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Glare Screen Use in Road Design: A Synthesis of the Practice

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Abstract

In 2011, TRB Geometric Design Committee (AFB10) drafted a research needs statement to complete an updated synthesis of the practice to the 1979 *Glare Screen Guidelines*, Synthesis of Highway Practice. This study completes the efforts of the 2011 research needs statement on glare screens and their use in road design. The research identifies the uses and types of glare screen in road design, examines national-level glare screen guidance, and provides a summary of the findings from 30 transportation agencies in the United States.

Headlight glare can cause disruption to vision, debilitating a driver and making the driving task less safe, potentially leading to crashes. In 1979, TRB published *Glare Screen Guidelines*, Synthesis of Highway Practice (*1*). In 2011, TRB's Geometric Design Committee (AFB10) developed a research needs statement (*2*) seeking a synthesis to update the 1979 findings. The 2011 research needs statement and synthesis were not funded. In 2016 and 2017, this need was addressed as part of a student's graduate work (*3*).

Across the United States, glare screens are used by transportation agencies to reduce glare caused by the headlights of traffic in opposing lanes. This synthesis identified that design requirements and guidance are not consistent from state to state and, although there has been some national-level guidance on use of glare screens, there are currently no consistent warrants for their use. This paper examines the use of glare screens by 30 state transportation agencies in the United States to determine the current warranting, design guidance, and practice regarding the use of glare screens.

Background on Glare

A driver may encounter many sources of glare in the driving environment, such as sunlight or its reflection during the day, roadway lighting systems at night, roadside billboards using light-emitting diode technology, headlight glare, night construction lighting, and other nearby sources such as field lights in recreation facilities, area lights in manufacturing facilities, or lighting in parking facilities. The focus of this research relates specifically to headlight glare as encountered when vehicles in opposing lanes of traffic approach each other. There are two main types of glare.

Discomfort Glare

Discomfort glare produces an uncomfortable feeling in the eyes and distracts from the visual task of driving, but does not reduce the ability to perform that task, other than it can cause fatigue if endured over long periods of time. Discomfort glare is a result of excessively bright light sources in the driver's field of view, such as from approaching headlights, and can cause responses ranging from increased blink rates to tears or pain in the eyes, but does not actually reduce visibility (*4*).

Disability Glare

Disability glare reduces visibility. When light from a high-intensity source passes through the eye, a haze is superimposed upon the retina, causing reduced contrast between the focus of the driving task and the background luminance, thereby reducing visibility. This haze, or veiling effect, is called veiling luminance, or disability glare (*4*). When driving at night and presented with the headlights of oncoming vehicles, it is hard to see past the headlight as it is much brighter than the background.

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Because disability glare reduces the contrast of the visual field, increasing the ambient light with stationary roadway lighting systems is a method to reduce the impact of headlight glare (*4*). As determined by prior research, larger exposure to glare increases the vision recovery time (*5*). Limiting exposure time is important for reducing the impact of headlight glare.

Controlling Glare

There are roadway elements that can be used to help reduce glare and mitigate the need to install glare screens including adjusting the geometrics, adding lighting, adding vegetation, and adding a berm.

Geometrics

The visual area between tangent and 20 degrees, measured from the driver's forward line of sight and swinging left to the opposing vehicle's headlights, is generally accepted as the critical area within which to mitigate headlight glare, based on testing and practical experience (*2*). Two main geometric features of a roadway design can have a large impact on reducing glare incident on the driver's eyes within that 20 degree angle: degree of curvature (or radius size) of horizontal curves and the width of the median.

Horizontal Curve Radius. A left-hand curve is the most common roadway feature in which drivers experience glare from the headlights of opposing traffic. Whereas vehicles are parallel to each other in tangent roadway sections, in a curved segment the angle between vehicles increases. Light from headlights becomes more direct toward the driver's eye as the severity of the roadway curvature increases.

Decreasing the degree of curvature in design can aid in reducing the headlight glare experienced by drivers. Increasing the separation between opposing roadways in areas where the roadway alignments are close is an alternative when factors do not allow reducing degree of curvature. For example, the Minnesota DOT (MnDOT) states that if the use of glare screens would affect the stopping sight distance (SSD), the degree of curvature should be flattened and the barriers be moved further away from the edge of the travel way, if the median has sufficient width to accommodate adjusting the barrier location (*6*).

Median Width. As the width of the median increases, the need to control glare is decreased. In rural areas in which median widths for multilane, separated highways can reach hundreds of feet, the impact of headlight glare is insignificant and generally does not affect the driver. In urban settings where multilane highways have narrow medians measuring less than 20 feet, the need for mitigating the impacts of headlight glare is substantial. In between those two extremes, there are varying levels of need, dependent on many other factors.

Lighting

The glare associated with headlights is generally caused by a high contrast in light levels experienced by the driver's eye. The presence of roadway lighting to increase the overall light levels can help reduce the impact of headlight glare by decreasing the contrast between high-intensity headlights and the surrounding area (*7*).

As an example of a state that accounts for ambient lighting in determining warrants for glare screens, Wisconsin (*8*) states that if there is ambient lighting present, either from linear roadway lighting systems or high-mast lighting systems, glare screens are not allowed. Similarly, the Arizona (AZDOT) *Roadway Design Guide* stipulates that glare screens should not be used when overhead lighting is present (*9*).

Vegetation

Plants, trees, or shrubs are another roadway design element often used to mitigate headlight glare. The use of a planted median to control glare is suitable on curves and in wide medians as part of a general landscaping effort. The designer must consider if the vegetation would be outside the clear zone, if it would present a hazard to a wayward vehicle, or if it would affect driver sightlines. In a cold environment, the vegetation may need to be resistant to de-icing materials.

Berms

In locations where median width allows, glare can be controlled by placing mounds of earth, or berms, between the opposing travel lanes, at heights sufficient to block headlight glare.

Glare Screen Uses and Types

The 1979 Synthesis identified the main three types of glare screens (*2*). These have remained the same and may be used for permanent or temporary traffic conditions. Type I are continuous solid screens that block light from all angles. This type includes concrete barriers with extended height. Type II are continuous and appear opaque to light in which the angles are between 0 and 20 degrees from the driver's eye and then appear increasingly transparent for angles beyond 20 degrees. Expanded metal mesh screens, chain link fences with small wire spacing, and fabric screens are examples (*10*). North Carolina DOT (NCDOT) allows the use of ½"

mesh chain link fence with an optional vinyl coating (*11*). Type III glare screens are made by arranging individual elements so that they block light coming from angles of 0 to 20 degrees while providing clear visibility between the elements beyond 20 degrees. Placing individually supported paddles at intervals so that they will block light from opposing headlights is the most common kind of Type III glare screen.

National-Level Guidance

A Policy on Geometric Design of Highways and Streets ("Green Book")

Chapter 4 Section 11 – Medians addresses the issue of headlight glare from opposing traffic across medians or outer separations and borders, especially at sharp curves in the road, or where the opposing alignments are uneven. It is suggested that "antiglare treatment should be considered as part of the median barrier installation, provided it does not act as a snow fence and does not create drifting problems" (*12*). Section 13 – Outer Separations notes that separations "should be sufficiently wide to minimize the effects of the approaching traffic, particularly the potentially confusing and distracting nuisance of headlight glare at night" (*12*). Chapter 8 – Freeways recommends a glare screen be used in the outer separation between the highway and frontage roads, particularly when no roadway lighting is provided (*12*). Chapter 9 Section 6.3 – Islands says that curbed islands can be hard to see at night because of headlight glare and other adjacent light sources. Therefore, it recommends that fixed-source lighting should be used at intersections with curbed islands, or delineations such as curb-top reflectors should be installed (*12*).

Roadside Design Guide

The AASHTO *Roadside Design Guide* does not address permanent installations of glare screen devices, but focuses on glare screen use in work zones. The guide states that the intended purpose of the glare screens is two-fold: reduce glare from oncoming traffic and reduce distractions by blocking the view of the work area from the driver (*13*). While not extensive, Chapter 9, Section 9.5.1 "Glare Screens" lays out several considerations and design parameters. Suggested locations for glare screens include horizontal curves, crossovers, and lanes adjacent to construction that are in a taper zone in which lanes are converging or being diverted from their normal lane configuration.

Manual on Uniform Traffic Control Devices

The *Manual on Uniform Traffic Control Devices* (MUTCD) addresses the use of glare screens in "Section 6F-8 Other Devices," primarily as a temporary traffic control device to improve safety through work zones by shielding drivers from oncoming headlight glare and to reduce distractions to drivers caused by work activities in a work zone. The design guidance offered by the MUTCD on placement of glare screens has two parts: (1) to ensure the screens will not infringe on drivers' ability to safely operate their vehicles; and (2) to ensure the screens will not adversely constrict sight distance (*14*). The MUTCD suggests that the glare screens may be mounted on temporary traffic barriers.

ITE Traffic Engineering Handbook

The handbook (*15*) discusses several issues related to glare and vision. It states how glare reduces the distance a driver can see a low-reflectance object by up to 50% when compared with when no glare conditions exist. It also states that the closer the source of glare is to the driver's line of sight, the more impact it has on a driver, with the peak level of impact occurring when the distance between approaching vehicles in opposing lanes are 130 feet apart (*15*). In discussing transportation operations strategies for work zones, the handbook notes that the temporary traffic barriers with glare screens mounted on top can be placed between opposing lanes of traffic or between traffic lanes and the physical work space in work zones and will reduce headlight glare and incidences of gawking. The reduction in gawking may also improve traffic flow through the work zone (*15*).

FHWA Handbook for Designing Roads for the Aging Population

On projects with crossovers or alternate travel paths, the handbook states glare screens should be mounted on temporary traffic barriers when used to separate opposing lanes of traffic, particularly in areas of transitions. It suggests the spacing of the screens should be no more than 24" apart (*16*).

Transportation Agency Use of Glare Screens

Thirty of the 50 United States, the District of Columbia, and Puerto Rico's transportation agency resources were reviewed. Of the 30 transportation agencies reviewed, 10 of the agencies did not have information pertaining to glare screens readily available. These 10 agencies included: Alaska, Arkansas, Hawaii, Iowa, Kansas, Maryland, Montana, Nebraska, North Dakota, and Wyoming. The 20 transportation agencies that had resources related to glare screens are as follows.

Alabama

The Alabama Department of Transportation (ALDOT) allows for the use of glare screens. No warrants were apparent in the document searches. Guidance provided indicates headlight glare screens may be mounted on guardrails or concrete median barriers, but consideration should be given to locations where small offsets are provided and truck overhangs may impinge on the glare screen (*17*). Their glare screen details indicate that both double reverse corrugated steel screen and paddle-style glare screens are permitted. The height of the double reverse corrugated steel screens is required to be 49" above the pavement and the paddles 24" or 30" tall (*18*).

Arizona

The Arizona Department of Transportation (AZDOT) requires the use of glare screens along highways with paved medians when 32" and 42" tall median barriers are used. The exception is that glare screens are not provided when overhead lighting is provided on urban freeways where the median barriers are constructed 42" tall (*9*). The glare screens are to be expanded metal with a 1.33" by 4.0" expanded diamond shape, with the strands oriented at 20 degrees from flush with the rest of the metal sheet (*19*). For use as a temporary traffic control item, the *ADOT Standard Specifications for Road and Bridge Construction* states glare screens should be placed in urban constructions zones in which barriers are being used to separate opposing lanes of traffic, and when a barrier is separating traffic from areas of construction work greater than 1,500 feet long. The glare screens may be made either of expanded metal or plastic that is attached to the concrete barrier (*20*).

California

The California Department of Transportation (CalTrans) allows glare screens on state highway facilities, but an engineering evaluation of glare screens must be performed and submitted in the initial design documents. The evaluation must indicate that the glare screens would benefit the motoring public, consider how grades, horizontal alignment, and traffic volumes would affect headlight glare, and take into consideration input from the motoring public regarding glare. If the evaluation indicates that the use of glare screens would not be cost effective or would negatively affect the safety performance of the highway, other methods of glare control should be considered, such as highway lighting (*21*). Once the engineering evaluation has been completed and glare screens shown to be of benefit, a 56" tall concrete barrier is recommended for permanent installations. If requested by local emergency responders, an emergency opening in the barrier should be provided at roughly 600-foot intervals, unless the highway segment has higher than average crash rates, then 300-foot intervals may be appropriate (*21*).

The *Highway Design Manual* addresses concerns about glare screens in segments with horizontal curvature. If the height of the screens will affect the sight distance such that it is reduced to below the SSD, the tall concrete barriers cannot be used, and shorter barrier should be installed (*22*). CalTrans also allows, and encourages, the use of vegetation as a glare screen. The plantings must meet clear recovery zone requirements and not interfere with other highway safety features or elements. Vegetation plantings may also be employed between the highway and frontage roads in the outer separation. In these locations, chain link fencing with slats to block the glare may also be appropriate (*22*).

Colorado

The Colorado Department of Transportation (CDOT) design documents indicate that glare screens are allowed on CDOT facilities. Permanent installations tend to be concrete glare screens, which are an additional 18" of concrete poured monolithically with the concrete median barriers for new installations (*23*) or precast sections attached to existing concrete median barriers with dowels (*24*). Paddle-type glare screens are also allowed. For temporary work zone situations, CDOT utilizes traffic screens attached to the concrete barriers to help minimize glare from oncoming vehicles and to reduce the driver's view of the construction activities, the goal being "to minimize rubbernecking delays and increase the safety of motorists and highway construction workers" (*24*).

Florida

The Florida Department of Transportation (FDOT) recognizes the value of glare screens in reducing glare from the headlights of oncoming vehicles. The FDOT "MUTCD" states that when the designer is picking a median barrier, consideration of the barrier type is needed to avoid headlight flicker through the barrier opening (*25*). FDOT allows several kinds of glare screens, including opaque visual barriers. These barriers are reinforced concrete panels measuring 27" tall by 5" wide which are attached to concrete barrier walls by means of a doweling system. They may be precast or cast-in-place, and on projects with new concrete barrier being placed, the opaque panels may be poured monolithically with the barrier (*26*). FDOT also allows temporary glare screens. These screens are paddle-style glare screens for use in construction zones (*27*).

Illinois

The Illinois Department of Transportation (IDOT) allows glare screens on state highway facilities. The typical glare screen installation for IDOT facilities consists of urban freeways with narrow medians and high traffic volumes or at interchanges where ramps of opposing traffic flows are immediately adjacent to one another (*28*). IDOT has not adopted warrants for glare screens, but does provide both a list of design considerations and a list of typical applications. Designers are encouraged to consider glare screens if the following conditions are present:

- Is the design speed greater than 50 mph on an undivided and unlighted highway with median widths less than 30 feet?
- Is the highway segment a divided highway that contains horizontal curves?
- Is there an unusually high level of nighttime crashes?
- Are there any unusual transition points that produce critical glare angles between traffic traveling in opposite directions?
- Are there any conflicting light sources that negatively impact the driver's field of vision or cause confusion?
- Further consideration should be given to areas where IDOT has received a significant number of complaints or comments from the driving public. The screens may be either a concrete glare screen or a modular glare screen system (*28*).

Three types of glare screens are allowed: concrete glare screens, glare screen blades, and fence glare screens. The concrete glare screens are cast-in-place screens, attached to an existing concrete barrier via a doweling system, or poured monolithically with the concrete barrier when new barriers are placed. The modular glare screen systems are mounted on concrete barriers and are a paddle style mounted to the barrier by a rail. The visual cutoff angle of the paddles must be 22 degrees. Fence glare screens are either a wire fence with slats woven into the wire fabric or a mesh fabric-lined fence.

The design of the glare screens must be such that the angle of cutoff is 22 degrees, measured from parallel to the barrier to the angle between the vehicles in opposing lanes. When the glare screens are used in a horizontal curve, the cutoff angle should be adjusted upward with Equation 1 (*28*).

$$\text{Cutoff Angle} = \theta = 22 + \frac{5729.6}{R} \quad (1)$$

where R = Horizontal Curve Radius (feet)

Indiana

Glare screens are allowed on Indiana Department of Transportation (INDOT) highway facilities. INDOT has not adopted specific warrants for glare screens, but has a list of considerations to be made and states that there are three typical areas where glare screens should be considered: on highways with narrow medians and high traffic volumes, at interchange ramps with sharp curves and adjacent ramps, and at locations where the public has made it known that glare issues exist (*29*). Design considerations state the cutoff angle of glare screens is to be 20 degrees (from centerline of the median to the line of sight between two opposing vehicles) and in curved sections of the road the degree of curvature must be accounted for using Equation 2.

$$\text{Cutoff Angle} = \theta = 20 + \frac{5731}{R}, \quad (2)$$

where R = Horizontal Curve Radius (feet)

In addition, the designer needs to check if the glare screens affect SSD, which is not allowed. The *Design Manual* (*29*) states that sag vertical curves do not need to be considered for the height of the glare screens, but height should be determined by reviewing the information in the *NCHRP Synthesis 66, Glare Screen Guidelines* (*2*).

INDOT allows concrete glare screens placed atop concrete barriers. Cast-in-place concrete glare screens are used when placing them atop existing concrete barriers. When placing new concrete glare screens, either cast-in-place or precast screens are allowed. Expanded wire mesh (Type II) or paddle-style (Type III) screens are options for INDOT, but design documents do not provide any support other than the cutoff angle discussion. Temporary glare screens are identified on temporary barriers. Vegetation is also allowed as a form of glare screen in areas such as the highway medians depending on the alignment and type of vegetation used (*29*).

Iowa

Glare screen use by the Iowa Department of Transportation (IOWADOT) is predominantly associated with work zones. Modular glare screens are to be used throughout the work zone, utilizing blades (also called paddles in their document) attached to a base rail and mounted atop a temporary concrete barrier. The blades are to be 24" or 30" tall and 6" or 9" wide, arranged and spaced in such a manner to produce a 22 degree cutoff angle (*30*).

No specific warrants were found for permanent glare screens. The *LRFD Bridge Design Manual* states that 44" tall barrier rail should be used where special concerns have been raised about headlight glare (*31*).

Maine

The Maine Department of Transportation (MaineDOT) does not provide warrants for use of glare screen on state highways, but does provide some design guidance. In the *MaineDOT Highway Design Guidelines*, in section 10-6.05 Glare Screens, the typical glare screen installation for MaineDOT facilities consists of urban freeways with narrow medians and high traffic volumes or at interchanges where ramps of opposing traffic flows are immediately adjacent to one another (*32*). *The Design Guidelines* indicates that paddle-style glare screens are the best choice because of their effectiveness and low maintenance, although other screen options are available. The screens must be arranged so that the cutoff angle, measured from the centerline to the line of sight between two opposing vehicles, is 20 degrees. For curved segments, the cutoff angle is found using Equation 3.

$$\text{Cutoff Angle} = \theta = 20 + \frac{5729.58}{R} = 20 + D \quad \text{where R = Horizontal Curve Radius (feet), and D = Degree of Curvature} \tag{3}$$

Michigan

Michigan Department of Transportation's (MDOT) *Road Design Manual* discusses the history of glare screen use and screen types. The agency has concluded that it will only use concrete glare screens for permanent installations. The glare screen concrete barriers are to be 51" tall. Paddle-style screens are only allowed for temporary installation on temporary median barrier. Section 7.03.03 of the *MDOT Road Design Manual* states that the criterion for glare screens is that they will be included whenever a new concrete median barrier is installed within their urban areas (*33*).

Minnesota

No warrants are provided by the Minnesota Department of Transportation (MnDOT), but design guidance is given. The *MnDOT Road Design Manual* allows for both traffic screens, which are meant to reduce "gawking" or "rubbernecking" at traffic incidents or other distractions in opposing lanes, and for glare screens. Both can be mounted to median barriers but the designer needs to verify the screens will not impede the SSD along the roadway. The traffic screens are an opaque screen and are effectively a Type I glare screen. They should be used to block gawking along highways with median barriers, only where the traffic volumes exceed 1,200 veh./lane/hour, and should be 56" tall (*6*). Currently, the only glare screens allowed are slip-formed concrete screens, which are poured monolithically with the concrete barrier. Glare screens should be placed on all new concrete median barriers, but the final decision is made by each district project by project. In rural areas, glare screens should be placed where glare is known to be an issue, such as in transitions from four-lane divided highways to two-lane roadways, and in horizontal curves. Plantings are also allowed to be used as glare screens but they must not create safety issues. Glare screens can be used between the highway and frontage roads to reduce glare from opposing vehicles on two-way frontage roads (*6*).

The *MnDOT Best Practices Handbook for Roadside Vegetation Management* recognizes the ability of vegetation to be used in medians as glare screens. The planting must not hinder sight distance or reduce other safety features or elements (*34*).

Mississippi

The Mississippi Department of Transportation (MDOT) allows for glare screen fencing along state facilities. No warrants have been adopted for their use. Section 607 Fences and Cattle Guards of the *MDOT Standard Specifications* states that the work described in the section can also consist of fencing designed and be constructed primarily for the purpose of screening or glare barrier (*35*). The height and materials can be modified to match the project needs. It appears these fences are for use in the outer separation only. In section 619 Traffic Control for Construction Zones it states that temporary glare paddles may be placed on concrete median barrier or other devices in a work zone. The paddles are to be 6" to 9" wide, 24" to 30" tall, and be spaced at a maximum distance of 24" in such a manner as to produce a 22 degree cutoff angle (*35*).

New York

The New York State Department of Transportation (NYSDOT) has one specific warrant for glare screens: divided highways where headlight glare has been a contributing factor in a significant number of crashes. They also have design guidance. NYSDOT has several methods of controlling glare. Typical locations of glare screens are on divided highways in areas of increased glare, such as curved highway segments in which the inside roadway is elevated slightly above the outside roadway. Also, glare screens are useful in construction zones to reduce gawking at construction activity, and along frontage roads that carry two-way or opposing traffic (*36*).

The *NYSDOT Highway Design Manual* in section 10.2.4.7 Glare Screens states that glare screens are a panel attached atop concrete median barriers, box beam barriers, and on the posts of heavy-post barriers. One disadvantage of paddle-style glare screens is that they can easily be damaged by snow plow activity and have

known maintenance issues such as access for maintenance workers, rusted bolts, and other damage. Thus, the NYSDOT recommends designers consider using taller concrete barriers when it is appropriate and advantageous (*36*).

In the Visual Screen Fencing section, glare fencing is discussed. This is designed specifically for concrete barriers and other barrier types to reduce headlight glare between opposing lanes of traffic. The glare fence has a system of paddles ranging in height from 24" to 48" in 6" increments. The paddles are 8.5" wide and are mounted to a horizontal rail every 2 feet at 45 degrees to traffic flow. Glare fences are used in a range of locations, such as between highways and frontage roads or railroads where traffic flows in the opposite direction (*36*).

In the Standards Specifications section 619-3.13 Temporary Glare Screen, the specifications discuss using either opaque screens or vertical blades. If blades are used, they need to be installed such that the spacing and orientation produce a 22 degree cutoff angle. The blades should be mounted to a horizontal bottom bracket affixed atop a concrete barrier per manufacturer recommendations (*37*). In the Standards Specifications section 729-17 Temporary Glare Screens, an opaque screen 2 feet tall that attaches to a horizontal bottom bracket affixed atop a concrete barrier is discussed (*37*).

North Carolina

The North Carolina DOT (NCDOT) *Road Design Manual* lists several criteria for the use of glare screens and although it states they are design criteria, they effectively are warrants. They have four levels of criteria, based mostly around the geometry of the roadway. Locations where glare screen use are recommended include multilane highways, highways where there are side roads or frontage roads in close proximity to the highway, and in interchange areas. Glare screens are highly recommended for a divided highway in which the median width is less than 20 feet wide. For highways in which the median width is 20 to 50 feet, the design engineer must provide justification for glare screen use for new facilities and when added to existing roadways. When adding to existing roadways, the justification will include consideration of the accident history in the area in question, including the ratio of crashes day to night, any unusual number of crash types at the location, and consideration to the age of the drivers involved in crashes. The justification must also look at the traffic volumes (day and night comparison) and input from the public regarding glare issues (*11*).

Ohio

The Ohio Department of Transportation (ODOT) design requirements allow for glare screens on Ohio state highway facilities. Glare screens should be installed with the following considerations (*38*):

- When concrete barrier is installed in medians of interstates and freeways to separate opposing traffic.
- Installations should be continuous, as much as it is practical.
- There should not be gaps in the glare screens of less than a mile.
- If there are glare issues on isolated sharp curves, it may be justified to install glare screens.

A variety of options are available to the designer. ODOT has three preferred options, all of which can only be used when a concrete barrier is required (*38*):

- Use a taller standard barrier (57" tall) instead of the 42" tall concrete barrier.
- Add a concrete barrier extension, or cap, that extends the height of the NJ Shape barrier (32" tall). Barrier thickness needs to be sufficient for this option to be used.
- Install a paddle-style glare screen or other intermittent type of screen on top of 32" tall NJ shape or 42" Single Slope concrete barriers. These can also be placed on top of steel beam guardrails. ODOT has several options in their prequalified products list. A cutoff angle of 20 degrees measured from the centerline of the barrier should be used.

In Section 904 of the *ODOT Roadway Design Manual*, there is discussion that landscaping can be used to shield headlight glare in the highway environment. The same is true of landscaping for roundabouts (*38*).

Oregon

The Oregon Department of Transportation (ODOT) allows paddle-style glare screens on state highway facilities. No warrants for glare screen were identified in a search of ODOT design manuals, specifications, and other available manuals and documents. The glare screens may be used for both temporary (*39*) and permanent (*40*) installations and must be attached to concrete barriers. The discussion of frontage roads and outer separations in the ODOT *Highway Design Manual* states that screening should be installed when a frontage road is adjacent to the highway with opposing traffic flows (*41*). Details are provided for permanent glare screen installation on both median and frontage road concrete barriers. The blades are 9.5" wide and a minimum of 24" tall.

Puerto Rico

In the Commonwealth of Puerto Rico, the Puerto Rico Department of Transportation and Public Works (DTOP) promotes the use of glare screens, but does not provide much design guidance or types of screen to use. In the *DTOP Highway Design Manual*, Chapter 4 on median design reveals they use median widths to help control headlight glare. Chapter 14 discusses plantings and notes that plantings are a good way to block headlight glare, but oftentimes materials other than plantings are needed to restrict glare. In Chapter 23 Fencing, it is noted that special purpose fencing can be used in blocking headlight glare (*42*).

Tennessee

In Tennessee, the Department of Transportation (TDOT) supports the use of glare screens. No specific warrants are provided and little in the way of design guidance is given in the *TDOT Roadway Design Guidelines* (*43*) or the *Standard Specifications* book (*44*), other than to say that use of tall concrete barriers (51" tall) is for the purpose of reducing glare from oncoming headlights.

Texas

The Texas Department of Transportation does not have warrants for the use of glare screens, but provides some design guidance. Paddle-style glare screens are allowed and they must adhere to the following requirements, as explained in the *Departmental Materials Specification 8610*– Modular Glare Screens for Headlight Barrier (*45*). They must be a modular system of paddles attached to a base rail, with paddles a nominal height of 24". The minimum cutoff angle is 22 degrees and in a curve section, the cutoff angle is determined using Equation 4.

$$D = W_B\left(\sin\theta_B + \frac{\cos\theta_B}{\tan\theta_S}\right) \quad (4)$$

where

D = Distance between blades on barrer(feet);

W_B = Width of glare blades (feet);

and $\theta_S = 22°$ = minimum cutoff angle.

Washington

Washington State Department of Transportation (WSDOT) supports the use of glare screens on state highways. The initial guidance is that where there is a concern with headlight glare, glare screens can be used, and WSDOT's preferred option is taller concrete barriers over alternative screen types that mount on top of concrete barrier, since their experience has been that those tend to have high maintenance requirements (*46*). The three basic types of glare screens allowed are tall concrete barrier, paddle style, and chain link fence. WSDOT provides a list of considerations for the designer. They state it is hard to justify using glare screens when the medians

Table 1. Warrants and Design Requirements for Glare Screen Installations

State, district, or territory	Agency acronym	Has warrants (explicit or implicit)	Has design requirements
Alabama	ALDOT	No	Yes
Arizona	AZDOT	Implicit	Yes
California	CalTrans	Engineering evaluation required	Yes
Colorado	CODOT	No	Yes
Florida	FDOT	No	Yes
Illinois	IDOT	No	Yes
Indiana	INDOT	No	Yes
Iowa	IOWADOT	No	No
Maine	MaineDOT	No	Yes
Michigan	MDOT	No	Yes
Minnesota	MnDOT	No	Yes
Mississippi	MDOT	No	Yes
Montana	MDT	No	Minimal
New York	NYSDOT	Yes	Yes
North Carolina	NCDOT	Implicit	Yes
Ohio	ODOT	Yes	Yes
Oregon	ODOT	No	Yes
Puerto Rico	DTOP	No	Yes
Tennessee	TDOT	No	Yes
Texas	TxDOT	No	Yes
Washington	WSDOT	No	Yes
Wisconsin	WisDOT	Analysis submitted for approval	Yes

Table 2. Glare Screen Type, Size, and Cutoff Angles

State, district, or territory	Agency acronym	Typical glare screen heights	Type of glare screen	Typical glare screen cutoff angle	No data found
Alabama	ALDOT	49”	Double Reverse Corrugated Steel Screen	n/a	–
		24” or 30” + Barrier Height	Paddle-Style Glare Screens	20°	
Alaska	ADOT&PF	–	–	–	X
Arizona	AZDOT	–	Expanded Metal Screen	20°	
Arkansas	AHTD	–	–	–	X
California	CalTrans	56”	Tall Concrete Barrier	n/a	–
Colorado	CODOT	18” + Barrier Height	Concrete Glare Screen	n/a	
Florida	FDOT	27” + Barrier Height	Concrete Opaque Barrier	n/a	–
Hawaii	HDOT	–	–	–	X
Illinois	IDOT	Must be calculated by designer for roadway context	Tall Concrete Barrier (Type I) Paddle Style (Type III) Fence Glare Screen (outer separation)	22° + D	–
Indiana	INDOT	45” not specified	Tall Concrete Barrier Type II or III, Temp	20° + D	–
Iowa	IOWADOT	24”–30” + Barrier Height 44”	Modular Glare Screen (Paddle Style) Permanent Tall Concrete Barrier	22°	X
Kansas	KDOT	51”	Permanent and Temp Concrete Safety Barrier	n/a	X
Maine	MaineDOT	not specified 42”	Type III Paddle Style Concrete Barrier (not specified as GS)	20° + D n/a	–
Maryland	MDOT	–	–	–	X
Michigan	MDOT	51”	Concrete Glare Screen on Concrete Barrier	n/a	–
Minnesota	MnDOT	56”	Tall Concrete Barrier with Integral Glare Screen	n/a	–
Mississippi	MDOT	Varies 60” or 70”	Chain Link Fence – Styled as Project Need	n/a	–
Montana	MDT	46”	Tall Concrete Barrier Rail	n/a	–
Nebraska	NDOT	42”	Concrete Median Barrier (not GS Specific)	n/a	–
		24”	Temporary Paddle-Style Glare Screens	Not specified	
New York	NYSDOT	24”	Temporary Glare Screens (Type II and III)	22°	–
		24”, 30”, 36”, 48”	Glare Fencing	45°	
North Carolina	NCDOT	50” (up to 80” in sag curves) 24” to 30” Height Varies	Extra Tall Concrete Barrier Paddle-Style Glare Screen 1/2” Chain Link Fence	n/a 20° n/a	–
North Dakota	NDDOT	–	–	–	X
Ohio	ODOT	57” Not Found	Type BI Concrete Barrier Paddle-Style Glare Screens (Temp & Perm)	n/a 20°	–
Oregon	ODOT	24” (min)	Paddle-Style Glare Screens (Temp & Perm)	22°	–
Puerto Rico	DTOP	–	–	–	X
Tennessee	TDOT	51”	Tall Concrete Barrier	n/a	–
Texas	TxDOT	24” + Barrier Height	Modular Glare Screen (Paddle Style)	22°	–
Washington	WSDOT	42”, 48”, and 54” 36” 72”	Tall Concrete Barrier Wire Fabric Glare Screen Chain Link Fence Glare Screen (w/or w/o slats)	n/a n/a n/a	–
		Varies	Vegetation	n/a	
Wisconsin	WisDOT	Varies	Conc. Barrier/Vegetation	n/a	
Wyoming	WYDOT	–	–	–	X

Note: D = Degree of Curvature.

are wider than 20 feet or there is permanent linear highway lighting present or the average daily traffic is less than 20,000 vehicles per day. The crash history must also be analyzed to find if the highway segment experiences higher than average nighttime crashes compared with statewide rates or higher than usual nighttime crashes involving older drivers. Of great importance is any complaints from the public about areas of glare concern, or if there are direct observations of glare problems (*46*).

Additional locations include along frontage roads in the outer separation to block headlight glare from opposing traffic and at interchange ramps with sharp radius curves of adjacent ramps where glare may be bothersome. They do suggest that highway lighting may be a better solution at interchange ramps. For temporary traffic control, expanded metal traffic screens and paddle-style glare screens are permitted. The use of plywood panels for eliminating gawking or "rubbernecking" are also allowed, with approval from the design engineer (*46*).

WSDOT encourages the use of roadside vegetation to block headlight glare, both in the median and in outer separation between highways and frontage roads. The plantings must maintain the design clear zone and not reduce sight distance (*47*).

Wisconsin

The Wisconsin Department of Transportation (WisDOT) allows both glare and gawker screens, but review and approval must be obtained for each installation, which is reviewed on a case by case basis by the Bureau of Project Development. Submittals for review must include a documented need for the screens and cost associated with the screen installation. The submittal must also define multiple alternatives to glare or gawker screens that would address the glare or gawking issues (*8*).

Glare screens will not typically be installed when medians are greater than 20 feet wide. Also, ambient lighting, either from any form of roadway lighting or adjacent properties that provide necessary lighting, typically precludes the use of glare screens. Other locations that might include the use of glare screens are between highway and frontage roads with two-way or counter-directional traffic flows. The type of glare screens allowed is not stipulated or described. The use of vegetation as glare screens is discussed in the Chapter 27, Section 27 (*8*). Full glare screening plantings that block all headlight glare are recommended in areas where the headlights of oncoming traffic are directly affecting the driver, but where it is likely only to be a distraction to the driver, a partial vegetation glare screen may be used. Care should be taken so as not to place any plantings in vision triangles near intersections (*8*).

Findings

Of these transportation agencies, few have warrants on when to use glare screens, but several do have requirements to follow when they are used. Not all transportation agencies approach the use of glare screens in the same way. Some states have developed comprehensive criteria for when glare screens can be used on state highway facilities, whereas others do not mention them at all in their design resources. Some agencies have specific requirements on the type of glare screens to use, and others offer a range of options or none at all; this is summarized in Table 1. A consistent glare screen warranting method should be investigated. The result of that effort is included in a subsequent paper. For the states that utilize glare screens, a summary of the types, sizes, and cut-off angles is included in Table 2.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Mr. Johnson. Dr. McDonald. Author; data collection: Mr. Johnson. Author; analysis and interpretation of results: Mr. Johnson. Author; draft manuscript preparation: Dr. McDonald. Mr. Johnson. All authors reviewed the results and approved the final version of the manuscript.

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