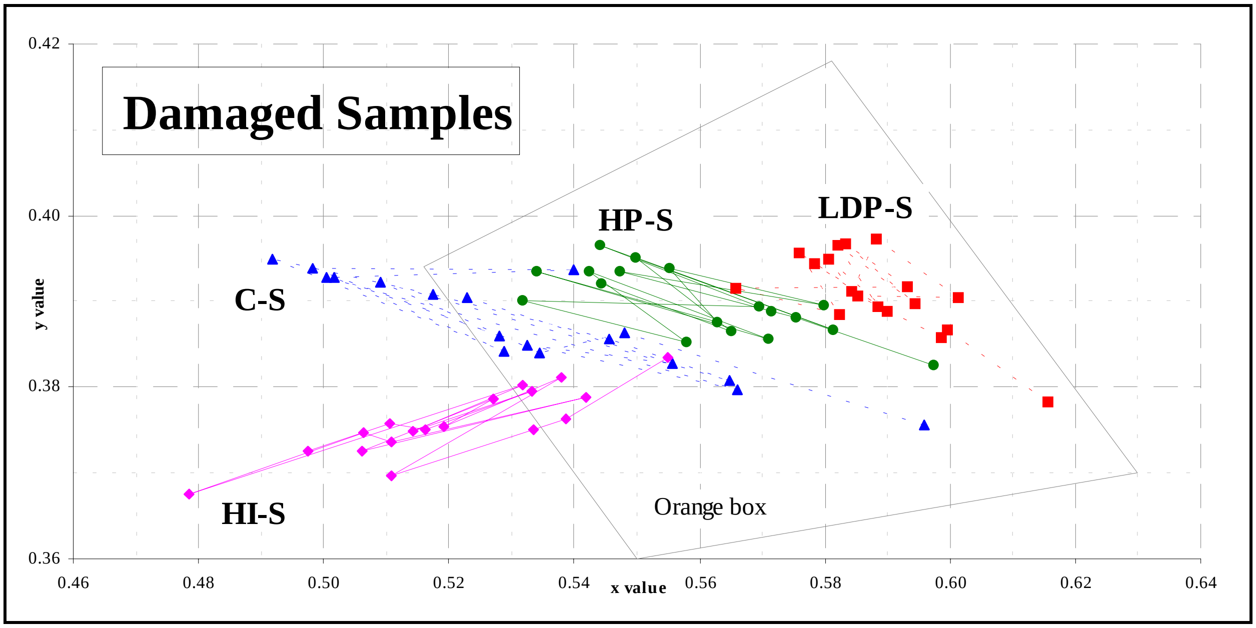

Figure 10. Color Performance of Damaged Non-Fluorescent Products

Fluorescence

Due to the costs of measuring the fluorescent samples, the fluorescent properties of the damaged samples were not measured.

SUMMARY OF FINDINGS

The results of the retroreflectivity, color, and fluorescent measurements are analyzed in the following paragraphs.

Retroreflectivity

The results of the measurements described in the preceding sections were compared to the requirements of ASTM D4956-95 (3). Table 19 summarizes the retroreflective performance of the samples. As shown in Table 19, all of the samples exceeded the retroreflectivity requirements of the ASTM specification for new sheeting.

Although the ASTM specification does not include a procedure for outdoor weathering performance, it does contain one for artificial weathering. For vinyl sheeting, the artificial weathering requirement is 50 percent of the initial values after 250 hours of artificial weathering. For rigid sheeting, it is 80 percent of the initial values after 500 hours of artificial weathering. Table 19 also indicates whether the retroreflectivity of the product meets the artificial weathering requirement. However, it should be pointed out that the 24 months of outdoor exposure are significantly longer than the duration of the artificial weathering. All of the rigid sign products met the proposed minimum retroreflectivity values that are expected to be implemented by FHWA (see Table 3). The FHWA proposal does not include minimum values for roll-up signs.

Table 19. Summary of Retroreflectivity Performance

Material		ASTM Retroreflectivity Requirements		Meets ASTM Retroreflectivity Requirements		
Manufacturer	Product	R_A cd/lux/m^2	Artificial Weathering	0 months	24 months	
					Before Cleaning	After Cleaning
Reflexite	C-S	70	50% of initial value 250 hours	Yes	No	Yes
	C-F			Yes	No	Yes
	SB-F			Yes	No	Yes
3M	HI-S	100	80% of initial value 500 hours	Yes	Yes	Yes
	LDP-S			Yes	Yes	Yes
	LDP-F			Yes	Yes	Yes
Stimsonite	HP-S			Yes	Yes	Yes
	HP-F			Yes	Yes	Yes

Although all of the products meet minimum retroreflectivity values, there are significant differences in the retroreflectivity properties of the various products. Table 20 indicates the relative ranking of the eight products from a retroreflectivity standpoint for various conditions. All of these products are prismatic except the 3M High Intensity. Therefore, it is not surprising that all of the prismatic materials have a higher initial retroreflectivity than the High Intensity. The Reflexite products have a high initial retroreflectivity, but these products lose significant retroreflectivity, particularly if they are not kept clean. The before-cleaning Reflexite products have a retroreflectivity that is less than the High Intensity. The retroreflectivity of the 3M Diamond Grade products is significantly greater than the retroreflectivity any of the other products.

Table 20. Ranking of Retroreflectivity Performance

Rank Order	Undamaged			Dent Damage	
	R_A 0 Months	24 Months		24 Months	
		R_A Before Cleaning	R_A After Cleaning	R_A Before Cleaning	R_A After Cleaning
1st	LDP-S (574)	LDP-S (539)	LDP-S (614)	LDP-S (441)	LDP-S (492)
2nd	LDP-F (395)	LDP-F (331)	LDP-F (362)	LDP-F (265)	LDP-F (281)
3rd	SB-F (247)	HP-S (210)	HP-S (255)	HP-S (170)	HP-S (210)
4th	C-S (210)	HP-F (177)	HP-F (201)	HP-F (153)	HP-F (165)
5th	HP-S (199)	HI-S (112)	C-S (156)	HI-S (102)	C-S (158)
6th	C-F (179)	C-S (34)	SB-F (145)	SB-F (37)	SB-F (151)
7th	HP-F (178)	C-F (30)	HI-S (129)	C-S (35)	C-F (125)
8th	HI-S (110)	SB-F (29)	C-F (72)	C-F (35)	HI-S (113)

Color

Table 21 summarizes the color performance of the samples with respect to the orange *x y* chromaticity limits and the orange Luminance Factor (Y) established by the ASTM D4956 specification. Only two of the products were within both the *x y* and Y limits at the start and end of the weathering period (3M LDP-S and Stimsonite HP-S).

With respect to the ASTM color coordinate limits, two products were in another color's zone at 0 or 24 months. The Reflexite C-F product faded into the yellow zone within one month, then faded into the white zone by the sixth month. The Stimsonite HP-F product was in the red zone at 0 months and faded into the orange zone between 6 and 12 months. Only two products remained in the orange zone throughout the evaluation period. Those products are 3M LDP-S and Stimsonite HP-S.

Table 21. Summary of Color Performance

Material		ASTM Color Limits		Within *x y* Limits		Within Y Limits	
Manufacturer	**Product**	***x y***	**Y**	**0 months**	**24 months**	**0 months**	**24 months**
Reflexite	C-S	*x* *y* 0.553 0.360 0.630 0.370 0.581 0.418 0.516 0.394	14-30	Yes	No	No	No
	C-F			Yes	No	No	No
	SB-F			No	No	Yes	Yes
3M	HI-S			Yes	No	Yes	Yes
	LDP-S		15-30	Yes	Yes	Yes	Yes
	LDP-F			No	Yes	No	No
Stimsonite	HP-S			Yes	Yes	Yes	Yes
	HP-F			No	Yes	No	No

Table 22 summarizes the fluorescent performance of three of the fluorescent samples. Since there are no TxDOT or ASTM performance specifications for fluorescent sign materials, only the percentage change in the peak spectral radiance factor due to fluorescence is provided. The Reflexite SB-F product lost almost all of its fluorescence within the first six months. The 3M LDP-F product lost about half of its fluorescence over 24 months, while the Stimsonite HP-F product lost about one-eighth of its fluorescence. Most of the loss of fluorescence for the Stimsonite product occurred in the first six months, with little loss after that.

Table 22. Summary of Fluorescent Performance

Material		Fluorescence[1]		
Manufacturer	**Product**	**0 months**	**24 months**	**Change**
Reflexite	C-S	not applicable		
	C-F	not applicable		
	SB-F	51.84	0.4	-99.2%
3M	HI-S	not applicable		
	LDP-S	not applicable		
	LDP-F	74.66	40.92	-45.2%
Stimsonite	HP-S	not applicable		
	HP-F	77.45	67.79	-12.5%

Notes: [1]Indicates the peak spectral radiance factor due to fluorescence (unitless) at 0 and 24 months.

CHAPTER 4
COLOR RECOGNITION

Probably the most significant advantage of fluorescent orange signing is that the fluorescent properties, combined with the more intense orange color, give these signs greater conspicuity, thus making them more visible to drivers. This conspicuity also aids the color recognition of these signs. Assessing the color recognition of fluorescent orange signs was the second of the major research efforts of this project.

The color recognition evaluation was conducted by presenting a variety of 50 mm^2 (2×2 in) samples to drivers. The samples include orange, fluorescent orange, yellow, white, and red sheeting that were mounted on the side of the road on a closed course. Drivers drove the course in both day and night conditions and identified the color of the samples as they drove the course.

COLOR RECOGNITION STIMULI

A total of 20 separate stimuli were presented to test subjects in the course of conducting the color recognition evaluation. These stimuli are identified in Table 23.

Table 23. Stimuli for Color Recognition Evaluation

Type of Material		Number of Stimuli				
Manufacturer	**Product**	**Orange**	**Fluorescent Orange**	**Yellow**	**White**	**Red**
Reflexite	Vinyl roll-up sheeting	2 C-S	2 SB-F	—	—	—
3M	High Intensity	2 HI-S	—	2	2	2
	Diamond Grade	2 LDP-S	2 LDP-F	—	—	—
Stimsonite	High Performance	2 HP-S	2 HP-F	—	—	—

Stimuli were placed on the right side of the road. They were affixed to a wooden stake, 0.9 m (3 ft) off the ground, 1.8 m (6 ft) from the edge-of-pavement. The stimuli consisted of a 150×150 mm (6×6 in) black backplate with a 50×50 mm (2×2 in) hole in the center. The sample was affixed to the back of the backplate so that it was visible through the hole. The stimuli and sample size were selected on the basis of initial pilot testing. Initially, a 100 mm (4 in) square sample size was selected for daylight and night testing. After pilot tests, the size was reduced to a 50 mm (2 in) square for both lighting conditions in order to obtain detection distances that were appropriate for the test course. Figure 11 illustrates a typical stimuli.

Figure 11. Illustration of Typical Stimuli for Color Recognition Evaluation

COLOR RECOGNITION EVALUATION SETUP

The color recognition evaluation was conducted by driving a test subject through a closed course road network. As subjects approached a stimuli, the distance at which they correctly identified the color of the stimuli was recorded. The results were then analyzed.

Course

The color recognition evaluation was conducted on the Riverside Campus roadway network. Figure 12 is an illustration of the road network and stimuli location. After some initial pilot testing, it was discovered that the sheeting samples were affected greatly by orientation direction. Therefore, all samples were oriented south (visible when traveling north). After making a northbound evaluation run, the car traveled south to the starting point of the next run. Five roads were used for the course with multiple samples on each road.

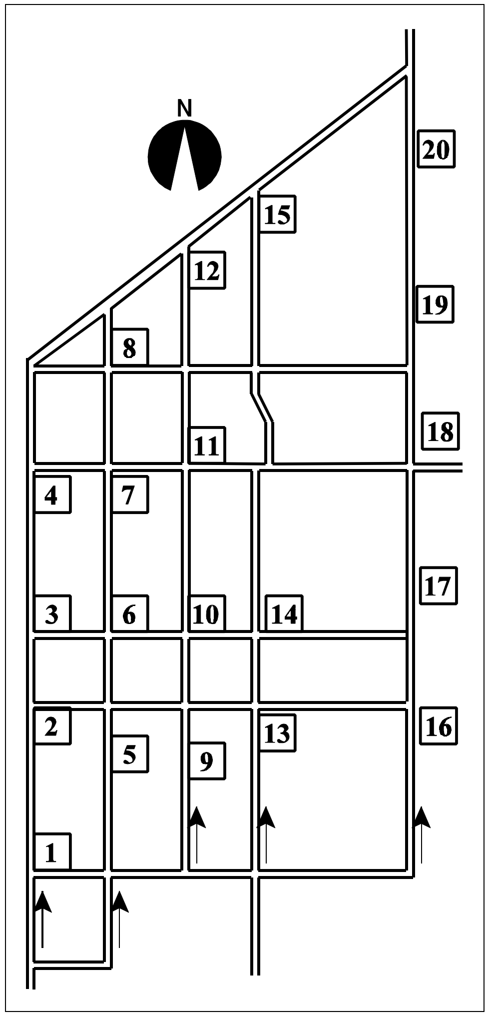

Figure 12. Color Recognition Course

The same locations of the stimuli were used for all subjects except that the first and third samples were switched for the night evaluation. Subjects were told that the stimuli had changed before the second run. This reduced the likelihood of recalling the position of certain colors on the course.

Vehicle and Data Recording

A 1991 Ford Crown Victoria was used as the test vehicle in the color recognition evaluation. Interior lighting was minimized for the evaluations. The subject sat in the front passenger seat and called out the color of the stimuli from that position. The vehicle was driven by the experimenter at a constant speed of 20 miles per hour. The data were recorded using an 8 mm camcorder in the vehicle. The camcorder was pointed at the display of a distance measuring instrument (DMI) and subjects' responses were recorded on the audio portion of the tape. The DMI was synchronized with measurement stations at the beginning of each run.

The data were analyzed by listening to the subjects' responses for each stimuli. When the correct color was identified, the corresponding distance was recorded. If the response was incorrect, only the color identified by the subject was recorded. In some cases, test subjects correctly identified the color, but only after passing the stimuli. For the data analysis, only correct responses at distances greater than zero were classified as correct.

Test Subjects

There were 41 subjects who participated in the evaluation. Each subject participated in both daytime and nighttime trials. Tables 24 and 25 identify the age, visual acuity, and contrast sensitivity characteristics of the test subjects. All subjects were tested prior to data collection. Visual acuity was measured using a Snellen Chart. Contrast sensitivity was measured using a VCTS® contrast sensitivity chart.

Table 24. Number of Subjects by Age and Visual Acuity

Age Group	Visual Acuity			
	20/15 to 20/20	**20/25 to 20/40**	**20/50**	**Totals**
Young (≤55)	16	3	0	19
Old (>55)	8	13	1	22
Totals	24	16	1	41

Table 25. Number of Subjects by Age and Contrast Sensitivity

Age Group	Contrast Sensitivity			
	Good	**Acceptable**	**Marginal**	**Totals**
Young (≤55)	15	4	0	19
Old (>55)	10	8	4	22
Totals	25	12	4	41

Preparation for subjects continued with a simplified familiarization procedure. Actual samples of standard sheeting were utilized for color familiarization. Subjects were shown sheeting samples in white, yellow, green, blue, red, brown, and orange and asked to identify the color of each as it was presented. All test subjects correctly identified each of the colors.

Subjects participated in the color recognition evaluation for both daytime and nighttime conditions. About 45 minutes were required to complete both evaluations for a given condition (day or night). The daytime evaluation was conducted first, followed by the nighttime evaluation. The evaluations were conducted in July and August, with the daytime evaluations typically starting about 6:30 pm and the nighttime evaluations typically starting about 9:30 pm. During the course of the evaluation, each subject viewed two samples of each of the 10 colors/products. This resulted in a total of 820 total trials (41×2×10).

COLOR RECOGNITION EVALUATION RESULTS

After reducing the data, the researchers tabulated the number of correct responses for each sample and the average distance at which the samples were correctly identified. This information was calculated for all subjects and also was calculated according to subject age group. The researchers then determined the accuracy of the color identification and plotted this information. The results of the daytime color recognition evaluations are presented in Tables 26 through 28. The results of the nighttime evaluations are presented in Tables 29 through 31. Figures 13 and 16 graphically present the recognition data.

Table 26. Color Recognition Results in Daytime

Stimuli			Color Perception of Stimuli								
			Correct Responses						Number of Incorrect Responses[3]		
Manufacturer	Product	Color	Number of Correct Responses[1]			Average Recognition Distance (ft)[2]					
			all	young	old	all	young	old	all	young	old
Reflexite	C-S	orange	68	38	30	172	214	118	14	0	14
Reflexite	SB-F	orange	72	37	35	271	339	200	10	1	9
3M	HI-S	orange	62	34	28	165	197	125	20	4	16
3M	LDP-S	orange	59	32	27	206	279	123	23	6	17
3M	LDP-F	orange	69	36	33	259	321	191	13	2	11
Stimsonite	HP-S	orange	67	36	31	150	197	96	15	2	13
Stimsonite	HP-F	orange	70	38	32	257	310	195	12	0	12
3M	HI-S	yellow	56	33	23	115	148	68	26	5	21
3M	HI-S	white	74	38	36	250	331	164	8	0	8
3M	HI-S	red	72	37	35	144	194	91	10	1	9

Notes: [1]Number of trials when driver correctly identified the stimulus color.
[2]Average distance at which the stimulus was correctly identified.
[3]Number of trials when driver could not correctly identify the stimulus.

Table 27. Accuracy of Color Identification in Daytime (all drivers)

Sample			Color Perception of Sample (percent)				
Manufacturer	**Product**	**Color**	**Orange**	**Yellow**	**White**	**Red**	**No Color**
Reflexite	C-S	orange	82.9%	0.0%	0.0%	12.2%	4.9%
	SB-F		87.8%	0.0%	0.0%	8.5%	3.7%
3M	HI-S		75.6%	4.9%	0.0%	12.2%	7.3%
	LDP-S		72.0%	0.0%	0.0%	20.7%	7.3%
	LDP-F		84.1%	0.0%	0.0%	11.0%	4.9%
Stimsonite	HP-S		81.7%	0.0%	0.0%	9.8%	8.5%
	HP-F		85.4%	0.0%	0.0%	9.8%	4.9%
3M	HI-S	yellow	6.1%	68.3%	2.4%	0.0%	23.2%
		white	1.2%	1.2%	90.2%	0.0%	7.3%
		red	4.9%	0.0%	0.0%	87.8%	7.3%

Note: Results for all drivers.

Table 28. Accuracy of Color Identification in Daytime (older drivers)

Sample			Color Perception of Sample (percent)				
Manufacturer	**Product**	**Color**	**Orange**	**Yellow**	**White**	**Red**	**No Color**
Reflexite	C-S	orange	68.2%	0.0%	0.0%	22.7%	9.1%
	SB-F		79.5%	0.0%	0.0%	13.6%	6.8%
3M	HI-S		63.6%	6.8%	0.0%	18.2%	11.4%
	LDP-S		61.4%	0.0%	0.0%	31.8%	6.8%
	LDP-F		75.0%	0.0%	0.0%	15.9%	9.1%
Stimsonite	HP-S		70.5%	0.0%	0.0%	15.9%	13.6%
	HP-F		72.7%	0.0%	0.0%	18.2%	9.1%
3M	HI-S	yellow	6.8%	52.3%	4.5%	0.0%	36.4%
		white	2.3%	2.3%	81.8%	0.0%	13.6%
		red	6.8%	0.0%	0.0%	79.5%	13.6%

Note: Results for older drivers.

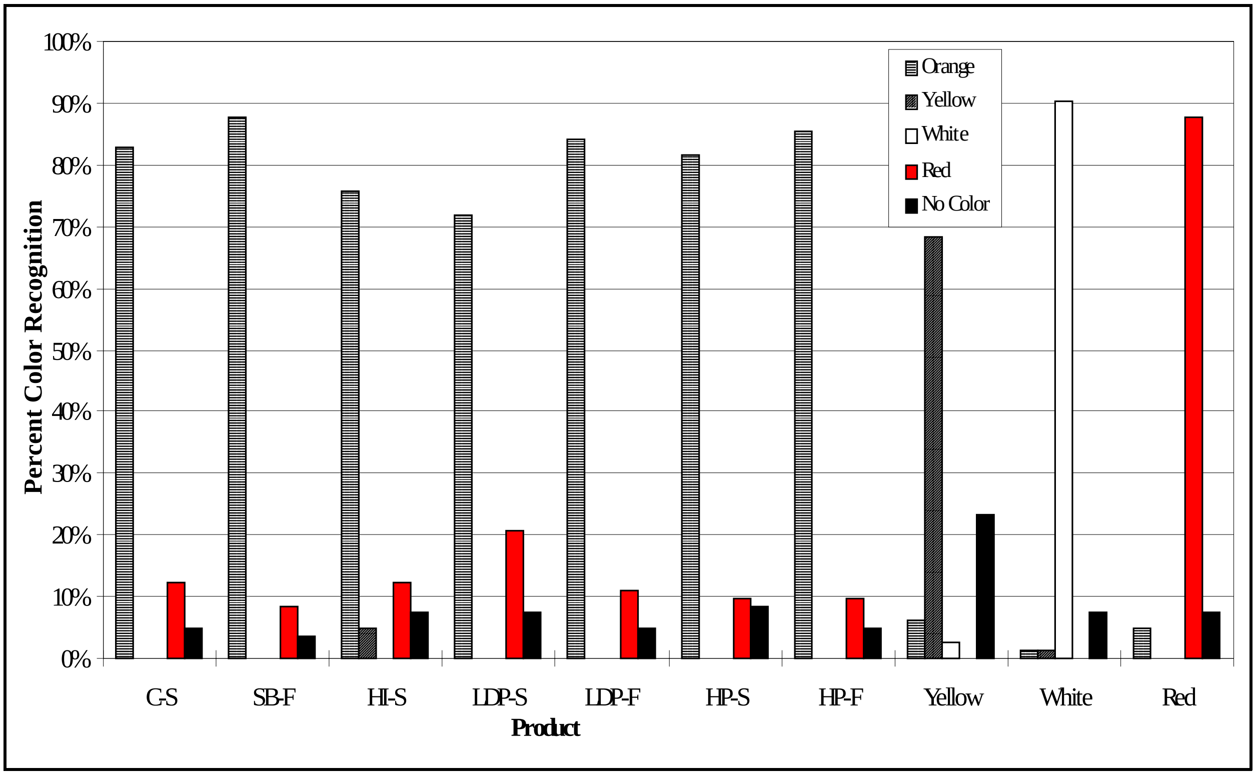

Figure 13. Daytime Color Recognition (all drivers)

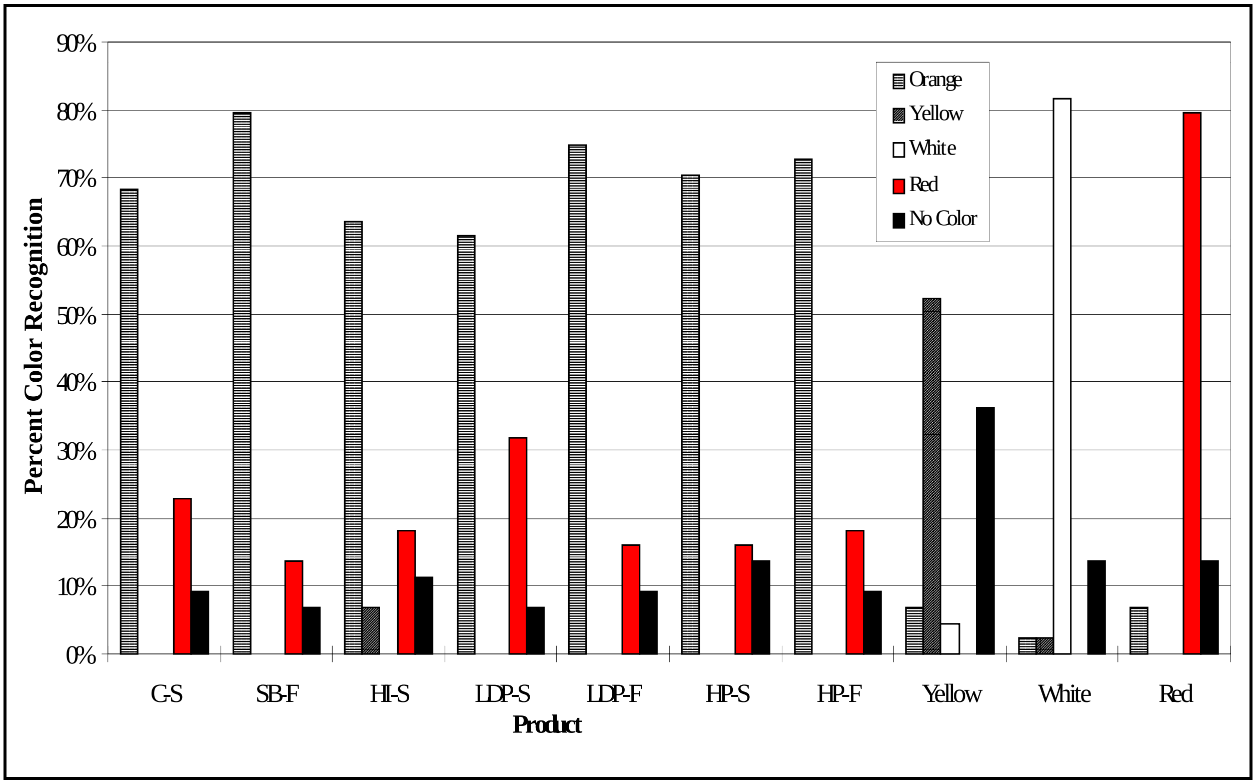

Figure 14. Daytime Color Recognition (older drivers)

Table 29. Color Conspicuity Results in Nighttime

Stimuli			Color Perception of Stimuli								
			Correct Responses						Number of Incorrect Responses[3]		
Manufacturer	Product	Color	Number of Correct Responses[1]			Average Recognition Distance (ft)[2]					
			all	young	old	all	young	old	all	young	old
Reflexite	C-S	orange	52	28	26	375	446	290	30	12	18
	SB-F		70	35	37	436	536	339	12	5	7
3M	HI-S		67	35	34	384	465	284	15	5	10
	LDP-S		72	39	35	531	647	405	10	1	9
	LDP-F		63	35	29	456	501	403	19	5	15
Stimsonite	HP-S		55	24	32	414	474	365	27	16	12
	HP-F		69	38	33	471	539	397	13	2	11
3M	HI-S	yellow	62	37	27	273	302	225	20	3	17
		white	77	38	41	500	599	402	5	2	3
		red	62	30	33	390	459	341	20	10	11

Notes: [1]Number of trials when driver correctly identified the stimulus color.
[2]Average distance at which the stimulus was correctly identified.
[3]Number of trials when driver could not correctly identify the stimulus.

Table 30. Accuracy of Color Identification in Nighttime (all drivers)

Sample			Color Perception of Sample (percent)				
Manufacturer	Product	Color	Orange	Yellow	White	Red	No Color
Reflexite	C-S	orange	63.4%	32.9%	0.0%	0.0%	3.7%
	SB-F		85.4%	3.7%	1.2%	4.9%	4.9%
3M	HI-S		81.7%	18.3%	0.0%	0.0%	0.0%
	LDP-S		87.8%	8.5%	0.0%	1.2%	2.4%
	LDP-F		76.8%	4.9%	0.0%	14.6%	3.7%
Stimsonite	HP-S		67.1%	30.5%	0.0%	1.2%	1.2%
	HP-F		84.1%	0.0%	0.0%	14.6%	1.2%
3M	HI-S	yellow	6.1%	75.6%	14.6%	0.0%	3.7%
		white	0.0%	2.4%	93.9%	0.0%	3.7%
		red	18.3%	1.2%	0.0%	75.6%	4.9%

Note: Results for all drivers.

Table 31. Accuracy of Color Identification in Nighttime (older drivers)

Sample			Color Perception of Sample (percent)				
Manufacturer	**Product**	**Color**	**Orange**	**Yellow**	**White**	**Red**	**No Color**
Reflexite	C-S	orange	59.1%	34.1%	0.0%	0.0%	6.8%
	SB-F		84.1%	2.3%	0.0%	6.8%	6.8%
3M	HI-S		77.3%	22.7%	0.0%	0.0%	0.0%
	LDP-S		79.5%	13.6%	0.0%	2.3%	4.5%
	LDP-F		65.9%	4.5%	0.0%	25.0%	4.5%
Stimsonite	HP-S		72.7%	25.0%	0.0%	0.0%	2.3%
	HP-F		75.0%	0.0%	0.0%	22.7%	2.3%
3M	HI-S	yellow	11.4%	61.4%	22.7%	0.0%	4.5%
		white	0.0%	2.3%	93.2%	0.0%	4.5%
		red	15.9%	0.0%	0.0%	75.0%	9.1%

Note: Results for older drivers.

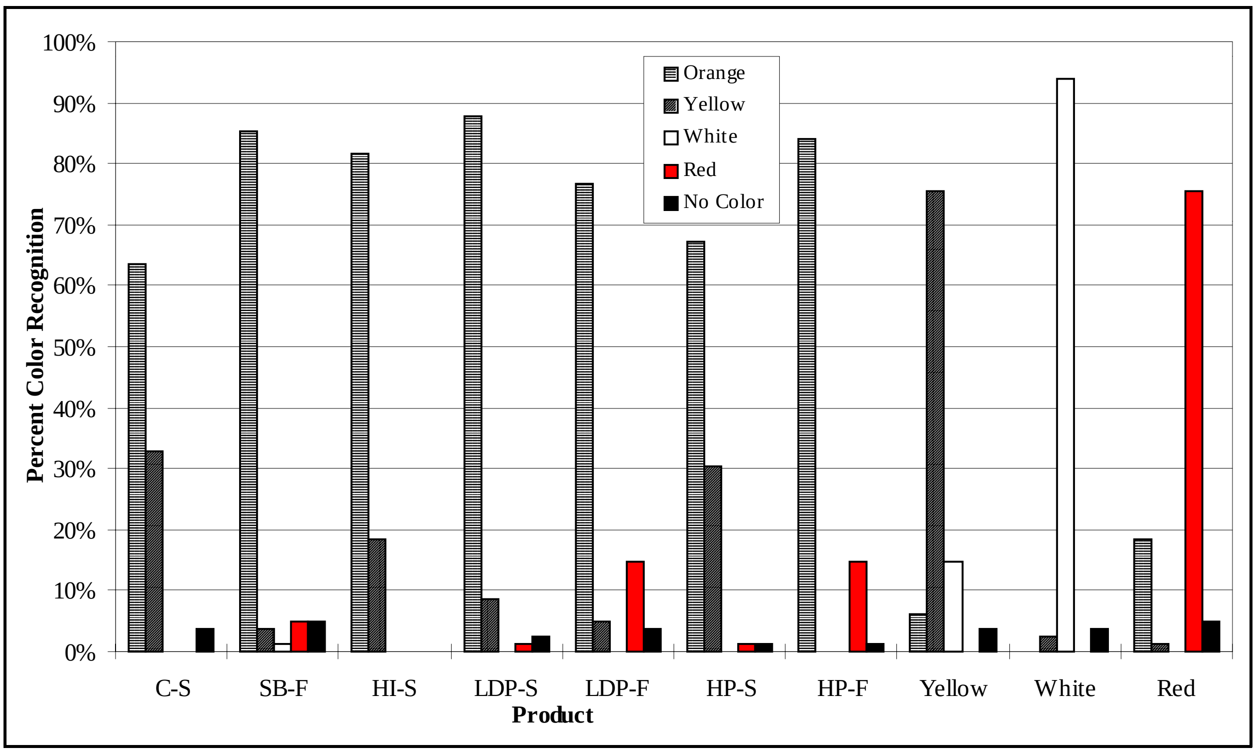

Figure 15. Nighttime Color Recognition (all drivers)

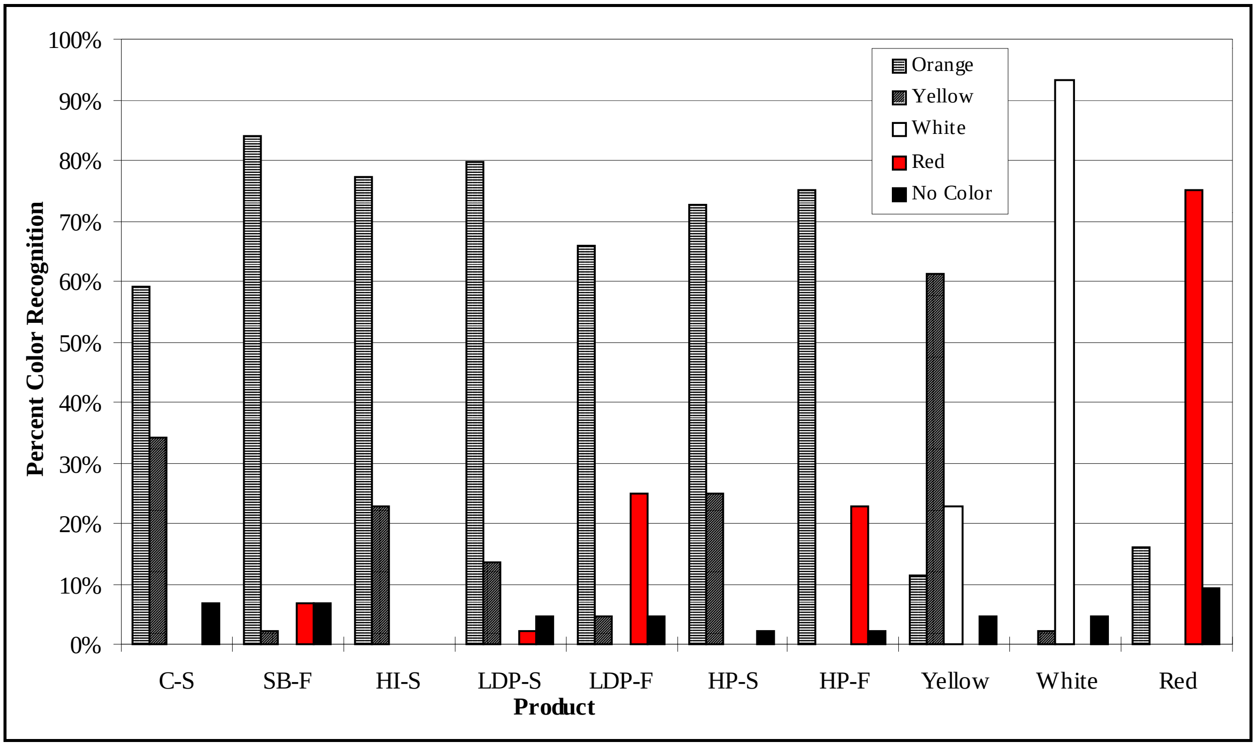

Figure 16. Nighttime Color Recognition (older drivers)

Table 32 summarizes the results from the preceding tables by relative order of performance for all drivers. Table 33 presents the same information for older drivers only.

Table 32. Relative Performance in Color Recognition Evaluation (all drivers)

Relative Order	Recognition Distance		Color Perception Accuracy	
	Daytime	Nighttime	Daytime	Nighttime
1st	SB-F (271 ft)	LDP-S (531 ft)	White (90%)	White (94%)
2nd	LDP-F (259 ft)	White (500 ft)	SB-F (88%)	LDP-S (88%)
3rd	HP-F (257 ft)	HP-F (471 ft)	Red (88%)	SB-F (85%)
4th	White (250 ft)	LDP-F (456 ft)	HP-F (85%)	HP-F (84%)
5th	LDP-S (206 ft)	SB-F (436 ft)	LDP-F (84%)	HI-S (82%)
6th	C-S (172 ft)	HP-S (414 ft)	C-S (83%)	LDP-F (77%)
7th	HI-S (165 ft)	Red (390 ft)	HP-S (82%)	Yellow (76%)
8th	HP-S (150 ft)	HI-S (384 ft)	HI-S (76%)	Red (76%)
9th	Red (144 ft)	C-S (375 ft)	LDP-S (72%)	HP-S (67%)
10th	Yellow (115 ft)	Yellow (273 ft)	Yellow (68%)	C-S (63%)

Notes: There were 41 test subjects and 2 samples of each of 10 stimuli (820 total trials).

Table 33. Relative Performance in Color Recognition Evaluation (older drivers)

Relative Order	Recognition Distance		Color Perception Accuracy	
	Daytime	Nighttime	Daytime	Nighttime
1st	SB-F (200 ft)	LDP-S (405 ft)	White (82%)	White (93%)
2nd	HP-F (195 ft)	LDP-F (403 ft)	SB-F (80%)	SB-F (84%)
3rd	LDP-F (191 ft)	White (402 ft)	Red (80%)	LDP-S (80%)
4th	White (164 ft)	HP-F (397 ft)	LDP-F (75%)	HI-S (77%)
5th	HI-S (125 ft)	HP-S (365 ft)	HP-F (73%)	HP-F (75%)
6th	LDP-S (123 ft)	Red (341 ft)	HP-S (71%)	Red (75%)
7th	C-S (118 ft)	SB-F (339 ft)	C-S (68%)	HP-S (73%)
8th	HP-S (96 ft)	C-S (290 ft)	HI-S (64%)	LDP-F (66%)
9th	Red (91 ft)	HI-S (284 ft)	LDP-S (61%)	Yellow (61%)
10th	Yellow (68 ft)	Yellow (225 ft)	Yellow (52%)	C-S (59%)

Notes: There were 41 test subjects and 2 samples of each of 10 stimuli (820 total trials).

COLOR RECOGNITION EVALUATION CONCLUSIONS

The analysis of the color recognition of the sign sheeting products revealed the following findings:

- Recognition distances are much greater at night than during the day. Nighttime recognition distance is typically twice or more that of the daytime distance.
- White was the color with the highest color perception accuracy.
- For daytime, the fluorescent colors had the highest recognition distances. The fluorescent orange signs had higher color perception accuracy than the non-fluorescent orange signs in the daytime.
- The fluorescent properties had less of an impact on the color recognition at night.
- Yellow had the lowest recognition distances and among the lowest of the color perception accuracy.
- There appears to be little relationship between the R_A value and the recognition distance or the accuracy of the color perception.

Based on the information presented in Table 33, the fluorescent orange products have a greater recognition distance and color perception accuracy than the non-fluorescent orange products in the daytime conditions.

CHAPTER 5
SUMMARY AND RECOMMENDATIONS

The objective of this research effort was to determine whether the performance of fluorescent orange sign products is sufficiently better than that of non-fluorescent orange products to justify their use and whether the durability of fluorescent orange signs is sufficient for work zone applications. The research activities include a survey of state transportation agency practices relative to fluorescent orange signs, an evaluation of the durability of fluorescent and non-fluorescent orange sign products, and an evaluation of the relative color recognition of fluorescent orange signs.

Eight products were evaluated as part of this research. Those products are listed in Table 34. This table also indicates which product lines have been discontinued and/or updated. The Reflexite Classic Fluorescent product has been discontinued. Reflexite has also introduced a new fluorescent product, Marathon. The Stimsonite Series 4200 sheeting line has been replaced by the Series 6200 product line, including both the fluorescent and standard orange sheeting materials. In addition, the Stimsonite company was recently bought by Avery-Dennison and the name of the Series 6200 product line is now the T-7000 line.

Table 34. Material Information

Manufacturer	Product Name and Number		Fluorescent Material	ASTM Type	Label	Current Availability
Reflexite	Classic		No	VI	C-S	Available
	Classic Fluorescent		Yes	VI	C-F	Discontinued
	Super Bright Fluorescent		Yes	VI	SB-F	Available
3M	High Intensity	3824	No	III	HI-S	Available
	Long Distance Performance	3984	No	IV	LDP-S	Available
	Long Distance Performance	3924	Yes	IV	LDP-F	Available
Stimsonite	High Performance	4370	No	IV	HP-S	Updated
	High Performance	4380	Yes	IV	HP-F	Updated

USE BY OTHER TRANSPORTATION AGENCIES

Fluorescent orange signs are used by numerous state transportation agencies in the United States. These states believe that the use of fluorescent orange provides greater visibility and conspicuity for traffic control devices used in temporary traffic control zones.

DURABILITY EVALUATION

TxDOT is currently in the process of transitioning the Department's specification for sign sheeting from a TxDOT specification to the ASTM specification. Therefore, the evaluations of retroreflectivity and color are based on the current ASTM specification for retroreflective sheeting (D4956). All eight of the orange products meet the ASTM requirements for minimum retroreflectivity of new sheeting. Five of the eight products met the ASTM *x* and *y* color requirements. Four of the eight met the ASTM requirement for Y. Among the products for rigid signs, the non-fluorescent orange products always had higher retroreflectivity than the fluorescent orange products of the same grade from a given manufacturer.

Reflexite Products

The Reflexite products had high initial retroreflectivity, but the retroreflectivity of the exposed samples before cleaning was very low. However, these products regained a significant amount of retroreflectivity when cleaned. This finding indicates the need to clean these products on a regular basis. Although the proposed FHWA minimum retroreflectivity values (see Table 3) do not address roll-up signs, the R_A values before cleaning for these products at the end of the test period are very close to the minimums for other types of signs. The Super Bright Fluorescent product had higher retroreflectivity than the Classic Fluorescent product. There was significant color change in these products. The Classic Fluorescent Orange (C-F) product faded out of the ASTM orange zone in less than one month of exposure. At one month it was in the yellow zone, and by the sixth month it was in the white zone. In addition, the Y value was above the ASTM maximum at all measurement intervals. The color of the Super Bright Fluorescent product started near the ASTM red zone. At 12 months, it had faded out of the ASTM orange zone. Its Y value dipped below the minimum at the sixth month. The Classic Orange (C-S) product remained in the ASTM orange zone through the twelfth month, then faded out of the zone between the twelfth and twenty-fourth month. Its Y value started below the minimum and faded to above the minimum. Because of the color fading in the Classic Fluorescent product, the fluorescent properties were evaluated for only the Super Bright Fluorescent product. This product lost 90 percent of its fluorescence within the first six months.

Since the start of this research project, Reflexite has introduced a new fluorescent sheeting, Marathon, that it claims has better fluorescence retention properties. The Fluorescent Orange product has been discontinued.

3M Products

The 3M Long Distance Performance (LDP) sheeting had the highest retroreflectivity of any sheeting. This rating included initial retroreflectivity, retroreflectivity after 24 months of exposure (both before and after cleaning), and damaged sheeting after 24 months of exposure (both before and after cleaning). The *x* and *y* coordinates of the fluorescent LDP product began between the orange and red zones and faded into the orange zone. The Y of the fluorescent LDP product was above the maximum at 0, 12, and 24 months. The fluorescent product lost about one-fourth of its fluorescence within 6 months and almost half (45 percent) after 24 months. The non-fluorescent LDP product remained in the *xy* orange zone at all measured durations.

The non-fluorescent LDP product was between the minimum and maximum Y values at all measured durations. The 3M High Intensity sheeting had the lowest retroreflectivity of the rigid sign products. This ranking can be attributed to the fact that it is the only sheeting of those evaluated that is a beaded (non-prismatic) product. It also had the least amount of variability of those tested. Its color started in the orange zone and faded out of the zone between the sixth and twelfth months. Of the eight products evaluated, the High Intensity was the only product in which the direction of the *xy* color change was toward white. For the other seven products, the direction was toward yellow. The Y values for High Intensity were slightly above the minimum at 0 and 24 months and below the minimum at 6 and 12 months.

Stimsonite Products

The retroreflectivity of the fluorescent and non-fluorescent Stimsonite High Performance (HP) products was closer than any other pair of fluorescent and non-fluorescent products. The non-fluorescent HP product was within the *xy* orange zone at the beginning and end of the evaluation period. The non-fluorescent HP product was above the minimum Y value at all evaluation durations. The fluorescent HP product began in the red zone and faded into the orange zone between the sixth and twelfth months. The Y value of the fluorescent HP product was above the maximum at all evaluation durations. The fluorescent HP product exhibited the best fluorescence retention of the three fluorescent products that were evaluated. This material lost only about one-eighth of its fluorescence over 24 months.

It should be noted that the Stimsonite products evaluated in the research (Series 4200) are no longer available and have been replaced with a new product (Series 6200). The new products were not evaluated. It is unknown whether the performance of the new products is similar to that of the products evaluated in this research. Furthermore, the Stimsonite Corporation has been purchased by Avery-Dennison and the products are now marketed as Avery-Dennison retroreflective sheeting.

COLOR RECOGNITION EVALUATION

The color recognition evaluation indicated that the fluorescent orange materials had greater color recognition than the non-fluorescent products in daytime conditions. There were no large differences in the recognition distances of these products in nighttime conditions. Many of the test subjects had difficulty correctly identifying the color of the stimuli.

RECOMMENDATIONS

Table 35 summarizes the key findings from the various evaluations conducted as part of this research project. Based on the results of the evaluations, the researchers offer the following recommendations:

Table 35. Ranking of Retroreflectivity Performance

Evaluation Issue		Reflexite			3M			Stimsonite	
		C-S	C-F	SB-F	HI-S	LDP-S	LDP-F	HP-S	HP-F
Retroreflectivity (cd/lux/m^2)	0 months	210.3	178.9	246.9	109.8	573.8	395.2	199.0	178.4
	24 months	156.1	71.8	145.1	129.0	614.2	362.3	254.7	200.8
Within xy Color Zone	0 months	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	24 months	No	No	No	No	Yes	Yes	Yes	Yes
Fluorescence (β_F)	0 months	N/E	N/E	51.8	N/E	N/E	74.7	N/E	77.5
	24 months			0.4			40.9		67.8
Color Recognition Distance (feet)	Day	172	N/E	271	165	206	259	150	257
	Night	375	N/E	436	384	531	456	414	471
Color Recognition Accuracy (percent)	Day	83%	N/E	88%	76%	72%	84%	82%	85%
	Night	63%	N/E	85%	82%	88%	77%	67%	84%

Notes: N/E - Not evaluated in research.

- Compared to standard orange signs, fluorescent orange sign materials have sufficient durability and color recognition to justify their use in work zone applications. The only exception to this finding, Classic Fluorescent, is no longer available.
- The fluorescent properties of a fluorescent orange sign offer no benefit at night. Therefore, the use of fluorescent signs should not be based on nighttime performance.
- All products have some difficulty in staying within the color zone. FHWA is currently evaluating the color definitions and may establish new color zones in the future. TxDOT should wait for the results of that rulemaking effort before making any decisions regarding color of retroreflective materials.
- The researchers offer the following recommendations regarding the products evaluated in this research effort:
  - TxDOT should not allow the Reflexite Classic Fluorescent Orange product to be used. This product is no longer available.
  - If the Reflexite Classic Orange or Super Bright Orange products are used, TxDOT should implement a standard procedure for cleaning these products every six months.
  - The researchers cannot offer any insight into whether the performance of Stimsonite's new Series 6200 sheeting is any better or worse than the performance of the Series 4200 sheeting evaluated in this research.

CHAPTER 6
REFERENCES

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APPENDIX A
RESULTS OF STATE SURVEY

In December 1995, TTI distributed a survey to the state traffic engineer in 49 states (no survey was sent to TxDOT). This survey contained four parts, which addressed issues associated with four research projects being conducted at TTI at that time. One part addressed the use of fluorescent orange signs. The results of that part of the survey are described in this appendix.

A total of 35 states responded to the fluorescent orange signing survey. The responding states were:

Alaska
Arizona
Arkansas
Colorado
Connecticut
Delaware
Georgia
Idaho
Indiana
Iowa
Kansas
Kentucky
Massachusetts
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

The response percentages indicated in the results are the number of states that selected a given response divided by the total number of states responding to the survey (35). It should be noted that, due to multiple responses to some questions, many of the response percentages add up to over 100 percent.

1. **Does your agency use fluorescent orange work zone signs?**

23	(65.7%)	Yes
11	(31.4%)	No - if not, why
2	(5.7%)	No answer

Comments

- Just started using them on construction projects. Maintenance and Operations believes bright orange obscures legend in the daytime.
- Fade too fast. Other products provide better visibility.
- Daytime legibility is primarily manipulated by size. More emphasis is given to nighttime legibility through larger sizes and increased retroreflectivity.
- Did use for part of one construction season. Stopped because of high cost.
- Beginning with our April letting, we will require all "signal ahead" signs to be fluorescent orange. We are currently evaluating the effectiveness of fluorescent orange sheeting and will likely increase its use in the future.
- Use fluorescent orange signs for first sign in advance series for added target value.
- Experimental use on freeways now.
- We use them on a case-by-case basis. Using them in all cases would lose their affect.
- Not at present, but are seriously considering them for approach signing.
- On a limited test basis only - 1 year of experience on 2 projects.
- Used on capital construction.
- I attached our current roadway standard for stationary construction signs. The "Begin Work Zone" sign is the first sign in the series and is the only one required to be fluorescent orange.
- Construction uses them, maintenance does not.
- A field evaluation of experimental installations of fluorescent orange work zone signs was conducted during the 1995 construction season, with favorable results. A decision has not yet been made on whether to use this material.
- Fluorescent orange signs are required for "ROAD WORK AHEAD" or similar advance construction signs only.
- We use fluorescent orange signs on maintenance but the signs are smaller than the orange signs used on construction.

2. **How long has your agency been using fluorescent orange signs in work zone signs?**

4	(11.4%)	Less than 6 months
8	(22.9%)	6 to 12 months
3	(8.6%)	1 to 2 years
9	(25.7%)	More than 2 years
11	(31.4%)	No answer

Comments

- Some districts started using more than 2 years ago. All districts now use on Interstate and other high traffic roadways.
- Numerous inconclusive experiments over last several years.
- Not used.

- Construction industry said that it cost too much more per sign than standard specified encapsulated signs. Also, they felt there was no significant increase in safety on jobs using fluorescent orange.
- We used the old-fashioned nonreflective fluorescent sheeting on moving and mobile operations in late 70s and upgraded to engineering grade in the early 80s. We used fluorescent orange roll-up signs beginning in 1986 or 1987. We have been using diamond grade fluorescent orange sheeting since 1988 on an experimental project on I-394.
- Trial basis.
- Used on interstate, freeway, and parkway projects since January 1995. Required on projects for other highways in 1996.
- We will be in the process of possibly looking at more widespread use of the fluorescent orange sheeting in our work zones.
- We allowed contractors to mix in this past construction season to help in their inventory switch.
- Experimental.
- Since 1992.
- The Department began phasing in fluorescent signs in 1993. All orange construction signs were required to be fluorescent by January 1, 1996, except flexible non-fluorescent signs may also be used.

3. What type of work zones use fluorescent orange signs? You may check more than one box.

Type of Work Zone	*Time of Day*	*Work Zone Duration*
23 (65.7%) Construction	24 (68.6%) Daytime	17 (48.6%) Short Duration
13 (37.1%) Maintenance	24 (68.6%) Nighttime	22 (62.9%) Long Duration
9 (25.7%) No answer	10 (28.6%) No answer	10 (28.6%) No answer

Comments

- Contractors may use them in any work zone. Some high-volume projects require them. Maintenance crews use on Interstate and other high-volume roadways.
- Fluorescent orange W20-1 series now standard.
- None.
- I believe this will be our usage.
- In 1996 will be used on all capital projects regardless of time of day or duration.
- The sheeting is required on the stationary construction signs.
- Used on freeways and expressways.
- Flexible signs are also still allowed for daytime work. Retroreflective flexible signs are also for emergency operations for up to one night period.

4a. Do you mix fluorescent orange signs and standard orange signs in the same work zones?

16	(45.7%)	Yes - how do you determine which should be fluorescent orange?
12	(34.3%)	No
7	(20.0%)	No answer

Comments

- W20-1 series only.
- As required by state manual on Traffic Control for Work Zones.
- Did not permit mixing on jobs calling for fluorescent orange.
- Until July 1, 1996, all cons zone signs may use either until contractors get their signs changed to all fluorescent orange. Much the same is true in maintenance zones.
- All signs on selected projects.
- First sign in advance series.
- We use both fluorescent orange and orange in the same work zone, refer to section of Chapter 8 of the Traffic Engineering Manual.
- Occasionally for comparison.
- Case-by-case when high visibility needed.
- Usage by other states; cost.
- On test, we used fluorescent orange on advance signs only.
- Policy is to avoid mixing sign types within the same size series. Some intermixing did occur.
- We believed we needed the brighter sign as the first sign to capture the motorists' attention at the very beginning of the work zone. The first signs in our stationary sign series.
- Beginning in 1996, all construction signs will be fluorescent orange. For some devices such as drums, this material will not be available.
- Determined by each district.
- However, if fluorescent orange is adopted, it is not expected that there will be any mixing of fluorescent and standard orange signs.
- Experimental.
- Advance warning sign is required to be fluorescent orange, rest of the signs in work zone are engineering grade or high intensity depending on situation.
- We plan to evaluate using standard orange for permanent signs and fluorescent orange for lane closures, detours, etc. but have not done so yet.
- See attached.
- Lead-in signs "Work Zone Ahead" and "Flagger Sign."
- There will be older non-fluorescent signs used until they are replaced because of face condition.

4b. Also, if yes, please list any signs that are specifically designated for fluorescent orange:

- Arrowhead for reflective panels.
- A list of 20 signs.
- Usually curve warning signs on Interstate detours at bridge replacement, etc. We have used them for lane drop signage at temporary acceleration lanes.
- Flagger symbol.
- Post-mounted approach signing.
- ROAD WORK AHEAD, BRIDGE WORK AHEAD.

5. Have you noticed any fading, dulling, or accelerated deterioration of the fluorescent orange sign color?

5	(14.3%)	Yes - please explain
22	(62.9%)	No
8	(22.9%)	No answer

Comments

- No track record yet.
- Fluorescent orange sheeting fades badly on our test decks.
- Not past normal wear.
- Did not observe any of the above for the one construction season signs were used.
- Fluorescent orange roll-up signs degrade from orange in 27 days of continuous exposure to the sun. Diamond Grade fluorescent orange appears to have the same life of regular orange diamond grade sheeting.
- Rapid fading, less than 1 year's use.
- Cannot answer at this time.
- Fading of daytime fluorescence.
- Note only a limited test.
- A project in Raleigh used fluorescent orange signs in the portable sign series as a pilot test. The Resident Engineer reported the sheeting seemed more susceptible to cuts and tears. It needed to be treated more delicately.
- Have used for too short a time.
- Our signs are basically new. We haven't evaluated over time. We anticipate this will be a problem.

6. Do you believe the benefits of using fluorescent orange signs are worth the additional costs?

19	(54.3%)	Yes - please explain
4	(11.4%)	No
13	(37.1%)	No answer

Comments

- Except in bright sunshine.
- Generally, not felt to be cost effective in most work zone applications.
- Better daytime visibility.
- Unknown.
- Undecided.
- Yes, they seem to get attention of motorist earlier. Distance of legibility of messages was same for fluorescent orange as in encapsulated lens sheeting. Motoring public likes fluorescent signs.
- Currently researching the subject.
- They are much more visible, which equates to better conspicuity from a safety standpoint.
- Not sure. We have been notified by construction personnel that there may be a frost and dew problem with fluorescent orange signs.

- The cost of the prismatic fluorescent orange is approximately $1 per sq. ft. more than high intensity sheeting. The improved durability and color recognition make it worthwhile.
- We think the additional cost of our policy, if there is one, is worth it. We have never completed a detailed cost analysis. Although sheeting costs may vary, there are other factors, i.e., fabrication, inventory, delivery, installation, maintenance, etc., that must be included in such an analysis.
- For special signs at high accident locations.
- Not enough time to make an assessment.
- We believe (i.e., hope) the brighter color will be more noticeable.
- There should be a reduction in work zone accidents because of the added visibility.
- We are still trying to determine it. That is why we only require it on one set of signs instead of on all signs as other states have done.
- The signs definitely draw attention. Their durability is reported to be better when handled by workers.
- The favorable results of the field evaluation lead to this conclusion.
- Not yet evaluated.
- Fluorescent orange signs have replaced engineering grade signs with flashing beacon.
- The sign color attracts drivers' attention from a greater distance and alerts them of an approaching work zone.
- We do not have enough information yet to determine whether they are beneficial. However, we are favorably impressed with their appearance.
- Fluorescent signs attract the attention of the motorists more than the non-fluorescent. This promotes safety and eliminates the need to install flags with the signs.
- Only as described, not for every sign.
- If we do not have to use larger signs, then yes. If we use larger signs and fluorescent signs, then no.

7. Have you noticed a reduction in accidents in work zones that use fluorescent orange signs? Has such a reduction been documented?

1	(2.9%)	Yes
17	(48.6%)	No
17	(48.6%	No answer

Comments

- Unknown
- We have not attempted a study to determine the effects of the signs on the public.
- Over the last 5 years we have documented a 33 percent reduction in work zone accidents across our state. We do not feel that this reduction is a direct result of any single work zone traffic control and safety effort. This reduction is due to many factors and safety improvements.
- We use fluorescent orange signs on moving, mobile, flagging, detours, and other high accident potential areas as detailed in the Traffic Engineering Manual. Our guideline contains this use of both colors, so it gives us extra punch when we need it. We have received many comments from the traveling public on the effectiveness of the

fluorescent sheeting. We feel that if all signs were fluorescent we would lose this advantage.

- Not investigated.
- Do not know.
- Cannot answer at this time.
- Based on our observations, I believe the best asset of this sheeting is the visibility in fog, dawn, and dusk. Sometimes at night the sheeting may overpower the message.
- Not yet evaluated.
- No studies on accident reduction.

APPENDIX B
SUBJECT DATA

Tables 36 and 37 list the characteristics of the test subjects who participated in the color recognition evaluations for younger and older drivers, respectively.

Table 36. Subject Data for Younger Drivers

Subject Number[1]	Gender	Age	Visual Acuity[2]	Contrast Sensitivity[3]
3	F	29	20/20	Good
5	M	29	20/20	Good
8	F	21	20/20	Good
14	F	51	20/40	Acceptable
17	M	20	20/15	Good
18	F	24	20/15	Good
19	M	20	20/20	Acceptable
20	F	43	20/20	Good
37	M	21	20/40	Acceptable
38	F	26	20/20	Good
39	F	32	20/20	Good
40	F	20	20/20	Good
41	M	21	20/30	Acceptable
42	M	27	20/15	Good
43	M	21	20/15	Good
44	M	20	20/20	Good
45	M	20	20/20	Good
46	M	19	20/20	Good
47	M	19	20/20	Good

Notes:
[1]Subject number is the number assigned to individuals indicating an interest in participating in the study. For various reasons, some of these individuals were not able to take part in the experiment. Therefore, there are some missing subject numbers in the table.
[2]The visual acuity was measured using a Snellen chart.
[3]The contrast sensitivity was measured using a Vistech contrast sensitivity chart.

Table 37. Subject Data for Older Drivers

Subject Number[1]	Gender	Age	Visual Acuity[2]	Contrast Sensitivity[3]
7	F	74	20/50	Acceptable
9	F	58	20/40	Acceptable
10	M	64	20/20	Good
12	M	71	20/40	Acceptable
13	M	73	20/40	Acceptable
15	M	72	20/40	Good
16	M	72	20/40	Acceptable
21	F	64	20/40	Good
22	M	84	20/25	Acceptable
24	F	75	20/20	Acceptable
25	M	79	20/30	Marginal
26	M	65	20/40	Marginal
27	F	77	20/40	Marginal
28	M	82	20/20	Marginal
29	M	57	20/20	Good
30	F	58	20/25	Good
31	M	57	20/20	Good
32	F	64	20/20	Good
33	M	63	20/25	Good
34	M	63	20/40	Good
35	M	67	20/20	Acceptable
36	F	64	20/20	Good

Notes:
[1]Subject number is the number assigned to individuals indicating an interest in participating in the study. For various reasons, some of these individuals were not able to take part in the experiment. Therefore, there are some missing subject numbers in the table.
[2]The visual acuity was measured using a Snellen chart.
[3]The contrast sensitivity was measured using a Vistech contrast sensitivity chart.

APPENDIX C
DESCRIPTION OF FLUORESCENT MEASUREMENT DEVICE

The retroreflectivity and color properties were measured with single monochromator instruments that have been available for several years. In comparison, the availability of instruments using two monochromators for measuring fluorescent properties of sign materials has been limited until recently. One of the unique aspects of this research was the use of a new instrument for measuring fluorescent properties of the sign materials. Since this instrument has been commercially available for only a year, the following information describes the instrument and the measurements that resulted.

The color of fluorescent materials is the sum of the reflected radiance factor (β_R) and the luminescent radiance factor (β_F). The separated spectral data is called a bispectral radiance matrix. The advantage of the bispectral approach to color measurement is that it allows for the sample's color to be accurately calculated for any standard illumination condition. Separating the reflected and fluorescent components allows the color contribution of each to be identified. Bispectral measurement results can also be compared in terms of the chromaticity coordinates (x, y) and luminance factor Y. The bispectral measurement correctly locates the chromaticity of the sample under D65 illumination or any other defined illuminant.

Labsphere's BFC-450 Bispectral Fluorescent Colorimeter was used to accurately measure the fluorescent samples. This instrument is a high precision spectrophotometer designed for absolute measurement and quantification of the color appearance of fluorescent materials. All testing was performed by Labsphere personnel at their New Hampshire laboratories. The instrument operates in a 45°/0° geometry, using both monochromatic illumination and monochromatic detection. For any sample, complete analysis of the spectral radiance factor is obtained for every 10 nm band of incident illumination. The resulting "bispectral" matrix is a fundamental representation of the reflected excitation and emission spectra associated with fluorescent materials. The bispectral matrix is then used to calculate the sample's total radiance factor providing a complete and illuminant independent colorimetric characterization of a sample. Outputs of the measurements for each sample include a color report, stimulus function, and a bispectral radiance matrix. For this analysis, all measurements were made using a D65 illuminant. The stimulus function provided three components of the spectral radiance factor (β) (luminescent [β_F], reflected radiance factor [β_R], and total radiance factor [β_T]) at 10 nm wavelengths from 380 to 780 nm. The excitation wavelength range was 300 nm to 780 nm.