

# Safety against Head Light Glare

<sup>1</sup>Kasi Reddy Prathap Reddy, <sup>2</sup>Palle Sreekanth Reddy

<sup>1</sup>Research scholar, <sup>2</sup>Assistant Professor,

<sup>1,2</sup> Department of Civil Engineering

<sup>1</sup>Sri Satya Sai University of Technology & Medical Sciences Bhopal, sehere, M.P-466001

<sup>2</sup>Samskruti College of Engineering & technology, Kondapur (V), Ghatkesar (M), Medchal-501301

Email: <sup>1</sup>prathapreddy4@gmail.com <sup>2</sup>pallechina@gmail.com

## Abstract:

The long-term goal of the project is to develop the next generation headlights for vehicles, that are programmable, multi-task, react to the road environment and enhance driver safety. These smart headlights will better illuminate the road, spotlight obstacles, signs and lanes, project directions on the road, reduce glare and increase visibility in dangerous rain and snowstorms. The additional cost of the headlight will be small compared to the direct and indirect savings due to reduced crashes. The project has strong commercialization potential, with vehicle exterior lighting becoming more and more adaptive recently

## 1. Introduction

Drivers require enough lighting at night to see a variety of objects on the highway, including traffic control devices, lane lines, vehicles, pedestrians, animals, and other potentially hazardous objects. However, too much light or improper lighting can result in glare, which can be a major problem both in terms of the ability to see and visual comfort. There are only two practical methods of lighting the highway system at night: fixed overhead lighting and vehicle head lighting. While the fraction of roads with fixed overhead lighting increases significantly each year, this form of lighting is expensive and cannot be relied upon as the only means of providing for night visibility. Head lighting, from its inception, has involved a compromise between providing sufficient lighting for drivers to see (with adequate preview time), and avoiding excessive light that might produce glare. These two goals have been translated into standards in the form of minimum requirements to provide visibility and maximum limitations to control glare.

Along with improvements in headlight systems, glare resistant interior surfaces, glare-reducing mirrors, and changes to the highway environment have either directly reduced glare or indirectly reduced the effect of glare on drivers. However, every change has involved a tradeoff with hidden costs. For example, lowering headlamp mounting heights has a minimal monetary cost, but this change may result in a loss of forward visibility; making other changes, such as

installing dynamic headlight aiming systems, may be very costly. To best manage such costs, it is necessary to have a good understanding of the glare problem and of the importance of various aspects of the problem. Otherwise, the old adage, "be careful what you ask for, because you might get it," could apply.

The glare has a long history, marked by the competing perspectives of researchers in an international community. The seminal work, setting the framework for all subsequent discussions of glare in roadway lighting, was done by Holladay (1926) in the USA and by Stiles (1928— 29) in the UK. Holladay is the acknowledged originator of the concept of what is now known as disability glare, the glare that results in a loss of visibility.

The remainder of the introduction provides definitions of some basic terms used in the study of lighting and vision. The key terms to be defined are:

- Brightness
- Point light source
- Luminous intensity
- Luminance
- I luminance
- Reflectance
- Glare

**Brightness** is the attribute of visual sensation according to which an area appears to emit more or less light. Brightness is a relative term which describes the appearance of an object to an observer. An object of any brightness will appear brighter if the ambient light levels are lower. Brightness can range from very bright (brilliant) to very dim (dark). In popular usage, the term "brightness" implies higher light intensities, whereas "dimness" implies lower intensities.

**Point light source** is a light source that subtends an extremely small angle at the observer's eye so that its attributes are not affected by its size, only by its luminous intensity. An example of a point light source is a star.

**Luminous intensity** is the light-producing power of a source, measured as the luminous flux per unit solid angle in a given direction. It is simply a measure of the strength of the visible light given off by a point source of light in a specific direction, and

usually expressed in terms of candelas (cd), where one cd equals one lumen/steradian.

**Luminance** is the amount of luminous flux reflected or transmitted by a surface into a solid angle per unit of area perpendicular to given direction. More simply, it is a physical measure of the amount of light reflected or emitted from a surface and roughly corresponds to the subjective impression of "brightness." Luminance does not vary with distance. It may be computed by dividing the luminous intensity by the source area, or by multiplying Illuminance and reflectance. The most common units of measurement for luminance are candelas per square meter (cd/m<sup>2</sup>), foot-lamberts (fL), and mill lamberts (mL).

**Illuminance** is the photometric flux (or, more simply, the amount of light) incident per unit area of a surface at any given point on the surface. The illuminance  $E$  at a surface is related to the luminous intensity  $I$  of a source by the inverse square law  $E=I/d^2$ , where  $d$  is the distance between the source and the surface. The most commonly used units of measurement for illuminance are lux (lumens per square meter) and foot-candles (fc, or lumens per square foot). Retinal illuminance is the amount of photometric flux that reaches the retina of the eye; it is a function of the diameter of the pupil of the eye and the amount of light.

**Reflectance** is a measure of the reflected incident light (illuminance) that is actually reflected away from a surface. For many surfaces reflectance will depend on the angle of viewing and the angle from which it is illuminated, as well as the properties of the surface (including diffuseness or retro reflectivity of the surface).

**Glare** can be defined generally as a bright, steady, dazzling light or brilliant reflection that occurs when the luminous intensity or luminance within the visual field is greater than that to which the eyes are accustomed. Glare can cause discomfort, annoyance, or loss in visual performance and visibility. Direct glare is caused by light sources in the field of view whereas reflected glare is caused by bright reflections from polished or glossy surfaces that are reflected toward an individual (for example, a chrome nameplate on a leading vehicle). The entire visual field contributes to the glare level, and even a completely uniform field, such as that in a photometric sphere, will produce some glare.

## 2. LITERATURE REVIEW:

- Significance of Headlamp Glare Hemion (1969) estimated in the late 1960s that approximately 1% of accidents could be attributed, at least in part, to headlamp glare (i.e. "blinded by headlamps"). This review outlines the important characteristics of headlamp systems as they relate to glare while driving at night, focusing on intensity, spectrum, size

and temporal properties (frequency, duration) of headlamps.

- It is almost always the case that headlamp glare reduces visual performance under driving conditions relative to the level of performance achievable without glare (Mortimer, 1969; Ranney et al., 1999, 2000; Akashi and Rea, 2001). This effect has been shown to be consistent with predictions of contrast reduction caused by a uniform veil of brightness in the field of view (Stiles and Crawford, 1937; Fry, 1954), given by the following equation for a single glare source

## 3. FACTORS THAT CONTRIBUTE TO HEADLIGHT GLARE AT NIGHT:

To critically evaluate the potential effectiveness of any glare countermeasure, it is essential to understand the physiology of glare and its causative factors. Glare is usually classified according to its effect on an observer, but each type of glare has its own physiological explanation.

The two principal types of glare are disability glare and discomfort glare. Disability glare impairs the capability of the eye to perceive small changes in brightness (such as the luminance of the object to be seen), while discomfort glare, as its name implies, creates an uncomfortable sensation. There is a tradeoff between visibility and glare; for example, research (Hemion 1969a and Flannigan 1996) indicates that visibility is improved when opposing vehicles both use high beams, although this creates discomfort glare.

The automotive head lighting industry has always felt that discomfort glare was more important than disability glare, because discomfort glare is what drivers complain about.<sup>1</sup> However, disability glare may be equally important, because it is directly related to the driver's ability to see objects and thus may be more likely to result in crashes.

Generally, glare results from a bright, steady, dazzling light or its reflection from shiny surfaces; it occurs when the luminous intensity or luminance within the visual field is considerably greater than that to which the eyes are adapted. Direct glare is caused by light sources in the field of view (such as headlights, taillights, and luminaires). Reflected glare is caused by specular reflections from polished or glossy surfaces such as the steel or aluminum doors on tractor trailers, a rear-view mirror at night, or even bright matte surfaces, such as vehicle interiors and dashboards, that reflect light toward the driver. Glare affects both day and night driving performances. During the day, sunlight produces direct glare and gives rise to indirect glare from surface reflections. At night, automobile headlights produce direct glare by shining into the eyes of drivers in approaching cars, and indirect glare is experienced from rearview mirrors and vehicle

interiors that reflect light from trailing vehicles. The effects of glare on drivers are much greater at night than during the day, because at night drivers are adapted to lower light levels and so require a greater difference in luminance between objects and background to perceive objects on the road. This luminance difference is reduced by stray light coming either directly from a glaring light source or indirectly from reflections of headlamps on wet road surfaces, mirrors, or vehicle interiors. Lights that are barely noticeable during daylight can be uncomfortably glaring at night.

Disability and discomfort glare apparently have quite different physiological origins and so are very difficult to compare. Disability glare comes from light scattering in the ocular media, whereas the sensation of discomfort glare appears to be related to neuronal interactions similar to such physiological functions as skin resistance or the pupillary response to light (Fry and King 1975).

The two types of glare are affected differently by environmental parameters. For example, disability glare does not seem to be affected by source size or luminance, but it is affected by luminous flux and the angular offset from the line of sight. In contrast, for discomfort glare the apparent source luminance and size are major parameters. As long as the size and position of headlights are kept more or less the same, steps taken to reduce discomfort glare will also reduce disability glare.

However, if the size of the headlight source is reduced while keeping the emitted flux constant, the higher headlight luminance will increase discomfort while the disability effects will stay the same. This effect may explain the complaints about glare with some high-intensity discharge (HID) lamps, which, on any specific beam angle, project similar illumination as a halogen lamp, but through a smaller opening.

Another consequence of the different behavior of disability and discomfort glare is that when background luminance is low, glare sources may have a disabling effect on vision without being a source of discomfort. This problem has been addressed by using roadway lighting to provide minimum background luminance levels. With sufficient ambient illumination, a glare source may create a discomforting sensation without a measurable disabling effect.

### Disability Glare

Disability glare is created by a light so bright that its intensity results in a measurable reduction in a driver's ability to perform visual tasks. The reduction in visual performance is a direct result of the effects of stray light within the eye, which in turn are dependent on the age of the driver. Transient adaptation refers to a temporary reduction in basic visual functions, such as contrast sensitivity and form perception that occurs when the luminance's

from objects in the visual field change rapidly (Adrian 1991a).

The degree of reduction in function is dependent on the change in luminance to which the eye must adapt. Transient visual impairments are associated with rapid alterations in glare levels and changes in scene luminance, as well as sudden eye movements (or saccades). Glaring light scattered in the eye can be expressed as the superposition of a uniform luminance onto the retinal image. This "veiling" luminance, which is a function of the glare angle (the angle between the line of sight and the glare source), adds to scene luminance and reduces the contrast of the target to be seen. This formula for contrast  $C$  without glare is:

$$C = (L_T - L_B) / L_B,$$

where  $L_B$  is the background luminance and  $L_T$  is the luminance of the object to be seen (the target). If disability glare ( $L_{seq}$ , the equivalent luminance of stray light in the eye) is added to the luminance of both the target and background, the formula for contrast in the presence of glare becomes

$$C = [(L_T + L_{seq}) - (L_B + L_{seq})] / (L_B + L_{seq}) = (L_T - L_B) / (L_B + L_{seq}).$$

This formula indicates that contrast will be reduced as  $L_{seq}$  is increased. Visual acuity depends on the contrast between the background and the objects to be seen. The presence of glare reduces the ratio of target contrast to threshold contrast, and the target is less likely to be seen or drowns completely in the light veil. Direct glare in night-driving encounters has strong angular or spatial dependence, resulting in eye movements that almost invariably lead to transient changes in the luminance reaching the eye and so to either dark adaptation or light adaptation.

As part of the adaptation process, the retina adjusts to the quantity of light. Although different parts of the retina are exposed to different quantities of light (for normal scenes of non-uniform luminance), it is generally assumed that an instantaneous state of adaptation of the fovea (the central retinal region) can be described by an equivalent veiling luminance from a uniform source superimposed on the visual field. A given state of foveal adaptation, therefore, can be produced by many luminance configurations.

### Range Effect

The range effect is a shift in the subjective assessment of discomfort based on the range of intensities of the glare sources being evaluated (Lulla and Bennett 1981). If a subject is exposed to a wider

range of glare intensities, the level of glare that the subject considers tolerable is increased. Although the work of Lulla and Bennett was based on relatively short exposures in the laboratory, it might have consequences for measurements of discomfort glare during night driving.

### Task Difficulty

A laboratory study by Sivak et al. (1991) and a field study by Theeuwes and Alferdinck (1996) provide some support for the hypothesis that discomfort glare ratings are influenced by the difficulty of the task being performed. In the Sivak study, subjects performing a gap-detection task reported that a fixed amount of glare caused more discomfort as gap size decreased, making the gap more difficult to detect. Sivak et al. also noted the potential incongruity in discomfort glare models like that underlying equation 5: Conditions such as fog or a dirty windshield increase veiling luminance and thus disability glare, but according to equation 5 such conditions would reduce discomfort, because the peak intensity of the glare source ( $E$ ) would be decreased and the illumination in the rest of the retina ( $L_a$ ) would be increased. Yet these conditions make driving more difficult and might increase discomfort if task difficulty were included in the equation.

### Physiological Effects

Age — Research into the effects of age on discomfort glare appears to be inconclusive. Theeuwes and Alferdinck (1996) found that older drivers were more sensitive to stray light, but ratings of glare discomfort on the nine-point rating scale were not sensitive to age differences. In contrast, Bennett (1977) reported a small but significant negative correlation ( $r = -0.36$ ) between BCD and age. The discrepancy between these studies may be explained by the finding of Theeuwes and Alferdinck that the nine-point rating scale does not correlate well with BCD and that in actual driving situations subjects rate glare as less annoying than predicted by the models developed under laboratory conditions.

## 4. THE PROBLEM OF HEADLIGHT GLARE

Our awareness of a problem with headlight glare comes primarily from direct observation and from the reports of others. Mortimer (1988) cites his own dissertation, a study of drivers aged 19 to 39 in which 65% of the subjects said they were bothered by glare at night, and another study in which one-third of the subjects said glare was a frequent problem. The San Francisco Chronicle (June 28, 1999) reported, “Young and old alike, many drivers on the Bay Area’s busy, twisty roads complain of blinding lights in the windshield and rear-view mirror.” The article quoted an informal survey indicating that drivers are convinced that glare is worse than ever.

While there seems to be no scientific explanation for why glare is becoming a greater problem, contributing factors appear to be the introduction of high intensity discharge lights (HID), the proliferation of sports utility vehicles with headlights mounted higher than passenger vehicles, and the use of illegal aftermarket devices. As reported by the San Francisco Chronicle, many complaints about HID could actually be about fake HID, “which usually are installed by drivers seeking to look cool. The fakes cause more glare because they diffuse the beam ... posing a safety risk for everyone on the road.”

This chapter will consider two aspects of the headlight glare problem: first, what subgroups are most affected by glare, and second—and most critically—its consequences. Understanding the consequences of headlight glare is the basis for evaluating the importance of countermeasures.

## Subgroups Affected Most by Glare

Based on the factors contributing to glare that were identified in the previous chapter, it can be inferred that three subgroups of individuals are at high risk for nighttime glare: those with light eye color, those whose driving is mostly on high-volume, two-lane roads, and the elderly. Another potential high-risk subgroup is composed of drivers with corrective lenses, but this is only a serious factor if the contacts and lenses have been scratched or damaged. Some drivers who have had vision correction surgery, such as radial keratotomy or LASIK, also complain about glare.

Formula for disability glare was presented and introduced a factor to account for the effect of age. This formula indicates that, while there is some increase in disability glare among younger drivers, effects begin to increase significantly only after age 40. Results consistent with this model were obtained by Pulling et al. (1980), who conducted simulator experiments that defined threshold glare as brightness from “headlights on oncoming cars so great that potential hazards on the highway could not be distinguished in time...”

There is also evidence that older drivers may be bothered more than younger drivers by discomfort glare. Bennett (1977) reported some experiments which showed that the level of glare that caused discomfort (measured by the “borderline between comfort and discomfort,” or BCD) decreased rapidly with age until age 40, after which it continued to decline, although at a slower rate. Schwab et al. (1972) found that drivers, particularly older drivers, were willing to reduce the amount of remuneration they received from a research study in order to avoid having to participate in trials with high levels of glare. After taking family income into account, Schwab concluded that drivers appeared

willing to pay about what a polarized lighting system cost at that time. This suggests that, after adjusting for inflation, drivers today would be willing to spend approximately \$100 for a device that would reduce headlight glare to acceptable levels.

### Consequences of Headlight Glare

Documentation of the consequences of headlight glare is not readily available. It is far easier to speculate about what these consequences might be than to measure them. A controlled field study (Theeuwes and Alferdinck 1996) tested three levels of glare illuminance (namely 0.28, 0.55, and 1.1 lux, or 350, 690, and 1380 cd, at 500 m) and found that even the lowest level of glare resulted in reduced detection distances and, in some situations, greater speed reduction and more steering reversals (thought to be a surrogate measure of fatigue-inducing workload). Surprisingly, the discomfort glare ratings of these glare levels were not related to any of the performance measures.

Very generally, headlight glare has the potential to both increase the frequency of accidents and decrease the mobility of individuals by discouraging them from driving at night. Both of these consequences may be mediated by a reduction in visibility or an increase in fatigue or tension—or by the simple discomfort, and sometimes painful experience, which night driving presents. The following section will discuss the effects of glare on visibility, fatigue, accidents, driver behavior, and mobility.

### Effects Of Glare On Visibility

The effects of glare on visibility have primarily been studied in the laboratory, in studies that have produced the formulae discussed in the preceding chapter. Of interest here is what, if anything, can be said about the glare-related loss of visibility in field situations. One controlled field study by Cadena and Hemion (1969) demonstrated a reduction in visibility distance that was attributed to the level of headlight glare, although some of the reduction in visibility distance seemed to be due to the distraction of opposing vehicles both with and without headlights. Hare and Hemion (1968) used observations of encounters between opposing vehicles in two-lane, open road situations to develop a formula for the reduction in visibility distance.

### Effect Of Glare On Fatigue

One important consequence of headlight glare is its potential ability to cause feelings of stress and fatigue. Schiflett, Cadena, and Hemion (1969) defined fatigue as a state of increased discomfort and decreased efficiency resulting from prolonged exertion on a task. The extent to which a person experiences fatigue is a function of that person's surroundings, including visual conditions. Boyce (1981) pointed out that although the relationship

between visual conditions and induced fatigue has been studied for many years, little progress has been made in understanding their relationship. The slow progress could be due to the fact that fatigue is very difficult to define and measure. However, even without experimental evidence, personal experience with driving tells us that fatigue does occur and that lighting conditions, including glare from approaching headlights, may influence its occurrence.

Generally, fatigue is divided into two categories: physical fatigue and mental fatigue. Physical fatigue is well understood; it results from prolonged use of a given set of muscles. Physical fatigue includes physiological changes in the muscles that cause them to simply stop operating; either the muscles become incapable of contracting or the central nervous system stops sending them signals. Mental fatigue, by contrast, is not well understood. Boyce theorized that mental fatigue is nearly impossible to measure directly because it involves the entire body as well as the mind, not just a single muscle or muscle group. Although difficult to define or measure, there is no question that mental fatigue exists, because, as Boyce says, "It is a matter of common experience that prolonged and difficult mental work leads to feelings of tiredness."

Studies that attempt to determine how lighting conditions affect fatigue usually focus on one of the two types of fatigue. Physical fatigue associated with lighting conditions can impair the functions of the muscles of the ocular motor system. Binocular vision, according to Weston (1954), involves at least twelve muscles in every movement of the eye. In addition to these eye muscles, many different facial muscles are brought into play in situations with bright light: Muscles of the lower eyelid, cheeks, and upper lip cause the eyes to squint and give the face a look of grief or distress. Weston concluded that the prolonged use of these "grief" muscles also contributes to the fatigue associated with bright conditions.

Another source of physical fatigue while driving is the effort required to keep the eyes focused directly ahead of the vehicle. Weston described what happens when bright lights, such as passing headlights from opposing cars, pass into the peripheral field. In this situation, the bright light acts as a distraction, causing "visual confusion," and the eyes tend to automatically move toward the light. An effort must be made to keep the driver's gaze directed to the near side of the road instead of toward the blinding light of an approaching car.

### Effect Of Glare On Accident Frequency

Nighttime death rates have consistently been the highest in rural driving environments. Of the 18,874 nighttime traffic fatalities in 1998, over 56% took place on rural roads (FARS database). The hazardous nature of rural nighttime driving becomes

even more apparent when one considers that only 40% of all vehicle mileage occurs on rural roads (NTS 1999), and less than 15% of that is during the nighttime hours (National Safety Council 1999). For the past decade, the rural nighttime death rate has consistently been about three times the rural daytime rate and about two-and-one-half times the urban nighttime rate (National Safety Council 1988, 1990, 1994, FARS Database, NTS 1999). According to 1988 Pennsylvania Department of Transportation (PennDOT) data, rural accidents are more likely to involve fatalities, whereas urban accidents are more likely to involve property damage. The PennDOT database also showed that the two most common subgroups for nighttime accidents are rural unlighted and urban lighted areas.

Driving safety on rural roads is compromised by a number of factors, including heavy use, frequent curves and intersections, and decreased sight distance, all of which combine with high rates of speed to produce very dangerous driving conditions. NCHRP Report 66 (1979) indicates that glare from oncoming headlights is most often encountered on two-lane rural highways. Glare is also worse on roadways that curve to the left because opposing headlights are directed into the driver's eyes in proportion to the degree of curvature.

Despite the known deleterious effects of glare on the visual system, we seldom hear of a traffic accident caused by glare, and glare is seldom considered a major factor in accident causation. Hemion (1969) found very few states in which "accident reporting forms and procedures made specific reference to headlight glare as a causative factor in vehicle accidents." Seven states out of the 25 contacted by Hemion could readily provide relevant statistics; these states reported that only between 0.5% and 4.0% of all night accidents were attributable to headlight glare. Hemion believed glare data to be under-reported because reporting typically focuses on direct causes and would tend to not consider a vehicle that is no longer at the scene. A later report by Mortimer (1988) also stated that glare is rarely reported as a factor in accidents.

### **Effect Of Glare On Driving Behavior**

There has been very little research on the effects of glare on driving behavior. A study by Theeuwes and Alferdinck (1996) suggests that glare from oncoming headlights has a minimal effect on speed and steering. The study concluded that De Boer discomfort ratings have no predictive value with regard to how much drivers will adjust their speed. Drivers in the study did reduce speed in the presence of glare (by approximately 2 km/h), but not in relation to the amount of glare. The study's analysis of steering wheel reversals and gas pedal reversals showed no relationship to the presence of or the amount of glare.

### **Effect Of Glare On Mobility**

Since mobility is a primary goal of the transportation system, anything that degrades mobility is a cause for concern. There is some evidence that problems with glare during nighttime driving have a negative impact on some motorists' willing to drive at night. Chu (1994), reviewing evidence from the National Transportation Survey, concluded that elderly drivers are less likely to drive at night and during peak hours than middle aged drivers, and are less likely to drive at night than during peak hours.

An open-ended question in the driver biographical logs asked, "What is your greatest difficulty or biggest concern about driving at night?" One third of the total driver-log study group wrote "headlight glare" or "lights from oncoming traffic" as their primary or secondary answer. Forty percent of the urban subjects cited these factors as their greatest concern and 27% of the suburban subjects gave them as their most frequent response. Only four different concerns were cited by urban drivers, whereas suburban drivers cited 11 concerns or difficulties. For both groups, the most frequently cited difficulty regarding nighttime driving was headlight glare.

For this group of older drivers, 29% reported headlight glare to be their greatest concern and almost 21% said that poorly lit roads caused them the most concern. Another 24% of drivers responded with several other difficulties that could be related to roadway lighting: difficulty seeing, bright lights, vehicle breakdowns, and seeing pedestrians or bicyclists. Overall, 74% of the respondents indicated that nighttime driving comfort was related to some aspect of roadway lighting.

### **Causes Of Headlight Glare**

While the fundamental factors that determine disability and discomfort glare were discussed in Chapter 2, to better understand the basis of drivers' glare problems one must consider how these factors are affected by geometric and vehicle parameters. While it is not possible to attribute causality to any one factor, it is useful to identify the roadway and vehicle conditions that contribute to glare and to gather evidence to try to isolate the most serious offenders.

**Illuminance from the glare source** is determined by the photometric intensity distribution of the oncoming headlamps, the aiming and height of these lamps, whether high beam or low beam is used, and the distance of the glare source from the observer. The greater the intensity directed toward an observer, the greater the illuminance reaching the observer's eyes. Headlamp intensity is controlled by the headlamp design and the beam pattern, discussed elsewhere in this chapter. In general, headlamps are designed and aimed to produce greater intensity below the horizontal and to the right of the vehicle

center line. While the Federal Government's published standard FMVSS 108 is intended to control glare by limiting the amount of light above the horizontal axis, roughly half of all vehicles on the road are driven with improperly aimed headlamps (Copenhaver and Jones 1992). The reasons for this are numerous and are discussed below, under aiming as a countermeasure for glare.

While illumination increases with proximity to an oncoming vehicle, in practice the level of glare is often reduced. This happens because the glare angle increases as the glare source gets closer and, if the observer continues to look in a given direction, this increase in glare angle offsets the effects of increasing illuminance. The dynamic relationship between distance and veiling luminance is discussed. **The glare angle** from oncoming headlights is the angle between the direction of a driver's gaze and the direction of the glare source. Glare angle depends on the distance between the opposing vehicle and the observer vehicle, the road geometry, and the offset of the opposing vehicle paths, which is determined by the number of lanes in one direction, the lane of occupancy, and the median or shoulder widths. Overall, the glare angle is smallest when the opposing vehicle is furthest away so the illumination is low.

**Dynamic relationships between beam pattern and distance to an opposing vehicle** were evaluated for several lateral separations by Powers & Solomon (1965). This report showed that, for a typical two-lane road approach, the level of glare increases gradually as the oncoming car approaches from a separation of 2,000 feet until it reaches 300 to 400 feet; as the car comes closer than this, the glare level drops sharply. At first, the glare is caused by the portion of the beam pattern that is near the peak intensity point; although relatively bright, the source is far away. As the vehicles approach each other, the distance declines, but the driver is seeing less candlepower (further to the left of center on the headlamp beam distribution).

**Background luminance** is generally determined by the reflectance of background (usually the pavement) and the illuminance on the pavement (usually from headlights at near distances and ambient light or fixed roadway lighting at far distances). When driving, a driver may look at objects on or off the road. Some objects, such as overhead signs, may be seen with the sky as a background, while objects on the side of the road, such as signs, may be seen with buildings or foliage as a background. Most objects have the pavement as a background, so the luminance of the pavement is thought to have the greatest effect on driver eye adaptation.

**Size of the glare source** is determined by the physical dimensions of the glare source and the distance between the driver and the glare source. At close distances, headlamps are no longer point light

sources; increasing their size while holding their light output constant will reduce discomfort. On the other hand, as an observer approaches a reflective surface, the relative size of the surface increases but, as a result of the inverse-square law, the light intensity and the discomfort glare also 32 increase. This apparent disparity in the effect of source size on glare is due to the fact that when headlamp size is increased, luminance is reduced, whereas the luminance of a reflective surface generally remains constant when its size is increased under constant illumination. Headlamp size is generally not a significant factor in glare since there is not much variability in headlamp size with current designs. However, as we shall see in Chapter 8, the development of larger-sized headlamps is a potential countermeasure to discomfort glare, despite the current trend towards smaller headlamps.

**Glare source** luminance is determined by both the intensity and the area of the headlamp: Luminance is increased when either intensity is increased or area is decreased. As mentioned earlier, the intensity of the lamp is modulated by the beam pattern and luminance will vary depending on the angle from which it is viewed. As long as headlamp size is not varied, there does not appear to be any problem with headlamp luminance that is not related to headlamp intensity, beam pattern, or aiming.

**Driver age** affects the experience of glare on the road in the same way it does in the laboratory. Age, as we saw in Chapter 2, has a significant effect on the magnitude of disability glare: Older drivers encounter higher levels of disability glare than younger drivers under the same lighting conditions, and anecdotal reports indicate that older drivers complain more about glare and are more restricted in mobility at night. However, there is some inconsistency in the literature concerning whether older drivers are more discomforted by glare than younger drivers.

**Reflective surfaces** outside the vehicle can be a problem. For example, reflective surfaces on a leading vehicle stopped at a traffic light can be very discomforting. Interior surfaces of vehicles can also become illuminated and cause some glare, but under current Motor Vehicle Safety Standards, adopted in 1966, vehicle surfaces are required to have glare-reducing matte finishes (this is why the old chrome windshield wipers have disappeared). This countermeasure is already well implemented and so will not be discussed further. A removable object in the vehicle can also be a glare source, but the driver always has the option of moving such an item.

**Glare from mirrors** is the result of the reflection of headlamps; its magnitude is based on the optical distance to the image of the headlamps. Since mirrors simply redirect the optical path, it is the distance between the headlamp and mirror plus the distance between the mirror and the driver's eye that determine the illuminance at the driver's eye. The

transmission of the rear window and the reflection characteristics of the mirror (about 4% for a typical day/night interior mirror on its night setting, 50% for exterior mirrors) must be considered.

Olson and Sivak (1984) observed two distinct differences between glare from mirrors and glare from oncoming headlamps: First, there is typically more than one mirror, which increases the glare problem; and second, the following vehicle may remain in a relatively fixed position for a long period of time, which raises questions about the time-related effects of glare.

## Types of Safety measures

Describe various countermeasures that have either been implemented or proposed for controlling the effects of glare from vehicle headlights. Some of these countermeasures are intuitive and have been deployed to some extent for many years. Others rely on state-of-the art technology to achieve results that are not at all obvious. Lists a wide variety of potential countermeasures, characterized by the primary source of implementation, whether it be the driver, industry, or a government agency.

While there are many methods for reducing the amount of glare attributable to headlights, only a few countermeasures may be implemented unilaterally by the driver. Many countermeasures must either be implemented by a highway agency (usually the state department of transportation, or DOT) or by automobile manufacturers, with or without the Federal mandates that make specific types of equipment available or legitimize changes in vehicle or headlamp design. In Europe, headlight glare is limited by aiming the beam downward, whereas in the U.S., the beam is aimed upward. Both approaches recognize the tradeoff between glare and visibility; the European standard accepts reduced visibility while the U. S. standard accepts more glare. The implementation of these philosophies is discussed.

Reduction of intensity or luminance, some countermeasures reduce glare by reducing the luminance of the glare source or the intensity of light aimed in a driver's direction. Modification of the low-beam pattern and independent alignment of opposing directions of road are examples of this type of countermeasure.

Reduce illumination at driver's eye, another group of countermeasures is intended to block or filter light, thereby reducing the amount of illumination reaching a driver's eye. Anti-glare mirrors, glare screens and some types of night-driving glasses (those marketed

as glare reducers and not for optical corrections) are prominent examples.

Increase the glare angle, some countermeasures reduce glare by increasing the angle between the glare source and the road ahead. Wide medians are the most common method of implementing this strategy.

Indirect benefits, the last group of countermeasures do not themselves directly reduce glare, but have the potential to indirectly reduce glare by either reducing the illumination needed for vision or raising the adaptation level of drivers. Ultraviolet lighting and fixed roadway lighting are prominent examples of these countermeasures.

## 5. SAFETY MEASURES THAT REDUCE THE INTENSITY OF GLARE SOURCE

1. Photometric Distribution
2. Aiming
3. Adaptive Headlamps
4. Color Corrected Headlamps
5. Headlamp Height

Photometric Distribution:

Every driver is aware that some headlights are brighter than others. This variation in brightness is the result of variation in the beam pattern, aiming, and height of the headlamps. The beam pattern in the U.S. is governed by Federal Motor Vehicle Safety Standard 108 (FMVSS 108), which specifies minimum and maximum values of luminous intensity at approximately 20 test points given by the angles in degrees from the horizontal and vertical axis of the lamp. The minimum values are intended to insure the ability of drivers to see critical targets such as lane lines, signs, and pedestrians, whereas the maximum values are the countermeasure to control glare. Originally, FMVSS 108 had maximum limits but no minimum requirement for light output above the horizontal; recently, the standard was modified to require some minimum levels above horizontal so as to maintain the visibility of retro reflective overhead signs.

Research On The Low Beam Photometric Pattern:



There have been numerous attempts to improve low beam head lighting patterns, but, while these attempts have advanced understanding of the problem, a comprehensive solution has not been attained. The goal has been to develop a beam pattern that provides adequate visibility, such as of pedestrians, signs, lane lines, and obstacles, while at the same time minimizing glare for oncoming traffic and into rear mirrors. These efforts have included computer modeling, research, and policy efforts, a few of which are briefly described here.

In the 1970s, the Ford Motor Company supported the development of computer based visibility models that could be used to evaluate alternative lighting systems. In the 1980s, NHTSA became interested in developing a vehicle performance standard for head lighting that would improve safety while giving manufacturers more freedom in lighting design. These efforts contributed significantly to knowledge of roadway lighting, but did not result in any consensus for changes in FMVSS 108 due to disagreements over assumptions and methodological problems. Faced with difficulties in analytically evaluating headlamp performance and in defining a new performance standard, NHTSA turned its efforts to improving the aim of the beam patterns that presently exist. As a result, a revision was made to FMVSS 108 in 1997 that allowed for an optional 39 set of test points to improve objectivity and accuracy in the aiming of VOA headlamps. Currently, research is being conducted at the University of Michigan to develop a subjective rating of the photometric distribution of the forward illumination of different vehicles for different types of driving.

Headlamp comparisons with visibility models — beginning in the 1970s, researchers at the Ford Motor Company (Bhise et al. 1977) developed a computer model named CHESS (Comprehensive Headlamp Environment Systems Simulation) to evaluate the performance of low-beam head lighting

patterns. The model computes a weighted sum of several performance measures—including the fraction of pedestrians and delineation lines detected with and without an opposing glare car, and the fraction of drivers that were discomforted by glare—and so obtains a figure of merit (FOM) for each headlamp evaluated. The components of the FOM that the model computes are also useful performance measures by themselves. Basic inputs to the model for a headlamp evaluation include the headlamp beam pattern, height, and aiming; environmental variables, and driver vision variables.

Vehicle-based performance standard — One of NHTSA's primary goals has been to establish a set of vehicle specifications that could replace existing specifications that apply only to headlamps. In 1985, as part of its comprehensive review of FMVSS 108, NHTSA published a Notice of Request for Comment asking for suggestions on how to make the standard more performance-oriented and less design-restrictive. The goal was to reduce the burden on the regulated parties while simultaneously reducing the burden on NHTSA of responding to design-related requests for changes in requirements. Prior to this notice there had been an increasing volume of petitions from vehicle and headlighting manufacturers developing new headlighting systems. Another motivation for the review was concern that, because there were then no minimum requirements for headlamp light intensity above the horizontal, headlamps being introduced—mostly by European manufacturers— might not provide sufficient illumination for adequate visibility of signs.

Effects of Increasing the Intensity of the Low Beam Pattern — Flannagan et al. (1996) conducted an empirical study of the distance at which pedestrians could be seen, in which headlamp intensity was increased while the light intensity from an opposing glare vehicle was also increased proportionately. The study found that increasing the intensity of light from

both vehicles by a factor of 3.8 increased the visibility distance by 17%. This result is consistent with previous research (Hemion 1969a, Johansson et al. 1963), which found that visibility improved when high beams opposed high beams compared to situations when low beams opposed low beams.

**Need for Sign Illumination** — Lighting may be made more efficient by improving sign legibility, using larger, more readable letters and the most retro reflective sheeting available. Russell et al. (1999) concluded that with signs placed on straight and level roads and made of high-performance Type III sheeting, “better than 99% of the 1,500 vehicles observed would provide sufficient illumination for right-shoulder mounted signs and more than 90% of these vehicles would provide sufficient light for the left-shoulder mounted signs, but only about 50% of them would provide sufficient light toward overhead signs.” These figures dropped to 90%, 45%, and 10% for the more-common Type II sheeting, or if the Type III sheeting had been degraded for a few years. Sign legibility would be still less for older drivers; Russell defined “sufficient illumination” only in reference to younger drivers.

**Advantages to Altering the Low Beam Photometric Distribution:**

Altering the low-beam photometric pattern can reduce glare for on-coming drivers, improve the visibility of pedestrians, roadside objects, and left mounted and overhead signs, and make it easier to visually aim the headlamps. Achieving all three goals is generally not possible, so priorities must be set and tradeoffs made.

**Reduced glare:** Reducing light above the horizontal axis, for example by using the European beam pattern, can significantly reduce drivers’ exposure to glare.

**Improved visibility:** Requiring a minimum amount of light above the horizontal axis and to the left can improve the visibility of pedestrians as well as of

signs located to the left or overhead. This requirement has been implemented to some extent by the VOA beam pattern.

**Visual aiming:** Manipulating the beam pattern to have a recognizable horizontal cutoff makes it easier to visually aim the headlamps and to ensure that proper aiming is maintained. This can improve visibility as well as limit exposure to glare.

**Disadvantages to Altering the Lower Beam Photometric Distribution:**

The disadvantages of altering the low-beam photometric pattern are opposite the advantages: **Increased glare:** Attempts to provide light in certain locations for left-mounted and overhead signs can increase the level of glare, particularly when vehicles meet each other on horizontal curves.

**Reduced visibility:** The most significant disadvantage to lowering the photometric beam pattern or moving it more toward the right edge of the road is generally reduced sight distance and reduced visibility of left-mounted and overhead guide signs.

**Poor visual aiming:** Attempts to create a peak in the beam pattern to improve the visibility of certain 43 objects, such as overhead signs, reduce the accuracy of visual aiming and result in poor illumination of the desired targets on horizontal curves.

## **6. SAFETY MEASURES THAT REDUCE ILLUMINATION REACHING THE DRIVER’S EYE**

1. Polarized Lighting
2. Night Driving Glasses
3. Glare Screens
4. Anti-Glare Mirrors

### **Polarized Lighting:**

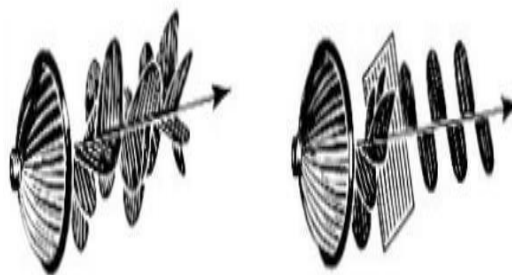
The technical development of a polarized headlight system consisting of polarizing filters on headlamps and a viewer filter on the driver’s eyes was begun by Edwin Land in the 1940s. Although polarized lighting on automobiles is still not

commercially available, extensive research was funded by the Federal Highway Administration (FHWA) in the 1960s. In reporting their research on polarized head lighting, Hemion, Hull, Cadena, and Dial (1971) describe the basic physics of polarized light.

Ordinary light, including light from an automobile headlight, consists of electromagnetic waves that vibrate in all directions perpendicular to the direction of the beam (Figure 5). When ordinary light passes through a polarizing filter, all of the light waves are absorbed except for those vibrating in a single plane (Figure 6) and the light becomes (linearly) polarized. The polarizing axis of a filter is the orientation of the electric or magnetic field of the light waves that are able to pass through the filter (for example, 45 degrees with respect to vertical).

The polarizer — The polarizing filter, or polarizer, can be made in different ways. The original polarizers of the 1940s were made from plastic sheets that were stretched to give their molecular structure a preferred orientation. These polarizers decreased visibility because they were inefficient and blocked out too much light. In addition, some of the original versions of the sheet polarizer were prone to overheating and degradation. Since the 1940s, more efficient ways of polarizing light have been found, some of which are summarized by Duncan (1996).

Scotch optical lighting film (SOLF) — SOLF is constructed from a pair of plastic sheets, each with a saw tooth cross-section on one surface, so that the saw tooth surfaces of the sheets are mated together to form grooves. Light polarized perpendicular to the grooves is transmitted and light polarized parallel to the grooves is reflected. While the original sheet polarizers absorbed light not matching the desired polarization axis, polarizers like SOLF redirect this light.



**Figure: 1 Ordinary Light produced by an automobile headlight. FIG: 2 Plane polarized light**

Liquid crystals — Liquid crystals with a helical structure are stacked into a filter so that the axis of the helix is perpendicular to the plane of the device. Liquid crystal filters are used to produce circularly polarized light, in which the plane of polarization rotates about an axis defined by the direction of the beam. Looking in the beam direction, the rotation can be either clockwise (left-hand circular polarization) or counterclockwise (right hand circular polarization).

Unpolarized light is a combination of right-hand and left-hand circular polarized components; when it passes through the liquid crystal filter, the component that is circularly polarized consistent with the curl of the crystal helix is reflected and the other component is transmitted. This type of filter will only affect light of a certain wavelength, letting all other wavelengths pass through unaffected. Therefore, in order to create a polarizer that will work for multiple wavelengths, different liquid crystal filters must be stacked together.

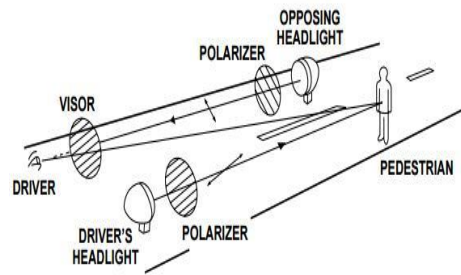
Technology	Manufacturing Complexity	Temperature Sensitivity	Efficiency	Chromatic Effects	Angular Effects	Total
Polaroid sheeting	5	1*	2	5	5	18
3M SOLF	2	5	5	3	3	18
Liquid Crystals	2	5	5	3	3	18
Polacor	5	5	2	5	5	22

**Table: 1 Relative Merit of Various Polarizer Technologies**

The polarized headlight system — A polarized headlight system can improve visibility for drivers by decreasing the amount of light from oncoming headlights. For this system to work, both vehicles must be equipped with the proper hardware. In the following description of the system, the beneficiary will be referred to as the “driver” and the opposing vehicle will be the source of the glare.

- A polarizer is placed over the opposing vehicle headlights with its polarizing axis at 45 degrees from vertical.
- Another polarizing filter is placed in front of the driver’s eyes with its axis parallel to that of the polarizer in front of the headlights. This polarizing filter is sometimes referred to as an analyzer.
- Both cars should have a polarizer and both drivers should have an analyzer.

Two types of analyzers were developed. One type, referred to as a visor, was a strip of sheet polarizer that was hung from the sun visor in such a way that its bottom edge intersected the line of sight from the driver to oncoming vehicles. When there was no visible opposing vehicle, the driver could look under the visor. Another type of analyzer took the form of either full- or half-glass spectacles. The half-glass type operated like clip on sunglasses and could be used in the same way as the visor. That is, drivers could look through the analyzer when a vehicle was approaching and through the bottom, unpolarized portion when the analyzer was not needed. The half-glass can be fitted over prescription glasses or over a pair of neutral glasses with no optical function (see Figure 8 below). The full-glass type, for use by passengers, is functionally identical to sunglasses.



**Fig: 3 Illustration of Polarized Lighting System**

In order to address the question of visibility during the transition period, Hemion (1969a) conducted experiments to determine the driver’s ability to see when vehicles equipped with polarization systems met vehicles not so equipped. Hemion measured disability veiling brightness and target detection distance for ten different cases.. Each case was ranked in terms of glare and relative visibility, with 1 being the best rank and 10 the worst. Hemion observed veiling brightness levels that ranged from 0.0046 foot-lamberts, in case 9, to 4.9 foot-lamberts, in case 1A. In only one case was the visibility reduced measurably from the normal low beam-to-low beam meeting, namely when the glare car was on low beam and the subject car was on polarized low beam with an analyzer in use. Hemion surmised that this case would be rare in practice because the subject driver would realize that the opposing car did not have polarized lights and would stop looking through the analyzer. Visibility was improved in four of the nine cases, all involving a modified vehicle, compared to unmodified high beam-to-high beam or low beam-to-low beam meetings. Hemion concluded that, “It appears that improved visibility of roadside obstacles will be achieved from the beginning of the period of transition to polarized lighting with greater and greater improvement as more vehicles are converted.”

Mode	Glare Car	Subject Car	Relative Glare	Relative Visibility	Mean Detection Distance, feet
1A	HiB*	HiB	10	5	305
1B	LoB	LoB	8	7	255
2	HIP w/A	HIP w/A	2	2	469
3	HiB	HIP w/A	9	9	208
4	HIP w/A	HiB w/A	3	3	442
5	LoB	LoBP w/A	5	10	146
6	HIP w/A	LoB w/A	4	8	231
7	LoB	HIP w/A	7	1	479
8	LoB	HIP w/A	6	4	433
9	LoBP w/A	LoB w/A	1	6	293

**Table: 2 Target Visibility**

□ HiB – High Beam, LoB – Low Beam, HI – High intensity, P – Polarized, w/A – with analyzer for driver, wo/A – no analyzer for driver.

### Advantages

There are numerous advantages to a polarized headlight system, all of which are just as applicable today as they were thirty years ago, when the research was performed.

### Disadvantages

The disadvantages associated with polarized headlights seem to be minor, and a solution to each is presented below. The only major disadvantage of the system is the difficulty in implementing it.

## 7. NIGHT-DRIVING GLASSES

A distinction must be made between night driving glasses that are aimed at attenuating night myopia and those marketed specifically as roadway glare reducers. The former are untinted and include a small diopter lens correction (like that in prescription lenses) to counteract the intraocular lens's natural inclination to return to its tonus, or 59 resting position, in the absence of accommodative stimuli (i.e., something to focus on). At night, many people with normal vision tend to become myopic and many myopes tend to become even more nearsighted (Leibowitz and Owens 1976). Night-driving glasses for glare reduction are structurally and functionally very similar to sunglasses and, in fact, some models are merely a remarketing of what was originally a

pair of sunglasses. Like sunglasses, these glare-blocking glasses work by filtering light prior to its reaching the driver's eye. Many models use color filters to eliminate short-wavelength or "blue" light and so have a yellow tint.

Some are full-sized, some fit over prescription glasses, and others are smaller, filtering only a thin strip of light in the upper portion of the eye. A unique model developed in the 1950s (Bryan 1962), called "Nite-Site," used a green, ring-shaped filter that was affixed to prescription lenses so that the observer looked through the clear center.

The filter was purported to "...cause a shadow effect to fall across the pupil to eliminate the oncoming glare of headlights...." Another lens, described by Adrian (1979), had a clear circular center large enough to transmit light with a glare angle of less than 5 degrees surrounded by a shaded area that gradually increased in transmission according to the glare angle squared, so that the wearer could view glare from oncoming traffic through the shaded area. In most cases, the shading was not uniform over the ring, but only covered the sector in which glaring headlamps usually occur.

## 8. GLARE SCREENS

On divided highways without independent alignment or large medians, glare screens placed in the median of the roadway could be a cost effective way to reduce glare from opposing traffic. Screens can improve safety in temporary work zones, where lanes can be narrow and only a concrete barrier separates opposing traffic. Under these circumstances, blocking glare from oncoming headlights will dramatically increase the visibility of the concrete barrier and the delineation of the lane ahead. The National Cooperative Highway Research Program Report 66 (NCHRP-66 1979), a report of the Transportation Research Board, includes descriptions of the different types of glare screens and the advantages and disadvantages of each.

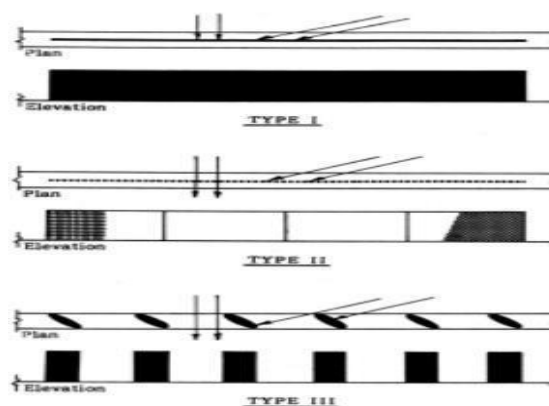
NCHRP-66 defines a glare screen as “. . . a device placed between opposing streams of traffic to shield drivers’ eyes from the headlights of oncoming vehicles. . .” (pg. 2). A glare screen can be any type of object of a certain width and placed at a certain spacing that will prevent glare from reaching drivers’ eyes. The object may be opaque or have intermittent openings that allow a view of the opposing lanes while at the same time screening out light at angles less than 20 degrees from the driver’s eye.

# TO BE EFFECTIVE, GLARE SCREENS SHOULD:

- Reduce a large portion of the glare.
- Be simple to install.
- Be resistant to vandalism and vehicle damage.
- Be repaired quickly and safely.
- Require minimal cleaning and painting.
- Accumulate a minimal amount of litter and snow.
- Be wind resistant.
- Have a reasonable installation and maintenance cost.
- Have a good appearance.
- Allow for emergency access to opposing lanes.



**FIG: 4 Paddles at angles less than 20 degrees appear to present a solid screen from the driver’s view.** (Courtesy glaregaard.com)



**Fig: 5 Plans and Elevations of Glare Screen Types I, II, and III**

Other types of glare screens not included in any of the above categories include plants and guardrails. Plants are suitable glare screens on curves in wider medians as part of a general landscaping effort. Back-to-back guardrails will block glare, but they may not be effective in blocking all of the light from an oncoming vehicle since they are only 27 to 33 in high. Some characteristics of the different types of screens are given by NCHRP-66

Characteristic	Type I	Type II	Type III
Prevent gawking accidents	yes	no	no
Prevent pedestrian crossings	yes	yes	no
Prevent slush & other objects from being thrown into opposing lane	yes	yes	no
Permit police surveillance of opposing lanes	no	yes	yes
Permit access to opposing lanes by emergency personnel	no	no	yes
Permit scenic viewing	no	yes	yes

**Table: 3 Characteristics of Different Types of Glare Screens. (Nchrp 1979)**

# SAFETY MEASURES THAT INCREASE THE GLARE ANGLE

- INCREASED MEDIAN WIDTH
- INDEPENDENT ALIGNMENT

# MEDIAN WIDTH

The American Association of State Highway and Transportation Officials (AASHTO) defines the median as that portion of a divided highway separating the traveled way for traffic in opposing directions (AASHTO 1994). AASHTO also defines the principal functions of medians: “to separate



opposing traffic, provide a recovery area for out-of-control vehicles, provide a stopping area in case of emergencies, allow space for speed changes and storage of left-turning and U-turning vehicles, minimize headlight glare, and provide width for future lanes” (AASHTO, 1994). Medians can be depressed, raised, or flush with the traveled way surface, and they should be highly visible during both day and night. The width of the median is defined as the distance between the through lane edges, including the left shoulders. Soaring traffic volumes after World War II created a need for the immediate design of many highway facilities. In response to the urgent need, designers often relied on rules of thumb in their approach to median design, some of which have proven to be incorrect. According to Hutchinson et al. (1963), “these experiences have greatly stimulated research on median performance and factors of influence in median design.” Among the “factors of influence” are benefits such as safety, comfort, and convenience. At the time of the report, the extent to which medians could provide these benefits was “more a matter of opinion than of record,” and so it was difficult to use safety or comfort to justify any cost increases involved in varying the median width. This left the choice of basic median width an administrative decision, to be backed by engineering judgment.

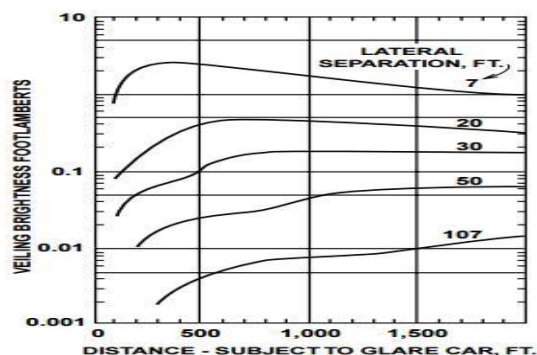


FIG: 6 DISTANCES - SUBJECT TO GLARE CAR, FT.

	General Set-up of Experiment	Results
Study 1	The opposing glare car and the target were stationary; the subject drove toward the target and indicated when he could detect it. Subjects also indicated when they experienced discomfort glare.	The distance at which the target was detected increased with lateral separation and approached those of a no-glare condition at a lateral separation of approximately 80 ft. The distance from the opposing car at which the subjects reported discomfort glare generally increased as lateral separation was decreased.
Study 2	The target and the test subject were stationary and the glare car moved toward the subject. The subject reported at what point he could and could not see the target.	For some runs with small lateral separations, the target was not visible until after the glare car passed the subject car. For some larger lateral separations, the target was visible during the entire run.
Study 3	The target and the subject car were stationary and the glare car moved toward the subject. As the glare car approached the subject, the subject varied the brightness of the target so that it remained at the threshold of visibility.	At a given distance from the subject car to the glare car, the brightness necessary to maintain threshold visibility decreased as the lateral separation increased.

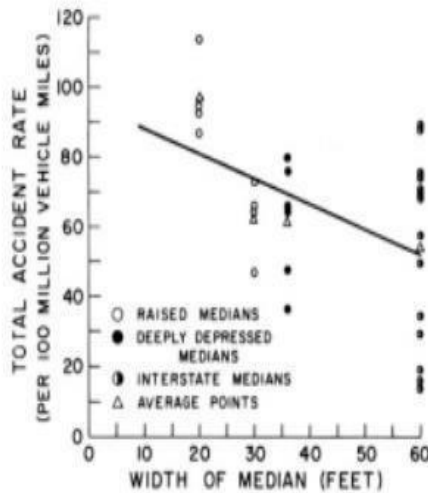
TABLE: 4 SUMMARIES OF STUDIES BY POWERS AND SOLOMON

The Garner and Deen results were confirmed by Knuiman, Council, and Reinfurt (1993), in a study that examined the effect of median width on the frequency and severity of accidents in homogeneous highway sections. Data for this study were obtained from the Highway Safety Information System (HSIS) for the states of Utah and Illinois. A total of 3,055 miles of highway where there had been 93,250 accidents between 1987– 1990 was used for analysis. The median widths along roadways in the study ranged from zero (no median) to 110 ft. Overall, the study found that accident rates do decrease with increasing median width.

## 9. INDEPENDENT ALIGNMENT

Independently aligned roadways are those with horizontal and vertical alignments developed independently to suit location and design requirements (Peet and Neuzil, 1972). Independent alignment places each roadway at a different elevation, with a variable amount of separation between the different directions of travel, in contrast to a narrow-median design, where each roadway is at or near the same elevation and a constant distance apart. With independent alignment, the driver on one roadway might not even see an approaching vehicle on the other roadway—which, of course, eliminates glare entirely.

Since independent alignment is used when there is a large median width, it provides all of the advantages of a wide median and more. Peet and Neuzil (1972) compared narrow median design with independent alignment and listed several advantages for independent alignment, which are shown below.



**Fig: 7 Width of Median (Ft)**

### 3.7 SAFETY MEASURES THAT INDIRECTLY MINIMIZE THE EFFECTS OF GLARE

1. Ultraviolet Headlights / LED Lights
2. Fixed Roadway Lighting
3. Restricted Night Driving
4. Corrective Lenses And Ophthalmic Surgery
5. Headlamp Area
6. Plantation
7. Light absorbing agents
8. Providing extra width for the divider

#### ULTRAVIOLET HEADLIGHTS/ LED Lights

Ultraviolet (UV) head lighting has the potential to reduce glare on the highway by reducing the need for visible light. Although not itself visible, UV radiation (UVR) can improve nighttime visibility of pedestrians, lane lines, signs, and other objects on the road. Either replacing high-beam headlamps with UV headlamps or modifying the low-beam photometric in a UV-enhanced lamp (perhaps using a European beam pattern) could eliminate much of the glare experienced by drivers of oncoming vehicles

and still maintain visibility. Even without any reduction in glare from visible light, disability glare effects may be reduced by the improved visibility. Ultraviolet radiation cannot be seen by most human observers, but, when it is absorbed by certain materials, UV is converted to longer-wavelength visible light. This phenomenon, called fluorescence, makes objects more easily seen and is the reason that UV headlamps have the potential to improve highway safety. Unlike standard automobile headlamps, UV headlamps' intensity and alignment can be adjusted to optimize visibility without concern for glare. UVR ranges from approximately 4 nm to 400 nm wavelength, but UV headlamps operate in the relatively long-wavelength UVA band, which ranges from 320 nm to 400 nm. The cornea and aqueous humor of the human eye absorb all UVR below 300 nm (Kinsey 1948) and approximately 50% up to 365 nm (Zigman 1983); the healthy adult lens absorbs nearly all of the remaining UVR (Ham, Mueller, Ruffolo, and Guerry 1980, Zigman 1983). However, two groups of individuals do experience significant transmission of UVA and perceive it as light: youths under the age of ten (Lerman 1983) and the elderly who have undergone eye surgery to remove and/or replace a lens (Anderson 1983, Sliney et al. 1994, Wald 1945, Zigman 1983).

- Develop a UVA headlamp specification
- Evaluate fluorescent infrastructure materials
- Quantify the glare and photo-biological risks
- Perform a cost/benefit analysis
- Conduct a demonstration and implementation of the system

#### PLANTATION:

Continuous plantation of trees & cutting heights in the form of a continuous block & providing some observing agents.



### **FIXED ROADWAY LIGHTING:**

In the U.S., fixed roadway lighting is generally designed according to one of the three methods described in the American National Standard Practice for Roadway Lighting (RP-8 2000), each based on illuminance, pavement luminance, or visibility. Fixed roadway lighting is installed for many reasons, including reduction in nighttime accidents (primarily on major arterial roads and freeways), pedestrian safety, crime reduction, and area ambience (on urban streets and areas with significant retail activity at night). In addition to these specific purposes, a secondary benefit of fixed roadway lighting is the mitigation of the effects of headlight glare.

During daylight, headlight glare is generally not a problem because of high visual adaptation in bright ambient light. At night, a driver's adaptation level is much lower and headlight glare becomes a problem. Adaptation level is determined by the entire visual environment, which can include the surrounding ambient lighting in visually complex areas, the steady stream of oncoming headlights, or the luminance of the pavement in areas without much traffic or ambient lighting. Fixed roadway lighting is a countermeasure against headlight glare whenever pavement luminance is a significant factor in determining the driver's adaptation level.

The effectiveness of fixed lighting systems in reducing night accidents has been evaluated by using daytime accidents as the basis of comparison between sites with different lighting systems and by comparing the accident rate at a given site before and after a change in lighting. These studies have invariably indicated that the night accident rate is reduced when supplementary fixed lighting systems are installed. According to RP-8:

The nighttime fatal accident rate is about three times the daytime rate based on proportional vehicular kilometers/miles of travel. This ratio can

be reduced when proper fixed lighting is installed because these lighting systems reveal the environment beyond the range of the vehicle headlights and ameliorate glare from oncoming vehicles by increasing the eye's adaptation level...the IESNA Roadway Lighting Committee is of the opinion that the lighting of streets and highways generally is economically practical. These preventive measures can cost a community less than the accidents caused by inadequate visibility.

According to the National Safety Council (1999) the nighttime traffic death rate in 1998 was 4.4 times the day rate. Of the 18,874 nighttime traffic fatalities in 1998, over 56% took place on rural roads. Surprisingly, although vehicle mileage is less on rural than on urban roads and even less at night, the nighttime rural death rate for the past decade has consistently been three times the rural day rate and 2.5 times the urban nighttime death rate. According to Keck, Wortman concluded that fixed lighting was warranted on a cost-benefit basis whenever the night-day ratio exceeds 3.0. Using this standard, there are likely to be many rural locations that would benefit from lighting; once in place, the lighting would also help mitigate the effects of glare.

### **RESTRICTED NIGHT DRIVING**

Throughout this report, countermeasures aimed at reducing or eliminating glare have been inventoried and evaluated. These remedies have dealt mainly with changing the glare source (for example, by intensity reduction or wavelength modification) or altering the conditions through which the light passes (such as those in windshields and ocular media). However, there is no glare problem that does not involve the performance loss or increased discomfort of a human operator. Discomfort and disability glare are not the inherent characteristics of a light source, but rather are the result of an interaction between light source, environment, and observer—and with regard to glare sensitivity, not all observers are

created equal. Therefore, one countermeasure which would alleviate at least part of the glare problem is to enforce or encourage night driving restrictions on those most sensitive to glare. This could be done through law or by means of self-imposed behavioral changes, as advocated by driving improvement programs aimed at older adults.

- Record keeping
- Equipment costs and maintenance
- Staffing
- Staff training
- Overhead (room costs and so on)
- Applicant time

## ANALYSIS & CONCLUSION

1. This report has discussed a wide range of countermeasures that could help mitigate the effects of headlight glare on the vision and discomfort of drivers at night. Many of these countermeasures are effectively used today, but some proposed solutions have regulatory and technological hurdles to surmount before they will be able to resolve the most intractable problems with headlight glare.

2. Within this report, countermeasures were grouped according to method of operation, including such approaches as reducing intensity, reducing illumination, increasing the glare angle, and providing an indirect benefit by some other means.

3. This section will provide a summary of these countermeasures, grouped by who should and who can take a particular action. This section will conclude with a discussion of the research needed to develop and/or justify the use of some of these countermeasures.

4. Research appears to show that, for most individuals, night-driving glasses are not an effective solution to the glare problem. What is gained in the reduction of discomfort is lost in visibility. This conclusion applies to both full-eye glasses and half-

glass analyzers that allow the driver to look through the analyzer only on demand.

5. Although one study suggested that discomfort glare had little effect on driving performance, the measurements of performance were entirely psychomotor and not visual. Research is needed to better understand the relationship, if any, between discomfort and eye fixations, attention, and fatigue.

6. The conclusion that the loss in visibility from wearing night-driving glasses is not offset by the reduction in discomfort is grounded in the assumption that discomfort results in no immediate performance deficit other than its effect on visibility and the annoyance it causes. This assumption originated in the laboratories and may not be valid on the highway, where people behave differently than they do when sitting in a research laboratory.

7. In addition, although we know how driving affects their rating of discomfort, we do not know how discomfort glare affects eye fixations, attention, and fatigue. There is research that suggests that drivers' eyes are attracted to light but are drawn away from glare sources. Additional research is needed to support or deny the assumptions being made and the conclusion that night-driving glasses (including half-glass analyzers) have no value for anyone driving at night.

8. Countermeasures That Will Require Government Involvement Include:

- Changing Beam Photometric Distribution.
- Maintenance Of Headlight Aim.
- License Restriction.
- Ultraviolet Headlights.
- Polarized Head lighting.

9. It seems that polarized lighting is the only countermeasure for headlight glare which has the potential to be used in all situations and resolve all problems. Research has shown that headlamp intensity must be doubled before polarized lighting

would be feasible; however, HID lamps offer three times the intensity of ordinary headlamps and can easily meet this requirement.

10. Thus, the only remaining challenge is developing a strategy for implementation.

## 10. CONCLUSIONS

1. One countermeasure that has been proposed is the elimination of HID lamps. The application of HID in both the UVA and polarized headlamp systems is a reason to remain active in this technology, but the elimination of low-beam HID lamps by government regulation may be an appropriate step to control glare, if these lamps are indeed the source of glare problems. Although HID lamps offer an enormous increase in visibility, they can also result in a comparable increase in glare.

2. Properly aimed and cleaned, they should be able to deliver improved visibility without excessive glare on roads without curvature; however, if these lamps become dirty, are misaimed, or are encountered on vertical or horizontal curves, the amount of glare can exceed levels considered tolerable. Such conditions result in glare with all headlamps, but the greater flux from HID sources will produce more glare when the lamps are dirty, and their greater illumination on some beam angles will result in more glare if they are misaimed.

3. If HID lamps are kept aimed and clean, they are likely to produce a net gain in performance and visibility with minimum discomfort; but if such steps are not taken, their removal from U.S. highways may be an appropriate countermeasure. This point was clearly made by Schoon & Schreuder (1993).

4. Still, the proper operation or removal of HID lamps will not solve all problems of headlight glare, nor would universal participation in older driver training courses. The design and selection of countermeasures for headlight glare are included in the basic tradeoffs that are incorporated in the design of headlamps.

5. The U.S. standard design, compared to the European standard, favors visibility over glare. The U.S. standard, which began as a conceptual exercise, has, over time, determined the design of traffic control devices. Many devices have been designed under the assumption that they will receive minimum levels of illuminance from headlights at the same locations in the beam pattern that also illuminate mirrors or the eyes of drivers in oncoming vehicles.

6. In this way, the highway infrastructure places restrictions on any manipulation of the beam pattern to reduce glare. Each countermeasure discussed in this report offers limited benefits in special situations, but, as stated earlier, only polarization provides a global solution. We hope that research in that area will go forward with as much dedication as is being devoted to the research and development of UVA and of adaptive head lighting.

7. It is not possible to recommend one countermeasure that would eliminate discomfort glare for everyone in all situations without unacceptable negative consequences for visibility and safety. However, a number of the countermeasures discussed can be implemented with minimal cost or with costs offset by benefits other than glare reduction.

8. Fixed roadway lighting, glare screens, and wide medians are, in certain situations, cost effective methods of accident reduction regardless of their effect on adaptation and glare. It would make the most sense to start simply by initiating those strategies that can be implemented with minimal or no cost.

## REFERENCES

1. AASHTO (1994). A policy on geometric design of highways and streets, American Association of State Highway and Transportation Officials, Washington, DC pp. 136-137.
2. Adler, B. and Lunenfeld, H. (1973). "Three-beam headlight evaluation." Report no. HS-238-411-1, Airborne Instruments Laboratory, Deer Park, NY.
3. Adrian, W. K. (1975). "Grundlagen der physiologischen und psychologischen Blendung und ihre numerische Darstellung" (Fundamentals of disability and discomfort glare and their numerical representation). *Lichttechnik* 27, 312-319.

4. Adrian, W. K. (1979). "Ueber eine neuartige Blendschutzbrille" (On a new anti-glare spectacle). 30. Sonderdruck der WVAO, Mainz. Die Fachvorträge des WVAO - Jahres Kongresser 1979 in Karlsruhe (ISSN 0171-6417), pp. 243–251.
5. Adrian, W. K. (1991a). "Transient adaptation process: A model to predict its effects on vision." CIE 22nd Session, 2, 121–133. CIE transactions of the International Commission on Illumination, 22nd session. Melbourne 1991, Vol 2, pp 121–133.
6. Adrian, W. K. (1991b). "Comparison between the CBE and the CIE glare mark formula and earlier discomfort glare descriptions." Proceedings of the First International Symposium on Glare, Orlando, Florida, pp. 155–164.
7. Adrian, W. (1997). "A method to predict visual function and visual performance in mesopic lighting levels." University of Waterloo, Ontario, Canada.
8. Adrian, W. and Bhanji, A. (1991). "Fundamentals of disability glare. A formula to describe stray light in the eye as a function of the glare angle and age." Proceedings of the First International Symposium on Glare, Orlando, Florida, pp. 185–194.
9. Alexander, G. J. and Lunenfeld, H. (1990). "A users' guide to positive guidance, third ed." Report No. FHWA-SA-90-017, U.S. Department of Transportation, Federal Highway Administration, Washington, DC pp. 1–39.
10. Applegate, R. A. (1991). "Acuities through annular and central pupils after radial keratotomy (RK)." Optometry and Vision Science, 68, 584–590.