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The Daniel Stern Lighting Consultancy welcomes the opportunity to comment on headlamp glare and related issues. Attached please find DSLC's response to the agency's request for comments. It includes responses only to questions DSLC is qualified to comment upon. Certain of the agency's questions are directed specifically at automakers, for instance, and these have been omitted from this response.

Included are many references to pertinent documents, including recent studies and other responses in NHTSA dockets. These references are highlighted for easy retrieval. There are also three attachments, including *Where Does the Glare Come From?,* the newly-revised edition of DSLC's report on headlamp seeing and glare, which analyses the issue using the most recent real-world headlamp performance data-set available.

Should you have any questions, comments or requests on any of the points in this response or the attachments, I am at your disposal. Please feel free to contact me.

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Question 1: Given the vast amount of new technology in headlamp hardware and design, and in the design of light sources, is the long-standing method of specifying a single headlamp's performance by test points irrespective of its particular vehicle application, still an effective way to consider the problem of glare? Please explain.

Photometric testing based on test points is an adequate and cost-effective method of determining the performance and compliance of motor vehicle headlamps. The problem of glare can be effectively addressed without changes to the method by which headlamps are tested. However, certain aspects of the currently-prescribed testing methodology are inappropriately lax. The agency should rescind the ±0.25° reaim permitted by FMVSS 108 (7.2(d)) at most every point in the beam during photometric testing, replacing this provision with a more stringent re-aim provision. The 0.25° re-aim allowance was originally intended to allow for compensation of different positional calibration among different photogoniometers. However, the allowance is being used to move individual headlamps under test 0.25° up, down, left and right to sidestep multiple test point failures . Multiple such re-aims result in headlamps that are nominally compliant, but which do not produce a compliant beam pattern when mounted on a vehicle. A headlamp, when installed, can only be aimed vertically and (sometimes) horizontally in its entirety. Different portions of the beam pattern cannot be shifted left, right, up or down relative to other portions of the beam pattern. This relates directly to the problem of glare, since the FMVSS 108 allowance for re-aim under test is being used to attain nominal compliance with lamps that produce more glare light at the specified test point(s) than is permitted by the Federal photometric standard.

Provisions can be made for compensation of differences in positional calibration of photogoniometers without allowing noncompliant beam patterns to "wiggle" their way past the test. The agency should consider emulating the re-aim provision present in ECE regulations. This provision (see e.g. ECE R20, 6.2.4) permits a one-time re-aim such that the beam axis is displaced by not more than 1° left or right after the headlamp has been vertically aimed according to test procedures. This one-time re-aim addresses the need to compensate for differences in photogoniometric setup. It also ensures that the beam pattern as tested on the photogoniometer is the same as that produced when the headlamp is installed on a vehicle; if the beam pattern must be shifted laterally in order to place the correct amounts of light in the correct locations, this can be achieved through headlamp mounting or final aim setting.

Question 2: Is there any feasible alternative, such as having many more test points in and near the glare areas in the beam? Would applying intensity zones for glare be appropriate instead of points? Would a whole vehicle roadway illumination specification solve the problem, limiting glare regardless of lamp mounting height? Please discuss these and fully explain your reasoning for your choice or suggestions.

In the absence of specific test points with explicit photometric requirements, control of a region is left to implicit requirements. For example, SAE J575e, referenced in FMVSS 108, states *"...the candlepower values between test points shall not be less than the lower specified value of the two closest adjacent test points (on a horizontal or vertical line) for minimum values."* Note that the current version of SAE J575 contains a less stringent version of this requirement; the values between test points are required to be not less than 60% of the lower specified value of the two closest adjacent test points. Implicit control of regions falling between test points provides a mimimum level of beam homogeneity, but does not serve adequately as a substitute for explicitly-controlled test points in regions where specifica amounts of light are crucial to meet seeing or glare-control needs.

There is significant variation in the amounts of light directed by US headlamps towards the glare regions; some designs approach ECE levels of glare control, while others just barely comply with existing US glare controls. Additional test points and zones, thoughtfully chosen and with reasonable and proper minimum and maximum intensity requirements, will considerably improve the consistency of photometric performance among US headlamps, without creating an undue compliance testing burden. While oncoming drivers' eyes on a straight and level road are with at least 50% frequency in the close vicinity of (0.5U, 3.5L) relative to an oncoming car, variations in road geometry, vehicle and headlamp height will shift the spacial relationship between drivers' eyes and the headlamps coming towards them. A glare-control zone, therefore, perhaps with one or more explicit glare-control points contained within it (e.g. ECE B50L) is an appropriate and effective way to reduce glare to oncoming drivers.

A whole-vehicle roadway illumination specification would impose unnecessary cost burdens upon lighting and vehicle manufacturers, and therefore upon consumers. It would also preclude the use of any kind of standardized headlamp system; for instance, sealed-beam headlamps would be problematic under a whole-vehicle standard, because sealed-beam headlamps can be installed on low as well as high vehicles. The relevant relationship between vehicle type and headlamp performance is the headlamp mounting height; therefore the desired control of glare and maintenance of seeing performance can be attained by prescribing aim standards that are dependent upon headlamp mounting height, as is done in Europe, and perhaps by reducing the maximum allowable headlamp mounting height.

Vehicles with high-mounted headlamps currently enjoy an "unfair" seeing-distance advantage that comes at the expense of severe glare to drivers of lower vehicles. Linking aim declination to headlamp mounting height is an easy and effective way to materially reduce glare from high-mounted headlamps, and will have an equalizing effect upon the seeing distance available to drivers of all vehicles. See Attachment 3, pages 17-21.

Question 3: To what extent do lamp or vehicle manufacturers consider potential glare from headlamps beyond the glare limits set in the Federal lighting standard?

Lamp and vehicle manufacturers are not legally required to consider potential glare beyond the glare limits contained in the Federal lighting standard. While some lamp manufacturers (see NHTSA-2001-8885-1576) have a corporate philosophy of producing low-glare lamps, there is no requirement for such a philosophy. The glare limits present in the Federal standard are the only effective means by which headlamp glare can be regulated. It should be noted that a major US automaker, which recently in response to glare complaints lowered the factory aim of certain of its truck and SUV headlamps and introduced new reflector-optic headlamps with lower glare than the former lens-optic units, is presently considering deleting all bulb shields from its headlamps as a cost-reduction measure. Automaker philanthropy cannot be relied upon to control headlamp glare.

Question 6: Should the U.S. adopt the HID glare control measures of automatic leveling and washing that have been adopted by Europe? Please identify the data and analyses that support your views. What costs would be incurred to do so?

Yes. It has been well documented (see e.g. NHTSA-2001-8885-1594) that extremely high levels of headlamp glare are produced under ordinary vehicle usage conditions, in the absence of automatic (dynamic) headlamp levelling systems. It has been equally well documented (e.g. by Alferdinck, Hella, Bosch, and others) that headlamp lens dirt accumulations typical of normal vehicle use can increase glare production by 200 to 300 percent relative to a clean lens. The increased glare produced by changes in vehicle pitch attitude and by lens dirt accumulation were of little consequence with older headlamp designs producing relatively low flux through relatively narrow horizontal observation angles and with relatively large observable illuminated lens surface areas. The advent of extremely high-flux light sources, extremely compact headlamp lenses and more robust beam patterns considerably aggravates the increase in glare due to vehicle loading and lens dirt accumulation.

These devices have been commonplace in Europe for many years, and a wide range of system components exists to satisfy various packaging and functional needs. Development costs to implement these devices in the US market would therefore be insignificant, provided the US standards for design, installation and performance of such equipment are identical or substantially harmonized with existing ECE requirements.

Question 7: Should the U.S. adopt the driver operated manual headlamp leveling for halogen and/or HIDs that has been the norm in Europe?

No. Manual headlamp levellers depend upon drivers' understanding and willingness to properly use the devices to "dip" their beams when their vehicles are heavily loaded, and to return the beams to the baseline position once the load is removed. Convincing evidence (e.g. Sivak and Flannagan's fog lamp usage study, SAE 970657) and simple observation suggest it is unrealistic to expect drivers to use manual levellers properly with reliability sufficient to make them worthwhile as safety devices.

Manual levellers are not permitted in Europe with HID and high-flux halogen (e.g. H9, HIR1, HIR2) low beams; these must have automatic levelling. Manual levelling also is not capable of compensating for changes in vehicle pitch attitude due to road geometry and load shift. Automatic (dynamic) headlamp levelling has this capability and will reduce not only steady-state glare due to laden vehicles, but also "flashing" glare due to road undulations.

Some people state that the glare from headlamps is so bad that we should all be required to use the same headlamps that we had in the 1960's.

A return to a standardized sealed-beam headlamp mandate is not an undesireable goal, and such statements should not necessarily be dismissed out-of-hand. Standardized sealed-beam headlamps provided adequate seeing and adequate glare control, were easily and inexpensively replaceable in the event of damage, were completely environmentally resistant, and were totally resistant to unauthorized modifications (e.g. blue or overwattage bulbs). These are the issues that give rise to this very questionnaire! A system of standardized headlamps, with updated photometrics and light sources, would serve America's headlighting safety needs admirably, though vehicle stylists probably would be unhappy about it.

Question 8: Because reducing glare might improve older persons' mobility, and improving roadway illumination may do so too, given the age trend, should the reduction of glare be a priority, even at the expense of some visibility?

Given the age trend, action to reduce glare is overdue and should be carried out as quickly and efficiently as possible.

Loss of down-the-road seeing is not necessarily a cost of reduced glare. There exist individual headlamps compliant with both US and ECE photometrics; e.g. the reflector headlamp in the 2002 Mercedes-Benz Geländewagen, and the halogen projector low beam in the European-market version of the 2001 Chrysler 300M (though this lamp unit is not used in the US-market version of the 300M headlamp, it has been independently tested to comply with all photometric requirements of FMVSS 108). There also exist low-glare headlamps not homologated to ECE photometrics, but certified as complying with FMVSS 108. One such headlamp is the HID projector low beam on the 2002 BMW X5. What is necessary is to reduce the degree of glare light variance in US headlamps by making the Federal photometric requirements less flexible. The GTB Harmonized low beam photometric standard is the result of much careful thought and study. It preserves high-performance US hot spot intensities and provides uplight for signs while explicitly controlling glare. Mandating GTB low beam photometrics would seem a logical action.

Question 9: To what extent do medical problems with eyes that are associated with aging, such as cataracts, and the current medical procedures such as Lasik, reduce or improve resistance to glare effects?

The agency should consult with ophthalmic surgeons for firsthand expert information on the degree to which increasingly-popular Lasik and similar eye surgeries worsen glare sensitivity.

A possible model for glare reduction would be to move toward the European beam pattern for headlamps. That headlamp beam pattern allows less glare than the current U.S. beam pattern, but it also offers less seeing distance and less visibility for road signs.

This is not necessarily true. ECE photometric requirements contain very explicit requirement for identical amounts of uplight at test points identical to those in US requirements (ECE Zone IIIa and IIIb, for instance). Nevertheless, much discussion and many modelling efforts have been devoted to the relative merits and drawbacks of the SAE and ECE low beam photometrics. Some researchers (e.g. Alferdinck, Padmos, Olson) have determined that performance differences among headlamps are largely independent of the photometric standard to which the lamps are designed. Several countries have changed from SAE-type low beam light distributions to ECE-type low beam light distributions (The UK in the mid-late 1970s, Australia in the 1980s, Japan in the 1990s). In keeping with its philosophy of rulemaking (including mandates and prohibitions) based on real-world information and not simply on theoretical or philosophical grounds, the agency should obtain from the authorities in these countries real-world data on the positive, negative or nil safety ramifications of changing from SAE to ECE headlamps.

NHTSA is not presently contemplating an adoption of the European standard because the roadway environment is quite different - Europe relies heavily on lighted signs

This is incorrect, most European overhead road signs are not self-illuminated. Germany's Autobahn signs are unlit retroreflectives, for instance, and France is in the process of removing the self-lighting from overhead signs on the Autoroute. Australia, which uses ECE headlamps, has a high percentage of unlit retroreflective overhead signs. The agency should check with the authorities in these and other relevant countries (those using ECE headlamps and unlit overhead signs) to determine the degree in the real world to which overhead signs are conspicuous and legible with such headlamps.

Question 10: Is it reasonable for the United States to sacrifice some visibility at night to address the glare problems identified by the driving public? Would a move closer to the European headlamp beam pattern effectively address glare concerns? Please provide any data that are available on the glare with European headlamps. What would be the effects on visibility at night from switching to a more European beam pattern with its downward aim?

Please see Attachment 3, pages 13-14. These tables demonstrate, using Sivak and Flannagan's headlamp data, that seeing with 50th-percentile ECE headlamps is not inferior to seeing with 50th-percentile US headlamps, and that glare with 50th-percentile US headlamp glare exceeds the thresholds of 28% disability and DeBoer Grade 5, while 50th-percentile ECE headlamps do not. The contrast is even more distinct with 75th-percentile headlamps. Please see Attachments 1 & 2 for isoscan diagrams of a like-to-like comparison of the US and ECE H7 low beam headlamps, made by the same manufacturer, for one specific late-model passenger vehicle.

The difference between aim declination of ECE headlamps on standard passenger cars (0.573° down) and of comparable US VOL headlamps (0.4° down) is a difference of only 0.173°. This is well within the variance found in recent US studies on visual aiming. Satisfactory seeing and reduced glare would result from moving towards ECE photometrics with height-dependent aim declination.

Question 11: What would be the cost impacts, if any, for lamp manufacturers if the U.S. headlamp beam pattern were changed for new lamps?

Cost impact would be positive (lower costs) If the new low beam pattern were sufficiently harmonized with existing ECE photometrics used outside North America and if the maximum allowable high beam intensity (at H-V) were commonized with ECE specifications, so that a single headlamp could be used for all right-hand-traffic markets that would not only satisfy all prevailing regulations, but also meet market preferences in both US and ECE jurisdictions.

Cost impact would be negative (higher costs) if the new low beam pattern were no closer to ECE photometrics than is the present US requirement, but were simply different. Costs would further be negatively impacted (higher costs) if a vehicle-based lighting performance standard were adopted.

There is strong financial incentive to move towards a global headlamp standard. With one standard to comply with instead of two, automakers would not have to split new-model headlamp development and production costs between two different headlamps for use on the same side of the road (e.g. US and ECE). This cost savings would justify the global standard being one of high stringency, since some of the costs saved by nonduplication of development and production could be spent towards better headlamps.

Question 12: Is it conceptually feasible to produce a viable beam pattern by retaining test points needed to ensure adequate sign visibility in the U.S. while moving to European values and test points to reduce glare for other drivers? If feasible, might this beam pattern be adopted as a global standard?

This is completely feasible and already exists as a global standard, with only the US holding onto its own standard. ECE minimum requirements for overhead sign light are identical to US minimum requirements at (4U, 8L) and (4U, 8R). The ECE requirement for 135cd at (2U,4L) is slightly better for sign lighting than the US requirement for 125cd at this location. The ECE standard contains an explicit requirement for at least 125cd of sign light at the crucial angle of (2U,V) - this is not a controlled point under FMVSS 108. The ECE standard does permit 876cd of upward stray light (10U to 90U), which is disadvantageous compared with the stricter US limit of 125cd in this region. However, the test procedures stipulated for the 10U to 90U region in FMVSS 108 are sufficiently ambiguous that headlamps with excessive upward stray light are getting past the test. Note that the GTB Harmonized low beam photometric standard maintains and improves upon the sign light requirements present in FMVSS 108, and contains the superior US control (125cd) of upward stray light.

Question 13: Because NHTSA's funds for safety initiatives are finite and the agency must use its judgment in deciding which initiatives are the most appropriate, is it appropriate for NHTSA to initiate an effort to develop an updated balance between glare and roadway illumination from headlamps at this time? On the other hand, if NHTSA does not undertake such an effort now and the public's complaints about glare continue to increase, what are the likely consequences?

NHTSA must act as quickly and efficiently as possible to reduce headlamp glare. Complaints of excessive glare have increased as technological advancements have pushed headlamp intensities higher without corresponding updates in headlamp regulations. Technological advancement tends to accelerate, which - together with initial reports (see NHTSA-2001-8885-1567) of traffic crashes attributable to excessive glare - suggests the problem will not "go away" by itself and will continue to worsen in the absence of action by NHTSA.

Question 14: If NHTSA begins such an effort, should the desired end be a new beam pattern with the rest of the headlamp portions of the lighting standard retained largely intact, or should the agency aim for a vehicle-based performance standard that evaluates the performance of headlamps as installed on the vehicle? With this latter approach, vehicle manufacturers would have much greater freedom in choosing headlamp location and attributes. The agency's goal could be to simply turn on the vehicle's headlamps and shine them on a screen, and assess the performance of the headlamps as they will perform when used and seen by the American public. What would be the impact on vehicle and headlighting manufacturers from such an approach?

Please see responses to questions 1, 2 and 11. A new beam pattern, slight modifications to the photometric testing protocol, height-dependent aim specifications, dynamic levelling and cleaning for high-flux headlamps, and a reduction in the maximum allowable mounting height will adequately and effectively address the problem. Complete destandardization of headlamp location and attributes could cause unforeseen negative consequences in the realm of e.g. vehicle conspicuity and accuracy of distance judgement by other motorists and pedestrians. The amount of research and modelling that would be required to begin to scope-out such potential issues would cause a serious delay in the reduction of headlamp glare, and would involve regulatory costs better spent on other projects.

For passenger cars, the general findings have been that, for every one inch the headlamp is lowered, the detection distance is decreased by approximately ten feet. Lowering light truck headlamps five inches could result in a loss of fifty feet of roadway visibility. It should be noted that roadway visibility would still be greater than passenger car roadway visibility because the lamps may still be higher than passenger cars lamps. Also, light trucks do not necessarily have different stopping distances than passenger cars. Consequently, there may be no safety reason that would need to be considered in such a decision.

Such "loss" would not place light truck drivers at a seeing-distance disadvantage, it would simply bring light-truck headlamp range closer to parity with that of passenger cars. As the agency is aware, LTVs have an inherent seeing-distance advantage due to the higher driver position. There is no reason LTVs should enjoy a headlamp range advantage over passenger cars, particularly when such advantage is at the cost of extreme glare to drivers of lower vehicles. A reasonably and properly stringent photometric standard, slight modifications to the photometric testing protocol, height-dependent aim specifications, dynamic levelling and cleaning for high-flux headlamps, and a reasonable reduction in the maximum headlamp height will facilitate seeing-distance parity and glare parity on the road, and that should be the goal.

Question 20: Do HID bulbs have too much light flux available for the roadway illumination task? If so, please discuss why and what could be done to resolve this.

There is practically no such thing as "too much light flux available". The advent of HID and high-flux halogen light sources has permitted more-robust headlamp beam patterns. It is the Federal beam pattern standards, particularly the glare control measures, that have failed to keep pace with the technological state of the art. It should be noted that ECE regulations explicitly call for stricter glare control and better seeing performance from HID headlamps, in recognition of the higher performance and higher glare potential of these lamps. This is reasonable and proper, but not necessarily essential. Thoughtfully- and properly-written photometric standards need not hold different light sources to different standards.

Question 21: How do HID headlamp lower beam patterns vary from halogen lower beam patterns? Do these differences necessarily result in higher levels of glare for other drivers?

US HID low beams tend to generally approximate ECE beam formations, with most of them being VOL (Calcoast Survey 2002). With an unladen vehicle on a level road, this generally results in less glare to oncoming drivers than from some halogen low beam patterns. However, US HID low beams also have considerably higher intensity immediately below H-H, and this results in extremely intense "flashing" glare with road undulations, and extremely intense steady-state glare in the event the vehicle is carrying a load (see NHTSA-2001-8885-1438). There are also considerable differences in the spectral power distribution of the HID light sources and in the colorimetry of the HID beam; these will be discussed in responses to the relevant questions.

Question 22: The agency is interested in receiving comments regarding human factors issues surrounding the use of whiter (and/or bluer) light in headlamp systems, whether from HID or halogen bulbs, that has uneven spectral density emission performance as do HIDs. Have there been any studies done regarding HID light sources, whether with automotive, industrial, home or any other venue that addresses this uneven energy emission and its visual perception by people?

Researchers Bullough, Van Derlofske and Fu in their oral presentation of SAE 2002-01-0010 presented an elaboration of evidence in the paper that shorter-wavelength light, including but not limited to that perceived as "blue", does increase glare.

Question 23: One theory is that drivers are attracted to HID headlamps because of the newness or different appearance. This theory suggests that drivers then end up staring into the HID headlamps.

Francis Crick, Ph.D., of the Salk Institute for Biological Studies, reports upon attentional conspicuity: if there is a sudden change outside (e.g., to the right or left) of the axis of a person's visual attention, the colliculi of the brain causes the person's visual attention to turn immediately and involuntarily towards the change. The arrival into a driver's visual field of a headlamp presenting a "different" appearance qualifies as a "sudden change" of the type described by Salk, and the theory presented in this question may have some basis in reality. It should not, however, be taken as a reason to suggest that the solution is for drivers to "look away from the glare". Involuntary physiological reactions to specific stimuli cannot be deliberately overridden without levels of vigilance and attention incompatible with safe maintenance of attention to the driving task.

Research into the long-term maintenance of the attention-getting ability of extraordinarily-bright/novel-appearing objects in a driver's field of vision (e.g. research conducted by TTI, at the University of Iowa and elsewhere during the investigation of Fluorescent Yellow Green as a new TCD color to indicate the presence of pedestrians) suggest that even after extended periods of acclimatization, drivers' attention is still attracted by extraordinarily-bright/novel-appearing objects to a greater degree than by other objects. This would seem to apply equally to extraordinarily-bright/novel-appearing HID headlamps.

Question 25: Are there any studies or data that support or disprove the claim that illumination that is more yellow (or any other color) provides vision improvements that could enhance driving safety during inclement weather in day or night? Please discuss these.

Rennselaer Polytechnic Institute Lighting Research Center researchers Bullough and Rea conducted a study (SAE 2002-01-0010, "Driving in Snow: Effect of Headlamp Color at Mesopic and Photopic Light Levels) in which the results suggest that under low light levels, when rain, fog or snow backscatters headlamp light, vision modes necessary for the driving task are facilitated by yellow light, for physiological reasons having nothing to do with the "Rayleigh scattering" explanations that were offered early in the 20th century and which have since been dismissed as scientifically invalid. The Bullough-Rea study provides data that supports the popular belief that yellow light can be superior to white light of equal intensity in reducing the detrimental effects of backscatter. It should be noted that the transmissivity and resultant scotopic/photopic ratio of the yellow filter used in this study were not close matches to the selective-yellow filters upon which the popular belief in the superiority of yellow light for poor-weather driving can reasonably be presumed to be based. Bullough and Rea further note that the high luminous output of HID headlamps means such headlamps could incorporate appropriately-colored filters to lower the scotopic/photopic ratio so as to reduce distracting glare, without substantially reducing the performance of the lamps.

Pending further study of the issue, the idea of yellow light for lamps specifically intended for use in conditions of reduced visibility (i.e., fog lamps) should not be dismissed, and may have additional advantages. Specifically, mandating selective yellow as the only acceptable color for front fog lamps will make enforcement of fog lamp usage regulations considerably easier, and can reasonably be expected to encourage proper identification and use of the fog lamp function by drivers, due to the pervasive popular belief that "white auxiliary lamps are driving lamps, and yellow auxiliary lamps are fog lamps". The reduction of subjective (discomfort) glare from such a regulatory action would be an added benefit. If selective yellow fog lamps are mandated, care should be taken to ensure that they remain yellow, e.g. with a yellow lens, a yellow reflector or a permanent transparent yellow bulb shield, so that the light color cannot be changed. Bulbs or lamps producing yellow light by means of dichroic filtration should not be permitted, because the irridescent nature of dichroic coatings reduces the sharpness of the filament image, creating blue haze outside the beam pattern and directing blue light to angles outside the axis of the beam.

Question 26: Are the conventional photometry and color measurement methods specified in current industry consensus standards and national and international regulations appropriate for HID powered headlamps? Does it accurately predict glare or does it underestimate it? What alternative testing methods should be used?

Photometric and radiometric studies of HID headlamps are currently under way (e.g. at the University of Iowa) to determine if there is some aspect of the output of HID headlamps that is not accounted for by present photometric and colorimetric testing methods.

Questions 27: Has there been any research on achieving a more uniform spectral power distribution from HIDs that would be similar to that of a heated metal filament?

Ichikoh Industries (Japan) has developed a line of HID automotive bulbs specifically designed to produce light having a color temperature of approximately 3100K, similar to the color temperature of a halogen bulb. The method by which this is achieved and the exact nature of the light output (yellow, white, etc.) are not yet known. Sample procurement procedures are underway in order to assess the nature and potential applicability of this development.

Question 28: The UMTRI-99-36 study found that to be considered similar in glare perception by test subjects, the halogen lamp had to be about 1.5 times or 50 percent brighter than the comparable HID lamp. What would be the safety and economic consequences if HID headlamps were required to meet photometric intensity performance but limited to about two-thirds of that now permitted? Please explain how your answer is determined.

Such an action would be ill advised without the results of the photometric and radiometric studies being carried out at e.g. University of Iowa. If a specific colorimetric or radiometric (or other) aspect of HID headlamp light can be isolated and shown to be responsible for the glare disparity between HID and halogen headlamps, and this aspect of HID light source performance can be attenuated or modified to reduce or eliminate the problem without a substantial loss in light output, this would be preferable.

Question 29: One would expect that manufacturers would be very cautious about installing HIDs in higher-mounted positions, because the likelihood of glare would seem to be very high. Nonetheless, HIDs are now offered on several LTVs

LTV-based SUVs comprise a large segment of the premium-vehicle category. HID headlamps are regarded as a premium feature, and so the demand for HID headlamps on SUVs is strong. In the absence of explicit and meaningful control of glare in the Federal headlamp standard, there is no incentive for vehicle manufacturers to refrain from equipping SUVs with HID headlamps, and there is strong market incentive for them to expand such usage.

Question 30: Given that HID light sources are being used in non-headlamp applications such as fog, auxiliary low beam and driving, and for OEM upper beam, should NHTSA regulate any or all exterior lighting devices that use HID light sources on motor vehicles?

NHTSA should regulate all exterior lighting and signalling functions. Given that fog lamps and HID headlamps are two separate but approximately equal subjects of glare complaints, the agency should regard the notion of fog lamps using HID sources with extreme prejudice unless a clear, present, substantial and universal safety benefit can be shown. Please see answer to question 25 regarding fog lamp color. Auxiliary low beam headlamps are unknown outside North America, and their use would be unnecessary with reasonable and proper low beam photometric requirements. Very few cars have auxiliary driving lamps.

Since 1983, many other interchangeability specifications for many other headlamp bulbs have been introduced into federal law. Many have black caps. Until recently, none had any other specified coating, filter, tinting or shielding. There are two types of bulbs, HIR1 and HIR2, that have special durable infrared reflective coatings on the bulb capsule.

Please note that only the General Electric HIR1 and HIR2 bulbs use a durable infrared coating. The Philips HIR1/9011 bulb does not use a bulb coating. Philips has attained the required luminous flux, current draw and life requirements without such a coating. (Philips does not presently manufacture an HIR2/9012 bulb.)

Question 31: Given the concern of commenters that "whiter" and "bluer" mean more glare, should any halogen bulbs be permitted to have emitted light with altered color that is different than that emitted by a heated wire filament through a colorless, unfiltered, uncoated glass or quartz bulb envelope ?

No. The preponderance of evidence suggests that blue-tinted bulbs, even those producing SAE "White" light, cause increased glare. It is impossible to predict reliably the effect of a bulb coating upon the output of every different headlamp in which such a bulb may be used. The marketing of a stylistic preference at the cost of increased glare (even discomfort glare) should not be permitted in the absence of a clear, present, substantial and universal safety benefit.

Question 32: Alternatively, and less restrictively, should NHTSA reduce the allowable tolerance for the measurement of color within the defined definition of the color white such that bulbs will emit color traditionally provided by halogen bulbs with colorless, coating-less, filter-less capsules?

Yes. The market for blue bulbs is a direct result of the relatively blue appearance of HID headlamps and certain drivers' desire to emulate that appearance. If all headlamps produce more or less the same light color, there will be no incentive for drivers to modify their headlamps in a glare-increasing manner (as by installing a blue bulb that may or may not be compliant). Further, the proliferation of different types of coated bulbs under the present inappropriately-wide "white" specification has created a situation of enforcement impossibility.

Would the procedure proposed to the United Nations Economic Commission for Europe's Working Party on Lighting and Light Signaling Docket (see NHTSA-2001-8885-5) be a reasonable one?

Police officers will still be burdened to determine the legality or acceptability of the myriad types of blue bulbs (legal and otherwise) they encounter on the road. The popularity and proliferation of these bulbs, as evident by simple observation of cars using obviously-non-compliant bulbs remaining unticketed by proximate police officers, suggests this is an unreasonable expectation. State laws with widely-varying language will continue, as is currently the case, to further confound enforcement efforts. The costs of enforcement at the importation, sale and use levels constitute an unjustified and unwise use of public resources in the absence of a clear, present, substantial and universal safety benefit to these bulbs, and can be entirely avoided if all "blue" bulbs are simply banned.

Question 33: What safety value do any of these colored bulbs have? If there are any safety claims made, please provide the data and studies that substantiate those claims. If there are safety claims, provide an analysis of how those claims offset the disbenefit of increased glare.

A recent study, much referenced in responses to Docket 8885, is said to show peripheral-vision benefit to a particular maker's "cool blue" bulbs. The agency should carefully consider the degree of benefit found by the actual research, in contrast to the marketing claims being made on the basis of that study's results. If there is serious scientific thought indicating there may be a clear, present and substantial benefit to blue-tinted bulbs, research funded by a party with no financial interest in the outcome should be carried out. There is an untested hypothesis that green-tinted light may present a more optimal spectral power distribution of the headlamp light, such that it is the closest possible match for the spectral sensitivity of the human eye, potentially improving peripheral vision to a greater degree than was found in the blue-bulb study, and without the extra glare of blue light sources. However, there is no market pressure to develop green-tinted bulbs, since HID headlamps, which are what blue bulbs try to mimic, do not at this time appear green.

Question 34: If there are substantiated safety claims that overwhelmingly offset the glare disbenefits, should NHTSA mandate these colored bulbs, or just allow them? Would mandating these bulbs ensure greater safety benefit to the public than the public pays in differential cost for these versus uncolored bulbs?

Mandating colored bulbs would be extremely problematic unless the colored bulbs were specifically designed not to be interchangeable with existing, uncolored bulb designs. It is impossible to predict the effect of installing a modified (e.g. colored) bulb in every different type of headlamp in which it may be installed, and since existing headlamps are designed to conform to the Federal requirements using uncolored bulbs, the possibility of a colored bulb creating a noncompliance must not be overlooked.

Question 35: If there are no substantiated positive or negative safety claims, should NHTSA prohibit these colored bulbs? What justification is there for being so performance or design restrictive?

If colored bulbs cannot be shown to have a clear, present, substantial and universal safety benefit, they should be entirely disallowed. Their presence on the market has created an enforcement nightmare, as numerous police agencies have commented in this docket. In addition, increased glare (even discomfort glare) is an unwarranted disbenefit in the absence of a clear, present and substantial safety benefit.

Question 36: Given the results of recent research documented in UMTRI 2001-9, indicating that discomfort glare ratings increase as the chromaticity moves toward the blue color range of the visible light spectrum, is there any reason not to ban headlamp bulbs and headlamps that alter the color of the light emission?

This question is perhaps too broad, given the potential for yellow light to improve seeing and reduce glare in some situations (see answer to question 25) and given the hypothetical potential for green-tinted light to improve peripheral vision (see answer to question 33). However, there is no reason for the agency not to ban headlamp bulbs, lamps and lamp components that alter the color of the light emission *in the direction of blue*.

Question 37: Should all replaceable light sources be designed to conform the specifications of the standardized OEM light sources, regardless of whether they are to be used as original or replacement equipment?

Yes. Otherwise the standardized specifications become meaningless.

Question 38: Because manufacturers appear to be reluctant (due in part to liability concerns) to modify the standardized OEM design specifications to account for the advertised performance enhancements that some of the replacement light sources are claimed to have, should NHTSA restrict manufacturers ability to modify Part 564 submission information to simply those modifications that correct errors in previous submissions?

The reluctance of manufacturers to modify the standardized specifications to account for the advertised performance enhancements may have more to do with the veracity of the advertising claims relative to reality than with liability concerns. However, NHTSA may wish to examine ways to streamline Part 564 submission and modification of prior submissions. The agency may wish to examine the prospect of replacing Part 564 with ECE Regulations 37 and 99, or integrating those ECE regulations into US replaceable bulb standards. These regulations contain an attractive prohibition of physical interchangeability of bulbs with different electrical, photometric or colorimetric performance.

Question 39: Many states have restrictions on the use of lamps on motor vehicles that have appearance similar to lamps required for emergency vehicles, i.e., lamps that have the emission of blue or red light. How has the enforcement of these state laws been affected since the introduction of replacement light sources that have bluish or other non-permitted colors?

There have been many reports of drivers of cars originally equipped with HID headlamps being cited by police for "improper headlamps" or "improper light color", with the vehicle owners incurring considerable inconvenience and expense as a result. Please see answer to question 32.

Question 40: Should NHTSA regulate any of these auxiliary lamps? If so, which ones, and why?

NHTSA should regulate all exterior lighting and signalling functions, for the same reasons it regulates headlamps currently: The installation and performance of exterior lighting devices is crucial to the highway safety not only of the driver on whose car the devices are installed, but to all other drivers on the same roads. There are numerous different state standards for performance and installation of auxiliary lamps, which creates a compliance and enforcement hassle for vehicle and equipment manufacturers. A single regulation for at least the performance (and preferably also the installation, aim and electrical connection) for each auxiliary lamp function would greatly simplify compliance and enforcement, and facilitate public education on the proper use and adjustment of these devices which is currently stymied by the great variance among state regulations.

As for which lamp functions to regulate in which order given NHTSA's finite resources, fog lamps should be the first auxiliary lamp function to come under NHTSA regulation, because fog lamps are overwhelmingly the most common auxiliary forward-lighting installation. Next should come auxiliary driving lamps. Auxiliary low beams should not be permitted; these are unnecessary If thoughtful and proper low beam photometric, testing and aim standards are in place. Please see answers to previous questions.

Question 41: For fog lamps, should NHTSA adopt either or both of the archaic SAE and the ECE performance requirements for this lamp?

Both the existing SAE and ECE fog lamp standards are indeed archaic, though there is considerable precedent for NHTSA referencing decades-old technical standards in FMVSS 108. ECE fog lamps tend to have better performance (wider beams with sharper cutoffs) and less glare than SAE fog lamps; this is probably due in part to the high-performance, high-precision halogen light sources such as H1, H2 and H3 that have been the norm (together with effective bulb shielding necessary due to the high luminance of these sources) in ECE fog lamps, while SAE fog lamps have tended to use less-precise, lower-performing sources such as the 800-series bulbs, often without any bulb shielding. The agency would do fine to adopt the current ECE Regulation 19 requirements for fog lamps.

The agency would do better, however, to adopt the upcoming new ECE R19 requirements and the new SAE standards for fog lamps. These two standards are nearly identical, and call for much higher performance and lower glare. Allowing both standards would lessen the compliance cost burden on vehicle manufacturers with existing fog lamp designs already type-approved under ECE R19.

The market demands compact, stylish, high-performance, low-cost fog lamps. The agency may well wish to evaluate the state of the art and base some aspects of future fog lamp regulation upon the performance of a newly-released lamp unit by Bosch (Bosch Germany Nº. 0 305 055 002). This lamp is a compact, inexpensive, high-performance design that meets the existing ECE R19 and SAE standards as well as the upcoming new standards.

Fog lamps should mandatorily produce selective yellow light; please see response to question 25.

Should NHTSA propose switching, wiring, and aiming hardware performance that, to the extent possible, reduces the incidence of fog lamp abuse? Please provide support for your answers and recommendations.

The absence of reasonable and proper standards for aiming hardware performance and the plethora of differing state requirements and allowances for switching and usage modes, together with the low performance and high glare of a great many "fog lamps" presently on the road, contribute to the problem of fog lamp abuse and fog lamp glare. NHTSA should promulgate aiming hardware standards comparable to those in place for headlamp aiming hardware standards. Any fog lamp photometric standard should require performance sufficiently high that fog lamps produce sufficient illumination for safe driving when used ***in lieu of*** low beam headlamps when weather conditions require it. Fog lamps should either be mandatorily inoperable with headlamps, or—less restrictively— should be on a "latching relay" switch similar to that employed for backglass defoggers, such that the fog lamps switch off and must be manually reactivated each time the low beam headlamps are switched off (either due to the headlamps being switched off or due to high beam being selected) and such that the fog lamps switch off and must be manually reactivated each time the vehicle ignition is switched off.

Question 42: Should NHTSA regulate any of the other auxiliary lamps to minimize, to the extent possible, aberrant performance and misuse?

NHTSA should regulate rear fog lamps (fog taillamps). Only one rear fog lamp should be permitted (to avoid confusion with stop lamps), to be mounted to the left of the vehicle's centerline, and wired such that the rear fog lamp is on a "latching relay" type switch similar to that employed for backglass defoggers, such that the rear fog lamp switches off and must be manually reactivated each time the vehicle ignition, front fog lamps, or headlamps are switched off. Please see Attachment 3, pages 35-37.

Providing a constant voltage to headlamps would make their performance be virtually the same as that achieved when they are tested. The effect would be that, regardless of the vehicle's performance, the headlamps would provide the intended illumination and the measured levels of glare. There would be an increase in vehicle purchase cost for this solution, however, because an electronic module that can perform this constant voltage supply would be required. The installed price of this module on a new vehicle would be similar to that of the modules used for many current daytime running lamps, typically less than $20.

The agency should consider the failure rate of PWM DRL modules. Such failures are commonly observed on vehicles in use in Canada, where PWM DRLs are common. In the case of DRLs, the failure of the module is of little primary safety effect; the vehicle with failed DRLs is still conspicuous due to the prevailing daylight conditions. In the event of headlamp constant-voltage module failure, however, a primary safety system, the vehicle headlamps, will be affected. Failsafe circuits to address this concern will increase the module cost considerably above the cost for a DRL module.

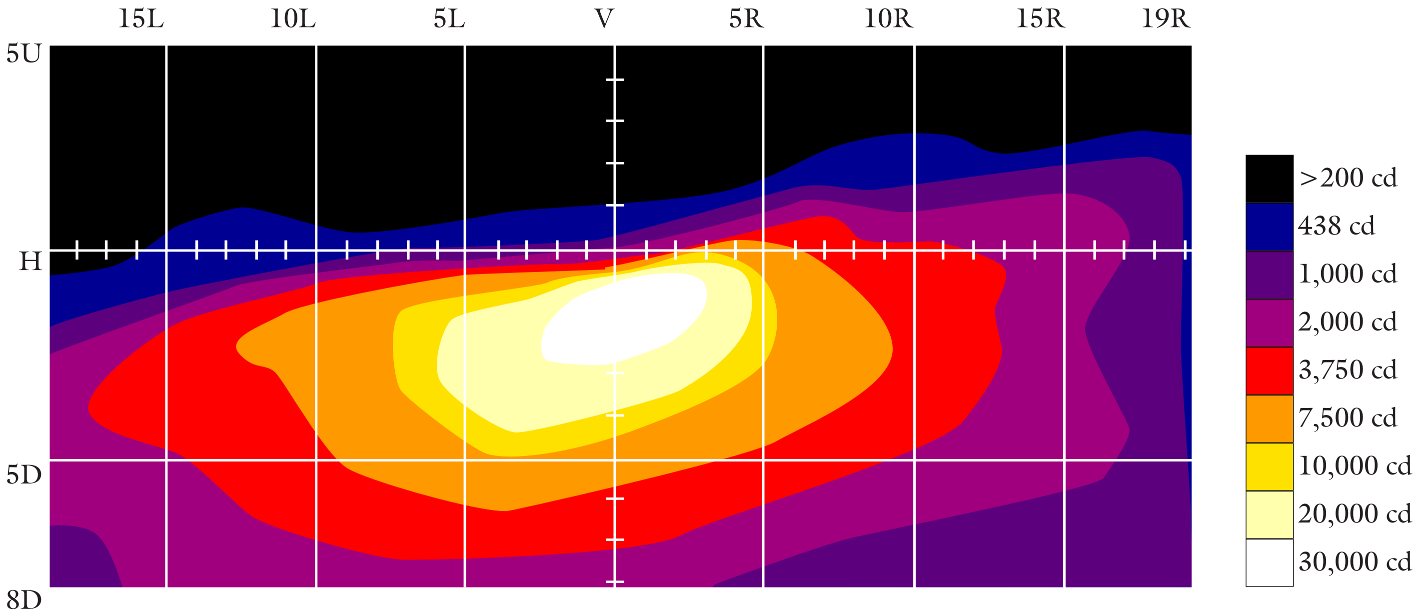
Question 43: Should NHTSA require a standardized voltage be applied to headlamps when they are operating on motor vehicles in service?

This is an unnecessarily difficult and costly solution to the very real problem of voltage discrepancy between laboratory and operating voltages. The agency should either change the test voltage of headlamps to 13.7 or adopt dual-voltage testing at 12 and 14 volts, without changing the nominal photometric minima and maxima at each test point and without changing the luminous output specifications for standardized replaceable light sources. This change, together with a reasonable and proper headlamp photometric standard, would effectively and immediately address the voltage discrepancy without adding to the cost or complexity of motor vehicles. Please see Attachment 3, pages 11-13.

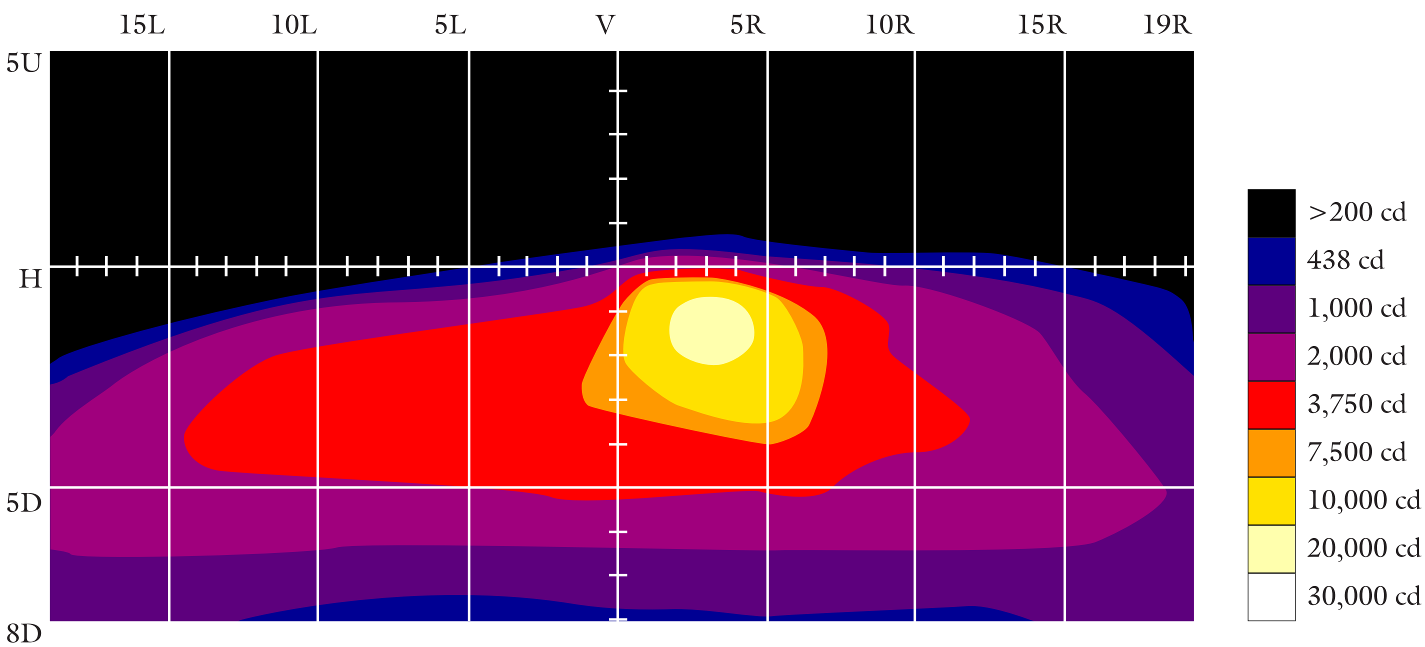
Question 45: What voltage levels will future vehicles provide to headlamps if left unregulated by FMVSS No. 108? Provide information and data to support your prediction.

The "12-volt" automotive electrical system has reached design maturity, as evidenced by the ongoing preparations for a transition to 42v systems. It is unlikely that the operating voltage characteristics of "12-volt" automotive electrical systems and their headlamp circuitry will change significantly from their present values.

Please see attachments 1, 2 and 3.



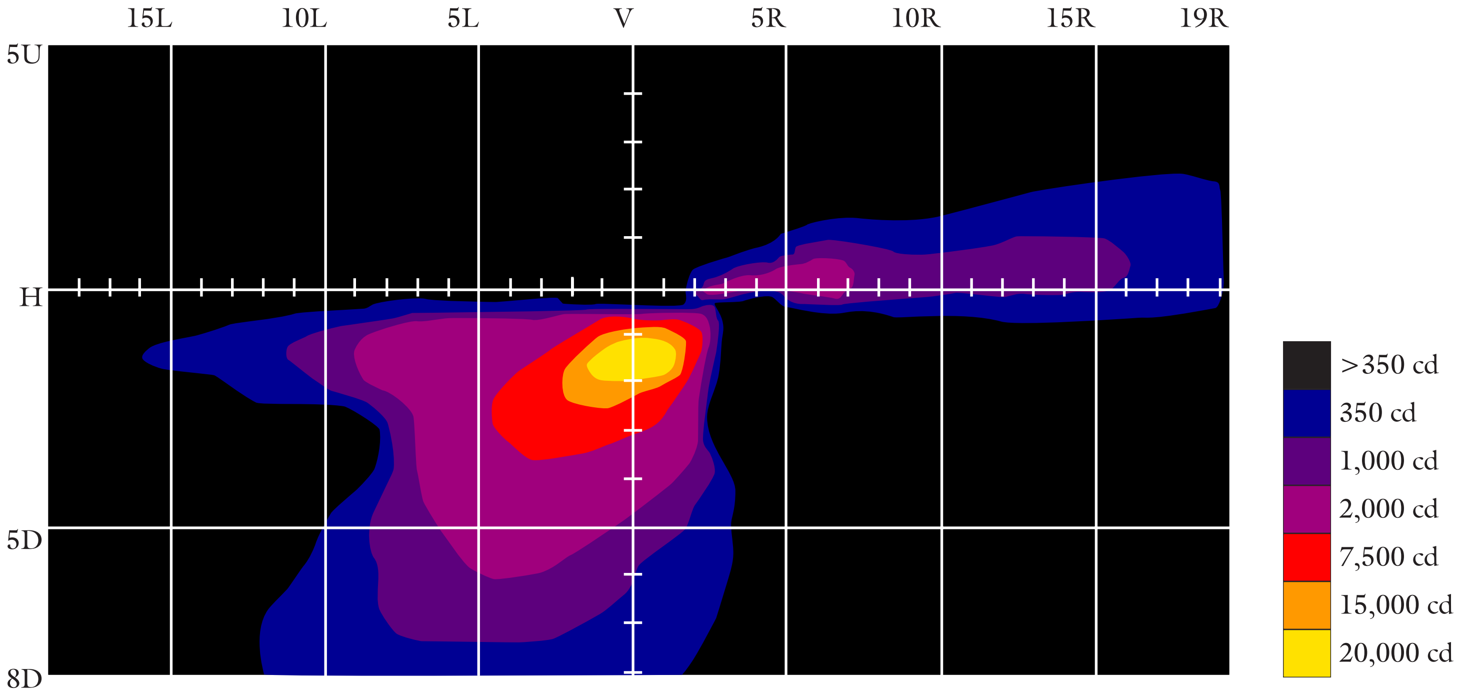
Low Beam ECE; MAX=38,808 cd (adapted from SAE 970913, p. 211)



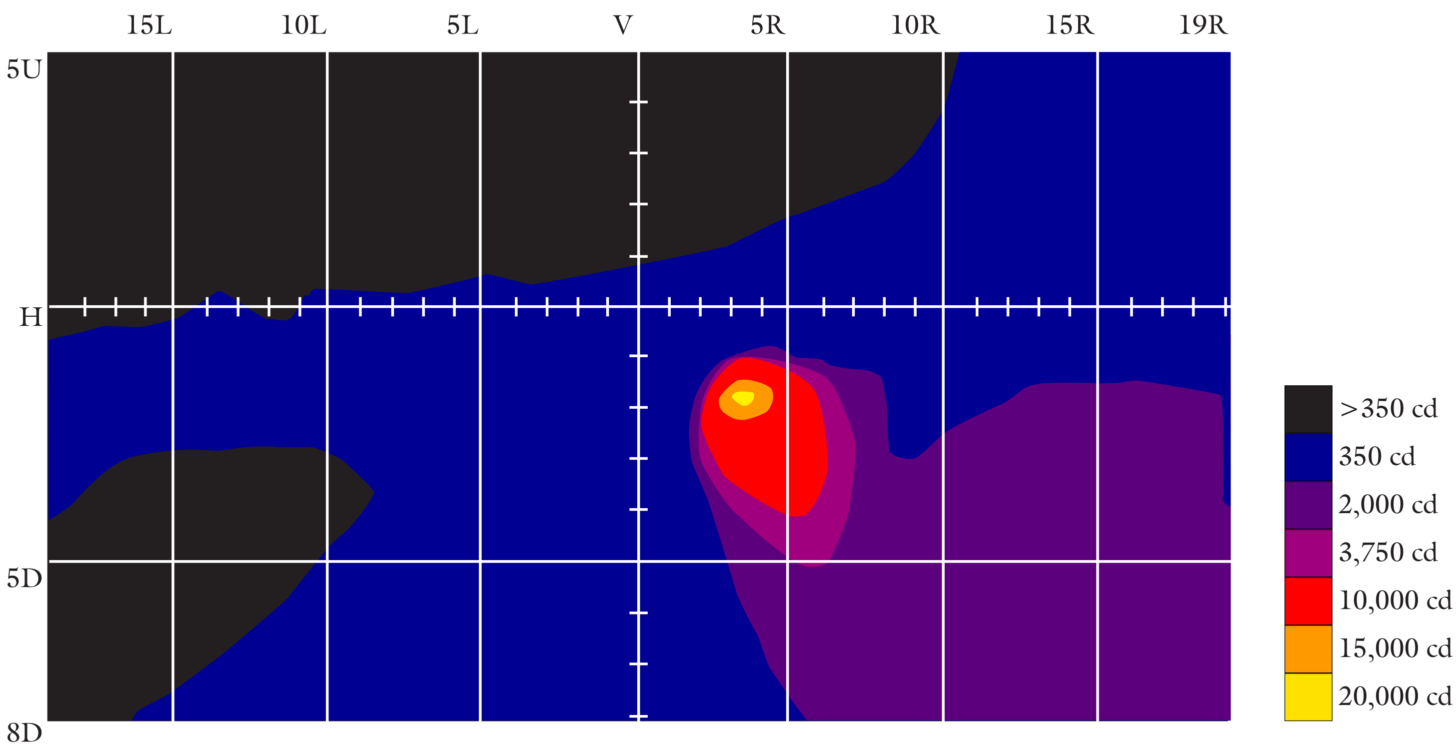
Low Beam US; MAX=28,474 cd (adapted from SAE 970913, p. 211)

ATTACHMENT 1

Isocandela diagrams (adapted from SAE 970913) of US and ECE low beam headlamps, made by the same lamp manufacturer for a single late-model vehicle model, tested in the same photometric laboratory by the same tester on the same photogoniometer, using the same accurate-rated H7 bulb at 12.8V. The ECE headlamp is aimed to US VOL specifications, with the cutoff set at 0.7%/0.4° down. This represents an increase in test voltage and aim height relative to ECE practice, however, this was necessary in order to control as many variables as possible in this like-to-like comparison. The lowest delimited candela value in these isoscans is 200 cd, which is insufficient to show that the ECE lamp's 125 cd contour extends through all relevant sign light test points. The ECE headlamp's hot spot of 38,808 cd is at (1.3D, 1R), while the US lamp's hot spot of 28,474 cd is at (1.8D, 3R). The ECE lamp's 10,000 cd contour extends from 6L to 5R, while the US lamp's 10,000 cd contour extends from 0.5L to 6R. The ECE lamp's 2,000 cd contour extends from 18L to 13R, while the US lamp's 2,000 cd contour extends from 23L to 18R.



Low Beam (ECE—US) MAX=26,274 cd (adapted from SAE 970913, p. 212)



Low Beam (US—ECE) MAX=13,699 cd (adapted from SAE 970913, p. 212)

ATTACHMENT 2

Adaptation of computer-generated differential beam (from SAE 970913) by subtracting ECE from US beam pattern (as per Attachment 1). The first chart shows the advantage of the ECE beam over the US beam. The 1,000 cd and 2,000 cd contours provide much better legibility of road signs located on the shoulder. Straight ahead of the vehicle beyond 20m, the ECE beam is substantially more intense. The difference of 26,300 cd is almost equal to the value of the US headlamp's hot spot. This equates to a 40% increase in object detection distance relative to the US headlamp.

Daniel Stern Lighting Consultancy

Where Does the Glare Come From?

A Comprehensive Discussion of Seeing and Glare in the Nighttime Roadway Environment

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Contents

Tables

Terms and Abbreviations in This Report

Beam Pattern: the distribution pattern of light from a lamp assembly.

Photometrics: the amounts of light produced at specific points in the beam by a specific lamp or type of lamp.

Photometric Requirements: amounts of light that are legally permitted at given locations in a beam pattern by a given technical standard. Expressed as a range of minimum acceptable ("minimum") and maximum allowable ("maximum") intensities at each test point or region in the beam pattern.

Test point: a location in a lamp beam for which a headlamp photometric standard requires a specific range of intensity. Expressed in degrees right ("R") or left ("L"), and up ("U") or down ("D") as viewed by an observer facing the same direction as the lamp is shining, and relative to a point straight ahead of the center of the lamp. This center point is visualized as the intersection of a horizontal ("H") and a vertical ("V") line, and is called (H, V). Except for the center point (H, V), the vertical location of the test point is given first, followed by the horizontal component, e.g.: (1.5D, 2R). For easy conceptualization: 1 degree in any direction is equal to approximately 13cm (5.25") at a distance of 7.62m (25'). So a test point located at (0.5U, 3.5L) would be 6.5cm above and 45.5cm to the left of the center point (H,V) if the lamp were 7.62m away from a vertical wall or screen. Simple geometry can be used to derive locations at any desired distance for any given test point.

Right/Left: refers in this report to beam, driver and opposing-vehicle locations relevant where traffic proceeds along the right side of the road, as in North America and Continental Europe. For conceptualization in a left-hand traffic country such as Australia, New Zealand, Great Britain or Japan, please substitute "right" for "left" and vice versa when reading about test points, driver locations, and placement of opposing vehicles.

ECE: refers to headlamp photometric standards and test procedures contained in auto safety regulations promulgated by the United Nations Economic Commission for Europe, and to the headlamps that comply with ECE standards. All industrialized countries worldwide except the United States require or permit ECE vehicle lighting and signalling equipment, including headlamps.

US: refers to headlamp photometric standards and test procedures contained in US Federal Motor Vehicle Safety Standards 108 (FMVSS 108), and to the headlamps that conform to FMVSS 108. Many industrialized countries worldwide prohibit US vehicle lighting and signaling equipment, due among other reasons to high levels of glare produced by US low beam headlamps. Canadian Motor Vehicle Safety Standard 108 is substantially the same as US FMVSS 108, and most cars in Canada have US headlamps. Canada, however, also permits ECE headlamps under CMVSS 108.1; US & Canadian Motor Vehicle Safety Standards 108 are collectively referred to herein as MVSS 108.

GTB or Harmonized: refers to a recent headlamp photometric standard from the Groupe de Travail Bruxelles 1952, or "Brussels Working Group 1952," an international vehicle lighting consortium, and to headlamps that comply with the GTB standard. The GTB harmonized headlamp standard is not a standalone, but is meant to bridge the gap between US and ECE headlamp regulations. Headlamps that comply with the GTB standard may also comply with the US or with the ECE standard. The GTB standard allows less glare than the US standard. Changes to the US headlamp standard in 1997 incorporated some of the photometric requirements contained in the GTB standard, but did not reduce the glare maximum to the lower-than-US level called for by the GTB standard.

VOA: refers to recent (1997) modifications to US FMVSS 108 and Canadian CMVSS 108 permitting low beam headlamps to produce a beam pattern that can be Visually/Optically Aimed in the vertical direction. Prior to the addition of VOA provisions, US headlamps could not accurately be aimed by any but mechanical means. This was done either with an external headlamp aiming device or with a bubble level or calibrated scale integral with the headlamp assembly.

Cutoff: a distinctly visible, relatively sharp transition from a region of high intensity to a region of low intensity. A horizontal cutoff on the side of the low beam pattern facing oncoming traffic (the left side, in right-hand traffic countries) is used in ECE low beams in order to prevent glare to oncoming drivers and to determine vertical aim. There is high intensity below the cutoff, and low intensity above the cutoff. GTB low beams often have a cutoff similar to ECE low beams. Conventional US low beams do not have a cutoff.

VOL: a type of US VOA low beam with a horizontal cutoff on the Left side of the beam. The horizontal cutoff is used to determine correct vertical aim of the headlamp. Some VOL headlamps produce beam patterns similar to ECE low beam headlamps.

VOR: a type of US VOA low beam with a horizontal cutoff on the Right side of the beam. The horizontal cutoff is used to determine correct vertical aim of the headlamp. Many VOR headlamps produce beam patterns similar to conventional US low beam headlamps.

Discomfort Glare: Light that causes discomfort or distraction, but which may not necessarily reduce a driver's ability to see visual targets. Measured with the DeBoer scale of 1 to 9, where the lower the number the worse the glare.

Disability Glare: Lights that reduces a driver's abiltity to see visual targets.

Overview

The proliferation of glare complaints from US drivers is *prima facie* evidence that US glare levels are too high. Interviews with drivers and observation of topical discussions confirms excessive discomfort and disability glare (one-on-one interviews are not a valid basis to derive any statistics, but can provide suggestive indication of phenomena). Anecdotal reports of older drivers stopping driving at night before stopping driving during the day, and stopping driving at night in the US but continuing to drive at night in Europe, also suggest that US glare levels are too high. There are several vehicle-based glare sources that have the capacity to contribute to excessive glare in the nighttime driving environment:

- Low beam headlamps producing excessive glare by design, through misaim, or as a result of inappropriate use (bulbs of improper color or power),
- New types of low beam headlamps with high efficacy sources, such as HID and very-high-flux halogen bulbs, that have much greater light flux throughout the beam pattern and/or produce higher wavelength (bluer) light that is perceived as glaring,
- High beam headlamps producing excessive glare as a result of inappropriate use in traffic,
- Auxiliary front lamps producing excessive glare by design, through misaim, or as a result of inappropriate use,
- Fog taillamps (“rear fog warning lamps”) producing excessive glare as a result of inappropriate installation and use.

Low Beam Headlamps

Low beam headlamps are the primary source of glare in the nighttime roadway environment, because they are overwhelmingly the most commonly used lighting device in nighttime traffic. While it has long been recognized that North American low beams tend to produce more direct glare than ECE low beams, it is only relatively recently that glare has become a problem apparent in North American headlamps. The large number of glare complaints being received by NHTSA raises the question of why current and recent headlamps are generating such vociferous glare complaints, which did not occur with older headlamps that were required to meet the same photometric requirements. US low beam glare and signal-image intensities are increasing. A glare threshold seems to have been crossed, above which people find the level of glare intolerable. The long-held assumption that North American drivers willingly tolerate high levels of glare, repeated in almost every study that compares US and ECE low beam photometrics, seems to have lost validity with increased glare and signal image intensity from recent and current US low beam headlamps. It must be remembered that there is little the average driver can do about excessive glare; when it gets dark, we must each drive on the roads despite the high glare level.

Facts, Figures and Premises

Regardless of the disparate philosophy that has led to differing low beam photometric requirements in different jurisdictions, the prescribed photometric minima and maxima in any headlamp standard are based on the need for minimum amounts of light at some locations in the beam to assure adequate detection of targets located in that area, and the undesireability of excessive amounts of light at other locations in the beam to guard against glare. Most headlamp glare studies to date have simulated headlamp glare with individual lamps (or sets of lamps) arranged so as to emulate an oncoming car, or with actual oncoming-vehicle passes on roads. No attention seems to have been paid to the cumulative effects of glare produced by a steady succession of oncoming cars, as is found on actual roads. This omission bears reconsideration, given recent quantifications of traffic crashes directly attributable to headlamp glare (NHTSA-2001-8885-1567). The traditional dismissal of discomfort glare as a safety factor may also require reconsideration. Cumulative and/or repetitive exposure to relatively high levels of discomfort glare may fatigue, distract and disturb the nighttime driver to the extent that safety is compromised. With today's increasing emphasis on the role of fatigued, distracted and disturbed (or "enraged") drivers in traffic crashes, safety levels may be improved by reduction in roadway environmental factors, such as discomfort glare, that tend to bring about fatigue, distraction and rage.

The cumulative effect of exposure to discomfort glare is known. Meeting a queue of closely following vehicles with headlamps on reduces detection distances of roadside objects more than would a single vehicle, due to the greater length of time that glare is present, and effectively increases glare intensity by 20% compared with a single glare vehicle (Hemion, 1969).

Seeing vs. Glare

Low beam headlamps must strike a balance between providing seeing light for the driver, and preventing glare to other road users. The ratio of seeing light to glare light (table 4), calculated by computing the ratio of intensity at E(max) and (0.5U, 3.5L), is crucial to overall visual performance, with higher ratios indicating a highly desirable combination of high visibility with low glare. (Padmos and Alferdinck, 1988; Sivak and Flannagan, 1995; Flannagan *et al.* 1996).

Glare

On the road, the eyes of oncoming drivers are, at least 50% of the time, focussed within a regular elliptically shaped region between 0.5U and 1U, and 2L and 4L. (Automotive Lighting, 2001). The primary direct-glare control point in worldwide low-beam photometric standards is in the close vicinity of (0.5U, 3.5L), which lies within this region. Analogous test points exist in all relevant low beam standards.

Seeing

"Down-the-road" seeing light is specified at one or two main seeing point(s) slightly rightward and downward (of (H,V) as viewed in the direction of projection). Analogous concentrations of light (a "hot spot") exist in all relevant low beam standards. Both of the ECE low beam's seeing-light minima, as well as the GTB hot spot, are closer to (H,V) than the comparable US hot spots. The closer the hot spot is to (H,V)—that is, the less the offset to the right and downward, the longer will be the down-the-road beam of light. By simple geometry, a lower hot spot intersects the road surface closer than a higher hot spot, and a hot spot shifted further to the right leaves the roadway sooner than a hot spot shifted further to the left. The ECE low beam, which emphasizes homogeneity of seeing light, has two seeing points of at least 15,000 cd/unlimited maximum (pair), one at (0.6D, 1.1R) and one at (0.9D, 1.7R), while the US low beam, which emphasizes intensity of the hot spot, has two seeing points, one of 20,000 to 40,000 cd (pair) at (0.5D, 1.5R) and one of minimum 30,000 cd (pair) at (1.5D, 2R). Here is a comparison of the latter point in each beam pattern Listed values are for a pair of headlamps at the US test voltage of 12.8V:

Table 1: Seeing Minima and Glare Maxima by Photometric Standard

US glare max:	2,000 cd @ (0.5U, 1.5L to L)
US seeing min:	30,000 cd @ (1.5D, 2R)
ECE glare max:	623 cd @ (0.57U, 3.43L)
ECE seeing min:	18,681 cd @ (0.9D, 1.7R)
GTB glare max:	1,680 cd @ (0.5U, 1.5L to L)
GTB seeing min:	24,000 cd @ (0.6D, 1.3R)

Market-weighted analyses of Model Year 2000 US and European (Sivak and Flannagan, 2002) low beam patterns provide 75th, 50th and 25th percentile light levels in these regions, for a pair of headlamps, at 12.8V. These levels are tabulated below.

Table 2: Seeing Light at E(max) In Beam

US 75:	55,876 cd @ (1.5D, 2.5R)
ECE 75:	55,868 cd @ (1.5D, 1R)
US 50:	51,096 cd @ (1.5D, 3R)
ECE 50:	40,778 cd @ (2D, 0.5R)
US 25:	42,402 cd @ (1D, 2.5R)
ECE 25:	24,580 cd @ (1.5D, 2.5R)

Table 3: Glare Light at (0.5U, 3.5L)

US 75:	1214 cd
ECE 75:	760 cd
US 50:	1010 cd
ECE 50:	578 cd
US 25:	950 cd
ECE 25:	324 cd

Table 4: Seeing/Glare Ratios By Percentile

US 75:	46/1
ECE 75:	74/1
US 50:	51/1
ECE 50:	71/1
US 25:	44/1
ECE 25:	76/1

Operating Voltage Considerations

The seeing and glare levels above were obtained when the headlamps were operated at 12.8 Volts. While this has long been the prescribed test voltage in the US, it - like the ECE test voltage of 12.0 - is unrealistically low. Real-world line voltages in running automobiles tend to be between 13.2 and 14.2 Volts. (Padmos & Alferdinck 1988; Meli 1992; Amerlaan & Vellokoop 1996; Hella KG Hueck 1997, Italian Transport Administration 1998, and NHTSA/Shelton, 1998). The mean voltage value for the ranges found is 13.7. Luminous flux change is not linear with voltage change. The flux of an automotive halogen bulb, if taken to be 100% at 12.8 Volts, is 126% at 13.7 Volts (Padmos and Alferdinck, 1988; Flannagan, 1998, and IES 1984 formula $(V_1/V_2)^{3.4}$ for determining light output with voltage change.)

Here are the market-weighted 75th, 50th and 25th percentile glare levels in the primary direct-glare region and seeing levels in the primary seeing region, recalculated at 13.7V, as well as the seeing/glare ratios by percentile, for a pair of headlamps:

Table 5: Glare Light at (0.5U, 3.5L)

US 75:	1530 cd
ECE 75:	959 cd
US 50:	1273 cd
ECE 50:	730 cd
US 25:	1197 cd
ECE 25:	409 cd

Table 6: Seeing Light at E(max) In Beam

US 75:	70,404 cd @ (1.5D, 2.5R)
ECE 75:	70,479 cd @ (1.5D, 1R)
US 50:	64,381 cd @ (1.5D, 3R)
ECE 50:	51,443 cd @ (2D, 0.5R)
US 25:	53,427 cd @ (1D, 2.5R)
ECE 25:	30,971 cd @ (1.5D, 2.5R)

Discussion and Significance

The nominal seeing minima in US and ECE low beam photometric requirements are based on target illuminance requirements relevant to the task of driving at night, and there is little concern that the minima need to be raised. While seeing light levels (where more light is better) are helped by the disparity between test voltage and real-world voltage, glare-light levels (where more light is worse) are aggravated by this disparity. The present report compares nominal intensity requirements (minima and maxima contained in photometric requirements) with real-world headlamp performance at 13.7V. This reveals the ways in which the disparity between test and operating voltages affects seeing and glare performance of low beam headlamps.

Considerations for Test Voltage Change

A change is warranted in the MVSS 108 headlamp test voltage from 12.8 to 13.7 Volts, without modifying the design of headlamp bulbs or nominal photometric beam requirements. A 13.7V test voltage would more closely replicate real-world conditions, and would reduce glare caused by headlamps that emit higher levels of glare on the road at 13.7V than they do in the laboratory at 12.8V. Alternatively, a dual-voltage test requirement can be implemented such that beam locations identified as seeing regions are tested at 12.8V, while beam locations identified as glare regions are tested at 14V. These two voltages represent approximately the 25th and 90th percentile voltages found in cars on the road under various conditions (idle, high speed, etc.). Dual-voltage testing would ensure acceptably high levels of seeing light under worst-case, lowest-voltage conditions, while simultaneously reducing glare under worst-case, highest-voltage on-road conditions. Such a dual-voltage testing requirement would much more closely replicate actual on-road conditions in which headlamps are used.

Seeing and Glare: US vs. ECE

Considerable discussion has been devoted to seeing distance with ECE low beams versus US low beams. The discourse has, over time, ossified into a debate based largely upon philosophical disagreements rather than actual safety benefits (Hella 1997, Olson 1977). A direct comparison of seeing-light intensities of ECE low beams at US hot-spot locations and of US low beams at ECE hot-spot locations is useful in order to reduce the confounding influence of philosophical differences upon the discussion of seeing distance with the US and ECE low beams. Within the resolution provided by the 75th, 50th and 25th percentile data, it can be seen that in the context of their own beams, the ECE and US headlamps' performance is substantially equal down to at least the 50th percentile level; only at the 25th percentile level do the US headlamps categorically outperform the ECE headlamps. All E(max) points are obtained with the beams aimed to their respective aim requirements, i.e., US headlamps aimed to US standards, ECE headlamps aimed to ECE standards.

Table 7: Seeing Light Comparison at US E(max) Location In Beam

US 75:	70,404 cd @ (1.5D, 2.5R)
ECE 75:	50,836 cd @ (1.5D, 2.5R)
US 50:	64,381 cd @ (1.5D, 3R)
ECE 50:	38,012 cd @ (1.5D, 3R)
US 25:	53,427 cd @ (1D, 2.5R)
ECE 25:	22,967 cd @ (1D, 2.5R)

Table 8: Seeing Light Comparison at ECE E(max) Location In Beam

US 75:	58,391 cd @(1.5D, 1R)
ECE 75:	70,479 cd @(1.5D, 1R)
US 50:	40,312 cd @(2D, 0.5R)
ECE 50:	51,443 cd @(2D, 0.5R)
US 25:	41,368 cd @(1.5D, 2.5R)
ECE 25:	31,008 cd @(1.5D, 2.5R)

Discussion and Significance - Disability Glare

The disabling effects of glare are nonlinear, and the relationship is such that small amounts of glare produce substantial reductions in seeing distance. The relationship is also not static, but dynamic and dependent upon the ratio of seeing light to glare light. (Moore, 1958; Olson, 1977). Drivers' object-detection performance is reduced by 28% with glare intensities of 1380 cd (Alferdinck & Theeuwes, 1997).

Table 9: Glare at (0.5U, 3.5L) as Percentage of 28% Disability Threshold

US 75:	111%
ECE 75:	69%
US 50:	92%
ECE 50:	53%
US 25:	87%
ECE 25:	30%

At least 75% of the US low beams approach the 1380 cd threshold of 28% disability; at least 25% of US low beams exceed this level. At least 75% of the ECE low beams are well under the 1380 cd threshold of 28% disability.

Discussion and Significance - Discomfort Glare

Discomfort glare exceeds DeBoer grade 5 ("barely acceptable") under actual driving conditions, including normal levels of dark adaptation, when glare illumination exceeds 700 cd, regardless of drivers' previous ECE or US headlamp experience (Alferdinck & Theeuwes, 1997).

Table 10: Glare at (0.5U, 3.5L) as Percentage of DeBoer Grade 5 Threshold

US 75:	219%
ECE 75:	137%
US 50:	182%
ECE 50:	104%
US 25:	171%
ECE 25:	58%

At least 75% of the US low beams and approximately 50% of the ECE low beams exceed the 700 cd DeBoer Grade 5 discomfort threshold. The US low beams exceed the threshold by approximately twice to three times the degree to which the ECE low beams exceed the threshold.

Discussion and Significance - Seeing

At least 75% of ECE low beams for MY2000 comply with the nominal intent of the US seeing-light minimum of 30,000 cd (pair). In addition, at least 50% of ECE low beams for MY2000 produce a hot spot considerably more intense than required by US low beam photometric standards at an angle closer to (H, V) in the vertical and/or horizontal direction than the analogous US low beam hot spots. At least 25% of ECE low beams for MY2000 produce a hot spot that is both more intense and closer to the beam axis than the comparable US hot spot. Thus, seeing illumination down the road ahead of the driver is longer and/or stronger than required by US low beam requirements with at least 75% of ECE low beams for MY2000.

Aim Factors

Headlamp aim influences low beam glare. The asymmetric light distribution produced by low beam headlamps places most of the flux downward and rightward with respect to the headlamp axis. Headlamps misaimed upward or leftward will shift high-intensity regions of the beam towards oncoming and preceeding drivers' eyes, increasing glare. ECE regulations, in recognition of this phenomenon, require headlamp levelling equipment (aim compensators) to minimize the incidence of glare due to misaim brought about by changing vehicle loads. Active (dynamic) aim compensators require no input from the driver, and alter the vertical aim of the headlamps in response to changing vehicle loads and changing vehicle pitch attitudes due to road conditions. Active aim compensators are required by ECE regulations on vehicles equipped with HID and high-flux halogen headlamps. MVSS 108 permits, but does not require aim compensators on any vehicle. Very little data exist to describe the degree to which recent US headlamps are correctly aimed prior to vehicles' first placement in service, as a part of periodic motor vehicle inspections, or when the beam pattern appears incorrect to the driver. Data are also scant concerning the degree to which recent US headlamps' aim deteriorates, and in what directions, in normal vehicle service and with routine maintenance, e.g. bulb replacement.

Opposing-Vehicle Height Mismatch

The last twenty years have seen simultaneous disparate trends in the US vehicle fleet towards lower-profile passenger cars and higher-profile trucks and sport-utility vehicles, with a concurrent increase in the use of SUVs and trucks as substitutes for passenger cars. Walker (1997) found that headlamp axis heights on popular recent-model SUVs and trucks can exceed 111 cm. This is over 85% higher than the 60 cm headlamp mounting height and in the close vicinity of the passenger car driver eye height of 110 cm found by Cobb (1990). The (0.5U, 3.5L) direct-glare control point corresponds to a driver eye height of 110 cm, a headlamp height of 60cm, lateral separation between the oncoming driver and the headlamps of 3m, and longitudinal separation between the oncoming driver and the headlamps of 50m (Sivak and Flannagan, 1995). This geometry represents a 50 cm vertical separation between the driver's eyes and the oncoming headlamps. However, in the increasingly-common situation of a passenger car driver (eyes at 110 cm) meeting the oncoming headlamps of a truck or SUV (headlamps at e.g. 104 cm), the vertical separation between the oncoming headlamps and the eyes of the driver is reduced to 6 cm. This geometry places the eyes of the driver at about (H, 3.5L) with respect to the oncoming headlamps.

Under North American (MVSS108) aiming specifications, headlamps are aimed with a fixed amount of declination regardless of lamp mounting height. ECE headlamp aiming regulations attempt to minimize glare and equalize seeing distance among short and tall vehicles by linking headlamp aim declination to headlamp mounting height.

The following tables show the glare at (H,3.5L) for pairs of US and ECE 75th, 50th, and 25th-percentile headlamps at 13.7V, with US fixed and ECE height-dependent aim. While a headlamp height of 104 cm is used in these calculations, higher headlamp heights exist (Walker, 1997). Glare is more severe with higher headlamp heights and North American fixed aiming. Under ECE Regulation 48, a headlamp mounted at 104cm would be aimed with the cutoff at between 1.5% and 2% (0.86° to 1.15°) declination. For this comparison, the ECE lamps' (H,3.5L) value has been selected from the candela matrix to equate to the center of the acceptable aim range, 1.75% (1°) declination.

Table 11: Glare at (H, 3.5L) with Fixed Aim

US 75:	2732 cd
ECE 75:	1212 cd
US 50:	2281 cd
ECE 50:	940 cd
US 25:	2071 cd
ECE 25:	572 cd

Table 12: Glare at (H, 3.5L) with ECE Height Dependent Aim

US 75:	998 cd
ECE 75:	824 cd
US 50:	917 cd
ECE 50:	585 cd
US 25:	733 cd
ECE 25:	310 cd

Discussion and Significance - Disability Glare

The disabling effects of glare are nonlinear, and the relationship is such that small amounts of glare produce substantial reductions in seeing distance. The relationship is also not static, but dynamic and dependent upon the ratio of seeing light to glare light. (Moore, 1958; Olson, 1977). Drivers' object-detection performance is reduced by 28% with glare intensities of 1380 cd (Alferdinck & Theeuwes, 1997).

Table 13: Glare at (H, 3.5L) as Percentage of 28% Disability Threshold, with Fixed Aim

US 75:	198%
ECE 75:	88%
US 50:	165%
ECE 50:	68%
US 25:	150%
ECE 25:	41%

Table 14: Glare at (H, 3.5L) as Percentage of 28% Disability Threshold, with ECE Height Dependent Aim

US 75:	72%
ECE 75:	60%
US 50:	66%
ECE 50:	42%
US 25:	53%
ECE 25:	22%

It can be seen from this comparison that at least 75% of the US low beams aimed to US specifications significantly exceed the 1380 cd threshold of 28% disability. The 75th percentile US low beams produce glare approaching double the 28% disability threshold. Increasing the aim declination of the US low beams by the same amount as is required of ECE low beams at this mounting height brings all of the US beams under the threshold of 28% disability

At least 75% of the ECE low beams are under the 1380 cd threshold of 28% disability with or without the height-dependent aim declination called for under ECE R48.

Discussion and Significance—Discomfort Glare

Discomfort glare exceeds DeBoer grade 5 (“just acceptable”) under actual driving conditions, including normal levels of dark adaptation, when glare illumination exceeds 700 cd, regardless of drivers’ previous ECE or US headlamp experience (Alferdinck & Theeuwes, 1997).

Table 15: Glare at (H, 3.5L) as Percentage of DeBoer Grade 5 Threshold, with Fixed Aim

US 75:	390%
ECE 75:	173%
US 50:	326%
ECE 50:	134%
US 25:	296%
ECE 25:	82%

Table 16: Glare at (H, 3.5L) as Percentage of DeBoer Grade 5 Threshold, with ECE Height Dependent Aim

US 75:	142%
ECE 75:	118%
US 50:	131%
ECE 50:	84%
US 25:	105%
ECE 25:	44%

It can be seen from this comparison that at least 75% of the US low beams and at least 25% of the ECE low beams exceed the 700 cd DeBoer Grade 5 discomfort threshold without height-dependent aim. The US low beams produce glare ranging from approximately 300 percent to nearly 400 percent of the DeBoer Grade 5 threshold. Increasing the aim declination of the US low beams by the same amount as is required of ECE low beams at this mounting height does not bring the US beams under the threshold of 28% disability, though it does reduce the severity of the exceedance.

At least 50% of the ECE low beams are under the 700 cd DeBoer Grade 5 discomfort threshold with height-dependent aim.

Overhead Sign Visibility

One of the main arguments against tighter control of low beam light in the region above horizontal and to the left of center is that upward light is needed in order to illuminate overhead retroreflective road signs. Both US and ECE photometric standards contain test points above the horizontal specifically for control of overhead sign light. FMVSS 108, via SAE J575E relative to (2U,4L), requires at least 270 (pair, nominal) cd at (2U,V). ECE regulations explicitly require at least 250 (pair, nominal) cd at (2U,V). This point corresponds to the following separations between the headlamps and the sign: lateral 0m, vertical 7.33 m, and longitudinal 210m. Here are comparisons between MY2000 ECE and US low beam headlamps at (2U,V) for a pair of lamps at 13.7V; given first as candela values at the control point and then as a percentage of the nominal MVSS 108 requirement:

Table 17: Overhead Sign Light at (2U,V)

US 75:	917 cd
ECE 75:	698 cd
US 50:	784 cd
ECE 50:	474 cd
US 25:	680 cd
ECE 25:	285 cd

Table 18: Overhead Sign Light as Percentage of MVSS 108 Required Value at (2U, V)

US 75:	340%
ECE 75:	259%
US 50:	290%
ECE 50:	176%
US 25:	252%
ECE 25:	106%

At least 75% of the US low beams exceed the nominal required illumination value at (2U, V) by at least 152%. At least 75% of the ECE low beams exceed the nominal required overhead-sign illumination value at (2U,V) by at least 6%.

Light Source Factors

The rapidly advancing state of the art has recently produced headlamp light sources of much higher efficacy than have traditionally been used. The light sources in US sealed beam headlamps and early RBHLs typically produced between 500 and 900 lumens (Stern, 1998). Headlamp designers currently have much more intense sources at their disposal. Halogen bulbs producing 1335 (H7) to 2300 (HIR1) lumens and gas-discharge capsules producing 2800 (D1R/ D2R) to 3200 (D1S/ D2S) lumens have become the sources of choice. Calcoast (2001) found that of 179 MY2000 US low beam headlamps examined, 171 (96%) used sources producing at least 1200 lumens at 13.7V, and 48 (27%) used sources producing at least 1680 lumens at 13.7V. With greater flux from the light source and more efficient optics, intensity caps (such as glare control point maxima) that once were out of practicable reach can now be approached and “pushed”. This may explain why recent headlamps provoke glare complaints not prompted by older headlamps meeting similar photometric requirements; the recent increase in glare complaints suggests that MVSS 108 glare maxima have always been too high, and with recent advances in headlamp technology that these limits can be closely approached.

This phenomenon is especially relevant with respect to gas discharge (HID) headlamps, which in addition to tremendously increased flux due to the high efficacy of the source, can also produce inherently more-dazzling light. It is for this reason that tungsten-halogen headlamps must direct 146% of the intensity of an HID lamp towards an observer for both lamps to cause the same level of discomfort glare (Flannagan et al. 1993). The concentration of inherently-dazzling (ibid.) blue light in the vicinity of the transition between seeing and glare regions of the beam, particularly in projector beams, can be minimized by careful design of the optical system (Lindae, 1985). The extremely high flux present in HID beams, however, means that drivers will be exposed to very intense glare when their eyes intersect the hot zone of oncoming or following HID headlamps. This may occur due to:

- Incorrect baseline aim of the HID headlamps
- Misaim of the HID headlamps due to cargo loading in the rear of the HID vehicle, in the absence of an aim compensator
- Inopportune relative placements of the two vehicles, with the glare car behind and to the left of a driver. This places the driver in the forward/rightward "target zone" of the HID headlamps, especially if the HID vehicle's headlamps are mounted at a relatively high height and/or lack an automatic aim compensator. Aim compensators are not required by FMVSS 108.
- Excessive glare intensity in the beam of the HID headlamps, due to insufficient glare control in the photometric requirements.

Headlamp Modification Factors

Overwattage Bulbs

Consumers have the means and opportunity to modify their headlamps in an attempt to remedy low perceived performance. Although they are illegal, headlamp bulbs of standard mechanical characteristics but of nonstandard color and/or power are readily available in the aftermarket. An informal survey of available headlamp bulbs in a popular automotive mail-order catalogue (JC Whitney, 2001) revealed a large selection of headlamp bulbs having low beam power ratings of at least 80W, in bulb formats designed for 45 to 55W ratings. Luminous intensity of such sources can be estimated from manufacturer data for similar sources made available for off-road use in Europe (Stern, 1998). Rated luminous intensity of a 55W H4 low beam filament is 1000 lumens, while rated luminous intensity of an 80W H4 low beam filament is 1500 lumens. This would have the effect of raising all intensity levels throughout the beam by 50%. Here is a comparison of the effect of such an increase on glare levels at (0.5U,3.5L) relative to 1380 cd disability glare and 700 cd discomfort glare thresholds for ECE and US headlamps:

Table 19: Glare at (0.5U, 3.5L) as Percentage of 28% Disability Threshold by Bulb Power

	Standard	Overwattage
US 75:	111%	167%
ECE 75:	69%	103%
US 50:	92%	138%
ECE 50:	53%	79%
US 25:	87%	131%
ECE 25:	30%	45%

Table 20: Glare at (0.5U, 3.5L) as Percentage of DeBoer Grade 5 Discomfort Threshold by Bulb Power

	Standard	Overwattage
US 75:	219%	392%
ECE 75:	137%	206%
US 50:	182%	273%
ECE 50:	104%	156%
US 25:	171%	257%
ECE 25:	58%	87%

Overwattage bulbs tend to increase glare intensity substantially above the levels produced with bulbs of proper power for a given headlamp. The increase in disability and discomfort glare is over twice as severe in US headlamps than in ECE low beams, with an average increase in glare intensity of 767 cd in US headlamps and 350 cd in ECE headlamps. This is because US headlamps produce higher levels of glare even with bulbs of proper wattage, while ECE low beams' tighter control of light in the glare region is better able to cope with additional source light.

Dichroic Coatings
Overwattage and standard-power bulbs are also readily available with various types of blue coating explicitly claimed to mimic the appearance of gas discharge headlamps. Many of these are multilayer interference dichroic coatings, though some are absorption coatings of extremely deep tint. Cummins (2001A) found that the irridescent nature of this type of coating defocuses the beam, decreasing hot spot intensity and increasing glare. When such coatings are combined with overpowered bulbs, the glare-increasing effects of the deviations from specifications can reasonably be expected to be additive. The bulbs with deep-tint absorption coatings tend to produce disproportionately high levels of inherently-glaring (Flannagan *et al.* 1993) blue light, while being severely deficient in the balance of the spectral output. This means such bulbs produce inordinately high levels of glare light while simultaneously producing insufficient seeing light. Marketing pressure is high, and sales tactics are designed to appeal both to consumers who specifically wish for their headlamps to have a blue appearance, and to consumers who wish for better seeing at night (AutoOptiks, 2001).

Legal Blues
DOT-certified colored bulbs are marketed by reputable, established bulb firms. These bulbs have a blue absorption coating or doped-glass envelope. The tint is insufficient to render the light color or output noncompliant with the MVSS 108, but is sufficient to shift the appearance of the operating headlamp towards blue as viewed by an observer. These bulbs may cause less beam pattern damage (or no such

damage) than bulbs with irridescent dichroic coatings. However, these bulbs increase discomfort glare. At an intensity sufficient to prompt a DeBoer glare response of 4.7 with an uncoated tungsten-halogen bulb, a headlamp prompted a DeBoer glare response of 3.8 when fitted with a legal blue-tinted bulb. There is no improvement in seeing performance with legal blue-tinted bulbs. (Sullivan and Flannagan, 2001).

Neodymium Oxide

A recent modification of the legal blue bulb concept is the Neodymium-doped bulb, for which the inventor claims dramatic glare reductions and seeing improvements (Karpen, 2001). Scientific investigation of the claims shows no improvement in seeing performance with Neodymium bulbs, but does reveal an increase in discomfort glare from DeBoer 4.7 to DeBoer 4.1, relative to an untinted halogen bulb (Sullivan and Flannagan, 2001).

High Intensity Danger

One type of improper light source bears special mention because of its extreme capacity to be severely detrimental to safety. "HID retrofit kits" are being widely marketed through readily-accessible retail and mail-order channels. These so-called "retrofits" consist of a D2R or D2S arc capsule (2800 or 3200 lumens, and one source is marketing "upgrade" capsules of approximately 4600 lumens) and associated electronic control equipment, with an adaptor by means of which the capsule can be inserted into a headlamp designed to accept a tungsten-halogen bulb. The massive degree by which such sources exceed the luminous intensity of the halogen bulbs correct for the headlamp creates tremendous glare. The light-producing arc within the D2R or D2S capsule is of a different size, shape and placement and, in the case of transverse-filament bulbs, orientation within the capsule than the light-producing filament within a halogen bulb. The edges and endpoints of the light source are also of very different demarcation characteristics (sharp for a filament, fuzzy for an arc). This is why gas discharge headlamps require different optics than tungsten-halogen headlamps. When a gas discharge source is placed into a headlamp designed to accept a tungsten-halogen bulb, extreme beam pattern damage occurs. The effects on seeing light are highly variable, but the effect upon glare is always severe and detrimental, i.e., vastly increased glare. There are also electric-shock hazards associated with the use of gas discharge equipment, which operates at high voltage, in headlamp systems not incorporating proper shielding or weatherproofing to cope with these high voltages.

Lens Markings

The lens marking requirements currently contained in MVSS 108 do not permit the ready detection of a headlamp improperly equipped with a gas discharge source. Especially with the current trend towards one clear (nonoptical) lens being used in front of several different reflectors or projectors depending on vehicle equipment within and across markets, it can be very difficult to detect an improper source. Examples abound; one such example is the headlamp lens on a MY2001 BMW 3 series, which contains markings applicable to six variations of the headlamp assembly:

- DOT certification marks for an H7 halogen/reflector setup
- DOT certification marks for a D2S discharge/projector setup
- ECE type approval marks for an H7 halogen/reflector setup for right-hand traffic
- ECE type approval marks for an H7 halogen/reflector setup for left-hand traffic
- ECE type approval marks for a D2S discharge/ projector setup for right- or left-hand traffic
- JIS certification marks for Japanese-market vehicles

High Beam Headlamps

High beam headlamps are a relatively insignificant source of glare. They are seldom used, even when lack of other vehicles on the road makes the high beam the appropriate selection for the conditions (Rumar, 2000; Hare and Hemion, 1968). However, there are some issues to be addressed concerning high beam headlamps. The present author has observationally studied inappropriate use of high beams in traffic, and conducted informal interviews with drivers using their high beams in traffic. When informed they are using high beams when low beams are called for, drivers give one of two responses:

- They are unaware they are using high beam headlamps (inadvertent inappropriate use of high beams)
- They are aware they are using high beam headlamps (deliberate inappropriate use of high beams)

Inadvertent Inappropriate Use of High Beams

Inadvertent inappropriate use of high beam headlamps is when drivers are unaware their headlamps are on high beam. Observation and debriefing of individuals who unknowingly use their high beams in traffic suggest that certain vehicle models tend to foment inadvertent inappropriate use of high beams. For example, vehicles such as the 1997 (and similar) Buick Century and the 1994 (and similar) Honda Accord seem particularly likely to be operated in traffic inadvertently with high beams. Interviews with drivers of these vehicles suggest that the high-beam telltale may be difficult to detect and/or to interpret, especially for older drivers. Informal coaching of drivers who are found using high beams in traffic by placing the vehicle in front of a wall and directing the driver's attention to the shift in beam patterns while switching back and forth between high and low beams tends to draw comments to the effect that there is minimal difference in the appearance of the high and low beam patterns. This suggests that improvements are warranted in the conspicuity and clarity of the high beam telltale. Rather than relying on the ISO symbol, it may be more effective for the words "BRIGHT" or "HIGH BEAM" to appear on the vehicle instrument cluster. There is precedent for such a requirement; MVSS 101 requires that the brake failure telltale illuminate the word "BRAKE", rather than relying on ISO symbols as is done outside North America.

Deliberate Inappropriate Use of High Beams

Deliberate inappropriate use of high beams is when drivers are aware their headlamps are on high beam, even though driving conditions (presence of other road users) call for low beams. Debriefing of individuals who knowingly use their high beams in traffic suggest that such drivers are not receiving feedback from other drivers (such as headlamp flashing) that their high beam headlamps are excessively glaring. Since they experience "better" visibility with high beams, they interpret the lack of negative feedback as tacit acceptance of in-traffic high beam usage. The rationale for deliberate high beam usage in traffic is almost always accompanied by disparaging remarks about the perceived level of performance of the vehicle's low beam headlamps. As is the case with inadvertent high beam use, certain vehicles (or, more accurately, certain headlamp systems) with low perceived levels of performance tend to foment deliberate inappropriate use of high beams. For example, many Chrysler passenger cars and minivans from MY1991 through MY2000, vehicles equipped with Type F and Type K sealed beam headlamps, and certain vehicles equipped with HB1 RBHL systems are widely considered to have poor low beam performance and have high observed incidence of deliberate inappropriate high beam usage.

Design and Photometric Factors

Police questioned about their failure to stop drivers inappropriately using high beams frequently state that unless a vehicle is equipped with a four-headlamp system in which all four lamps are illuminated on high beam, they find it difficult to discern vehicles inappropriately using high beams, unless the vehicle's high beams are extremely intense. This suggests that glare levels from low beam headlamps are too high and "glare" levels from high beam headlamps are too low (high beam headlamps are intended for use only in the absence of other road users, therefore all light from high beam headlamps can be considered seeing light.). Recent studies (e.g. Rumar 2000) draw attention to the contradiction of the high glare levels permitted in US low beams and low maximum-intensity ceilings in US high beams. The Rumar 2000 study strongly suggests that a shift to internationally-accepted high beam maximum intensity levels of approximately 140,000 cd (per lamp, at 12.8V) would materially improve seeing distance on high beam, and would discourage inappropriate use of high beams in traffic by dint of more reliable negative feedback (headlamp flashing, police enforcement).

Auxiliary Lamps

Original and aftermarket auxiliary fog, driving, and supplemental low-beam lamps are essentially unregulated under MVSS 108. Requirements for their photometric performance, mounting, electrical connection, aim and use are currently left up to individual states. In addition, there is no way to confirm compliance with e.g. SAE requirements.

Original Equipment Auxiliary Lamps

The lamps installed by vehicle manufacturers as original or authorized accessories are almost exclusively billed as "fog lamps," rather than driving or supplemental low beam lamps. A great many of these lamps (by comprehensive observational evaluation carried out by the present author and verified by colleagues) offer little benefit in poor weather conditions. However, these lamps also are frequently of designs that are inherently glaring. Specifically, the use of high-luminance halogen sources combined with small reflectors creates extremely high unit luminance of the reflector. This is why many "fog" lamps produce more glare than the low beam headlamps on the same vehicle. While low fog lamp placement and proper aim reduces glare, such reduction frequently cannot be attained for several reasons:

- The lamps are frequently placed by the vehicle manufacturer at headlamp height rather than below the headlamps,
- The lamps are frequently mounted to a part of the vehicle, such as a pliable plastic bumper fascia, that lacks sufficient rigidity to attain or maintain precise aim,
- The lamps are frequently provided without suitable instructions for proper use or for attaining correct aim, and may also be provided without sufficient range of vertical aim even when proper instructions are provided,
- The lamps are frequently of such small size (projected area) that extremely high levels of reflector and lens unit luminance are reached, causing the lamps to produce excessive glare regardless of aim,

- Many of the lamps produce such high levels of light above the cutoff that proper aim does not reduce glare levels sufficiently.

Aftermarket Auxiliary Lamps

The lamps offered to consumers as aftermarket add-ons vary extremely widely in their purported nature (“fog lamps,” “driving lamps,” “supplemental low beam lamps”), size (from 25mm x 37mm square to 222mm diameter round), technology (parabolic reflector, complex-surface reflector, projector), performance (strong seeing, weak seeing, high glare, low glare), color (white, yellow, selective yellow, blue) and compliance (SAE, ECE, no compliance with any standard). Aftermarket lamps produce glare in all the same ways as original-equipment lamps, but also present additional issues:

- General consumer ignorance regarding the purpose, proper mounting, aim, electrical connection and appropriate use of fog lamps, driving lamps and supplemental low beam lamps, resulting in deliberate or inadvertent inappropriate installation and use,
- Wide availability and low price of poorly-made lamps not compliant with any construction and/or photometric standard and bearing no (or fraudulent) certification marks,
- Wide availability of very intense driving lamps that may be deliberately or inadvertently used in traffic. 37 Auxilliary Lamps

Fog Lamps in Clear Weather

Approximately 64.5% of drivers in cars with fog lamps use their fog lamps at night in clear-weather conditions not warranting fog lamp use. Fewer drivers (60.6%) use their fog lamps in moderate-to-heavy fog conditions warranting fog lamp use. This indicates that drivers tend to use fog lamps to supplement their low beam headlamps, rather than as an aid to poor-weather visibility. (Sivak et al. 1997). Assuming the lamps in question at least approach the general character of a fog beam, providing primarily foreground illumination and lateral spread, the indication is that drivers want more and wider foreground illumination. They get it by using fog lamps. US low beams have traditionally had less and narrower foreground illumination than comparable ECE low beams primarily due to concern that excessive foreground illumination will limit distance vision by drawing the driver's visual attention to the foreground or by reducing the driver's level of dark adaptation. This may not be the case. Olson and Sivak (1983) studied driver eye movements at night as a function of foreground illumination. At high levels of foreground illumination, drivers tended to look further down the road. Olson & Sivak's interpretation is that with high levels of foreground illumination, drivers tend to use peripheral vision for the foreground and foveal vision for distant points. This may be why drivers prefer higher levels of foreground illumination than is traditionally provided by US low beams. Automotive lighting engineers have noted they have been asked to design original-equipment fog lamps explicitly to "fill the black hole on the road in front of the car". If, as seems to be the case, more and wider foreground illumination is not harmful and may be beneficial to safety, then it is better to encourage or require more and wider foreground illumination from regulated and controlled low beam headlamps than to leave this function to unregulated and frequently-misused devices with a high capacity to create excessive glare.

Fog Taillamps (Rear Fog Warning Lamps)

Some cars come from the factory equipped with fog taillamps (rear fog warning lamps). A fog taillamp is a high intensity rearward-facing red lamp of similar photometric performance to a stop lamp, though frequently fog taillamps are more intense than stop lamps. Fog taillamps are manually activated by the driver to increase the vehicle's conspicuity from the rear under conditions of reduced visibility distance. Some European and Scandinavian countries have required fog taillamps on new vehicles since the 1970s or 1980s, and EU requirements currently call for fog taillamps on new vehicles. In several countries where weather conditions frequently justify fog taillamp use, such as Sweden and Finland, pre-EU national requirements permitted only one fog taillamp per vehicle, mounted on the driver's side of the rear of the vehicle. Current EU requirements call for the installation of one or two fog taillamps, with dual fog taillamps to be mounted symmetrically. MVSS 108 permits, but does not require or regulate, the installation of one or two fog taillamps. Dual fog taillamps, especially when they are part of a vehicle's rear lamp cluster which also incorporates other rear signalling functions, very closely mimic the appearance of stop lamps. A driver following a vehicle with operating dual rear fog lamps must look constantly or frequently at the rear lamps of the leading car in order to discern the slight difference in appearance between the brake-off condition of two intense red lamps, and the brake-on condition of four intense red lamps (with the possible addition of a fifth in the form of the CHMSL). This situation is aggravated when red rear turn signals, permitted by MVSS 108, are present. The single fog taillamp is very much less likely to be mistaken for stop lamps, because stop lamps are required to be installed in multiples of two and mounted symmetrically. With a single fog taillamp, there is a far greater difference in appearance of the lead car between the brake-off condition and the brake-on condition. Therefore, the following driver need not focus his eyes constantly or frequently on intense lights facing him, and may focus instead on areas that require his attention in order to detect roadway obstacles.

Fog taillamps are often used when they are not warranted; current switching requirements do not adequately guard against misuse. Typically, fog taillamps are wired so that they can only be activated if a vehicle's front fog lamps, if present, are lit. A very common switching arrangement in Volvo, Saab, Jaguar, BMW, Mercedes and Oldsmobile and other models is for the fog taillamp switch to be wired to the front fog lamp switch. If the fog taillamp switch is left "on," the fog taillamps will illuminate whenever the front fog lamps are lit. Since 64.5% of drivers whose cars are equipped with fog lamps illuminate their fog lamps even in clear-weather conditions (Sivak et al. 1997), the potential is quite high for inappropriate use of fog taillamps, increasing glare levels and decreasing stop and turn signal conspicuity for following drivers. Although ECE regulations stipulate that a fog taillamp telltale consisting of an ISO symbol illuminate when fog taillamps are activated, few drivers recognize the symbol. Informal interviews with drivers observed to be using fog taillamps inappropriately reveals that overwhelmingly, drivers are completely unaware of the presence, purpose or proper use of fog taillamps on their vehicles.

Recommendations

The present report investigates and examines the various sources of glare in the US nighttime traffic environment. In the context of this investigation, several solutions suggest themselves to reduce the glare that currently makes driving at night in the US a driver-hostile experience, as well as to improve seeing. Here are some suggested courses of action, supported by the science and discussion in the present report.

Raise the test voltage contained in MVSS 108 from 12.8V to 13.7V, or establish a dual-voltage testing regimen in which seeing-light regions are tested at 12.8V and glare-light regions are tested at 14V, because the current test voltage is unrealistically low and substantially underestimates real-world glare intensities.

Lower the allowable glare intensities for low beam headlamps, particularly at (H, V) and (0.5U, 3.5L), because the currently allowable levels are too high.

Raise the allowable high beam intensity at (H, V) to match the European and Japanese maximum of 140,000 cd (nominal at 12.8V), because more intense high beams will increase visual performance in situations warranting high beam use, and will discourage misuse of high beams in situations warranting low beam use.

Require headlamps to be aimed lower if they are mounted high, because high-aimed high-mounted headlamps create severe glare to lower vehicles.

Permit low beam headlamps conforming to ECE photometric requirements, because

- such headlamps comply with the intent of US seeing and glare limits, in some cases better than their US counterparts,

- they do not appear to threaten any reduction in safety,
- they offer immediate and substantial relief from excessive low beam glare while offering equivalent or improved seeing performance,
- and they are more resistant to the safety negative effects of overwattage bulbs.

Establish stringent requirements for colorimetric, projected-area, mounting and photometric performance of original-equipment and aftermarket auxiliary lamps, because such lamps are currently a significant and uncontrolled source of glare.

Lower the degree to which "white" illumination may tend towards blue, because this will reduce the production of inherently-glaring blue light and will also reduce the motivation for individuals to attempt to attain a "blue" appearance with halogen headlamps.

Require automatic aim compensators (dynamic headlamp levelling) with HID and high-flux halogen headlamps, because such headlamps create severe glare with vehicle attitude changes.

Raise the stringency of MVSS 101 requirements for the high beam telltale so that the words "BRIGHT" or "HIGH BEAM" appear with (or instead of) the ISO symbol, because many drivers do not notice or recognize the ISO symbol.

Raise the stringency of headlamp lens marking requirements so that headlamp assemblies intended for gas discharge sources are clearly differentiated from those intended for halogen sources, because current regulations allow misinstallations to go undetected.

Raise the stringency of fog taillamp installation requirements to allow only one fog taillamp on a vehicle, mounted on the driver's side of the rear of the vehicle, because dual fog taillamp arrangements are difficult to distinguish from brake lamps and force following drivers to focus on glaring high intensity lights.

Raise the stringency of fog taillamp wiring requirements so that the fog taillamp deactivates and must be deliberately reactivated by the driver after low beam headlamps, fog lamps, or vehicle ignition are switched off.

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What is Selective-Yellow Light?

It's what happens when you subtract blue from an auto headlamp: Blue is the shortest wavelength and, as such, scatters the most readily. (To prove this to yourself, find a dark blue store front sign or something else that's a dark, pure blue against a dark background in the absence of white light. From any appreciable distance, it's almost impossible for your eyes to see the blue lighted object as a sharply defined form...the edges blur significantly.)

When blue light strikes water (rain, fog, snow) it scatters in all directions and makes on-road vision very difficult.

Blue also is a very difficult color of light to look at if it is at all intense...it stimulates the reaction we call "glare".

So the French figured to remove the blue from the output spectrum of their vehicles' front lamps. White light with the blue component subtracted is known as "selective yellow" light. It is a pure yellow color with little or no orange component--hence the French yellow headlamps. There haven't been any recent comparative studies. Yellow lamps were subjectively ranked as better in poor weather and lower in glare than white ones, and this matches my