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A Transportation Lighting Alliance Report

Vehicle Forward Lighting: Optimizing for Visibility and Comfort

A Transportation Lighting Alliance Scoping Study

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Abstract

This report outlines a literature review performed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute to identify opportunities and to suggest priorities for further understanding of vehicle forward lighting and how it can be best optimized for visibility and comfort.

Keywords: ....automotive, headlamp, lamp, intensity, HID, halogen, color, comfort, glare, visibility, beam

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ABSTRACT

This report outlines a literature review performed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute to identify opportunities and to suggest priorities for further understanding of vehicle forward lighting and how it can be best optimized for visibility and comfort.

INTRODUCTION

This report outlines a literature review performed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute to identify opportunities and to suggest priorities for further understanding of vehicle forward lighting and how it can be best optimized for visibility and comfort.

Responses to Lighting

Forward lighting on vehicles serves a number of objectives that are to be met simultaneously for the vehicle driver and other roadway users. These include:

- providing adequate forward visibility on and along the roadway
- providing peripheral visibility so that potential hazards not yet along the roadway can be detected
- maximizing driver comfort while minimizing discomfort to other drivers
- providing attractive appearance

These responses serve as the end objectives of lighting from the user's point of view. In order to meet these objectives, lighting systems must be developed with the appropriate characteristics.

Characteristics of Lighting

It is not enough to say simply that a forward lighting system should "provide adequate forward visibility" or "maximize comfort." In order to meet these objectives, specific aspects of lighting can be manipulated. These aspects form the palette of the lighting system designer, and include:

- intensity or illuminance
- aim and shape of the beam pattern
- location and mounting height of the light sources
- effects of dirt and water
- spectral power distribution or color
- system life and reliability

One of the objectives of the present report is to summarize existing information about these characteristics of lighting and to prioritize them in terms of their relative importance at meeting the objectives of lighting listed above, and the relative ease with which these aspects of lighting can be changed or modified. Such information will assist members of the Transportation Lighting Alliance in working together to optimize forward lighting systems.

Research Methods

The information summarized in this report is based on a combination of techniques and methods, including:

- analytical methods based on calculation using existing models of expected performance
- short-term laboratory and field study methods, directly measuring lighting or testing human responses to lighting
- long-term laboratory and field study methods, using simulation or observational techniques to understand how responses might change under long-term exposure to different lighting conditions

In the present report, each of the characteristics or aspects of forward lighting are discussed with respect to the different methods of understanding them. Brief summaries of important investigations of these aspects of lighting are also provided. A summary section at the end of the report provides recommendations for areas offering the greatest potential value for the design and optimization of forward lighting.

INTENSITY AND ILLUMINANCE

Analytical Methods

One of the most important factors related to the success of forward lighting systems is he intensity (or illuminance) the system provides. A number of quantitative models for predicting visual performance as a function of light level exist. One of the most important is the relative visual performance (RVP) model (Rea and Ouellette, 1991), which provides a prediction for the speed and accuracy of visual processing as a function of adaptation level, target size and contrast, and observer age. Another model used widely in the specification of roadway lighting in North America is the small target visibility (STV) model. Interestingly, this model does not incorporate the effects of headlamps, but it was found recently (Keck, 2001) that while the prediction for visibility provided by STV is not correlated with vehicle crashes, a modification of the model to incorporate headlamp illumination did result in a small but significant correlation with vehicle crashes, underscoring the importance of considering all roadway visibility elements.

In terms of peripheral visibility, few data are available upon which to make predictions. One recently developed model, still in preliminary form, uses the results of a series of similar investigations of forward visibility under headlamps and data on the detection of small targets located throughout the peripheral field of view. Combining results in this way provided a robust data set that provided a predictive model for peripheral visibility under different types of headlamp beams (Bullough, 2002).

Of course, not only forward visibility, but the potential for disability and discomfort glare are impacted by the intensity of a forward lighting system. Formulae for the prediction of disability glare (Fry, 1954) have been found to quite accurately predict the reduction in visibility that are caused by oncoming headlamps in the field of view. Similar formulae exist to predict the extent of discomfort felt under oncoming headlamp illumination (Schmidt-Clausen and Bindels, 1974), since discomfort and reduced visibility do not necessarily go hand in hand.

Laboratory and Field Methods

The study of forward visibility using field methods is common and generally, have used techniques like the measurement of reaction times and missed targets (Van Derlofske et al., 2001, 2002) and target visibility distance in the field of view (Hamm and Steinhard, 1999). These results generally are in agreement with model predictions.

One technique for assessing long-term performance and impacts of forward lighting involves the use of surveys and questionnaires to gauge drivers' acceptance and opinions about forward lighting. A recent survey of snowplow operators to ask what types of forward lighting were most suitable when driving in snow were fond to exhibit excellent agreement with field studies comparing different forward lighting configurations (Eklund et al., 1997).

AIM AND SHAPE OF THE BEAM PATTERN

Analytical Methods

One approach to understanding the impact of forward lighting beam patterns and aim is to quantify the types of forward lighting beam patterns used in a given jurisdiction. Market-weighted beam patterns providing average intensity values for a range of angles (i.e. Schoettle et al., 2001) provide useful analytical tools for estimating typical forward lighting configurations on the road. These data could be used in turn with models providing predictions of visibility and other responses. For example, Bullough and Rea (1997) developed a model to predict the impact of beam shape and aiming on subjective impressions of visibility and comfort while driving in poor weather. Such models and tools will be useful in the study of adaptive beam patterns that can adjust in responses to changes in the ambient environment.

Laboratory and Field Methods

The basis for many models to assess aim and beam pattern effectiveness will often need to be field studies where these patterns can be replicated most accurately. Comparisons of different beam pattern types for the distance at which targets can be detected is one such approach (Flannagan et al., 1995). Other responses to beam patterns might also be important, such as comfort while driving or even aesthetic appearance while performing a test drive. Studies of subjective impressions of headlamp beam uniformity have shown that this characteristic of lighting is often seen as important in providing visibility and maintaining visual comfort while driving (Schumann et al., 1997).

LOCATION AND MOUNTING HEIGHT

Analytical Methods

The mounting location and height of forward lighting sources can have a significant impact on driver visibility and comfort. Analytical tools for the assessment of the effects of these parameters include the model, described above, by Bullough and Rea (1997) to predict preferences of forward lighting as a function of mounting location, which in turn impacts the distance of the source from the line of sight. This factor is found to determine the intensity of back-reflected light in snow and fog conditions.

A simulation-based approach to predicting the effectiveness of forward lighting configurations was developed and refined by Mortimer (1974). Based on actual photometric measurements and responses to targets in field studies, a scenario-based simulation tool was developed that could then be used to compare various lighting configurations without conducting additional field studies.

Laboratory and Field Methods

Measurements of the range of conditions that can be experienced in the field is a useful approach to characterizing lighting. Field measurements of headlamp height and separation (Sivak et al., 2001) can provide data that will in turn support more refined laboratory and analytical approaches to studying lighting.

DIRT AND WATER

Analytical Methods

Few studies, if any, have provided tools for calculating or predicting the impact of dirt and water on forward lighting system performance.

Laboratory and Field Study Methods

All lighting and visibility systems along the roadway will undergo inevitable reductions in visibility caused by dirt or by water introduced by rain. These phenomena simultaneously reduce the illuminances produced by lighting systems in the points of their maximum intensity, reducing forward visibility, and increase illuminances along the points of their minimum intensity, potentially increasing glare. Studies of other visibility elements (e.g., signs, see Colomb and Michaut, 1986) can perhaps be useful in better understanding the effects of dirt and water on headlamps.

Of interest, a number of jurisdictions already require the use of headlamp cleaning devices in conjunction with certain headlamp technologies such as high intensity discharge headlamps. Thus the problem might be one of implementation countermeasures rather than changing lighting to adapt to conditions of dirt or water.

SPECTRAL POWER DISTRIBUTION

Analytical Methods

For forward visibility in terms of color rendering, the commonly accepted industry metric for predicting the ability of a light source to render colors well is the color rendering index (CRI) (Rea, 2000). In effect, this metric compares a light source's ability to render colors similarly to a reference source, either an incandescent lamp (for a yellowish-white source) or daylight (for a bluish-white source), not necessarily one's ability to accurately identify colors under that source. The gamut area metric (Boyce, 2003) appears to better predict the ability of a light source to result in accurate color identification.

In terms of forward visibility, spectrum can play a role at mesopic light levels, where both cones and rods provide visual input, for peripheral vision (He et al., 1997). In fact, a model of photometry for mesopic light levels typically experienced while driving at night has been developed that quantitatively takes into account the impact of spectral power distribution on peripheral vision. Of interest, since only cones and no rods are found in the central part of the human retina, mesopic vision does not apply for on-axis visual tasks such as reading or detecting objects in the center of the roadway.

Laboratory and Field Methods

Color naming accuracy is a useful technique for assessing the impact of a light source to assist in proper identification of colors. A study using this technique (McColgan et al., 2002) demonstrated that there were no differences among halogen, high intensity discharge and coated halogen lamps in color naming accuracy despite their large differences in color rendering index.

As with the study of illuminance and intensity, experimental methods such as the measurement of reaction times and target detection have been used to successfully tease out the impact of spectral power distribution on peripheral visibility (He et al., 1997; Van Derlofske and Bullough, 2003).

In terms of glare, spectral power distribution has been demonstrated in several field and laboratory studies using these methods to have no significant impact on either on-axis or peripheral visibility. The same is not true for discomfort glare using subjective ratings of discomfort on scales such as the De Boer scale. Various studies in the laboratory and the field have shown that high intensity discharge headlamps resulted in somewhat greater discomfort even at the same illuminance (Bullough et al., 2002; Flannagan, 1999).

SYSTEM LIFE AND RELIABILITY

Analytical Methods

Different forward lighting technologies have widely differing life and reliability characteristics. Filament-based halogen lamps have been the basis for headlamps for several decades, but increasing use of high intensity discharge headlamps (Jost, 1995) and the potential future use of light emitting diodes (Van Derlofske and McColgan, 2003) will result in very different assumptions for lamp and system life than are presently common. Rated life of these technologies is a thorny question given the very different operating conditions these systems undergo, in comparison to the relatively benign conditions they are often tested under.

Laboratory and Field Methods

It is important, in understanding life and reliability issues, to be able to quantify the actual hours of operation for which forward lighting is used. Observations of headlamp usage as a function of daylight availability (Boyce and Fan, 1994) can provide useful data in making accurate predictions.

Understanding life and reliability issues is also important because failure of a headlamp, for example, can be unnoticed for quite some time by a vehicle user, but will often result in significant reductions in visibility of objects along the roadway, such as traffic signs (Zwahlen et al., 1990).

DISCUSSION

The previous discussion of the various aspects of lighting, in the context of the types of responses that are important and the types of methods that can be used to assess their optimal characteristics, can be used to provide a preliminary assessment of the relative importance of each aspect at affecting visibility, comfort and appearance. Of course while some of these aspects will be more important than others, it is equally important to understand the methods that are available to investigate and address these aspects. To this end, Table 1 lists each of the aspects of lighting discussed in previous sections of this report, their relative importance in providing visibility, comfort and appearance, and the relative ease with which these aspects can be studied or addressed in forward lighting configurations.

Aspect	Significance of aspect	Ease of addressing
intensity/illuminance	high	medium
aim/beam shape	high	medium
location/mounting height	medium	high
dirt/water	low	high
spectral power distribution	medium	medium
life/reliability	medium	medium

Table 1. Relative Importance of Forward Lighting Aspects to Visibility, Comfort and Appearance

The literature review provided in this report demonstrates that there are several important areas where gaps in knowledge exist and where future study would likely be fruitful:

- Long term effects of driver comfort. Few of the methods used to evaluate the characteristics of forward lighting move beyond short-term, immediate impacts of lighting systems. Lighting conditions that are uncomfortable might only result in degradation in performance after several hours of use or longer; most studies do not use extended periods of time.

- Improved understanding of peripheral vision. Studies of mesopic vision, for example, show that spectrum and other factors play important roles in visibility in the periphery. Most recommendations for lighting in the driving task address only on-axis vision.

- Interactions between forward lighting and ambient (fixed) roadway lighting. Recommendations for lighting typically address only one "mode" of lighting or visibility, but as described above, these are known to interact.

The literature reviewed in this report point to these areas as ones in which collaborative research activities can have the greatest impact.

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ANNOTATED REFERENCES

A. Importance of Lighting

1. Lighting, Visibility and Crashes

Gimbel HV, Van Westenbrugge JA, Johnson WH, Willerscheidt AB, Sun R, Ferensowicz M. 1993. Visual, refractive, and patient satisfaction results following bilateral photorefractive keratectomy for myopia. Refractive and Corneal Surgery 9; S5-S10.

- most patients having refractive surgery reported little or no problems with nighttime driving

Hemion RH. 1969. A Preliminary Cost-Benefit Study of Headlight Glare Reduction, Report AR-683. San Antonio, TX: Southwest Research Institute.

- accidents in which headlight glare (or "blinding by headlights") could be stated as a cause numbered around 1% (or slightly less), based on results from several U.S. states

Olson PL, Aoki T, Battle DS, Flannagan MJ. 1990. Development of a Headlight System Performance Evaluation Tool, Report UMTRI-09-41. Ann Arbor, MI: University of Michigan.

- an average adaptation luminance of 1 cd/m2 while driving at night is derived

2. Accident Statistics

National Safety Council. 2002. Driving at Night.

- traffic death rates are three times greater at night than during the day; 90% of a driver's reaction depends on vision, and vision is severely limited at night; depth perception, color recognition, and peripheral vision are compromised after sundown

Opiela K, Andersen CK, Schertz G. 2003. Driving after dark. Public Roads 66(4).

- the fatal crash rate for nighttime driving is three to four times that for daytime driving according to data in Traffic Safety Facts 2000
- an analysis of the Fatality Analysis Reporting System (FARS) data for 2000 reveals that: (1) 49% of all fatal crashes occur at night; (2) 81% of fatal crashes occur on dry pavement, both day and night; (3) 40% of all fatal crashes involve alcohol as a factor, with more than 60% of those occurring at night; and (4) problems with driver vision, vehicle hardware, or environmental conditions are cited as "related factors" in 15% of all fatal crashes
- based on estimates of vehicle miles traveled, the overall nighttime crash rate is approximately 1.6 times that of the daytime rate, while the fatal crash rate is three to four times greater at night

Hakamies-Blomqvist L. 1994. Compensation in older drivers as reflected in their fatal accidents. Accident Analysis and Prevention 26(1): 107-112.

- relatively fewer accidents of older drivers occurred under difficult conditions than of younger drivers
- older drivers were less often in a hurry, intoxicated, or distracted by nondriving activities than others

B. Characteristics of Lighting and Impact on Vision

1. On-Axis and Off-Axis Vision

Baker H. The course of foveal light adaptation measured by the threshold intensity increment. Journal of the Optical Society of America 39(2).

- sensitivity is low immediately after the onset of the adapting light; it increases to a maximum several minutes after the onset of the adapting illumination and then declines to an intermediate final level

Bullough JD, Rea MS. 2000. Simulated driving performance and peripheral detection at mesopic and low photopic light levels. Lighting Research and Technology 32(4): 194-198.

- driving performance in terms of speed and on-axis obstacle detection did not depend upon spectrum
- detection of peripheral objects improved for "cooler" or "bluer" light sources relative to "warmer" or "yellower" sources

He Y, Bierman A, Rea MS. 1998. A system of mesopic photometry. Lighting Research and Technology 30(4): 175.

- peripheral detection response speeds improve for rod-dominated spectra increasingly as light level is reduced
- a model of photometry at mesopic (low, nighttime) light levels is presented to predict peripheral visibility as a function of spectrum

He Y, Rea MS, Bierman A, Bullough J. 1997. Evaluating light source efficacy under mesopic conditions using reaction times. Journal of the Illuminating Engineering Society 26(1): 125-138.

- off-axis detection (at 15o) improved with a "bluer" spectrum (metal halide) relative to a "yellower" one (high pressure sodium) as light level decreased below 1 cd/m2
- on-axis detection did not depend on spectrum at any light level

Lingard R, Rea MS. 2002. Off-axis detection at mesopic light levels in a driving context. Journal of the Illuminating Engineering Society 31(1): 33-39.

- detection of peripheral objects from 12o to 29o off axis and with varying contrasts was improved with metal halide illumination relative to high pressure sodium illumination at mesopic light levels

Van Derlofske J, Bullough JD, Hunter CM. 2002. Visual benefits of high-intensity discharge forward lighting. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2002-01-0259).

- detection of peripheral targets under typical HID headlamps is improved relative to typical halogen headlamps because of increased peripheral light from HID lamps

Wright WD. 1937. The foveal light adaptation process. Proceedings of the Royal Society of London, Series B, Biological Processes 122(827): 220-245.

- the perception of brightness or glare and the performance of some visual tasks do not necessarily use the same visual channels
- it might be possible to design a stimulus to provide good visibility while reducing glare, for example

2. Spectrum

Van Derlofske J, Bullough JD. 2003. Spectral effects of high-intensity discharge automotive forward lighting on visual performance. SAE 2003-01-0559.

- the spectral distribution of HID headlamps produces a small, but measurable, improvement over halogen systems for off-axis visual performance
- even 'cooler' sources can significantly increase the effectiveness of the light, and 'warmer' sources can decrease effectiveness

Akashi Y, Rea MS. 2002. Peripheral detection while driving under a mesopic light level. Journal of the Illuminating Engineering Society 31(1): 85-94.

- the spectral power distribution of fixed-pole lighting impacted peripheral detection more than one's own headlights

Alpern M, Ohba N. 1972. The effects of bleaching and backgrounds on pupil size. Vision Research 12: 943-951.

- The pupil mechanism is dominated by rods and thus has a spectral sensitivity similar to rods

Berman SM, Fein G, Jewett DL, Ashford F. 1993. Luminance-controlled pupil size affects Landolt C task performance. Journal of the Illuminating Engineering Society 22: 150-165.

- identifying the orientation of briefly-flashed (200 ms), low-contrast letter-c-shaped targets improved slightly under blue illumination relative to red-pink illumination

Bouma PJ. 1936. The problem of glare in highway lighting. Philips Technical Review 1: 225-229.

- discomfort glare was stated to be caused more by blue than by yellow light

Bullough JD, Boyce PR, Bierman A, Hunter CM, Conway KM, Nakata A, Figueiro MG. 2001. Traffic signal luminance and visual discomfort at night. Transportation Research Record (1754): 42-47.

- red and green saturated-color glare sources were rated more uncomfortable to view than yellow sources of equal luminous intensity

De Boer JB, van Heemskerck Veeckens JFT. 1955. Observations on discomfort glare in street lighting. Proceedings of the CIE, Zurich.

- illumination from yellow-filtered incandescent street lighting needed to be about 25% higher than from unfiltered incandescent lighting in order to be considered equally uncomfortable by observers

Flannagan M, Sivak M, Ensing M, Simmons CJ. 1989. Effect of Wavelength on Discomfort Glare from Monochromatic Sources, Report UMTRI-89-30. Ann Arbor, MI: University of Michigan Transportation Research Institute.

- six wavelengths (480, 505, 550, 577, 600 and 650 nm) were presented at four light levels
- De Boer ratings were highly correlated with glare illuminance (0.03 to 3 lx)
- older subjects gave lower De Boer ratings
- 577 and 600 nm sources were least glaring; 480 and 505 nm sources were most glaring

Flannagan MJ. 1999. Subjective and Objective Aspects of Headlamp Glare: Effects of Size and Spectral Power Distribution, Report UMTRI-99-36. Ann Arbor, MI: University of Michigan Transportation Research Institute.

- glare illuminance from about 1 to 4 lx had a strong relationship with De Boer ratings and with threshold contrast of a visual target
- SPD (halogen versus HID) did not impact disability glare but did impact De Boer ratings, with lower ratings for the HID glare sources
- size (0.3 or 0.6 deg) did not impact either disability or discomfort glare

Jehu VJ. 1954. A comparison of yellow and white headlamp beams. Light and Lighting 4(10): 287-291.

- no disability glare differences were found between white and yellow headlamps
- subjects preferred to drive with white headlamps, but some preferred to see yellow headlamps in an oncoming situation

Schreuder DA. 1976. White or Yellow Lights for Vehicle Head-Lamps? Voorburg, Netherlands: Institute for Road Safety Research.

- literature on SPD of headlamps is reviewed supporting small benefits of yellower sources for discomfort glare but no appreciable differences for forward visibility or disability glare

3. Light Output, Intensity and Illumination

Van Derlofske J, et al. Visual benefit of HID automotive forward lighting. SAE 2002-01-0259.

- it was found that, HID headlamps producing SAE beam patterns do produce greater off-axis visual performance than traditional halogen systems due to their increased light output and SPD; the difference depends on the off-axis angle and the beam pattern

Bergström S. 1963. Visible distances during night driving. In Lighting Problems in Highway Traffic, Vol. 2. New York, NY: Pergamon Press.

- seeing distance increased with high beams against high beams over that obtained with low against low beams

Dickinson HC. 1931. Report on vehicle and highway mechanics as related to traffic: Headlighting. Highway Research Board Proceedings (11): 388-409.

- concludes that visibility with low versus low beams and high versus high beams is equivalent, with small benefits for right shoulder viewing obtained in the low beam case

Hemion RH. 1969. Night Visibility Improvement Through Headlight Glare Reduction, Report AR-696. San Antonio, TX: Southwest Research Institute.

- "safe" driving speeds were computed to be higher when using high beams with opposing high beams than when using low beams against low beams

Mortimer RG. 1965. The effect of glare in simulated night driving. Highway Research Record (70): 57-62.

- glare illuminance (3 or 9 lx) negatively impacted simulated driving performance but 9 lx was not statistically significantly worse than 3 lx
- duration of glare (7 or 15 sec) did affect performance under some conditions
- frequency of glare (once, twice or four times per min.) did not significantly affect performance
- forward light level affected performance, and it is concluded that headlamp illumination might be increased to improve forward visibility without making glare problems worse

Mortimer RG. 1969. Requirements for automobile exterior lighting. In Visual Factors in Transportation Systems. Washington, DC: National Academy of Sciences.

- research showing that reductions in visibility distance are correlated with the logarithm of glare illuminance at the eye is discussed
- use of a spot lamp to increase forward illumination did not seem to increase glare to oncoming drivers as evidenced by headlight dimming requests

Schwab R. 1965. Night visibility for opposing drivers with high and low headlight beams. Highway Research Record (70): 87-88.

- it is concluded that the amount of forward light from headlights, which determines adaptation level, is the primary determinant of visibility and that glare is less important; higher intensities would increase glare but also adaptation and still result in net visibility gains

Schwab RN, Hemion RH. 1971. Improvement of visibility for night driving. Highway Research Record (377): 1-23.

- a correlation between disability glare and subjective ratings of discomfort was found
- no strong relationship between glare and fatigue (performance reduction over longer periods of time) was identified

Van Derlofske J, Bullough JD, Hunter CM. 2001. Evaluation of high-intensity discharge automotive forward lighting. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2001-01-0298).

- HID headlamps produce similar amounts of light as halogen headlamps in the center of the beam pattern, but much more light in the beam periphery
- the light distribution leads to shorter response times to peripheral targets

Fisher AJ. 1974. The luminous intensity requirement of vehicle front lights for use in towns. Ergonomics 17(1): 87-103.

- intensity requirements were largely independent of observer attributes, the luminance of the road surface and its surrounds and the number and movement of the vehicles
- the results suggest that conspicuity and brightness are different attributes of a light; while both increased with increasing luminous intensity, the observers found that, for a given intensity, a larger source was more conspicuous but that a smaller source caused more discomfort
- optimum lighting appears to be a town beam, based on dimming the present dipped headlight, giving a straight ahead intensity of 80 cd

4. Glare

Bichao I, et al. 1995. Disability glare: effects of temporal characteristic of the glare source and of the visual-field location of the test stimulus, J. Opt. Soc. Am. A 12(10).

- a transient glare source raised threshold by 0.5-0.75 log unit more than a steady glare source, and the transient glare effect was more pronounced and more long lasting in the periphery

Irikura T, et al. 1999. Recovery time of visual acuity after exposure to a glare source. Lighting Res. Technol. 31(2): 57-61.

- the time taken for the recovery of visual acuity after exposure to a glare source with a duration of 1.6 s or less, was determined by visual experiments where the background luminance was set to 0.1 cd/m2 or 0.32 cd/m2
- recovery time increases as the exposure time increases; at every luminance of the glare source, recovery time clearly grows shorter as the background luminance increases
- recovery time is determined by the product of the luminance of the glare source and the exposure time

Pohl W et al. 2001. Enhancing visibility by reducing glare of street luminaries and headlamps. PAL 2001 Symposium, Darmstadt University of Technology.

- glare from the headlamps of oncoming vehicle is much higher than the glare caused by the street luminaires
- decomposed headlights and streetlights are recommended to use to reduce the glare and the visibility could be increased and the light level could be decreased

Akashi Y, Rea MS. 2001. The effect of oncoming headlight glare on peripheral detection under a mesopic light level. Progress in Automobile Lighting Symposium, Darmstadt, Germany: Darmstadt University of Technology (pp. 9-22).

- oncoming low beam headlight glare degraded detection performance of a target 23^{o} off-axis but not 15^{o} off-axis

Alferdinck JWAM, Varkevisser J. 1991. Discomfort Glare From D1 Headlamps of Different Size, Report IZF 1991 C-21. Soesterberg, Netherlands: TNO Institute for Perception.

- De Boer ratings were highly correlated with glare illuminance
- size (from 0.0006 to 0.15 deg2) had a small influence on rated discomfort (less than 1 De Boer unit total) using the De Boer scale

Anderson SJ, Holliday IE. 1995. Night driving: Effects of glare from vehicle headlights on motion perception. Ophthalmic and Physiological Optics 15(6): 545-551.

- glare from oncoming high beam headlights greatly reduces visual acuity and threshold contrast especially when minor lens opacities are present

Bhise VD, Farber EI, Saunby CS, Troell GM, Walunas JB, Bernstein A. 1977. Modeling vision with headlights in a systems context. Society of Automotive Engineers Congress and Exposition, Detroit, MI: Society of Automotive Engineers (Paper 770238).
- regions of acceptable and unacceptable discomfort glare from headlights are bounded by situations giving a De Boer rating of 4 and the conditions created by 110% of the illuminance caused by properly aimed low beam headlights
- previous research is cited that 0.1 lx is an upper limit for the border from nonglaring to glaring conditions (from a comfort perspective)
- four-headlamp systems resulted in more dimming requests than two-headlamp systems having the same glare illuminance
- it was found in field studies that dimming requests from oncoming drivers began to occur when the calculated De Boer rating reached a value of 4 or lower
- depending upon adaptation level, U.S. low beams at the time of the report had corresponding calculated De Boer ratings from 4 to 6, U.S. high beams from 1 to 4, and European ("H4") low beams from 6 to 8; all were calculated for oncoming distances from 400 to 1800 feet
- a model for dimming request prediction is developed that shows the probability of a request as a function of De Boer rating and the exposure time to glare

Bichão IC. 1995. Existing glare testers and the evaluation of night driving glare problems. Vision Research 35: S79.
- transient glare affected peripheral detection more than foveal detection
- the difference between transient and steady glare was greater in the periphery

Bullough JD, Fu Z, Van Derlofske J. 2002. Discomfort and disability glare from halogen and HID headlamp systems. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2002-01-0010).
- De Boer ratings were strongly correlated with glare illuminance (0.04 to 2.6 lx)
- threshold contrast was strongly correlated with glare illuminance
- HID glare sources were consistently rated as more glaring than halogen sources, but less so than blue-filtered halogen sources, although the blue source had higher scotopic content than both the HID and unfiltered halogen sources
- different sources did not result in different threshold contrast once glare illuminance was constant
- De Boer ratings were more highly correlated with glare illuminance calculated using a short-wavelength cone luminous efficiency function

Bullough JD, Rea MS. 2001. Driving in snow: Effect of headlamp color at mesopic and photopic light levels. In Lighting Technology Developments for Automobiles, SP-1595. Warrendale, PA: Society of Automotive Engineers.
- an analysis of discomfort glare studies relating to street lighting provided initial evidence that rod photoreceptors might play a role in discomfort glare under some conditions

Bullough JD, Van Derlofske J, Fay CR, Dee P. 2003. Discomfort glare from headlamps: Interactions among spectrum, control of gaze and background light level. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2003-01-0296).
- a background light level ranging from 0.1 to 3 cd/m2 did not affect the spectral discomfort response to headlight glare
- a fixed gaze resulted in similar trends for ratings of discomfort as a free gaze

Ferguson HM, Reeves J, Stevens WR. 1953. A note on the relative discomfort from mercury, sodium and tungsten light sources. GEC Journal (July).

- low-pressure sodium illumination required a luminance approximately three times that of mercury vapor illumination to appear equally "uncomfortable"

Flannagan MJ, Sivak M, Battle DS, Sato T, Traube EC. 1993. Discomfort Glare from High-Intensity Discharge Headlamps: Effects of Context and Experience, UMTRI-93-10. Ann Arbor, MI: University of Michigan Transportation Research Institute.

- HID headlamps were rated on the De Boer scale as more glaring than halogen headlamps (approximately 50% difference in illuminance to achieve equivalent ratings)
- older drivers gave lower De Boer ratings
- having HID headlamps on one's own vehicle increased De Boer ratings
- for sources with more saturated colors, the order in increasing 'glariness' is: red, yellow, green, blue

Flannagan MJ, Sivak M, Gellatly AW, Luoma J. 1992. A Field Study of Discomfort Glare from High-Intensity Discharge Headlamps, Report UMTRI-92-16. Ann Arbor, MI: University of Michigan Transportation Research Institute.

- glare illuminance from 0.02 to 4.6 lx was strongly correlated with De Boer ratings
- SPD (HID or halogen) significantly impacted De Boer ratings with HID lamps having lower ratings
- for equal De Boer ratings, halogen lamps needed to be more than 50% higher in intensity than HID lamps

Flannagan MJ, Sivak M, Traube EC, Kojima S. 2000. Effects of overall low-beam intensity on seeing distance in the presence of glare. Transportation Human Factors 2(4): 313-330.

- based on visibility alone, there is no obvious upper limit for glare
- however, based on discomfort, subjects find glare objectionable long before it will negatively impact visual performance

Fry GA. 1954. Evaluating disability effects of approaching automobile headlights. Highway Research Bulletin (89): 38-42.

- concludes that the effect of disability glare can be predicted by using a veiling luminance concept to capture the impact of scattered light in the eye

Hadden OB, Ring CP, Morris AT, Elder MJ. 1999. Visual, refractive, and subjective outcomes after photorefractive keratectomy for myopia of 6 to 10 diopters using the Nidek laser. Journal of Cataract and Refractive Surgery 25: 936-942.

- most patients receiving refractive surgery reported no significant night vision problems, some patients reported improvements in night visibility and reduced glare at night

Hare CT, Hemion RH. 1968. Headlamp Beam Usage on U.S. Highways, Report AR-666. San Antonio, TX: Southwest Research Institute.

- most drivers tended to overdrive their own headlights, even without glare, and more so with glare
- dimming from high to low beams seems to be a function of discomfort, or more likely, the anticipation of discomfort

Lehnert P. 2001. Disability and discomfort glare under dynamic conditions: The effect of glare stimuli on human vision. Progress in Automobile Lighting Symposium, Darmstadt, Germany: Darmstadt University of Technology (pp. 582-592).
- halogen lamps were used as glare stimuli
- De Boer ratings were highly correlated with glare illuminance (0.1 to 10 lx)
- De Boer ratings were highly correlated with glare duration (0.2 to 10 sec)
- glare illuminance had a greater impact on De Boer ratings than duration

Miles PW. 1954. Visual effects of pink glasses, green windshields and glare under night driving conditions. American Medical Association Archives - Ophthalmology 51: 15-23.
- glare is stated to be inversely proportional to the size of the glare source (for the same intensity), and it is proposed that headlights be designed larger in area

Mortimer RG, Becker JM. 1974. Some operational considerations affecting the performance of current and proposed head-lamp beams. Transportation Research Record (502): 34-40.
- a glare illuminance of 0.1 lx from headlamps is proposed as the point at which discomfort begins

Olson PL, Sivak M. 1984. Discomfort glare from automobile headlights. Journal of the Illuminating Engineering Society 13(3): 296-303.
- glare illuminance (0.0004 to 6.5 lx in a laboratory study and 0.003 to 11 lx in a field study) was highly correlated with De Boer ratings
- De Boer ratings were higher in the field study than in the laboratory study
- older subjects reported lower De Boer ratings
- authors conclude that estimates of acceptable discomfort glare based on laboratory results might be too conservative

Powers LD, Solomon D. 1965. Headlight glare and median width: Three exploratory studies. Highway Research Record (70): 1-28.
- as expected, threshold contrast increased as the amount of glare light increased

Ranney TA, Simmons LA, Masalonis AJ. 1999. Prolonged exposure to glare and driving time: Effects on performance in a driving simulator. Accident Analysis and Prevention 31: 601-610.
- intermittent glare presented over two 8-hour sessions reduced performance, but glare did not increasingly impair performance more after 8 hours than it did after shorter periods

Ranney TA, Simmons LA, Masalonis AJ. 2000. The immediate effects of glare and electrochromic glare-reducing mirrors in simulated truck driving. Human Factors 42(2): 337-347.
- the presence of glare negatively impacted simulated driving performance in terms of target detection and lane control
- reduction of glare with electrochromic mirrors did not significantly improve performance although subjects preferred the mirrors

Rumar K. 2001. Intensity of high-beam headlights. Progress in Automobile Lighting Symposium, Darmstadt, Germany: Darmstadt University of Technology (pp. 829-848).
- reference is made to previous research that dimming of one's own high beams occurs when the discomfort from oncoming vehicles is between 4 and 5 on the De Boer scale
- reference is made to previous research that a glare illuminance just higher than 1 lx is the maximum acceptable by drivers

Schmidt-Clausen HJ, Bindels JTH. 1974. Assessment of discomfort glare in motor vehicle lighting. Lighting Research and Technology 6(2): 79-88.
- discomfort as measured by the De Boer rating was highly correlated with the logarithm of the glare illuminance (from 0.003 to 20 lx)
- discomfort was reduced at higher background adaptation levels (from 0.015 to 15 cd/m2)
- discomfort was reduced at larger angles from the field of view (from 1 to 20 degrees)
- discomfort from multiple sources was the same as from a single source within the range 1 to 5 degrees and 0.003 to 9.6 lx
- a formula for the predicted De Boer rating is provided for the range of conditions used in the experiments reported

Schreuder DA. 1969. Side Lights and Low-Beam Headlights in Built-Up Areas. Voorburg, Netherlands: Institute for Road Safety Research.
- it is stated that without high ambient light levels along roadways provided by fixed lighting, glare from low beams is unacceptably high because the resulting veiling luminance reduces contrast of important objects along the road

Sivak M, Flannagan MJ, Miyokawa T. 2000. A First Look at Visually Aimable and Harmonized Low-Beam Headlamps, Report UMTRI-2000-1. Ann Arbor, MI: University of Michigan Transportation Research Institute.
- visually aimable and harmonized beam lamps tend to result in reduced glare to oncoming drivers, compared with conventional headlamps in the U.S.

Sivak M, Flannagan MJ, Traube EC, Kojima S. 1999. The influence of stimulus duration on discomfort glare for persons with and without visual correction. Transportation Human Factors 1(2): 147-158.
- glare illuminance from 0.5 to 8 lx had a strong relationship with De Boer ratings
- glare duration (from 0.125 to 2 sec) also had a correlation with De Boer ratings but less so than illuminance
- subjects with glasses or contact lenses had slightly lower De Boer ratings but the difference was not statistically significant

Sivak M, Flannagan MJ. 1993. Human factors considerations in the design of vehicle headlamps and signal lamps. In Automotive Ergonomics (Peacock B, Karwowski W, eds.). London, UK: Taylor and Francis.
- the authors challenge the conventional notion that disability glare and discomfort glare are separate phenomena
- nonetheless, experimental results described tended to focus on one or the other aspect

Sivak M, Olson PL, Zeltner KA. 1989. Effect of prior headlighting experience on ratings of discomfort glare. Human Factors 31(4): 391-395.
- German subjects reported lower De Boer ratings to headlamps than American subjects, presumably because of reduced experience with headlamp glare in Europe

Stiles WS, Crawford BH. 1937. The effect of a glaring light source on extrafoveal vision. Proceedings of the Royal Society of London, Series B, Biological Sciences 122(827): 255-280.
- the impact of glare on peripheral vision is well predicted by treating the source of glare as a uniform field of brightness that reduces contrast

Sivak, M., Flannagan, M., Ensing, M., Simmons, C.J., Discomfort glare is task dependent. International Journal of Vehicle Design, v 12, n 2, 1991, p 152-159

- an increase in the difficulty of a concurrent task resulted in an increase in discomfort glare
- subjects with poorer task performance tended to assign more discomfort to the glare stimuli than subjects with better task performance

Olson, Paul L., Glare from following vehicles, SAE (Society of Automotive Engineers) Transactions, v 99, n Sect 6, 1990, p 237-242

- glare from sources in front of or behind a vehicle can be quite significant; methods of reducing the glare levels are discussed.

5. Age Effects

Schmitz S, Dick HB, Krummenauer F, Schwenn O, Krist R. 2000. Contrast sensitivity and glare disability by halogen light after monofocal and multifocal lens implantation. British Journal of Ophthalmology 84(10): 1109-1112.

- older subjects with different types of lens implants did not experience glare to different degrees; contrast threshold in the presence of glare was the same in both groups

Theeuwes J, Alferdinck JWAW. 1996. The Relation Between Discomfort Glare and Driving Behavior, Report DOT HS 808 452. Soesterberg, Netherlands: TNO Human Factors Research Institute.

- actual driving in the field was performed
- glare illuminance from 0.28 to 1.1 lx from rig mounted sources (halogen SPD)
- De Boer ratings less 'glaring' than predicted by Schmidt-Clausen and Bindels (1974) but depended on task difficulty
- De Boer ratings correlated with willingness to look into glare source (e.g., to see a turn signal)
- older drivers gave higher De Boer ratings
- European and American drivers gave equivalent De Boer ratings
- 0.55 and 1.1 lx impaired driving performance about equally (detection of targets and distance at which they were detected), and older drivers performed worse, despite higher De Boer ratings

Tsongos NG, Schwab RN. 1970. Driver judgments as influenced by vehicular lighting at intersections. Highway Research Record (336): 21-32.

- older drivers reported lower discomfort from oncoming headlights than younger drivers

Corwin A. Bennett, The demographic variables of discomfort glare, IERI project 102

- older people are more sensitive to discomfort from overly bright lighting systems than young people
- the average population is more sensitive in direct proportion to their age from the 20s to the 70s

Chrysler, Susan T., Danielson, Suzanne M., Kirby, Virginia M., Age differences in visual abilities in nighttime driving field conditions Proceedings of the Human Factors and Ergonomics Society, v 2, 1996, p 923-927

- older drivers' legibility distances were 65% those of the younger drivers
- age differences in the object detection task ranged from a 20% to a 45% reduction for older drivers across visibility conditions

Decarlo, Dawn K.; Scilley, Kay; Wells, Jennifer; Owsley, Cynthia, Driving habits and health-related quality of life in patients with age-related maculopathy,Optometry and Vision Science, v 80, n 3, Mar 1, 2003, p 207-213

- questionnaires were administered via telephone interview to 126 patients with age-related maculopathy
- over 50% of drivers reported that because of their vision, they had difficulty with or did not drive at all in rain, at night, on freeways or interstate highways, in heavy traffic areas, or during rush hour

Keskinen, Esko; Ota, Hiro; Katila, Ari, Older drivers fail in intersections: speed discrepancies between older and younger male drivers,Accident Analysis and Prevention, v 30, n 3, May, 1998, p 323-330

- a high percentage of older drivers' accidents occur in intersections when entering traffic or crossing a main road
- the problems may be in perception or attention, motor performance or inadequate interaction with other road users

C. Technical Aspects of Forward Lighting

1. Forward Lighting Task and Design Goals

Anon, Vehicle Lighting Design for Optical Visibility and Performance, SAE Special Publications, n 857, Feb, 1991, Vehicle Lighting Design for Optical Visibility and Performance, 92p

- driver performance is discussed in terms of reaction times to brake lamps; other topics covered include: electrochromic mirrors, driver confidence, curved reflectors for headlamps, light distributions, foglamps, dipped beam patterns, and brake lamps

2. Headlamp Beam Patterns

Sivak, M., (2002). Performance of the first generation of HID headlamps in the U.S., the University of Michigan, Transportation Research Institute, Report No. UMTRI-2002-14.

- HID lamps produced more light on all parts of the beam pattern except for a central area near the horizontal, and an area above the horizontal in the far left periphery

3. Headlamp Mounting Height

Headlamp Mounting Height Task Force, 27 November 2000 Draft.

- near-foveal eyepoint illuminance levels of 3 to 4 lux for short duration were found0
- for longer periods of time, the discomfort glare tolerance decreases to the range of 1.5 to 3 lux
- apparent tolerance in the peripheral areas of vision is greater by a 3.24-times-factor
- the task force determined side mirror illumiance limits of 10 to 20 lux
- a rapid increase in glare begins at about a 10cm height differential from reference
- maximum headlamp mounting height should include the 85th percentile driver.

4. Headlamp Leveling

Harris AJ. 1953. The meeting beams of headlights: Effects of deterioration and misaim. Illuminating Engineering Society Transactions 18(8): 207-220.

- visibility in the presence of a stationary glare source is found to be the same as that in the presence of a moving glare source

Kare Rumar, Visibility distances in night driving with misalighed meeting dipped headlights, Department of Psychology, University of Uppsala, Sweden, Report 28, 1965

- compared to correctly adjusted meeting lights, the visible distance was not increased, or at least noting worth mentioning, by a downward misalignment of meeting headlights, while on the other hand an upward misalignment of 1-2 degrees of meeting headlights decreased the "normal" visible distance by about 25%

5. Headlamp Cleaning

Alferdinck JWAM, Padmos P. 1988. Car headlamps: Influence of dirt, age and poor aim on glare and illumination intensities. Lighting Research and Technology 20(4): 195-198.

- headlamps on many vehicles were found to be misaimed and dirty, increasing glare illuminance to other drivers and reducing one's own forward illuminance

Kare Rumar, Dirty Headlights – frequency and visibility effects, Department of Psychology, University of Uppsala, Sweden, Report 136, 1973

- even in dry weather on seemingly clean roads, light reduction is normally 10-20%
- in bad (slushy) road conditions few cars have light reduction below 50%
- drivers normally do not react to light reduction below 60%
- 60% light reduction causes a 20% reduction of high beam visibility and a 15% reduction of low beam visibility

6. AFS Headlamps

Adler, B., Lunenfeld,H., Evaluation of a three-beam vehicle lighting system, Transportation Research Record 502, pp.22-33,1974

- one new-term improvement for vehicle forward lighting is a 3-beam 4-head-lamp system: High beam, low beam and midbeam
- a computer program calculated the glare in the rearview mirror as a following vehicle with different headlighting system approached from the rear and evaluated the 4 modes achieved by combining the 3-phase beams
- the results shows very minor difference in glare among any of the beam configurations on the Tame mode. The equation used for the glare evaluation is E=K(candela output * reflectivity)/(oblique distance)^2
- The high-beam mode using all 4 head lamps appears to be the best configuration because it doesn't represent excessive glare and doesn't yield greater dimming requests, but does yield greater seeing distance

Josef Kalze, Hella KG Hueck &Co., German, Situation adapted light distributions for AFS-Headlamps, PAL 2001, pp.474-484

- Hella's concept for AFS was summarized, the headlamp system is composed of a basic light model (VarioX-module), high beam, and static bending light and provides a comfortable compromise between visibility distance, reduced glare for oncoming traffic and comfortable spread of homogeneity
- 5 kinds of lighting functions: Town light, Country light, Motorway light, Adverse weather light and Static and dynamic bending light
- In TL, the basic light modules(left and right VarioX-modules) provide a symmetrical cut-off-line geometry. Depending on the momentary speed, the modules are swiveled in divergent mode
- For AL, in a typical night rain situation, the left basic light model (VarioX-module) generates a horizontal cut-off-line and is forced into divergent mode with an angle of 15 degree. This ensures high visibility distance on drivers lane and reduces reflex glare for the oncoming traffic
- For AL, in a heavy wet situation, both VarioX-modules generate a horizontal cut-off-line and go into the maximum divergent mode (30 degree), this beam pattern is similar with TL
- For AL, in a heavy fog situation, both VarioX-modules generate the motorway beam pattern, go into divergent beam orientation and are leveled downwards

Franz-Josef Kalze, Static bending light- A new light function for modern headlamp system, 1999 SAE.

- The side area close to a car up to a distance 20-30m, called "No man's land", is considered to be illuminated by a new light function called static banding light
- Computer software—LDE was used to simulate and analysis the new light distribution

Stuart Birch, Adaptive front lighting, aei December 2001 PP.39-42

- VARILIS program was introduced and its aim is to enhance the lighting performance via a clearer definition of the cutoff in terms of sharpness and geometry of the light, reduction of illuminance in the area in front of vehicle and a reduction of self-glare
- The paper describes Hella's AFS concept—five principle lighting functions as the following:
- Town light: a symmetric cutoff, wide scatter and homogeneity across the entire area of illumination
- Country light: recognition of the course of the road, recognition of objects in the vicinity of the road, guidance of the driver's attention to relevant areas of the road and low level of dazzle to other road users
- Motorway type light: provide the driver with greatest range of vision while dazzling the traffic in front as little as possible
- Adverse weather light: provide the driver with good illumination and guidance by producing a high intensity of light in the distant zone at the outward edge of the road, illuminate the width of the road (with orientation on the right hand or left hand side of the road) and reduce the level of illumination in the immediate frontal zone—up to about 20m in front of the vehicle—to keep reflection dazzle to oncoming traffic down to an acceptable level
- Bending light: static bending light—a headlight on one side is switched on and/or increased in brightness. Dynamic bending light—produced by swiveling the whole beam according to the radius of the curve either on both sides of the car or the inner lamp to the curve curve

Takashi Sato and Shinichi Kojima, the smart headlamp system with variable low-beam pattern, SAE 2001-01-0845

- SHS (smart headlamp system) was evaluated in terms of visibility and discomfort glare. Discomfort glare evaluation used Schmit-Clausen's and Bindels formula (de Boer scale)
- Visibility, isolux and glare were evaluated between SHS and conventional headlamp system
- On coming glare of the SHS is slightly higher than conventional headlamp system but still within acceptable range

Joseph S. Stam, Automatic vehicle high-beam headlamp control system, SAE 2001-01-0318

- An automatic switching of the high-beam headlamps system is introduced, with which vehicles provide a significant safety and less glare.

Michael Sivak, Michael Flannagan, Brandon Schoettle, Yoshhiro Nakata, Quantitative comparisons of the benefits of applying adaptive headlighting to the current U.S and European –low beam patterns

- The potential benefits of applying two embodiments of adaptive lighting to the U.S and European beam pattern: curve lighting that involves shifting the beam horizontally into the curve, and motorway lighting that involves shifting the beam vertically upward, were examined
- Curve lighting would substantially improve seeing performance on curves for both types of beams. On right curve there would be an increase in disability glare for oncoming traffic. No major discomfort glare problems would be expected
- Motorway lighting would substantially improve seeing performance

Alexander von Hoffmann, Analysis of adaptive lighting distribution with AFSim

- Presents requirements for simulation software derived from measurements of the glare illuminance
- Maximum swiveling angle: aMAX=asin(h*100/2R). h is the headlamp height and R is the radius of curve
- Glare illuminance from oncoming AFS headlights with different cutoff angle was measured
- One kind of simulation software AFSim is introduced

Paul Sharke, Let light be there,10 June 2001, Mechanical engineering

- This paper reviewed the AFS technology and introduced the EURKEA study
- Lighting that reduced glare on wet roads helped both the driver and oncoming drivers.
- The more intense a glare, the more it disturbed oncoming drivers
- The size of the light source affected the level of discomfort. After sources were normalized to the same luminous intensity, the small areas of glare are more disturbing than large ones
- Light pulses lasting longer than 8 to 10 seconds degraded visual performance because of the longer time for eyes to readapt to lower light levels one the pulse ceased
- NHTSA reported complaints about glare from identify HID headlamps and sport utility vehicle headlamps, claiming that both are too bright and the latter are too high

Preeti Bajaj, Shubhalaxmi Kher, Smart control of headlight intensity of automobiles for improved night vision, SICE'99 July 28-20, Morioka

- This paper proposed design of a controller to provide optimal illumination at all distances when the vehicles are in vicinity. It uses a fuzzy logic method to decide proper headlight intensity based on driving speed, distance from other vehicles, driving action, weather condition and road geometry

Michael Hamm, Ernst-olaf Rosenhahn, System strategies and technology for improved safety and comfort with adaptive headlamps

- Glare effects during road driving for different headlamp algorisms are carried out. Theses investigations show that adaptive curve lights can reduce glare by using suitable curve light parameters
- Predicting curve light system and steering wheel controlled light systems are better than conventional system in regarding glare

Kobayashi, Shoji, Takahashi, Kazuki,Yagi, Seiichiro, Development of new forward lighting systems with controllable beams, SAE Special Publications, v 1249, New Concepts in International Automotive Lighting Technology, 1997, 970646, p 19-35

- New forward lighting system has been developed. This system controls and adjusts to optimum settings headlamp and fog lamp system beams and beam patterns, based on data collected by onboard sensors which are either currently incorporated in vehicles, or are comparatively easy to develop. Through beam optimization control, this system aims to radically improve nighttime driving safety and comfort. The low beams of this forward lighting system enable independent control of the oncoming vehicle and forward vehicle side cut off line in a range of +1.5° to -0.5°. The high beam system enables control of the irradiation angle to a maximum of 6°C. Furthermore, the fog lamp system allows control of the beam pattern side irradiation in a range of 30° to 50° toward the road shoulder. The results of prototype testing of this forward lighting system are presented

Kormanyos, Christopher M., HID system with adaptive vertical aim control ,SAE Special Publications, v 1323, Feb, 1998, 980003, Automotive Lighting Technology, p 13-18

- A high intensity gas discharge headlight with integrated adaptive vertical aim control is described that provides improved driving, comfort and safety and also reduces glare for oncoming drivers by maintaining optimal vertical adjustment of the headlight beam during varying driving situations

Miura, Jun(Osaka Univ); Ito, Motokuni; Shirai, Yoshiaki, Three-level control architecture for autonomous vehicle driving in a dynamic and uncertain traffic environment,IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC, 1997, p 706-711

- This paper proposes a novel control architecture for autonomous vehicle driving in a dynamic and uncertain traffic environment. The architecture is composed of three levels: (1) the operational level deals with a reactive control of a vehicle in a short time cycle; (2) the tactical level decides proper maneuvers based on prediction of future states using probabilistic traffic models; (3) the meta-tactical level, which is the feature of the architecture, timely activates an appropriate tactical-level planning procedure according to both the history of maneuvers and the current traffic condition. A utility-based maneuver evaluation method is also described. The proposed architecture was tested on a highway driving simulator in various traffic scenarios; simulation results show the feasibility of the architecture.

7. Lighting on Trucks and Buses

Helder, Dorothy J., Large-area variable reflectance mirrors for trucks and buses, SAE Technical Paper Series, 912705, 1991, 6p

- variable reflectance mirrors, such as those utilizing electrochromic and liquid crystal technology, are capable of multiple reflectance levels; with variable reflectance, the driver can select a high reflectivity level during daytime driving or when reversing into loading docks, and can select a reduced dimmer reflectance level when driving during glaring conditions

8. Lighting on Motorcycles

Kim, K.,Kim, S. Yamashita, E., Alcohol-impaired motorcycle crashes in Hawaii, 1986 to 1995: An analysis, Transportation Research Record, n 1734, 2000, p 77-85
ISSN: 0361-1981 CODEN: TRREDM

- using comprehensive police crash data, the differences between impaired and nonimpaired riders involved in crashes, in terms of various demographic characteristics, helmet use, license status, roadway environments, and injury outcomes, are described
- in addition to age-specific determinants of impaired crash involvement, time factors such as weekends and night-time, and licensing (out-of-state or no licenses) are strongly associated with impaired rider crashes

D. Light Source Technology

1. Halogen Source Characteristics

Young, Paul; Hobbs, Bonnie, Halogen lamp design life improvement for automotive applications, SAE Special Publications, v 1249, 970909, New Concepts in International Automotive Lighting Technology, 1997, p 169-173

- the design life of the entire halogen forward lighting series for automotive applications is redesigned
- effects of the known design parameters and how they affect halogen lamp life are discussed along with supporting design choices
- the contribution/cost tradeoffs are examined in order to explain the final product configuration.

Engelhard, Klaus, Low voltage tungsten halogen lamps, Electrical World (Melbourne, Australia), v 61, n 1, Jan, 1996, p 18

- low-voltage tungsten halogen lamps have now a place in automotive and signalling systems as well as in general indoor and outdoor lighting
- lamp life, luminous flux, a luminaire efficiency are influenced by external factors to a much greater degree than standard incandescent lamps

2. Xenon Gas Discharge Light Sources (HID)

Aoike, N.; Hoshino, M.; Iwabuchi, A., Automotive HID headlamps, IEEE Industry Applications Magazine, v 8, n 1, January/February, 2002, p 37-41

- multichip ICs can be used to produce compact, lightweight, low-cost electronic ballasts for automotive HID headlamps

Jost, Kevin, Anatomy of high-intensity discharge headlamps, Automotive Engineering (Warrendale, Pennsylvania), v 103, n 11, Nov, 1995, p 38-42

- for automotive high-intensity discharge lighting, modifications were made to address component size and lighting performance parameters, and governmental standards for forward lighting had to be altered before the systems could be introduced
- ompared to conventional halogen headlamps, discharge systems provide higher performance and efficiency, improved durability, white light, and more consistent output regardless of voltage supplied by the vehicle

Lee, Kyu-Chan(Seoul Natl Univ); Cho, Bo H., Design and analysis of automotive HID lamp ballast system using auxiliary winding, PESC Record - IEEE Annual Power Electronics Specialists Conference, v 1, 2000, p 544-549

- a new scheme for automotive high intensity discharge (HID) lamp ballast systems is proposed
- the proposed scheme separates the input voltage of the ignitor from the dc link voltage using auxiliary winding, which results in the use of the lower voltage rating power devices for the HID lamp ballast system, compared with the conventional system
- as a result, the proposed system has a lower cost and higher efficiency

3. LED Light Source Characteristics

Van Derlofske, John F.; McColgan, Michele, White LED sources for vehicle forward lighting, Proceedings of SPIE - The International Society for Optical Engineering, v 4776, 2002, p 195-205

- due to their reliability, small size, lower power consumption, and lower heat generation LEDs are a natural source choice for automotive lighting systems
- with the advent of new higher packages, and with the promise of even higher light output in the near future, the use of white LEDs sources for all vehicle forward lighting applications is beginning to be considered

4. Distributive Lighting, Fiber Optics and Light Guides

Van Derlofske, John F. (Lighting Research Center, Rensselaer Polytechnic Institute), Low beam head lamp design using distributive lighting system, Proceedings of SPIE - The International Society for Optical Engineering, v 4445, 2001, p 119-129

- due to their small size, lower power consumption, and lower heat generation, LEDs are a natural source choice for display illumination
- the conversion of an LED's output flux distribution to one that is uniform over a given area can be accomplished with plastic, injection-molded light pipes

Hoines, Lilian(North American Lighting, Inc); Potter, Brant; Lekson, Matthew; Strauss, Benjamin, Design considerations in exterior automotive courtesy lighting, SAE Special Publications, v 1323, Feb, 1998, 980009, Automotive Lighting Technology, p 45-49

- use of LEDs, light guides, and electroluminescence can result in pleasing styling along with the ability to outperform conventional sources

E. Roadway Lighting Systems

1. System Interaction and Optimization

Keck, Merle E. A new visibility criteria for roadway lighting, Journal of the Illuminating Engineering Society, v 30, n 1, Winter, 2001, p 84-88

- in order to evaluate the visibility of real roadway objects it is necessary to include the effect of both the vehicle head lighting system and the fixed lighting system
- light coming towards the observer from a fixed lighting luminaire does not improve the visibility of large or complex objects seen against a background other than pavement or which are recognized by internal contrasts

Akashi Y, Rea MS. 2002. Peripheral detection while driving under a mesopic light level. Journal of the Illuminating Engineering Society 31(1): 85-94.

- the spectral power distribution of fixed-pole lighting impacted peripheral detection more than one's own headlights

Lewin, Ian, Lamp spectral effects at roadway lighting levels Source: Lighting Journal, v 64, n 2, 1999, 6 pp
- research has been conducted to determine whether the spectral distribution of a light source has any effect on the visibility it produces
- it was found that lamp spectral distribution influences human perception in several different ways at low light levels

F. Regional Differences

1. U.S. Beam Patterns in Comparison to European and Japanese Patterns

Sivak, Michael; Flannagan, Michael; Chandra, Divya; Gellatly, Andrew, Visual aiming of European and U.S. low-beam headlamps, SAE Technical Paper Series, 920814, 1992, p 1-10
- the location of the perceived cutoff of a headlamp beam was generally near the location of the maximum contrast between adjacent vertical parts of the beam pattern
- the variability of the aiming performance was systematically related to the magnitude of the maximum contrast

Rendu, Robert; Definition of the cut-off in a dipped beam pattern, SAE Special Publications, n 857, Feb, 1991, Vehicle Lighting Design for Optical Visibility and Performance, p 41-46
- aiming of dipped-beam headlamp is currently performed visually in Europe, using the cut-off line in the beam pattern
- a good definition of a visual cut-off would allow uniformity in interpretations