Evaluation of Type XI Retroreflective Sheeting for White Background Signs

Requested by
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Table of Contents

List of Tables

List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CIE	Commission Internationale de l'Eclairage
DOT	department of transportation
EG	engineering grade
HIP	high intensity prismatic
MUTCD	Manual on Uniform Traffic Control Devices
NYSDOT	New York State Department of Transportation
TTC	temporary traffic control
VPD	vehicles per day

Executive Summary

Background

In recent years, two prominent manufacturers of reflective sheeting for roadway signs in California (3M and Avery Dennison Corporation) have discontinued production of Type IX retroreflective sheeting. For the California Department of Transportation (Caltrans) to meet its current specifications, sign panel fabricators that use retroreflective sheeting systems by these vendors can offer only Type VIII sheeting for white background signs. This industry transition has raised concerns about the long-term availability of sheeting materials and the feasibility of manufacturing signage that complies with Caltrans' requirements.

While Type XI could serve as an alternative sheeting material, Caltrans is aware of reports suggesting that the high brightness level of Type XI retroreflective sheeting when used as a white background may cause a halo effect around the legend of the roadside or overhead sign, potentially compromising visibility and legibility and posing a safety hazard at night.

Caltrans is seeking information that can inform an assessment of the suitability of Type XI sheeting for white background roadside and overhead signs used on the State Highway System. Such an assessment will determine if Type XI sheeting can meet performance and safety requirements, before industry-driven changes limit viable production options of other currently approved materials.

To gather information that will aid Caltrans' investigation, CTC & Associates surveyed state departments of transportation (DOTs) about their experiences with Type XI retroreflective sheeting. A review of in-progress and completed research, relevant specifications and agency guidance, as well as outreach to manufacturers' representatives, supplemented survey findings.

Summary of Findings

Survey of Practice

An online survey distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Traffic Engineering sought information about member agency use of Type XI retroreflective sheeting for white background signs, including its performance and impacts on safety.

Thirteen state DOTs responded to the survey. Eight of the responding agencies permit the use of Type XI retroreflective sheeting for white background signs:

- Arizona
- Indiana[1]
- Maryland
- Michigan
- Oregon
- Pennsylvania[2]
- Utah
- Virginia

1 While Indiana DOT permitted the use of Type XI sign sheeting in 2019, the respondent is unaware of Type XI installations and was unable to address questions related to use of the material.

2 Pennsylvania DOT does not require the use of Type XI sheeting. Instead, Type XI sheeting is permitted along with other sheeting types, and the sign fabricator selects a sheeting type from among those approved for use.

Type XI Sheeting Used for Roadside Signs

The earliest adopter of Type XI sheeting for white background roadside signs among the seven responding agencies began using this material in 2007; two state DOTs began using the material within the last six years. Reasons for use varied, with three of the seven agencies citing longer service life and increased long-distance legibility; two identified cost benefits and reduced maintenance. None of the agencies transitioned to Type XI sheeting because other sheeting was discontinued.

Responding agencies were most likely to report no known or reported issues when asked about factors that could reduce effectiveness or introduce unwanted impacts when using Type XI for white background roadside signs. Those citing concerns offered anecdotal reports of signs being too bright or noted that signs may be too bright when newly installed or in rural environments. Another responding agency received some complaints about glare.

None of the respondents reported issues with safety when using Type XI sheeting for white background roadside signs. Only one respondent reported an issue with durability, citing a report that brightness diminished by 30% within three years of installation. Three states reported economic benefits associated with longer retention of retroreflectivity and lower material cost.

Only one respondent uses a single manufacturer — 3M — to obtain Type XI sheeting for white background roadside signs. All other responding agencies obtain sheeting material from all three manufacturers considered in the survey — 3M, Avery Dennison Corporation and ORAFOL Americas.

Type XI Sheeting Used for Overhead Signs

The first-use dates for Type XI sheeting used for white background overhead signs matched those for use of this sheeting material in roadside signs, and ranged from 2007 to 2020. Respondents were more likely to cite longer service life for an overhead sign as compared to a roadside sign fabricated with Type XI sheeting. Three respondents reported reduced maintenance and increased long-distance legibility for Type XI overhead signs. All but one of the seven responding agencies indicated that Type XI sheeting used for white background overhead signs eliminated the need for sign lighting.

All but two respondents reported no known or reported issues or did not provide a response when asked about issues associated with sign brightness, glare, nighttime visibility and legibility of Type XI white background overhead signs. The two agencies reporting issues received a report that a sign's brightness diminished 30% within three years of installation or received some complaints about glare under foggy conditions.

None of the respondents reported issues with safety and none reported durability issues with Type XI sheeting used for white background overhead signs. Several respondents reported economic benefits associated with eliminating sign lighting and longer retention of retroreflectivity.

As was the case for roadside signs, only one respondent uses a single manufacturer — 3M — to obtain Type XI white background sheeting for its overhead signs. All other responding agencies obtain sheeting material for overhead signs from all three manufacturers considered in the survey.

Assessment and Best Practices

Respondents were most likely to highlight the removal of lighting for overhead signs and improved visibility as the successes associated with Type XI sheeting used for white background signs. Four of the seven responding agencies reported no challenges or limited use of Type XI sheeting. Other respondents

identified a higher cost for Type XI sheeting and noted that signs are too bright on rural roadways. Another respondent reported that, over time, the reflective material peeled away on some signs and became less reflective, but the text remained legible.

Almost all of the best practices and lessons learned shared by respondents addressed sign materials, fabrication or installation. A sampling of respondents' recommendations:

- Learn the differences among the three manufacturers' materials
- Use an appropriate cleaner and the correct components for Type XI sheeting
- Exercise care when aligning signs fabricated with Type XI sheeting
- Avoid the placement of Type XI signs in certain locations

Specifications

Respondents from five of the responding states — Arizona, Oregon, Pennsylvania, Utah and Virginia — shared relevant specifications. Specifications from states not participating in the survey are included in the **Related Research and Resources** section of this report.

Agencies Not Regularly Using Type XI Sheeting

Respondents from Connecticut, Georgia, Missouri, Ohio and Tennessee DOTs reported that their agencies do not make regular use of Type XI retroreflective sheeting for white background signs.

Roadside Signs

Only Tennessee DOT has used Type XI sign sheeting for white background roadside signs, with the respondent noting, "We base our usage more off the size than the color. So [for] larger extruded panel signs, we use AASHTO M 268, Type D." Sign brightness and nighttime visibility were the most frequently cited reasons by other respondents for using something other than Type XI sign sheeting for white background roadside signs. These agencies are most likely to use Type IV and Type IX sheeting.

Overhead Signs

Connecticut and Tennessee DOTs use Type XI sign sheeting for at least some white background overhead signs. In Tennessee, most overhead signs conform to AASHTO M 268, Type D, which includes Type XI sheeting. Tennessee DOT made the change to Type XI a few years ago when the cost of this material more closely matched the cost of material that meets the requirements of AASHTO M 268, Type B. The remaining respondents cited various reasons for not using Type XI sheeting from among the five possible impacts considered in the survey — sign brightness, glare, nighttime visibility (halo effect), legibility and cost. These agencies are most likely to use Type IV and Type IX sheeting.

Consultation with Experts

Feedback on issues associated with the use of Type XI sheeting from three sign sheeting manufacturers — 3M, Avery Dennison Corporation and ORAFOL Americas — is presented below in three topic areas: availability, safety concerns and trends in state use. Further details of this outreach appear in the **Detailed Findings** portion of this report.

Availability

Of the three manufacturers, only ORAFOL continues to offer Type IX sheeting. However, ORAFOL may also discontinue Type IX production within the next five years. All three manufacturers have no issues with the availability of Type XI sheeting.

Safety Concerns

All three manufacturers' representatives pointed to various publications that examined potential safety concerns associated with Type XI sheeting. The 3M representative highlighted a December 2019 report sponsored by the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety, which the representative noted indicates "the effects of the different headlamps and less light is being thrown at traffic signage as compared to pavement markings."

When recommending selected publications for review, the Avery Dennison representative commented that "findings can sometimes conflict with each other as the variables can get complex." He also noted that research in this topic area may be dated, some of the sheeting types addressed are no longer available, and issues such as sign fabrication and supply chains may not be considered. The ORAFOL representative cited a 2015 *Transportation Research Record* journal article, noting that its author "concluded that the use of Type XI for some signs can be too bright" in certain applications, and commented separately that "the use of Type XI for shoulder mount signs may be too bright."

Trends in State Use

3M's internal research indicates that more than 28 states use Type XI sign sheeting for warning and regulatory sign series, four states use a combination of Type XI and other sheeting types, and the remaining 18 states use a sheeting type other than Type XI. Avery Dennison's representative noted that most states currently use Type IV and full-cube products, with some using Type IV for the background of guide signs. If Caltrans wishes to confirm current usage, the ORAFOL representative recommended reviewing each state's Qualified Product List or Approved Material List. The ORAFOL representative observed that more states are using Type XI sheeting in work zones and on traffic control devices such as barrels, cones and barricades, and expressed concern that these materials "may be too bright for these applications."

Related Research and Resources

Related research examined for this project included an October 2014 Caltrans Preliminary Investigation that considered the use of Type XI sheeting for overhead signs, and the cost and potential adverse effects of not lighting these signs. National research includes a Federal Highway Administration assessment of nighttime visibility sign retroreflectivity, and a 2022 National Cooperative Highway Research Program project that provides guidance for selecting sign sheeting, including Type XI, and the areas where further research is needed regarding luminance.

Supplementing the specifications provided by the state DOTs responding to the survey are specifications describing use of Type XI sign sheeting by Alabama and Iowa DOTs. Related research sponsored by other state DOTs includes a 2015 Kansas DOT report that used a survey of state DOTs and laboratory testing to determine the sign sheeting that "best improves sign visibility."

Discussion of sign sheeting performance in a 2021 Minnesota DOT research synthesis cites the same 2015 *Transportation Research Record* article shared by the ORAFOL representative, which "indicated that the use of high-beams on signs utilizing Type XI legends showed a smaller legibility distance as compared to Type III, indicating that in remote areas, the use of high intensity sheeting may be inappropriate." Preceding the author's recommendations for sign sheeting practices was an acknowledgment that while "there are no definitive rules for selecting sign sheeting," the guidelines that followed "appear reasonable based on prior research and expert opinion."

A 2014 New York State DOT study developed "a practical methodology for conducting field measurements of sign performance along roadways" and a spreadsheet tool "for calculating sign luminance and visibility." In related resources, researchers examined the factors affecting sign visibility, conspicuity and legibility, considered the use of high intensity reflective sheeting without the addition of external lighting for overhead signs, and presented a summary of "the latest methodology for evaluation of sign sheeting materials" as of the publication date of the 2015 conference paper.

Gaps in Findings

The survey received a limited response, with survey feedback from seven agencies describing current use of Type XI sheeting for white background signs. In some cases, the agencies responding provided limited details of current practices. Reaching out to a targeted group of agencies that did not respond to the current survey but are expected to use Type XI sign sheeting could yield useful information.

As one researcher noted, with no "definitive rules" for selecting sign sheeting, additional research may help to identify the most appropriate use of Type XI sign sheeting — and other sheeting types — to address Caltrans' needs for white background signs on the State Highway System.

Next Steps

Moving forward, Caltrans could consider:

- Reaching out to one or more states describing use of Type XI sign sheeting for white background signs to delve deeper into agency use of this sheeting material.
- Consulting with state DOTs reporting issues or concerns with Type XI sheeting used for roadside signs to assess the magnitude of those concerns:
    - Michigan – glare
    - Oregon, Pennsylvania and Virginia – brightness
    - Utah – installation
- Consulting with state DOTs reporting issues or concerns with Type XI sheeting used for overhead signs to assess the magnitude of those concerns:
    - Maryland – reduction in brightness over a short period of time
    - Oregon – glare in foggy conditions
- Engaging with all three sign sheeting manufacturers — 3M, Avery Dennison Corporation and ORAFOL Americas — to learn more about anticipated changes in sign production:
    - Possible cessation of production of Type VIII sheeting (3M and Avery Dennison Corporation)
    - Possible cessation of production of Type IX sheeting (ORAFOL Americas)
- Reaching out to states expected to use Type XI sign sheeting but not participating in the current survey to solicit feedback on agency practices.
- Reviewing recent research on retroreflective materials to examine in detail recommendations for sign sheeting material selection and the topic areas recommended for further research.

Detailed Findings

Background

Industry trends are indicating a shift away from certain retroreflective sheeting materials specified in California Department of Transportation (Caltrans) standards for white background signs. Section 82-2, Sign Panels, in Caltrans' 2025 Standard Specifications, includes this requirement regarding white background signs:

> *Retroreflective sheeting must be Type XI, except for white background signs, it must be Type VIII or IX.*

Prominent manufacturers of reflective sheeting for roadway signs have discontinued production of Type IX retroreflective sheeting. For Caltrans to meet its current specifications, sign panel fabricators that use retroreflective sheeting systems by these vendors can offer only Type VIII sheeting for white background signs. This industry transition has raised concerns about the long-term availability of sheeting materials and the feasibility of manufacturing signage that complies with Caltrans' requirements.

While Type XI could serve as an alternative sheeting material, Caltrans is aware of reports suggesting that the high brightness level of Type XI retroreflective sheeting when used as a white background may cause a halo effect around the legend of the roadside or overhead sign, potentially compromising visibility and legibility and posing a safety hazard at night.

Caltrans is seeking information that can inform an assessment of the suitability of Type XI sheeting for white background signs used on the State Highway System. Such an assessment will determine if Type XI sheeting, when used as a white background material for roadside and overhead signage, can meet performance and safety requirements, before industry-driven changes limit the availability of other currently approved materials.

Below is a presentation of information gathered about these issues. The materials and experience discussed in this investigation were gathered through a survey of state departments of transportation (DOTs) and a review of in-progress and completed research.

Survey of Practice

An online survey distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Traffic Engineering sought information about agency use of Type XI white retroreflective sheeting used as the background for roadside and overhead signs. Thirteen state DOTs responded to the survey:

- Arizona
- Connecticut
- Georgia
- Indiana
- Maryland
- Michigan
- Missouri
- Ohio
- Oregon
- Pennsylvania
- Tennessee
- Utah
- Virginia

Survey findings are summarized below in two topic areas:

- Users of Type XI retroreflective sheeting (begins immediately below)
- Agencies not making regular use of Type XI retroreflective sheeting (see page 20)

Users of Type XI Retroreflective Sheeting

Eight state DOTs permit the use of Type XI retroreflective sheeting for white background signs:

- Arizona
- Indiana[1]
- Maryland
- Michigan
- Oregon
- Pennsylvania[2]
- Utah
- Virginia

1 While Indiana DOT permitted the use of Type XI sign sheeting in 2019, the respondent is unaware of Type XI installations and was unable to address questions related to use of the material.

2 Pennsylvania DOT does not require the use of Type XI sheeting. Instead, Type XI sheeting is permitted along with other sheeting types, and the sign fabricator selects a sheeting type from among those approved for use.

Roadside Signs

Feedback from the seven agencies describing use of Type XI sheeting for white background roadside signs is summarized below in four topic areas:

- Type XI sheeting usage
- Impact of selected factors
- Other concerns and benefits
- Material manufacturers

Type XI Sheeting Usage

Michigan DOT, the earliest adopter of Type XI sheeting for white background roadside signs among the seven responding agencies, began using this material in 2007; two state DOTs began using the material within the last six years (*Oregon* and *Pennsylvania*). Reasons for use varied, with three agencies citing longer service life and increased long-distance legibility; two identified cost benefits and reduced maintenance. The Arizona DOT respondent noted that Type XI sheeting improves daytime color brightness and nighttime retroreflectivity. None of the responding agencies cited the discontinuation of other sheeting types as a reason for transitioning to Type XI sheeting.

Table 1 identifies when agencies began to use Type XI sheeting for white background roadside signs and highlights the reasons cited for its adoption.

Table 1. Year of Adoption and Reasons for Using Type XI White Background Sheeting (Roadside Signs)

State	Year First Used	Longer Service Life	Cost Benefits	Reduced Maintenance	Increased Long-Distance Legibility	Other Reason(s) for Use
Arizona	2015		X			Improves daytime color brightness and nighttime retroreflectivity at a lower cost while maintaining compliance with ASTM D4956[1] and the MUTCD[2].
Maryland	2009					Federal Highway Administration recommended Type IX; the agency elected to use Type XI.
Michigan	2007	X			X	

State	Year First Used	Longer Service Life	Cost Benefits	Reduced Maintenance	Increased Long-Distance Legibility	Other Reason(s) for Use
Oregon	2019	X				Pressure from sheeting manufacturers to the agency's director's office and state legislature.
Pennsylvania	2020					The agency does not require the use of Type XI. Type XI is permitted along with Types III, IV, VIII and IX. The sign fabricator selects the sheeting type from among those approved for use.
Utah	2016		X	X	X	
Virginia	2008	X		X	X	
Total		**3**	**2**	**2**	**3**	

1 ASTM D4956 = American Society for Testing and Materials D4956 Standard Specification for Retroreflective Sheeting for Traffic Control.

2 MUTCD = Manual on Uniform Traffic Control Devices.

Impact of Selected Factors

Responding agencies were most likely to report no known or reported issues when asked about factors that could reduce effectiveness or introduce unwanted impacts when using Type XI for white background roadside signs. When offering feedback about potential concerns associated with use of this sheeting material, respondents provided anecdotal reports of signs being too bright (*Oregon*, *Pennsylvania* and *Virginia*) and minimal glare (Maryland), with the Virginia DOT respondent noting that a sign may be too bright when newly installed or in rural environments. Michigan DOT has received some complaints about glare. The Utah respondent reported potential nighttime visibility issues for digitally printed signs that are improperly installed or hit at certain distances.

Table 2 summarizes respondents' assessment of certain factors related to the use of Type XI white background sheeting used for roadside signs.

Table 2. Experience with Selected Factors Associated with Type XI White Background Sheeting (Roadside Signs)

State	Sign Brightness	Glare	Nighttime Visibility (e.g., Halo Effect)	Legibility
Arizona	No known or reported issues.	No known or reported issues.	No known or reported issues.	No known or reported issues.
Maryland	Maximum with low light.	Minimal	Legible under low light.	Legible under low light.
Michigan	Better brightness than using Type IV or Type IX sheeting.	There have been some complaints from drivers.	Good visibility at night.	The combination of Type XI sheeting and Clearview fonts provides good results.
Oregon	Some have mentioned that signs are too bright.	No known or reported issues.	No known or reported issues.	No known or reported issues.

State	Sign Brightness	Glare	Nighttime Visibility (e.g., Halo Effect)	Legibility
Pennsylvania	Signs are very bright compared to other sheeting types. The agency has received complaints from motorists regarding the signs being too bright on rural roadways with no external lighting.	No known or reported issues.	No known or reported issues.	No known or reported issues.
Utah	Signs are more visible.	No known or reported issues.	Digitally printed signs can make text hard to read if the sign gets warped from improper installation or hit at certain distances.	No response
Virginia	Sometimes a sign may be too bright when newly installed or in rural environments.	No known or reported issues.	See sign brightness comments. No other known or reported issues.	No known or reported issues.

Other Concerns and Benefits

None of the respondents reported issues with safety when using Type XI sheeting for white background roadside signs. Only the Maryland respondent reported an issue with durability, citing a report that brightness diminished by 30% within three years of installation.

Three states reported economic benefits:

- *Arizona*. Lower material cost and longer service life translate to fewer replacement signs needed.
- *Michigan*. Retroreflectivity has improved from 15 to 18 years when using Type XI instead of Type IV sheeting.
- *Utah*. Signs seem to maintain an acceptable level of retroreflectivity longer.

Material Manufacturers

Arizona DOT is the only respondent to use a single manufacturer — 3M — to obtain Type XI sheeting used for white background roadside signs. All other responding agencies obtain sheeting material from all three manufacturers considered in the survey —3M, Avery Dennison Corporation and ORAFOL Americas. Maryland State Highway Administration also uses Nippon to supply this sign sheeting; Michigan DOT estimates that 95% of its signs have been fabricated with 3M sheeting.

Overhead Signs

Feedback from the seven agencies describing use of Type XI sheeting for white background overhead signs is summarized below in four topic areas:

- Type XI sheeting usage
- Impact of selected factors

- Other concerns and benefits
- Material manufacturers

Type XI Sheeting Usage

The first-use dates for Type XI white sheeting used as the background in overhead signs matched those for use of this sheeting material for roadside signs, ranging from 2007 (*Michigan*) and 2008 (*Virginia*) to 2020 (*Pennsylvania*). Respondents were more likely to cite longer service life as a reason for using Type XI sign sheeting for overhead signs as opposed to roadside signs; three respondents reported reduced maintenance and increased long-distance legibility. All but one of the responding agencies (*Arizona*) indicated that Type XI sheeting eliminated the need for sign lighting.

Table 3 identifies when agencies began to use Type XI sheeting for white background overhead signs and highlights the reasons cited for its adoption.

Table 3. Year of Adoption and Reasons for Using Type XI White Background Sheeting (Overhead Signs)

State	Year First Used	Longer Service Life	Cost Benefits	Reduced Maintenance	Increased Long-Distance Legibility	Eliminated Need for Sign Lighting	Other Reason(s) for Use
Arizona	2015		X				Improves daytime color brightness and nighttime retroreflectivity at a lower cost while maintaining compliance with ASTM D4956 and the MUTCD.
Maryland	2009		X	X		X	
Michigan	2007	X			X	X	
Oregon	2019	X				X	Pressure from sheeting manufacturers to the agency's director's office and state legislature.
Pennsylvania	2020					X	The agency does not require the use of Type XI. Type XI is permitted along with Types III, IV, VIII and IX. The sign fabricator selects the sheeting type from among those approved for use.
Utah	2016	X		X	X	X	
Virginia	2008	X		X	X	X	
Total		**4**	**2**	**3**	**3**	**6**	

Impact of Selected Factors

All but two respondents reported no known or reported issues or did not provide a response when asked about issues associated with sign brightness, glare, nighttime visibility and legibility of Type XI white background overhead signs. The two respondents reporting issues identified concerns associated with sign brightness and glare:

- *Maryland*. The agency received one report that a sign's brightness diminished 30% within three years of installation.
- *Oregon*. The agency has received some complaints about glare under foggy conditions.

None of the respondents described other issues with safety and none reported durability challenges with Type XI sheeting used for white background overhead signs. Several respondents reported economic benefits:

- *Arizona*. No electrical connectivity is needed to power luminaires.
- *Maryland*. Elimination of overhead sign lighting is expected to reduce energy costs. New installations with adequate sight distance do not require sign lighting.
- *Michigan*. Increased durability.
- *Utah*. Signs seem to maintain retroreflectivity longer and the removal of lighting saves on initial costs, power and maintenance.

Material Manufacturers

As was the case for Type XI white background roadside signs, Arizona DOT is the only respondent to use a single manufacturer — 3M — to obtain Type XI sheeting for overhead signs. All other responding agencies obtain sheeting material for overhead signs from all three manufacturers considered in the survey.

Assessment

Briefly highlighted in the following section are the successes and challenges reported by respondents using Type XI sign sheeting for white background signs.

Successes

Respondents were most likely to highlight the removal of lighting for overhead signs and improved visibility as the successes associated with Type XI sheeting used for white background signs. Table 4 summarizes survey responses.

Table 4. Successes Associated with Use of Type XI White Background Sheeting

Success Factor	State	Description
Cost Savings	Arizona	The agency is realizing cost savings by removing or not installing lighting luminaires for overhead signs.
Improved Visibility	Maryland, Pennsylvania	*Maryland*. Visibility is better. *Pennsylvania*. Signs are brighter and more visible than signs using a lower type of sheeting.
Increased Retroreflectivity	Michigan	Sign retroreflectivity has increased from 15 to 18 years.

Success Factor	State	Description
Removal of Lighting from Overhead Signs	Arizona, Maryland, Utah, Virginia	*Virginia*. While the agency does not maintain a lot of signs with white background on overhead structures, when Type XI sheeting is used on overhead signs, the ability to eliminate sign lighting is beneficial to the agency and initial and long-term maintenance.

Challenges

Four of the seven responding agencies reported no challenges (*Arizona*, *Michigan*, *Virginia*) or limited use of Type XI sheeting (*Oregon*). The Pennsylvania DOT respondent identified a higher cost for Type XI sheeting and noted that signs are too bright on rural roadways. In Maryland, over time, the reflective material on some signs peeled away and became less reflective, but the text remained legible.

Best Practices and Lessons Learned

Almost all of the best practices and lessons learned shared by respondents addressed sign materials, fabrication and installation.

Administrative Processes

- Follow agency specifications (*Virginia*).

Sign Materials

- Learn the differences between 3M, Avery and ORAFOL materials (*Michigan*).
- Use 3M Type XI material to benefit from its greater ease in cutting and managing as compared with other manufacturers' materials (*Michigan*).

Sign Fabrication

- Clean the Type XI signs using 70% isopropyl alcohol before applying components for better adhesiveness (*Maryland*).
- Use correct components for Type XI sheeting (*Maryland*).

Sign Installation

- Exercise care when aligning signs. If the signs are angled back at the driver the signs can seem too bright, especially on rural roads where high beams are likely to be used (*Utah*).
- Recommend not using Type XI sheeting for white background signs on rural roadways because they are "too bright" (*Pennsylvania*).

Relevant Specifications

Respondents from five states — Arizona, Oregon, Pennsylvania, Utah and Virginia — shared relevant specifications. Additional specifications appear in the **Related Research and Resources** section of this report.

Arizona

Subsection 380, Sign Materials, Section 300 – Signs, ADOT Traffic Engineering Guidelines and Processes, Arizona Department of Transportation, June 2015.
https://azdot.gov/sites/default/files/2019/05/tgp0380-2015-06.pdf

From the guidance: The type of sheeting to be used in any given application should be called out on the project plans. Table 380-1 below lists the sheeting alternatives that are acceptable for each category of signing.

Use of sign sheeting other than that specified in this section shall require approval by the State Traffic Engineer.

Table 380-1. Sign Sheeting Selection by Sign Type or Application

Sign Type or Application	Sheeting Type					
	I	IV	VI	VIII	IX	XI
Permanent Regulatory, Warning, and Overhead Guide Signs (including sign legends and borders)						X
Information, Ground Mounted Guide, or Marker Signs (including sign legends and borders)[1]					X	X
Permanent Object Markers (including rigid delineators), Guard Rail Markers, and Impact Attenuators					X	X
Flexible Delineators				X	X	X
Temporary Signs (other than with orange backgrounds) [2]		X		X	X	X
Temporary Signs (rigid - with orange backgrounds) [2 3]				X	X	X
Temporary Signs (flexible or roll-up - with orange backgrounds) [2 3]			X			
Temporary Channelizing Devices (barricades, etc.)		X		X	X	X
Adopt A Highway Signs	X	X				X
Specific Service (Logo) Signs	X				X	X

1 County Route Shields for independent mounting (not on a larger guide sign) and M1-102 series scenic road signs may use Type I sheeting.
2 Non-reflective sign backgrounds may be used for temporary signs where the signs may be clearly visible under available natural light.
3 Temporary signs with an orange background shall use fluorescent orange sheeting conforming to Section 1007 of the Standard Specifications and the ADOT Approved Products List, except for signs in Note 2.

Oregon

Chapter 2, Designing Signs, Traffic Sign Design Manual, Delivery and Operations Division, Traffic Roadway Section, Oregon Department of Transportation, January 2026.
https://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Sign-Design-Manual.pdf
From page 39 of the manual (page 49 of the PDF):

2.1.2 – Sign Sheeting
There are numerous types of sign sheeting available and each type has its advantages and disadvantages. It is important to specify which type of sheeting to use on each sign designed.
….

2.1.2.3 – ASTM Type IX
This is a highly retroreflective sheeting and should be for overhead sign installations (or type XI). This sheeting has a much wider angularity and is not quite as bright as the Type VII used in the past. It can be used for ground mounted signs but should be reserved for places where high impact is needed. It is commonly used for legend on overhead mounted signs and can be used as background where more high impact is needed. Viewing distance is up to 800 feet away. The warranty on this sheeting is 12 years. It also comes in fluorescent colors: Yellow, yellow-green and orange. In the fluorescent colors, a 10-year warranty applies.

2.1.2.4 – ASTM Type XI
This wide angle, highly retroreflective sheeting should be used for overhead sign installations (or type IX) or for signs placed at angles or locations where a lesser retroreflective sheeting would require illumination. It can be used for ground mounted signs but should be reserved for places where high impact is needed. Some have commented that this type of sheeting can be extremely bright, especially in rural areas where there are few other light sources at night. The warranty on

this sheeting is 12 years. It also comes in fluorescent colors: Yellow, yellow green and orange. In the fluorescent colors, a 10-year warranty applies.

2.1.2.5 – Other ASTM Type Sheeting
The following sheeting types are no longer used on Oregon's state highway system.

- ASTM Type I.
- ASTM Type II.
- ASTM Type V.
- ASTM Type VI.
- ASTM Type VII.
- ASTM Type VIII.
- ASTM Type X.

From page 83 of the manual (page 93 of the PDF):

4.4.6 – Legend Color
There are three columns where legend color information can be entered. Choose only one of these columns for the sign legend and enter the appropriate legend color.

- "ASTM Type III or Type IV" column.
- "ASTM Type IX or Type XI" column.
- "Non-Reflective" column.

Whenever the legend color is black, enter the abbreviation "BK" into the "Non-Reflective" column. Black legend is always non-reflective. No other colors will be entered in the "Non Reflective" column.

For all other legend colors, use the same abbreviations referred to previously in footnote 1. Enter the abbreviation for the sign color into whichever column is appropriate.

Pennsylvania

Section 1103—Traffic Signing and Marking, Specifications, PUB 408/2020, Pennsylvania Department of Transportation, Change 11, effective October 10, 2025.
https://www.pa.gov/content/dam/copapwp-pagov/en/penndot/documents/public/pubsforms/publications/pub_408/408_2020/408_2020_11/408_2020_11.pdf
From page 1221 of the PDF:

1103.02 EXTRUDED ALUMINUM CHANNEL SIGNS (FOR POST MOUNTED SIGNS, TYPES A AND E AND STRUCTURE MOUNTED)—

….

(c) Reflective Sheeting. Use precolored Type III, IV, VIII, IX, or XI sheeting, according to the Department's Specification for Retroreflective Sheeting Materials and Process Inks for Traffic Control.

Apply the sheeting to the face and a 3/8-inch width along both edges of the channel sections, using a procedure specified by the sheeting material manufacturer. Apply free of bubbles or wrinkles greater than 3 inches in length and with total sheeting shrinkage of not more than 1/8-inch. A maximum of one splice may be made in the sheeting for any channel section. Make the splice

perpendicular to the longitudinal centerline of the channel, with the edges of adjacent pieces butted together throughout the entire seam length, without any overlap or separation. If covered sections are stacked before sign fabrication, then use microfoam between sign faces and store sections in a vertical position.

(d) Legend and Border. Use direct-applied cutout Type VIII, IX, or XI reflective sheeting material for letters, numerals, accessories, borders and symbols.

(e) Sign Fabrication. Apply the reflective sheeting, then firmly bolt channels together with the webs in the same plane, to form a smooth and uniform surface. Adjust channel ends for correct position so the edges are free from projections. Securely fasten assembled sign panels to a rigid framework, before application of legend and before shipment. Lay out the legend and border on the sign face as indicated. Apply cutout Type VIII, IX, or XI legend and border to sign face according to manufacturer's instructions. Fabricate signs in a single unit. If necessary, ship large signs sectionalized in panels. When shipping sectionalized signs, slit any legend and border, which overlaps the panels.

From page 1226 of the PDF:

1103.04 FLAT SHEET SIGNS (FOR POST MOUNTED SIGNS, TYPES B, C AND F; AND DISTANCE MARKERS)—

(c) Reflective Sheeting. Section 1102.02(c).

1. General. Apply the sheeting to the sign face using a procedure according to the sheeting manufacturer, free of bubbles or wrinkles greater than 3 inches in length, and with total sheeting shrinkage of not more than 1/8-inch.

On signs larger than 48 inches on the shorter side, sheeting may be spliced with the edges of adjacent pieces butted together throughout the entire seam length without any overlap or separation.

Use Type III, IV, VIII, IX, or XI sheeting for all signs.

(d) Ink. As recommended by the manufacturer of the reflective sheeting.

(**e) Electronic Cuttable (EC) Film.** Use film as recommended by the manufacturer of the reflective sheeting. Apply the sheeting to the sign face using a procedure according to the sheeting manufacturer, free of bubbles or wrinkles greater than 1 inch in length.

(f) Legend and Border. Apply legend and border of the color, size and dimensions according to Publication 212, Publication 213 and the MUTCD or as indicated. Use silk screens with a mesh of 12XX or finer for reverse screening. Use stencils with sharp clear-cut edges, uniform curvature and straight lines. Silk screen in a manner resulting in uniform color and tone, with sharply-defined edges and without blemishes on the sign background. Air dry or bake signs after silk screening to achieve a smooth hard finish. Blisters appearing during the drying process will be cause for rejection. If direct-applied legend is indicated for any directional or destination sign, use Type III, IV, VIII, IX, or XI reflective sheeting. Slip-sheet and pack signs to ensure delivery in an undamaged condition.

Utah

Section 02890 Retroreflective Sheeting, 2026 Standard Specifications For Road and Bridge Construction, Utah Department of Transportation, April 2025.
Available at https://drive.google.com/drive/folders/1N9yXr7OJmtYVG3nNtpxoo3vMEP6b0QXi
From page 783 of the PDF:

2.2 Permanent Applications

A. Permanent Traffic Signs and Traffic Control Devices
   1. Meet or exceed the minimum requirements of ASTM D 4956 Type XI.
   2. Use fluorescent sheeting for orange, yellow and yellow-green.

B. Miscellaneous Signs
   1. Use ASTM D 4956 Type I for Adopt a Highway and Sponsor a Highway signs.
   2. Use ASTM D 4956 Type I for Memorial signs.
   3. Use fluorescent pink retroreflective sheeting for Traffic Incident Management Area signs.

2.3 Work Zone Applications

A. Work Zone Signing
   1. Standard signs
      a. Meet or exceed the minimum requirements of ASTM D 4956 Type XI.
      b. Use fluorescent retroreflective sheeting for orange, yellow and yellow-green.
   2. Project specific signs
      a. Meet or exceed the minimum requirements of ASTM D 4956 Type III high intensity prismatic sheeting.
      b. Use fluorescent retroreflective sheeting for orange, yellow and yellow-green.
   3. Traffic incident management area signs
      a. Use fluorescent pink.

B. Flexible Work Zone Devices
   1. Meet or exceed the minimum requirements of ASTM D 4956 Type VI.

C. Channelization Devices
   1. Vertical panels, barricade Types I, II and III, and directional indicator barricades.
      a. Meet or exceed the minimum requirements of ASTM D 4956 Type XI.
      b. Use of standard orange acceptable.
   2. Meet or exceed the minimum requirements of ASTM D 4956 Type V for temporary raised pavement markers.
   3. Meet or exceed the minimum requirements of ASTM D 4956 Type IV for all other channelization devices.
   4. Use fluorescent retroreflective sheeting for orange and yellow.
   5. Do not obscure retroreflective sheeting with paint or other materials.

Virginia

Section 701, Traffic Signs, 2022 Supplement to the VDOT 2020 Road and Bridge Specifications, Virginia Department of Transportation, effective December 31, 2021.
https://www.vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/construction/migrated-acc/2022Supplement_to_the_2020SpecBook_acc071522.pdf
From page 90 of the PDF:

SECTION 701 – TRAFFIC SIGNS is amended as follows:

Section 701.02(a)1 – Overhead Permanent Signs is replaced with the following:

Overhead Permanent Signs (signs attached to sign structures which overhang travel lanes) shall use ASTM D4956 Type XI sheeting.

Table VII-1A – Reflective Sheeting is replaced with the following:

TABLE VII-1A
Reflective Sheeting

Background Color of Sign	Sheeting Type[1]
White	ASTM D4956 Type XI
Red	ASTM D4956 Type XI
Fluorescent Yellow	ASTM D4956 Type XI[2]
Fluorescent Yellow-Green	ASTM D4956 Type XI[3]
Green	ASTM D4956 Type XI
Black	ASTM D4956 Type XI
Purple	ASTM D4956 Type XI
Brown	ASTM D4956 Types IV, IX, or XI
Blue	ASTM D4956 Types IV, IX, or XI

[1]The following signs may use ASTM D4956 Types IV, IX, or XI, regardless of color: Pushbutton education signs (R10-series signs mounted adjacent to pedestrian pushbuttons), Signs erected on bikeways physically separated from adjacent roads, R7- or R8-series parking restriction signs located on non-limited-access highways, D10-series Reference Location Signs (mile markers) and Intermediate Reference Location Signs, and Post-mounted street name signs.
[2]The yellow portions of all signs shall be fluorescent yellow.
[3]All temporary and permanent warning signs related to school zones, pedestrians, or bicyclists (including associated supplemental plaques) shall use fluorescent yellow-green sheeting where required by the VA Supplement to the MUTCD unless otherwise specified on the Plans.

Section 701, Traffic Signs, 2020 Road and Bridge Specifications, Virginia Department of Transportation, 2020.
https://www.vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/construction/VDOT_2020_RB_Specs_acc071522.pdf
From page 812 of the specifications (page 840 of the PDF):

701.02—Materials

(a) Reflective sheeting shall conform to Section 247 and shall be selected from the Department's Approved List 46. The color for the legend and background shall be in accordance with the MUTCD and as specified in the Plans.

1. Overhead Permanent Signs (signs attached to sign structures which overhang travel lanes) that are not illuminated with sign lighting shall use ASTM D4956 Type XI reflective sheeting. Overhead permanent signs that are illuminated with sign lighting shall use ASTM D4956 Type IX sheeting.
2. Non-Overhead Permanent Signs (including ground-mount signs, signs attached to traffic signal supports, and signs attached to sign structures that do not overhang travel lanes) shall use ASTM D4956 reflective sheeting shown in Table VII-1A.

TABLE VII-1A
Reflective Sheeting

Background Color of Sign	Sheeting Type[1]
White	ASTM D4956 Type XI
Red	ASTM D4956 Type XI
Yellow	ASTM D4956 Type XI[2]
Fluorescent Yellow-Green	ASTM D4956 Type XI[3]
Green	ASTM D4956 Type XI
Black	ASTM D4956 Type XI
Purple	ASTM D4956 Type XI
Brown	ASTM D4956 Types IV, IX, or XI
Blue	ASTM D4956 Types IV, IX, or XI

[1] The following signs may use ASTM D4956 Types IV, IX, or XI, regardless of color: Pushbutton education signs (R10-series signs mounted adjacent to pedestrian pushbuttons), Signs erected on bikeways physically separated from adjacent roads, R7- or R8-series parking restriction signs located on non-limited-access highways, D10-series Reference Location Signs (mile markers) and Intermediate Reference Location Signs, and Post-mounted street name signs.

[2] The yellow portions of all yellow W1-series (horizontal change of alignment) signs, W10-series (railroad warning) signs, and object markers, including supplemental plaques erected beneath those signs, shall be fluorescent. All other yellow sheeting on signs may be fluorescent or non-fluorescent.

[3] All temporary and permanent warning signs related to school zones, pedestrians, or bicyclists (including associated supplemental plaques) shall use fluorescent yellow-green sheeting where required by the VA Supplement to the MUTCD unless otherwise specified on the Plans.

Agencies Not Making Regular Use of Type XI Retroreflective Sheeting

Respondents from Connecticut, Georgia, Missouri, Ohio and Tennessee DOTs reported that their agencies do not make regular use of Type XI retroreflective sheeting for white background signs.

Roadside Signs

Only Tennessee DOT has used Type XI sign sheeting for white background roadside signs, with the respondent noting, “We base our usage more off the size than the color. So [for] larger extruded panel signs, we use AASHTO M 268, Type D.”

Sign brightness and nighttime visibility were the most frequently cited reasons cited by other respondents for using something other than Type XI sign sheeting for white background roadside signs. Table 5 summarizes survey responses.

Table 5. Reasons for Not Using Type XI White Background Sheeting (Roadside Signs)

State	Sign Brightness	Glare	Nighttime Visibility (e.g., Halo Effect)	Legibility	Cost
Connecticut	X	X	X		
Georgia	X	X			
Missouri			X	X	
Ohio	X		X	X	X
Total	**3**	**2**	**3**	**2**	**1**

Respondents' current use of sign sheeting for roadside signs:

- *Connecticut.* Type IX sheeting.
- *Georgia*. Type IX for green, white and brown background signs; Type XI for yellow background signs.
- *Missouri*. Type IV for all nonfluorescent colors; Type XI for fluorescent colors.
- *Ohio*. Type IV for all but fluorescent yellow/green, which is Type XI.
- *Tennessee*. Reflective sheeting that meets the requirements of AASHTO M 268, Type D, for all permanent panel signs; AASHTO M 268, Type B, used for all other signs.

Overhead Signs

Connecticut and Tennessee DOTs use Type XI sign sheeting for at least some white background overhead signs. In Tennessee, most overhead signs conform to AASHTO M 268, Type D, which includes Type XI sheeting. Tennessee DOT made the change to Type XI a few years ago when the cost of this material more closely matched the cost of material that meets the requirements of AASHTO M 268, Type B.

Table 6 provides the remaining respondents' reasons for not using Type XI sign sheeting for white background overhead signs.

Table 6. Reasons for Not Using Type XI White Background Sheeting (Overhead Signs)

State	Sign Brightness	Glare	Nighttime Visibility (e.g., Halo Effect)	Legibility	Cost	Not Needed
Georgia	X	X		X		
Missouri		X	X			
Ohio	X		X	X	X	X
Total	**2**	**2**	**2**	**2**	**1**	**1**

Respondents' current use of sign sheeting for overhead signs:

- *Georgia*. Type IX for green, white and brown background signs; Type XI for yellow background signs.
- *Missouri*. Type IV white; Type XI fluorescent.

The Ohio DOT respondent did not describe the sheeting currently used for overhead signs.

Consultation with Experts

Outreach to representatives of the three primary manufacturers of Type XI sign sheeting sought feedback on issues associated with the use of this sheeting from a vendor's perspective. Summarized below is the feedback offered via email by representatives of the three manufacturers contacted as part of this outreach:

- 3M
- Avery Dennison Corporation
- ORAFOL Americas

3M Company

Contact: Eric Dornak, Government Transportation Safety Account Executive, Commercial Branding and Transportation Division, 702-743-0012, ejdornak@mmm.com.

Background

3M's materials are designed and tested to meet ASTM D4956, state and federal specifications. Performance of an installed sign depends on multiple factors beyond the material itself, but 3M verifies that its materials perform to these specifications.

3M products are manufactured in Texas and Alabama. Three distribution warehouses across the United States store the material. The company is unaware of any supply issues.

Safety Concerns

Dornak identified no safety concerns, commenting, "Multiple states across the United States utilize Type XI sheeting as background for regulatory signs (white)."

Trends in State Use

States continue to specify Type XI for all their signing needs. 3M's internal research indicates that more than 28 states use Type XI sign sheeting for warning and regulatory sign series, four states use a combination of Type XI and other sheeting types, and the remaining 18 states use a sheeting type other than Type XI. [**Note**: While 3M's internal research indicates that 28 states use Type XI sign sheeting, only eight states responding to the current Caltrans survey reported on the permitted use of Type XI material.]

Related Resources

Dornak provided or recommended the following publications "that support the use of Type XI reflective sheeting":

> **Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians**, L. Staplin, K. Lococo, S. Byington and D. Harkey, Federal Highway Administration, May 2001. https://www.fhwa.dot.gov/publications/research/safety/humanfac/01051/01-051.pdf
> Dornak noted that this publication identifies "what older drivers need in terms of traffic safety." *From page 19 of the report (page 25 of the PDF):*
>
> > It is recommended that the signs listed in Recommendation (4a) above be fabricated using retroreflective sheeting that provides for high retroreflectance overall, particularly at the widest

available observation angles, to provide increased sign conspicuity and legibility for older drivers.

A Market-Weighted Description of Tungsten-Halogen and LED Low-Beam Headlighting Patterns in the U.S., Michael J. Flannagan, The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety, December 2019.
https://deepblue.lib.umich.edu/bitstreams/068a346e-d17c-4709-9617-45ce7782cd1d/download
Dornak noted that this report indicates "the effects of the different headlamps and less light is being thrown at traffic signage as compared to pavement markings."

"3M Research Synopsis: In-the-Field and Modeled Luminance of Retroreflective Sign Sheetings," Faut Aktan and David M. Bruns, *Proceedings of the 87th Annual Meeting of the Transportation Research Board*, January 2008.
Provided to Caltrans separately.
The text below, including the footnote, is excerpted from the synopsis of this 2008 conference paper:

Tested Products: ASTM D4956 Retroreflective Sheeting Types* III (High Intensity Beaded), VIII, IX, X and 3M™ 4090 (Diamond Grade™ DG^3 Reflective Sheeting)

Key Findings:

1. Sign luminances were measured in typical right shoulder, overhead and left shoulder sign placements on a straight and level roadway for beaded ASTM Type III, truncated-cube microprismatic (ASTM Types VIII, IX and X), and full-cube microprismatic 3M DG^3 sheeting.
2. In general, the tested ASTM Type III beaded sheeting provided the lowest luminances in all three sign placements.
3. In general, the full-cube microprismatic sheeting (3M DG^3) provided the highest luminances for all sign placements. The only exception was for the left shoulder placement within 250 feet of the sign, where the ASTM Type IX sheeting performed similarly to DG^3 .
4. The tested truncated-cube microprismatic sheetings (ASTM Types VIII, IX and X), provided luminances in between Type III beaded and the full-cube microprismatic sheeting. The relative order of performance among truncated-cube microprismatic sheetings varied with the distance to the signs.
5. In general, the luminance of all sheetings changed substantially with sign placement: Right shoulder mounted signs had the highest luminances, followed by the left shoulder signs, and overhead signs had the lowest luminances. However, the sign placement had only minimal affect on the relative luminance ranking of tested sheeting types.

Bottom Line: The tested microprismatic retroreflective sheetings (ASTM Types VIII, IX, X and the full-cube DG^3 sheeting) generally provided much higher luminances than did the beaded high-intensity sheeting for all sign placements. Yet, within the traffic sign legibility range (within 800 feet of the signs), the full-cube microprismatic sheeting was generally the best performer among the tested sheeting samples. The relative performance amongst the truncated-cube microprismatic sheetings (ASTM Types VIII, IX and X) varied as a function of distance to the signs.

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* Only one brand of commercially available beaded sheeting of each of the ASTM D4956 Types III, VIII, IX and X was tested, and all sheeting conforming to the same ASTM D4956 type may not perform identically to the ones shown here. Further, only a single sample of each of the commercially available ASTM D4956 Types III, VIII, IX, X and 3M DG^3 were evaluated, and these samples may not necessarily be accurate representations of all samples of their respective sheeting brands and types.

Avery Dennison Corporation

Contact: Moe Madar, North America Regulatory and Market Manager, Reflective Solutions, 312-543-0907, moe.madar@averydennison.com.

Background

Madar offered a brief discussion of retroreflectance and described the three sheeting technologies:

> Fundamentally speaking, the performance of retroreflective sheeting comes down to its ability to return light as efficiently and effectively as possible. A sign's brightness is the product of the amount of light a sign receives and the sheeting's efficiency. The amount of light the sign receives depends on headlight design and location in relation to the sign.
>
> There are three sheeting technologies: glass beads, truncated prisms and full-cube prisms:
>
> - **Glass beads** (Engineering Grade sheeting (EG)) have the lowest efficiency, but have a uniform appearance and are easy to work with. That combination makes them ideal for parking or ped[estrian] signs.
> - **Truncated prisms** (high intensity prismatic (HIP) sheeting) are significantly more efficient than beaded products, able to return over 50% more light. They are recommended for most traffic applications that receive a lot of light, such as work zone devices, speed limit signs and so on.
> - **Full-cube prisms** (Avery Dennison OmniCube or 3M DG^3 for example) are most efficient, capable of returning nearly all the light they receive. They should be used for more "disadvantaged" signs that do not receive a lot of light, such as guide signs, keep right, do not enter and so on.

As Madar noted, the classification of types of retroreflective sheeting in ASTM D4956 are “a ‘catalog’ of various ways the three technologies [glass beads, truncated prisms and full-cube prisms] could be used, but don't always capture the full capability of available products.” When specifying Type XI material, Madar recommended ensuring that it is "full-cube Type XI” or “you can just use Type IV.” Avery Dennison has identified no availability issues associated with full-cube products.

Safety Concerns

When asked about potential safety concerns associated with Type XI sheeting, Madar highlighted a Texas DOT report (see **Related Resources** below for a citation):

> There are no "safety concerns" with Type XI or full-cube per se, but there is at least one paper (that I am aware of) (FHWA/TX-14/9-1001-4) concerned with the fact that objects, animals or people can be difficult to see when within 100 ft of a shoulder mounted sign on rural roads. The general recommendation is to only install signs when absolutely necessary, and to use Type IV sheeting when necessary. *Note the paper states Type III, but that has since been discontinued as well.*

Trends in State Use

Madar noted that currently, most states use Type IV and full-cube products, with some using Type IV on the background of guide signs. For Caltrans, Madar recommends Type IV sheeting for shoulder mounted signs and a full-cube product for all other applications.

Related Resources

Madar provided several publications for review, commenting that "findings can sometimes conflict with each other as the variables can get complex." Madar also noted that research in this topic area may be dated, some of the sheeting types addressed are no longer available, and issues such as sign fabrication and supply chains may not be considered.

Traffic Control Device Evaluation Program: Technical Report, Paul J. Carlson, Michael P. Pratt, Laura L. Higgins and Alicia A. Nelson, Texas Department of Transportation, January 2014.
https://static.tti.tamu.edu/tti.tamu.edu/documents/9-1001-4.pdf
See Chapter 3, Guidelines for Sign Sheeting Material for Rural Applications, which begins on page 57 of the report (page 67 of the PDF). *From the objective on page 58 of the report (page 68 of the PDF)*:

> The objective of this study is to determine if signs along rural highways can be so bright that they cause reduced legibility and glare to the point of being a safety concern. If evidence suggests that either can experienced, then recommendations for rural traffic sign retroreflectivity criteria must be developed.
>
> A key factor of this study is the thought that the brightest signs are typically white and yellow shoulder-mounted signs located on rural two-lane highways where nighttime drivers may be using their high beam headlamps. The typical background of this environment is dark with practically no visual complexity besides roadside signs.

The following excerpts from the discussion of results that begins on page 73 of the report (page 83 of the PDF) consider Type XI material:

- The average detection distance from a condition with no sign to signs made with Type III decreased about 70 ft and then decreased by almost another 50 ft with signs made with Type XI material.
- The maximum luminance of the Type III material was measured near 200 cd/m2 and over 500 cd/m2 for the Type XI material.
- The largest difference in object detection was over 100 ft. More specifically, a white sign made with Type XI sign sheeting material decreased the average object detection distance versus no sign present by over 100 ft. For a sign made with Type III sign sheeting materials, the impact was almost 70 ft. For perspective, the braking distance of a contemporary vehicle (one having antilock brakes and maintained tires) on a typical pavement going about 45 to 50 mph is 95 to 120 ft.
- The most evident finding from the object detection task is that unnecessary signs should be removed because even signs made with Type III material impact (decrease) target detection. In addition, removing unnecessary signs eliminates the objects that vehicles might hit and likewise removes the need to maintain those assets.

Benefits of Full Cube Sheeting, Avery Dennison Corporation, 2024.
https://reflectives.averydennison.com/content/dam/averydennison/reflective-responsive/documents/english/brochures/benefits-of-full-cube-sheeting.pdf
This publication highlights the benefits of full-cube prism technology as compared to the other two sheeting technologies (glass beads and truncated prisms). Included is a description of how headlights, light on a sign and a driver's location impacts the "cone of retroreflection"— described as the cone of light returned back toward a vehicle's headlights by retroreflective sheeting.

ORAFOL Americas

Contact: Chris Gaudette, Manager of Specification and Testing, 860-676-7181, chris.gaudette@orafol.com.

Background

Gaudette observed that ORAFOL's "competitors have reduced their offerings to primarily Type IV and Type XI. ORAFOL continues to currently offer Type IV, IX and XI. However, due to market direction, Type IX may be discontinued in [approximately] five years. This direction has limited user choice and minimized the ability to choose materials appropriate for an application. For work zones and Temporary Traffic Control Devices (TTC's), Type IV and Type VI are often utilized."

Safety Concerns

Noting that research in the area of safety has been limited, Gaudette recommended review of the 2014 Caltrans Preliminary Investigation, Overhead Sign Sheeting and Illumination: A Survey of State Practice and Related Research (see the citation on page 27), which highlighted the ability to eliminate lighting from overhead signs when using Type XI sheeting. Gaudette also noted that a 2015 *Transportation Research Record* journal article "concluded that the use of Type XI for some signs can be too bright" (see **Related Resource**) and offered an additional comment regarding safety and brightness:

> From an experience point of view, the use of Type XI for shoulder mount signs may be too bright. For example, on a stop sign the legend could have what is referred to as a halo effect and make it difficult to read the sign.

Trends in State Use

Gaudette noted that states typically specify the use of either ASTM D4956 or AASHTO M268 sheeting types. In many cases, more than one type is allowed. For example, a state could allow Type IV, IX and XI. To identify specific state use of sheeting material, Gaudette recommends reviewing each state's Qualified Product List or Approved Material List.

With more states using Type XI sheeting in work zones and on traffic control devices such as barrels, cones and barricades, Gaudette expressed concern that these materials "may be too bright for these applications. The sheer quantity of devices in a typical zone, the high brightness, and an ideal location for retroreflection are all reason[s] why this may not be appropriate."

Related Resource

Note: The full text of the article cited on page 27, which was accepted for publication and presentation in *Transportation Research Record,* is available at https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2015-7.pdf. Excerpted below are recommendations that appear on page 10 of this author's manuscript:

> The following recommendations have been derived for sign sheeting material to be used on low-volume rural highways (roads with an ADT [average daily traffic] of 5000 vpd [vehicles per day] or less):
>
> - Avoid installing unnecessary signs. When assessing signs in reference to the MUTCD minimum retroreflectivity levels, consider removing unnecessary signs as well. Not

only do these signs provide a potential hazard for errant vehicles, they also add to the overall maintenance responsibility, breed disrespect for traffic signs, and reduce the visibility of potentially hazardous objects along the roadside.

- Specify Type III or Type IV materials for regulatory signs and warning signs. Although warning signs were not tested in this project, object detection was diminished with Type III white regulatory signs compared to no signs at all. Therefore, this recommendation was extended in an effort to minimize the impact of potentially over-bright warning signs.
- If an agency chooses to use fluorescent signs such as fluorescent yellow and fluorescent yellow green, the only options (as of November 2014) are to use the sheeting material Types VIII, IX, or XI. While there are positive benefits to using fluorescent warning signs, agencies should use these signs sparingly to avoid the potential hazards of reducing nighttime drivers' ability to detect objects such as deer and pedestrians along the rural highway. Preferably, manufacturers will begin to produce a Type IV fluorescent sheeting material in the near future. If so, then agencies should begin to specify fluorescent Type IV materials for rural applications.

"Can Traffic Signs be Too Bright on Low-Volume Roads?" Paul J. Carlson, *Transportation Research Record 2472,* Issue 1, pages 101-108, 2015.
Citation at https://journals.sagepub.com/doi/10.3141/2472-12
From the abstract: The objective of this study was to investigate the concern that signs along rural highways can be so bright that they cause reduced legibility or glare, or both, to the point of their being a safety hazard. The researchers recruited participants and conducted visibility studies on a closed-course facility to assess how various levels of brightness of speed limit signs can affect nighttime participants' ability to read the signs and detect various types of potentially hazardous objects along the edge of the traveled way. From the findings, considerations are provided for low-volume rural highways with average daily traffic of 5,000 vehicles per day or less. To avoid glare and reduced object detection distances, ASTM Type III or IV materials should be specified for regulatory and nonfluorescent warning signs on these low-volume roads. Also, because of reduced object detection distances, recommendations are made to avoid the installation of unnecessary signs. Not only do unnecessary signs provide a potential hazard for errant vehicles, but they also add to the overall maintenance responsibility, breed disrespect for traffic signs and reduce the visibility of potentially hazardous objects along the roadside.

Related Research and Resources

A review of domestic published and in-progress research and related resources sought information about the use of Type XI retroreflective sheeting for white background signs. Findings are presented in four topic areas:

- Previous Caltrans Preliminary Investigations.
- National research.
- State specifications.
- State research and practices.
- Related resources.

Previous Caltrans Preliminary Investigations

Overhead Sign Sheeting and Illumination: A Survey of State Practice and Related Research, Preliminary Investigation, California Department of Transportation, October 2014.
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/type-xi-sign-sheeting-pi-a11y.pdf

Note: This investigation did not specifically address the use of white background signs.

From the background: Since the December 1999 adoption of a program directive to use retroreflective sign sheeting for new overhead signs, Caltrans has been turning off sign illumination for some overhead signs as signs are upgraded with retroreflective sheeting. Caltrans is investigating the impact of possible statewide implementation of high-intensity Type XI reflective sign sheeting and wants to better understand the state of the practice for using some form of reflective sheeting among state departments of transportation (DOTs). In support of Caltrans' inquiry, this Preliminary Investigation aims to assess the current state of the practice with regard to use of retroreflective sign sheeting and illumination on overhead signs through an examination of recent Caltrans survey results and a new survey effort directed to state DOT respondents. Supplementing the state-of-the-practice review is an investigation of related research.

National Research

Nighttime Visibility Sign Retroreflectivity: Frequently Asked Questions, Federal Highway Administration, last updated February 2024.
https://highways.dot.gov/safety/other/visibility/nighttime-visibility-sign-retroreflectivity-frequently-asked-questions
This web page includes the most frequently asked questions about maintaining minimum sign retroreflectivity.

Guidelines for Selecting Sign Sheeting Materials for AASHTO M268, NCHRP Project 20-07, Task 374, H. Gene Hawkins, Jr., May 2022.
https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07-374FinalResearchReport.pdf
From the introduction:

> The objective of this project is to provide agencies with guidance for selecting sign sheeting materials using AASHTO M268 using a simplified approach based on a limited number of roadway scenarios and other input data. The objective is only partially realized due to resource limitations that impacted the creating of retroreflectivity data representing a broad spectrum of sign sheeting products. The limitations included the number of retroreflectivity measurements of each product and the number of products measured. The limitations on the scenarios and input data were

necessary due to the limited resources and budget associated with this project. The limitations of the project are addressed in more detail in the Limitations section near the end of the report.

Appendix E provides guidelines for sheeting types A, B, C and D, as defined and classified in AASHTO M268, *Standard Specification for Retroreflective Sheeting for Flat and Vertical Traffic Control Applications*. Page 102 of the report (page 111 of the PDF) provides guidelines for the use of Type D sheeting, which includes Type XI, as defined and classified in ASTM D4956, *Standard Specification for Retroreflective Sheeting for Traffic Control*.

Recommendations that begin on page 21 of the report (page 30 of the PDF) address the need for additional research on a variety of issues related to luminance:

- There is a need for a luminance calculation tool that can be used by agencies and practitioners to analyze the supply luminance produced by specific sheeting products in specific roadway scenarios for a range of vehicle types. It is recommended that an agency, or group of agencies (as in a pooled-fund study), sponsor research to create such a tool and place it in the public domain for agencies, practitioners and researchers to use.
- In order to calculate supply luminance, agencies need a retroreflectivity array for each product and color of sheeting to be evaluated. It is recommended that agencies that purchase large quantities of retroreflective sheeting work with the manufacturer to develop a fully characterized retroreflectivity array for each product the agency purchases, including colored sheeting. Such arrays should be updated on an annual or biannual basis.
- There is a need for better guidance on the demand luminance that is appropriate for various roadway scenarios. Many older drivers (upon which the demand luminance for this project is based) restrict their nighttime driving activities in some situations. As such, basing sheeting selection on drivers that may not be present could be circumspect.
- Additional research is recommended to evaluate luminance needs for a wider variety of signs and drivers so that better demand luminance values can be established. In particular, demand luminance needs for symbols signs should be included in future research evaluations.
- Research should be performed to measure the retroreflectivity performance of sign sheeting products after extended exposure. No research in the public domain has been performed where weathered sheeting is fully characterized (a retroreflectivity array) in a manner that allows for the calculation of sign luminance across a range of conditions.
- Future evaluations of sign supply luminance should consider a wider variety of input variables, especially the impact of vehicle type, heavy vehicles and headlamps on the luminance produced in specific situations.

State Specifications

Note: Supplementing the specifications below are specifications provided by five states responding to the survey — Arizona, Oregon, Pennsylvania, Utah and Virginia; see **Relevant Specifications** on page 14.

Alabama

Section 710, Roadway Signs, Special Provision No. 18-0222(2), Alabama Department of Transportation, September 2021.
https://www.dot.state.al.us/publications/Construction/pdf/Specifications/2018/GASPSummary/18-0222(2).pdf

This special provision replaces sections 710 and 880 appearing in the 2018 edition of Alabama Standard Specifications. A table on page 10 of the special provision provides types and descriptions of sign sheeting, including the following entry:

Type XI	A super-high-intensity unmetalized cube corner microprismatic sheeting (ASTM D 4956, Table 10). Typical applications are temporary traffic control devices, delineators and permanent highway signing.

Iowa

Section 4186, Signing Materials, Standard Specifications for Highway and Bridge Construction, Iowa Department of Transportation, undated.
https://ia.iowadot.gov/erl/current/GS/content/4186.htm
Section 4186.03, Retro Reflective Sheeting, includes the following applications of Type XI sheeting for "permanent signs and devices":

a. Meet the following requirements:
    1) Type XI sheeting is used for all signs with white, green, red, blue or brown background, unless otherwise specified.
    2) Type XI yellow sheeting is used for portions of a green sign requiring yellow sheeting.
    3) Type XI Fluorescent sheeting is used for signs with yellow or yellow-green background.
    4) The legend on white, yellow and yellow-green signs is fabricated using black nonreflective sheeting that is applied directly, or by silk screening with black opaque ink.
    5) The legend on green signs is fabricated using white Type XI sheeting that is applied directly.
    6) The legend on red signs is fabricated using transparent red ink that is reverse silk screened on white Type XI sheeting, or fabricated using white Type XI sheeting that is applied directly on a red Type XI sheeting background, or transparent film, as approved by the retro reflective sheeting manufacturer.
    7) The legend on blue and brown signs is fabricated using transparent ink that is reverse silk screened on white Type XI sheeting, or white Type XI sheeting that is applied directly, or transparent film, as approved by the retro reflective sheeting manufacturer.
b. Use Type XI sheeting for permanent road closure barricades.

State Research and Practices

Kansas

Overhead Guide Sign Retroreflectivity and Illumination, Mohammed Obeidat, Malgorzata Rys and Eugene R. Russell, Sr., Kansas Department of Transportation, January 2015.
https://rosap.ntl.bts.gov/view/dot/28555/dot_28555_DS1.pdf
From the abstract:

> This report presents results of a survey related to overhead sign lighting usability by states, a laboratory experiment to compare the light distribution of five light sources used to illuminate overhead guide sign by several states, a cost analysis for the tested light sources, a field experiment to compare the visibility of three retroreflective sheeting used by states, a cost analysis for the tested retroreflective guide signs, and an analysis by determining the most cost-effective method of increasing overhead guide sign visibility to drivers during nighttime.

A laboratory experiment was conducted to compare the light distribution of three conventional light sources: Metal Halide, Mercury Vapor and High Pressure Sodium, and two new generation light sources: Induction lighting and Light Emitting Diode. Combining two decision criteria, the light distribution and the cost, resulted in finding the Induction lighting to be the recommended light source for those states that want to continue illuminating their overhead guide signs. A field experiment was conducted to compare three types of sign sheeting, Engineering Grade (type I), Diamond Grade (type XI) and High Intensity (type IV), in order to determine the sign sheeting material that best improves sign visibility. Combining the decision criteria to compare these three retroreflective sheeting, the visibility and the cost, High Intensity (type IV) is the recommended sign to be used by DOTs, followed by Diamond Grade (type XI).

From the conclusions on page 97 of the report (page 112 of the PDF):

According to statistical analysis of the field experiment, distance, sign retroreflective sheeting type and sign-distance interaction are the resulting significant variables. Consequently, in order to improve driver safety on highways, careful consideration should be given to these important variables. Based on statistical analysis, the Diamond Grade (Type XI) sign sheeting enables drivers to read a sign's legend from a longer distance, followed by the High Intensity (Type IV). Engineering Grade (Type I) was the worst performing sign sheeting. The conclusion is made that when sign retroreflectivity values for legend and background are high, the sign's 97 visibility will increase, and this leads to recommending Diamond Grade (Type XI) sign sheeting which has the highest retroreflectivity values for legend and background.

In addition, based on the frequency of human subjects at each headlight brightness level in the field experiment, the Diamond Grade (Type XI) sign was read by a majority of subjects at lower illuminance averages: 0.035 lux and 0.037 lux at 180 ft and 240 ft, respectively. In addition, all participating subjects were able to read the legend on the Diamond Grade (Type XI) sign, but not the High Intensity (Type IV) and Engineering Grade (Type I) sheeting. Therefore, it is concluded that the Diamond Grade sign has the best visibility compared to High Intensity (Type IV) and Engineering Grade (Type I) signs.

The cost analysis of the retroreflective sheeting showed that the most cost-effective retroreflective sheeting is the High Intensity (Type IV). In conclusion, combining the different decision criteria used for evaluating retroreflective sign sheeting: statistical analysis, minimum illuminance values based on frequency of human subjects at the different brightness levels, legend and background retroreflectivity values, and the cost analysis, the recommended retroreflective sheeting to be used by DOTs for guide signs is the High Intensity (Type IV), followed by the Diamond Grade (Type XI).

Minnesota

Research on Traffic Sign Retroreflective Sheeting Performance: A Synthesis of Practice, H. Gene Hawkins Jr., Transportation Research Synthesis, Minnesota Department of Transportation, April 2021.
https://mdl.mndot.gov/items/TRS2101
From the abstract:

Sign retroreflectivity is an important characteristic of traffic signs, and it is a critical factor in defining the effectiveness of signs in a nighttime environment. This synthesis summarizes previous research on various aspects of sign sheeting retroreflectivity in nine areas: basic retroreflectivity science; retroreflectivity materials, specifications and measurement; sign performance; sign degradation, minimum retroreflectivity; field measurement of sign retroreflectivity; economic benefits;

fluorescent materials; and safety. The synthesis of previous research serves as the basis for recommendations for selecting sign sheeting based on sheeting grade and roadway environment.

A discussion of sign performance addresses Type XI sheeting. *From page 11 of the report:*

> For sheeting material selection, a study by Zwahlen et al. (6) indicated that drivers typically preferred Type VII or Type XI legends on Type III backgrounds for legibility, readability, conspicuity and appearance. Type XI legend showed preference however due to the minimal glare it produced in unlighted conditions as compared to Type VII. This information is useful for DOT's when determining the proper sign sheeting materials to use for street signs as well as overhead guide signs as legibility needs are to be considered for all users on the roads in order to promote safety and provide driver with the information to make decisions. However, in a study by Carlson (7) in determining if traffic signs could be too bright for low volume roads, it was indicated that the use of high-beams on signs utilizing Type XI legends showed a smaller legibility distance as compared to Type III, indicating that in remote areas, the use of high intensity sheeting may be inappropriate.

The author provides recommendations for sign sheeting practices, excerpted in part below, preceding the recommendations with this context:

> The findings from previous research efforts provide some insight into the complexities of selecting retroreflectivity sign sheeting. While there are no definitive rules for selecting sign sheeting, the following guidelines appear reasonable based on prior research and expert opinion.

Excerpted from recommendations that appear on page 17 of the report:

- Fluorescent materials are available only in microprismatic materials.
- The expected life of a microprismatic sign can generally be assumed to be 15 years or more based on retroreflectivity performance. In some locations, there is the potential for shorter life due to environmental conditions.
- There are no end-of-life criteria for the color of traffic signs. Limited research has shown that color may have more impact than retroreflectivity on end-of-service life. For white, yellow and green microprismatic signs, the life of the color can generally be assumed to be 15 years or more if the color is a manufactured color (i.e., not screened).
- In temporary traffic control applications (TTC), fluorescent orange signs should be used due to the fact that the life of TTC signs is relatively short.
- In urban areas where there is significant need for drivers' attention and competing light sources at night, an agency should strive to use the highest grade of sheeting it can provide.
- In suburban areas where there may be isolated locations with significant visual complexities, an agency should strive to use the highest grade of sheeting it can provide at locations with high driver demand, such as intersections, interchanges, approaches thereto and alignment changes requiring significant speed reductions.
- In low-volume rural areas (ADT of 5,000 vehicles per day or less), Type IV signs should be used for white signs and nonfluorescent yellow signs.
- In rural areas, the use of fluorescent signs should be limited to locations where additional emphasis is desirable, such as alignment changes with significant speed reductions.

New York

High Visibility Reflective Sign Sheeting Evaluation, John D. Bullough, Nicholas P. Skinner and Ute C. Besenecker, New York State Department of Transportation, December 2014.
https://utrc2.org/sites/default/files/pubs/Final-High-Visibility-Signs.pdf
From the abstract: Highway signs are a critical part of the roadway infrastructure, providing important information to drivers to assist in navigation, identify potentially hazardous roadway locations, and to remind drivers of safe operating practices. Ensuring that signs have sufficient visibility to the driving public is a key undertaking by transportation agencies such as NYSDOT [New York State DOT]. In order to assist NYSDOT in evaluating and comparing different materials for photometric and visual performance, the present project was conducted to select and validate a visibility model for use as a basis for performance specifications, to develop a practical methodology for conducting field measurements of sign performance along roadways, and to develop practical tools to assist highway engineers in making informed quantitative decisions about the levels of performance provided by different materials. In addition to describing the methods for an approach to visual performance based specifications, a spreadsheet tool for calculating sign luminance and visibility was also developed.

Related Resources:

"High Visibility Reflective Sign Sheeting Materials: Field and Computational Evaluations of Visual Performance," John D. Bullough and Nicholas Skinner, *Transport*, Vol. 33, Issue 2, pages 1-9, October 2016.
https://www.researchgate.net/publication/309325303_High_visibility_reflective_sign_sheeting_materials_field_and_computational_evaluations_of_visual_performance
From the abstract: Highway signs provide important information to drivers to assist in navigation, to identify potentially hazardous roadway locations, and to remind drivers of safe operating practices. Ensuring that signs have sufficient visibility to the driving public is a key undertaking by transportation agencies. In order to assist in evaluating and comparing different materials for photometric and visual performance, the present study was undertaken to assess the utility of specifying sign sheeting performance in terms of visual performance. As part of this effort, a practical methodology for conducting field measurements of sign luminance along roadways was developed. In addition to describing the methods for an approach to visual performance based specifications, a spreadsheet tool for calculating minimum sign luminance and visibility from different sign sheeting materials was also developed.

Highway Sign Photometric Calculation Spreadsheet, Lighting Research Center, Rensselaer Polytechnic Institute, NYSDOT SPR Project C-07-03, New York State Department of Transportation, undated.
https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/NYSDOT-C-07-03-SignCalculator.xls
This Excel workbook allows the user to enter values (see the excerpt from the Main Sheet below) to generate results on three spreadsheets:

- Headlamp intensity
- Retroreflection coefficient
- Visual performance

From the Main Sheet:

	Enter values:		
Headlamp height	3.58	ft	*(2.13 passenger car, 2.79 SUV, 3.58 truck)*
Eye height	7.67	ft	*(3.77 passenger car, 4.83 SUV, 7.67 truck)*
Sign height	8.5	ft	*(21.5 overhead, 8.5 right side)*
Lateral offset	16	ft	*(0 overhead, 16 right side)*
Sign tilt	0	deg	
Background color	1		*(1=white, 2=yellow, 3=orange, 4=red, 5=green, 6=blue, 7=brown)*
Sheeting type	B		*(A, B, C, D, I, II, III, IV, V, VI, VIII, IX, XI)*
Letter height	12	in	
Windshield transmittance	0.8		*(Default 0.8)*
Driver age	60	yr	*(Default 60)*

Related Resources

"Factors Affecting Sign Visibility, Conspicuity and Legibility: Review and Annotated Bibliography," John D. Bullough, *Interdisciplinary Journal of Signage and Wayfinding*, Vol. 1, Issue 2, June 2017. Publication available at https://www.researchgate.net/publication/320604763_Factors_Affecting_Sign_Visibility_Conspicuity_and_Legibility_Review_and_Annotated_Bibliography

From the abstract: This paper summarizes published research studies, technical reports, and codes and standards related to the visibility (i.e., conspicuity and legibility) of signage. In the summary that follows, publications are grouped and discussed according to several different topics. First, the typographic and symbolic characteristics of signs and the information they carry are described (e.g., letter size, font selection, etc.); second, photometric, colorimetric and temporal properties of signs as they affect visibility; finally, environmental considerations (e.g., daytime versus nighttime viewing, whether a sign is located in a rural or urban area, etc.) as they influence sign design are reviewed. Annotated summaries of each publication in the literature review are included at the end of this paper.

"Use of High Intensity Reflective Sheeting In Lieu of External Lighting of Overhead Roadway Signs," Fan Ye, Paul Carlson and Mike N. Jackson, *Transport*, Vol. 33, Issue 2, pages 1-9, January 2017. Publication available at https://www.researchgate.net/publication/312476301_Use_of_high_intensity_reflective_sheeting_in_lieu_of_external_lighting_of_overhead_roadway_signs

From the abstract: Overhead guide sign lighting has been used by many agencies to improve visibility. However, the availability of newer and more efficient retroreflective materials has created a new challenge for state transportation agencies going through sign sheeting upgrade programs and considering the need for using sign lighting, as there is no existing answer regarding whether upgraded sign sheeting itself can meet drivers' nighttime visibility demands without external sign lighting. The purpose of the paper is to investigate whether high intensity reflective sheeting can be used to replace overhead guide sign lighting. The conclusion of the study provided a guidance for agencies to adopt their current sign lighting policy. A luminance computation model is used in the paper to calculate overhead guide sign legend luminance under various situations, including different sign lighting technologies, different geometrics and overhead guide sign locations, and different amounts of sign dirt and sign aging. By comparing the calculated luminance of a specific overhead guide sign at a specific situation

with the legibility luminance levels required by older drivers, sign lighting needs are assessed. In addition, a life-cycle cost spreadsheet is developed and used to calculate the cost of replacing the current sign sheeting with high reflective sheeting and the cost of installing/upgrading sign lighting. Eventually, the most cost effective approach to maintain overhead guide luminance is discussed.

"Performance Evaluation of Retroreflective Traffic Signs," Paul J. Carlson, *TRB 94th Annual Meeting Compendium of Papers*, Paper #15-2963, 2015.
Citation at https://trid.trb.org/view/1337851
From the abstract: Today, retroreflective sign sheeting is mostly cataloged using ASTM D4956. A new specification by AASHTO (M268) is also being used in some state departments of transportation (DOTs). Both of these specifications catalog products using the coefficient of retroreflection (also known as retroreflectivity) as the key performance indicator. While retroreflectivity is a metric that can be easily measured, at the current specification geometries, the retroreflectivity by itself is not always a good indicator of the performance of the material as seen at night from the perspective of a driver. Over the past few years, there have been various attempts to develop other criteria to catalog sign sheeting materials. This paper summarizes the latest methodology for evaluation of sign sheeting materials. The methodology was developed within the scope of the Commission Internationale de l'Eclairage (CIE) Technical Committee 4-40. The TC4-40 report is currently being balloted by member countries. The method described provides a way to evaluate the nighttime performance of traffic signs as they are used and with a metric of luminance rather than the coefficient of retroreflection. The report is supplemented with a computation tool (small computer program) that can be used to quickly assess sign sheeting performance using the methodology described.

Contacts

CTC engaged with the individuals below to gather information for this investigation.

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Appendix A: Survey Questions

The online survey represented below was distributed via email to the member list of AASHTO Committee on Traffic Engineering.

Caltrans Survey on Type XI Retroreflective Sheeting for White Background Signs
Industry trends are indicating a shift away from certain retroreflective sheeting materials specified in the California Department of Transportation (Caltrans) standards for white background signs. This industry transition has raised concerns about the long-term availability of sheeting materials and the feasibility of manufacturing signage that complies with Caltrans' requirements. While Type XI could serve as an alternative sheeting material, Caltrans is aware of reports suggesting that the high brightness level of Type XI retroreflective sheeting when used as a white background may cause a halo effect around the legend of the roadside or overhead sign, potentially compromising visibility and legibility and posing a safety hazard at night.

The survey below is seeking information about your agency's experience with using Type XI retroreflective sheeting for the white background of regulatory and roadway guide signs. The survey inquires about your agency's experience with this material on both roadside signs and overhead signs. We estimate the survey will take approximately 20 minutes to complete. We would appreciate receiving your responses by **Friday, November 7**.

If someone else in your agency would be more appropriate to address questions related to this issue, please forward this survey to that person.

The final report for this project, which will include a summary of the responses received from all survey participants, will be available on the Caltrans website.

If you have questions about completing the survey, please contact Chris Kline at chris.kline@ctcandassociates.com. If you have questions about Caltrans' interest in this issue, please contact Tori Kanzler at tori.kanzler@dot.ca.gov.

Thanks very much for your participation.

(Required) Please provide your contact information.

Name:
Title/Division:
Agency:
Email Address:
Phone Number:

Note: Responses to the question below determined how respondents are directed through the survey.

(Required) Does your agency allow Type XI retroreflective sheeting for white background signs?

- Yes. (Directed the respondent to **Use of Type XI Retroreflective Sheeting**, **Assessment** and the **Wrap-Up** sections of the survey).
- No. (Directed the respondent to **Reasons for Not Using Type XI Retroreflective Sheeting** and the **Wrap-Up** sections of the survey).

- No, but we are considering the use of this material. (Directed the respondent to **Considering the Use of Type XI Retroreflective Sheeting** and **Wrap-Up**.)

Use of Type XI Retroreflective Sheeting

Roadside Signs

The survey questions below ask about your agency's experience using Type XI sign sheeting for white background **roadside signs.**

1. Please indicate approximately what year your agency began using Type XI retroreflective sheeting for white background roadside signs.
2. Why did your agency begin using Type XI sign sheeting for white background roadside signs? Select all that apply.
    - Other sheeting discontinued
    - Longer service life
    - Cost benefits
    - Reduced maintenance
    - Increased long-distance legibility
    - Other (Please describe.)
3. Please briefly describe your agency's experience with the following factors related to the use of Type XI sheeting for white background roadside signs:
    - Sign brightness
    - Glare
    - Nighttime visibility (e.g., halo effect)
    - Legibility
    - Other (Please describe.)
4. Has your agency experienced any issues with **safety**?
    - No
    - Yes (Please describe.)
5. Has your agency experienced any **economic benefits**?
    - No
    - Yes (Please describe.)
6. Has your agency experienced any issues with **durability**?
    - No
    - Yes (Please describe.)
7. Please indicate which manufacturer(s) of Type XI retroreflective sign sheeting your agency allows to be used along your state roadways. Select all that apply.
    - 3M
    - Avery Dennison
    - ORAFOL
    - Other (Please describe.)

Overhead Signs

The survey questions below ask about your agency's experience using Type XI sign sheeting for white background **overhead signs**.

1. Please indicate approximately what year your agency began using Type XI retroreflective sheeting for white background overhead signs.
2. Why did your agency begin using Type XI sign sheeting for white background overhead signs? Select all that apply.
    - Other sheeting discontinued
    - Longer service life
    - Cost benefits
    - Reduced maintenance
    - Increased long-distance legibility
    - Eliminated need for sign lighting
    - Other (Please describe.)
3. Please briefly describe your agency's experience with the following factors related to the use of Type XI sheeting for white background overhead signs:
    - Sign brightness
    - Glare
    - Nighttime visibility (e.g., halo effect)
    - Legibility
    - Other (Please describe.)
4. Has your agency experienced any issues with **safety**?
    - No
    - Yes (Please describe.)
5. Has your agency experienced any **economic benefits**?
    - No
    - Yes (Please describe.)
6. Has your agency experienced any issues with **durability**?
    - No
    - Yes (Please describe.)
7. Please indicate which manufacturer(s) of Type XI retroreflective sign sheeting your agency allows to be used along your state roadways. Select all that apply.
    - 3M
    - Avery Dennison
    - ORAFOL
    - Other (Please describe.)

Assessment

1. What **successes** has your agency observed in using Type XI retroreflective sheeting for white background signs?
2. What **challenges** has your agency experienced with using Type XI retroreflective sheeting for white background signs?
3. Please share any **best practices** for using Type XI retroreflective sheeting for white background signs.
4. Please describe any **lessons learned** from using Type XI retroreflective sheeting for white background signs.

5. Please provide links to documents associated with your agency's specifications, policies or guidance for using Type XI retroreflective materials. Send any files not available online to chris.kline@ctcandassociates.com.

Considering the Use of Type XI Retroreflective Sheeting for White Background Signs

1. Please briefly describe the factors your agency is considering related to using Type XI retroreflective sheeting for white background signs.
2. What is needed for your agency to begin implementing this material?
3. When do you anticipate your agency will adopt Type XI retroreflective sheeting?

Reasons for Not Using Type XI Retroreflective Sheeting

1. Please indicate why your agency does not use Type XI sign sheeting for white background **roadside signs**. Select all that apply.
    - Sign brightness
    - Glare
    - Nighttime visibility (e.g., halo effect)
    - Legibility
    - Cost
    - Other (Please describe.)
2. Has your agency ever used Type XI retroreflective sheeting for white background **roadside signs**?
    - No
    - Yes (Please respond to Question 2A below.)

2A. Please briefly describe why your agency discontinued the use of this material.

3. What type of sign sheeting does your agency use for **roadside signs**?
4. Please indicate why your agency does not use Type XI sign sheeting for white background **overhead signs**. Select all that apply.
    - Sign brightness
    - Glare
    - Nighttime visibility (e.g., halo effect)
    - Legibility
    - Cost
    - Other (Please describe.)
5. Has your agency ever used Type XI retroreflective sheeting for white background **overhead signs**?
    - No
    - Yes (Please respond to Question 5A below.)

5A. Please briefly describe why your agency discontinued the use of this material.

6. What type of sign sheeting does your agency use for **overhead signs**?

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.