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SURFACE VEHICLE INFORMATION REPORT

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Pedestrian Visibility—Low Beam Optimization to Reduce Night-time Fatalities

RATIONALE

Not applicable.

INTRODUCTION

The performance of low beam headlights has improved dramatically with the development of higher efficiency light sources and computer generated optical systems. At the same time, there is increasing debate concerning to the age old dilemma relating to the balance and compromise between providing adequate forward illumination and avoiding glare complaints from oncoming drivers. Governmental agencies throughout the word are increasingly concerned about reducing the number of pedestrian fatalities at nighttime and much research in the US, Europe and Japan is underway.

It is clear that vehicle headlighting plays a significant role in the effort to reduce the pedestrian fatality rate but current legislation only addresses the minimum performance requirements of an individual headlamp (or a system in the case of the Adaptive Front-lighting System (AFS) introduced into ECE regulations). Other factors such as installation height, separation, aim and operating voltage actually influence the effectiveness of the headlamp performance in the real-world driving context.

The SAE Pedestrian Visibility taskforce was established to review the recent research concerning pedestrian fatalities and to investigate possible approaches to define the minimum requirements, both in terms of visibility and glare, of a headlighting system operating under actual vehicle conditions.

Although differences exist between the US and ECE approach to headlighting design, the taskforce has attempted to take a global view and the conclusions and recommendations are based upon global best practice. Opportunity has also been taken to work closely with the CIE TC4-45 committee that is working to define a standard method of headlighting performance assessment as the definition improved headlighting systems and their performance appraisal are closely allied.

It should be emphasized that this report does not attempt to provide precise requirements for minimum performance levels relating to glare or visibility and any comparisons of the performance of headlamp systems are presented solely as examples to illustrate the conclusions reached by the taskforce. In particular, attention is drawn to statements relating to the limiting value for the acceptability of opposing glare. These are based upon experience of the taskforce members and research is required to determine a validated value. Further, no account has been taken of the effects of opposing glare upon the minimum visibility requirements.

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1. SCOPE

The primary purpose of vehicle forward lighting is not to see the world but to see the road! In their simplest form, headlights help drivers negotiate a safe path on the road. They do this by lighting the roadway according to (a multitude of) specific standards.

For decades, discussions concerning the niceties of illuminating potential obstacles in the roadway were little more than an academic pursuit as there simply were not sufficient lumens available from filament light sources to achieve all of the desired tasks no matter how worthy they might be. Not unexpectedly, the technology has evolved with the introduction of high output metal-halide sources, multi-task standards combined with multilevel lighting devices and discrete LED sources offering high luminous efficiencies and the means to deliver the light where it can be most useful. The question now becomes one of determining where the available light should be directed.

Every standard advisory group, industry, manufacturer and every driver might have their particular favorite approach to the question of how best to illuminate the road, but few would disagree that a single, vulnerable set of candidates to benefit from improved forward lighting exist. These are pedestrians walking in the roadway and unfortunately, they can exist literally anywhere in the road scene. Some regions of the road are clearly more perilous than others, specifically those located where the light is weaker on the side of the beam directed toward the opposing lane (the left side in the majority of countries).

Work by Sullivan and Flannagan (2001), Kosmatka (2003) and Sullivan (2007) has demonstrated the fatality rate (2300 fatalities) and vulnerability (twice as many left-crossing than right-crossing) of pedestrians in the roadway. This could lead to the conclusion that it is necessary to put more lumens in the opposing lane (left) side of the roadway. However, this is the simple answer; the hard questions are how much light, where on the left and how can this be achieved?

The low beam pattern, by its nature, is a compromise between the need to provide adequate illumination of the road ahead of the vehicle while minimizing the effects of glare to oncoming road users. This means that any study to identify improvements in the low beam to achieve better pedestrian visibility must respect the balance between the needs of the vehicle driver and the other road users.

While various approaches to reduce pedestrian fatalities are being pursued it is clear that the effectiveness of headlighting can play an important role. As noted earlier, the performance of the low beam light distribution has improved with the introduction of new headlamp technologies and more efficient light sources. However, the compromise between providing adequate forward illumination while minimizing the effects of glare to the other road users remains a constraint.

With research findings providing a clearer indication of the nature of the collisions with pedestrians and identifying critical areas in the road scene it is now appropriate to review the requirements of the low beam headlamp system with a focus upon mitigating the pedestrian fatalities.

1.1 Purpose

The SAE Pedestrian Visibility taskforce was established in 2005 with the following objectives:

- Identify the critical areas of the road scene from the pedestrian collision perspective using results of recent research based upon real accident data.
- Review the effectiveness of current low beam headlamp systems and identify areas of improvement.
- Identify opportunities to improve the low beam that could be introduced across a wide range of headlamp systems including low cost solutions applicable to the developing world.

This report documents the work of the SAE Pedestrian Visibility taskforce. The recommendations are available for further development by appropriate committees for upgrading lighting standards. Additionally, these recommendations are suitable for incorporation into New Car Assessment Programs (NCAP) where the relative performance of headlighting systems are evaluated against clearly defined criteria.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein.

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3. AREAS OF THE ROAD SCENE HAVING THE HIGHEST RISK OF COLLISION WITH PEDESTRIANS

In their report “UMTRI 2007-03 – Characteristics of Night-time Pedestrian Crashes – Implications for Headlighting”, Sullivan and Flannagan analyzed the 2003 MDOT crash dataset of single-pedestrian, single vehicle collisions. They concluded that:

a. Prior pedestrian actions involving road crossings either at intersections or at non intersections made up the majority of crashes. The highest proportion of crashes in darkness occurred at non intersections (30.7%), while in daylight the highest proportion of pedestrian crashes occurred at intersections (36.2%). It was also found that proportionally more crashes occurred in darkness involving pedestrians walking in the roadway in the direction of traffic (9.6% versus 4.7% in light).

b. With respect to the prior vehicle actions, most pedestrian collisions occur with a vehicle going straight, both in darkness (68.5%) and in daylight (50.8%), with darkness having a proportionally higher share of these crashes. It was suggested that the higher outcome in darkness is likely to be related to the fact that vehicles traveling straight may also, on average, be traveling at a higher speed than turning vehicles. With the limited forward preview provided by low-beam headlamps, any travel condition that permits a higher travel speed is also likely to increase the crash risk in the dark.

c. In daylight, turning maneuvers were found to account for proportionally more crashes than in darkness. It was suggested that one explanation for this is that turning to merge into traffic is more challenging in daylight, when there are more vehicles on the road and gaps in traffic are less abundant. A driver’s attention may be drawn away from monitoring the whereabouts of pedestrians, increasing the potential of a pedestrian collision.

d. With respect to the roadway environment, most pedestrian crashes occurred on straight roadways both in daylight and darkness. This is not surprising as straight roadways are plentiful and exposure is likely to be high. However it was also found that there are proportionally more pedestrian crashes in darkness than in daylight on straight roadways. In as much as straight roadways are conducive to high speed, as mentioned earlier, risk in darkness is likely to be elevated.

e. Neither road class nor traffic way configuration interacted with ambient light level. The latter result was considered to be especially surprising given that glare from oncoming traffic can be expected to be worse on roadways with limited two-way traffic separation in darkness. Perhaps reduced traffic density during periods of darkness also reduces the amount of glare from opposing traffic, offsetting any effect of road class or configuration.

f. Nearly half of all pedestrian-vehicle crashes occur on 2-lane roadways, regardless of light condition. However, it also appears that 5-lane roadways present a special problem in darkness that may be related both to travel speed and insufficient illumination of the center lane.

g. Wet road conditions and rain involved proportionally more pedestrian crashes in darkness than in daylight. This may be caused by a variety of factors that affect visibility (roadway surface reflectance multiplies the number of potential glare sources, negative contrast is lost and lane markings disappear on a wet roadway, and water droplets on windshields may obscure the forward view) as well as reduced driver expectation to see pedestrians on the roadway during bad weather.

h. Results derived from the examination of geometric details recovered from the diagrams and narrative content contained in police reports suggest that there is valuable supplemental information in these reports that can go beyond the information captured in the conventional crash data tables. For example, from the perspective of whether an approaching driver may have seen a pedestrian before a collision, it may be less important to identify whether the collision occurred while a turn was being executed than to identify whether a turn was executed any time in the several seconds preceding the collision. It is similarly important, from the perspective of vehicle lighting, to establish geometric relationships between pedestrians and vehicles using a vehicle-centric reference basis. Thus, it is more important to know that a pedestrian is crossing in front of a vehicle from the left or right direction than to know each party's absolute heading. When pedestrian location was recast in this manner, a consistent pattern was found in the left-turn pedestrian-vehicle collisions that suggest the visibility of pedestrians is poorer on the left side of the roadway, consistent with low-beam light distribution. A similar, although not statistically significant, pattern was also observed for pedestrians crossing in front of vehicles traveling straight. No such pattern was apparent for right-turning vehicles, perhaps because driver attention is normally directed to the left, regardless of light condition, when attempting to merge with oncoming traffic. In this case, pedestrians approaching from the right side of the roadway are the principal victims.

These conclusions were used as the main motivation for the subsequent activity of the taskforce that identified that the performance of the left side of the beam pattern to be the target for further study and improvement.

4. CALCULATION OF REQUIREMENTS FOR DETECTION DISTANCE AND ILLUMINANCE

Kosmatka (2003) suggested that for a pedestrian moving at a constant velocity and a vehicle doing the same, the approximate angle of the pedestrian to the potential contact point on the vehicle remains constant and is simply the arc tangent of the ratio of the two velocities. Assuming a given a velocity of 1.3 m/sec for the pedestrian, the (more-or-less) constant angle of approach lies in the range of approximately 3 to 6 degrees left for a reasonable range of vehicle velocities. At *lesser angles*, pedestrian detection occurs too late. The critical area for detection is in the opposing lane near or at the lane divider.

In order to be relevant at more *extreme angles*, at-risk pedestrians must either be moving at a high speed or must reach the left side of a vehicle at the very last moment before impact. Rather than confound already complicated circumstances and address behavior modes that appear to be extreme, efforts were concentrated on nominal pedestrian speeds and rational behavior.

In the discussion that follows it was decided to concentrate on opposing lane (left side) light levels, recognizing that what can be done on the left side of the beam is more readily achievable on the right).

4.1 Illuminance Requirements

It has long been alleged, and correctly, that bringing a fast moving vehicle to a stop short of many nighttime roadway obstacles is difficult, and frequently impossible, with contemporary headlamp illumination patterns and with the light available. Given certain assumptions such as lamp aim, glare restrictions and obstacle reflectance factors, this is particularly true for left-approaching pedestrians walking in the glare-controlled left side of the roadway and wearing dark clothing.

Kosmatka (2006 - SAE Technical Paper 2006-04-0949), looked at an alternative, assuming that early detection will allow the driver to slow the vehicle and will give the pedestrian time to escape by walking beyond the vehicle's path. The temporal bonus, owing to early detection of a crossing pedestrian, reduces the detection distance requirement. There are illumination conflicts with the glare-controlled left zone.

The table in Figure 1, taken from Kosmatka (2006 - SAE Technical Paper 2006-04-0949), demonstrates the differences between the assumptions of *stopping* to avoid a collision and *beginning to slow early enough* to allow the pedestrian to clear the vehicle path. At higher speeds the effects of "slowing" versus "stopping" the vehicle are evident.

Speed mph/kph	Detection distance (m) required for **slowing** (avoidance) maneuver (1.1 sec. driver reaction delay)	Detection distance (m) required for **stopping** vehicle (1.1 sec. driver reaction delay)	Headlamp **illumination** required (cd) for "slowing" (10% reflectance factor)	**Lateral location** of visual centroid at an elevation 25 cm (degrees)
30/48	**26**	28	**2000**	0.88D – **5.8L**
40/64	**39**	43	**3800**	0.59D – **4.3L**
50/80	**54**	61	**7500**	0.42D – **3.4L**
60/96	**69**	82	**14000**	0.33D – **2.9L**
70/112	**85**	106	**27000**	0.27D – **2.5L**

FIGURE 1 - ILLUMINATION REQUIREMENT FOR AN ASSUMED "EXPECTANT" DRIVER

This "slow and avoid" news, overall, is good, at least better than the old "stop the vehicle" news:

At 64 kph (40 mph) there is little if any concern about illumination sufficiency on the right side of most headlamp systems. Even for left side pedestrians the light level is a *fiat accompli* for some high lumen output systems.

At 80 kph (50 mph), 7500 cd at 3.4 degrees can be achieved on the right berm by many contemporary systems. On the left, a centroid location at 0.42 degrees down is *The Significant Issue*.

For the 96 kph (60 mph) assumption, a light level from two light sources of 14 000 cd at about 2.9 degrees right is achievable. On the left side, the issue of a centroid location, at 0.33 degrees down, looms large.

Contributing to this partial victory are assumptions about the highways on which we *do not expect pedestrian* traffic. These include most if not all high-speed roads such as limited-access highways and turnpikes. The daunting implications of addressing distances attributed to the 112 kph (70 mph) vehicle speed can (mercifully) be disregarded owing to the predictable absence of pedestrians.

The task force concluded that for reasonable vehicle speeds it is technically possible to produce light levels that help drivers see and react at a distance sufficient to allow a moving pedestrian to clear a slowing vehicle's path even if the vehicle does not (cannot) stop within that detection distance.

Furthermore, it was the task force's decision to adopt a benchmark "minimum" distance. For the purposes of comparing headlamp systems, a minimum detection distance of 40 m was selected. This is reasonable in that it addresses two common roadway speeds, 48 and 64 kph (30 and 40 mph), where pedestrian traffic is not only possible but likely.

4.2 Exactly Where Do We Direct the Light?

Emphasis on the requirement to illuminate "the road" gave rise to standards that were based on points and zones on the roadway itself. These did not take account of the vehicle-specific installation parameters. In addition, glare-averse drivers encouraged glare-averse standards that emphasized repression of light directed above the roadway-based points or zones.

This, amalgamated, adversarial-needs approach to road scene illumination does not readily lend itself to providing illumination for detecting obstacles "on" the roadway. In this case "on" (almost) always dictates a visual centroid above the road surface and this is where the conflict is seated.

In order to see an obstacle on the roadway at night with a headlight system the obstacle must be illuminated. Some significant portion of the obstacle must be illuminated sufficiently to cause visual brightness in excess of the driver's luminance threshold.

As the retinal image enlarges greater numbers of light sensing cells are stimulated. The visual "system" receives stronger signals (from more cells) and responds more readily to the visual stimulus. We all have experience the visual effect of "size"– we know it is easier to discern a gray cat than a gray mouse – and attribute this to their relative size.

In order to estimate the (average) illumination of the visually relevant area of the pedestrian we must select a visual centroid location representing the average of the area's luminance. The centroid of a roadway obstacle is elevated above road plane as an attribute of visual area.

As a basis for the values shown in Figure 1, the "*visual centroid*" of the pedestrian was chosen to be located *25 cm above the ground plane*. This was based on well-reasoned recommendations from the University of Michigan Transportation Research Institute (Flannagan et al, 2002). For a generic obstacle, 25 cm is a rational value and it is also reasonable for an opposing lane pedestrian.

Unfortunately, this (and any "seeing" point above the ground plane) will be in conflict with glare-zone limits. A system producing elevated illuminance levels on left-side obstacles will have a higher probability of provoking glare complaints.

This is most apparent in the data in Figure 1 for the "60/96" case. Elevating a target point above the road surface will dictate points close to the H-H line. The illumination requirement in combination with the vertical location of the centroid is clearly incompatible with left-side-glare-zone limits.

4.3 Ways to Achieve the Required Obstacle Illuminance

The fundamental question of how to illuminate the roadway or roadway obstacles, while minimizing glare for opposing lane drivers, is *THE* key conflict in forward illumination specifications.

In order to see more by means of headlamp illumination, additional light will be required at the location where the visibility improvement is desired. In order to explore the *distance improvement* as a function of *illuminance,* Kosmatka (2007) added pedestrian illumination by moving the left-side light (the cutoff) upward. A similar method, a "flattop" beam pattern, was explored in a paper presented at the 2003 PAL symposium (Rice, 2003).

Kosmatka's calculations for an expectant driver shown in Figure 2 used "weighted-average" beam pattern data collected by the University of Michigan (UMTRI, Sivak, Flannagan *et al*, 1997, Sivak, Flannagan *et a*l, 2000 and Sivak, Flannagan *et al*, 2002).

Since the results are *based on weighted average data of multiple lamps,* the numbers s*hould not be interpreted* to indicate the current state-of-the-art. "Averaged" data reduces the gradient in the cutoff zone due to *small discrete differences* of the individual lamp aim and cutoff gradients. The effects of the beam shift that are shown in the table are diminished as a result.

Light Source Type	Upward-shift of left light (degrees)	Detection Distance (m) for Expectant Drivers		
		Vehicle Velocity (mph/kph)		
		40/64	50/80	60/96
9007 SAE Beam	0	40	43	45
	0.2	45	48	50
	0.4	49	53	55
	0.6	54	57	60
H4 & H7 ECE Beam	0	36	37	37
	0.2	42	44	44
	0.4	48	51	52
	0.6	54	57	59
HID SAE Beam	0	43	46	45
	0.2	51	54	53
	0.4	59	62	62
	0.6	66	68	68

FIGURE 2 - DETECTION DISTANCE PREDICTED FOR LEFT-APPROACHING PEDESTRIANS FOR UPWARD SHIFTS OF LEFT-SIDE LIGHT
(REFLECTANCE FACTOR: 10%, PEDESTRIAN CROSSING FROM THE LEFT AT 1.3 M/S, 1.1 SEC. DRIVER REACTION DELAY)

The numbers in the shaded areas meet the detection distances in Figure 1.

5. THE EFFECTS OF GLARE AND THE NEED FOR ADEQUATE ILLUMINATION

When establishing the terms of reference of the taskforce it was acknowledged that any study to define how to improve the illumination of the road scene would have to include an assessment of the glare implications. This is an extremely complex question as glare is a cause of discomfort and diminishes the forward visibility. In the specific case of pedestrians the effects of the illumination from opposing headlamps will depend upon the levels of glare being generated. Arguably the illumination of the road scene by the opposing headlamps can improve the visibility of a pedestrian under conditions of controlled glare from low beam headlamps but increasing glare levels will detract from this benefit by reducing the observer's forward vision. In view of this it was decided to limit this study to consider the potential of a headlamp system to cause discomfort and to suggest minimum visibility requirements in the case of no opposing glare.

Various methods were considered and it was decided to adopt the procedure being developed in the CIE TC4-45 technical committee. This method is based upon the findings of Damasky(1995) that show that the majority of meeting situations on normal two lane roads occur within an ellipse approximately 9 degrees wide and 1 degree high. Within this ellipse a statistical distribution of the probability of occurrence of the oncoming driver's eyes can be derived.

A detailed description of the method used to determine the glare effects is given below in 6.2. The values calculated provide a weighted value of the luminous flux in the defined glare zone and can be used in conjunction with the illuminance calculations described in 6.1. Further work is required to develop guidelines to be used during the design and evaluation of lighting systems in terms of minimum requirements for illuminance and maximum values of weighted luminous flux in the glare zone.

6. LIGHTING SYSTEM EVALUATION

6.1 Evaluation of Illuminance – The Uniform Detection Characteristic (UDC) Locus

Kosmatka (2006 - SAE Technical Paper 2006-04-0948) describes an extension of the algorithm for defining the threshold at which a roadway obstacle would likely become discernible when illuminated by a headlamp system. The *Uniform Detection Characteristic (UDC) Locus* is the circumscribed area ahead of a vehicle at which an obstacle with selected characteristics would meet the luminance criteria for detection. Figure 3, representing a moving obstacle and a pedestrian approaching from the left side of the vehicle, shows the plan view of a roadway on which a vehicle is approaching a pedestrian moving from the left. The time-line, defined by the ratio of the two velocities, intersects the UDC locus. This is the distance at which the detection criteria are met.

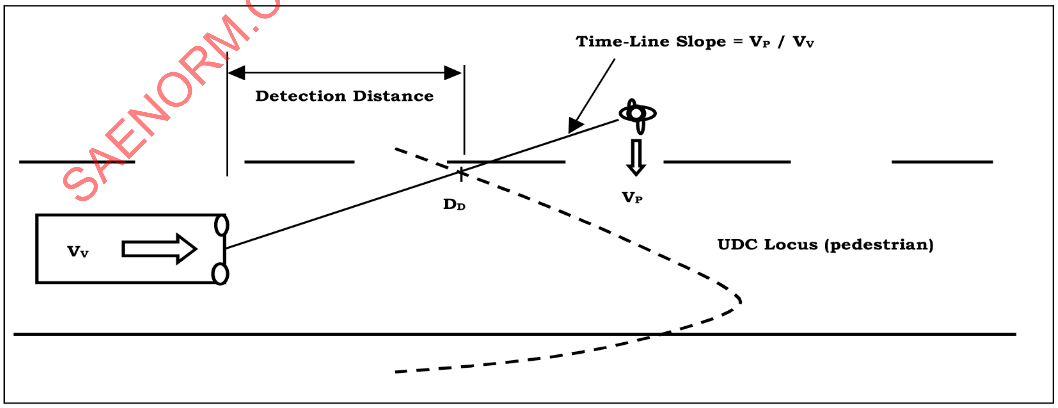


FIGURE 3

Based on Kosmatka's calculation methodology, a software tool has been developed (Kosmatka and Rattunde, 2005) to calculate the UDC locus for a vehicle equipped with the user's selection of forward lighting devices. Using measured luminous intensity data for any number of discrete devices and vehicle mounting parameters, the software will determine the illuminance distribution at a vertical plane selected to represent the most prominent portion of the obstacle. The UDC locus is calculated based on the reference plane illumination, taking into account user-selected factors such as reflectance, size, and driver-expectancy (or "surprise"). By selecting headlamp systems or modifying mounting or aim parameters, engineers can estimate and appraise the effects of the vehicle or lighting-based parameters. Figures 4a and 4b shows examples of the output of Rattunde's software reproduced from the 2005 paper. Appendix A shows the UDC curves calculated for a range of 16 ECE and 6 USA headlighting systems. This calculation is based upon a point on a pedestrian's leg situated at 250 mm above the road surface and assumes a reflectance of 10% and an expectant driver.

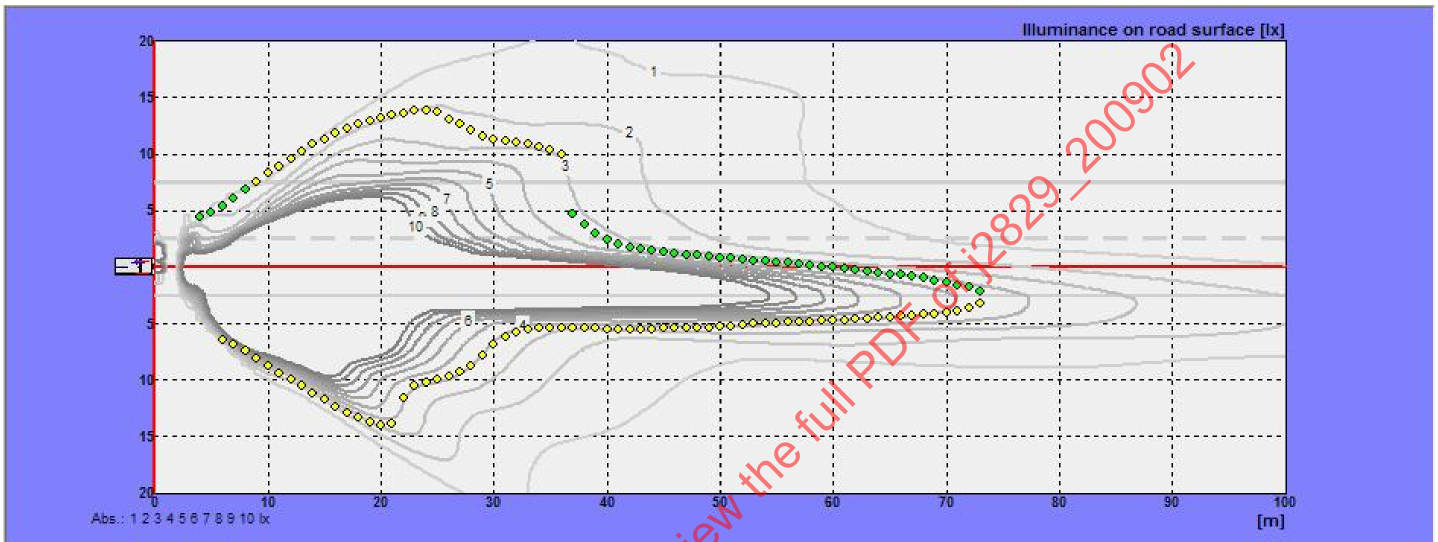


FIGURE 4A - "BIRD'S EYE" VIEW SHOWING THE ROAD ILLUMINANCE AND UDC FOR A TYPICAL US HEADLAMP

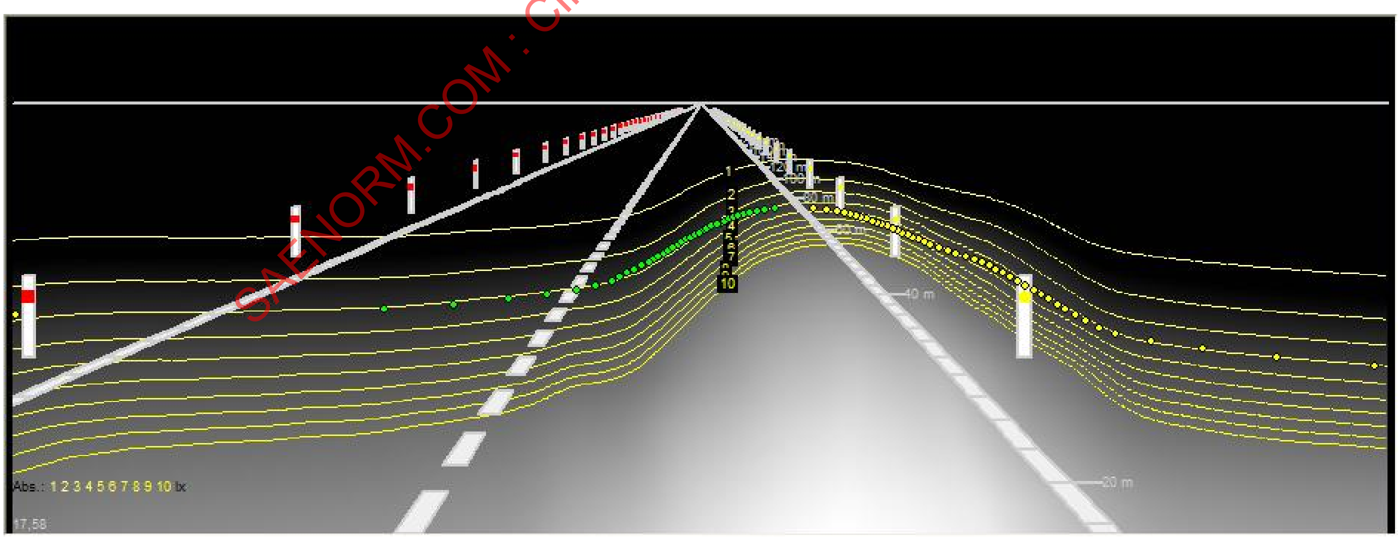
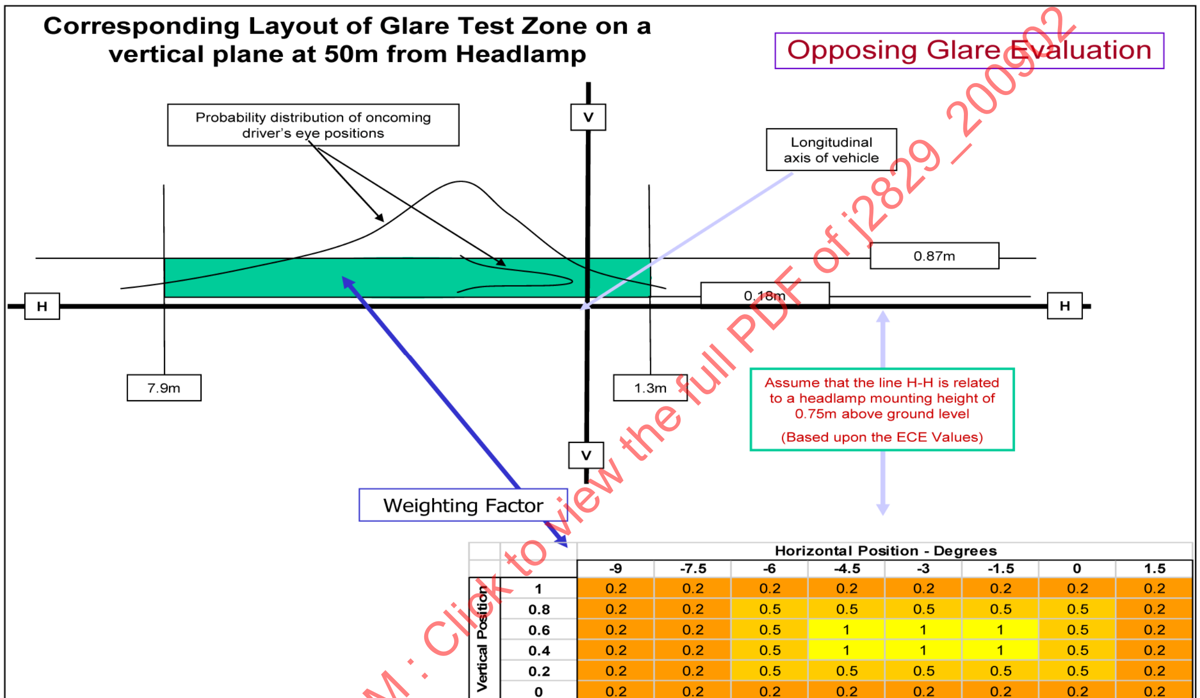


FIGURE 4B - PERSPECTIVE VIEW SHOWING THE ROAD ILLUMINANCE AND UDC FOR A TYPICAL US HEADLAMP

6.2 Evaluation of Glare Effects – The CIE TC4-45 Method

To evaluate the potential glaring effect for each headlamp system, the rectangular glare zone shown in Figures 5 and 6 is divided into a number of segments and the luminous flux values are taken from this grid and then multiplied by the weighting factor (representing an approximation to the probability of occurrence of the oncoming driver's eye). The indication of the glaring effect is a calculation of the weighted luminous flux from the sum of these individual values. This procedure provides a means of determining the weighted value of luminous flux in the glare zone but of course it does not provide information relating to the acceptability of the headlamp system when installed on the vehicle. However, by evaluating existing headlamp systems and determining their weighted luminous flux value in the glare zone a database can be established to provide an indication of the value in the glare zone that is likely to be tolerated in actual driving conditions.



Vertical Position	Horizontal Position - Degrees: -9	-7.5	-6	-4.5	-3	-1.5	0	1.5
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.8	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2
0.6	0.2	0.2	0.5	1	1	1	0.5	0.2
0.4	0.2	0.2	0.5	1	1	1	0.5	0.2
0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2
0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

FIGURE 5 - THE CIE TC4-45 PROPOSED GLARE ASSESSMENT METHOD

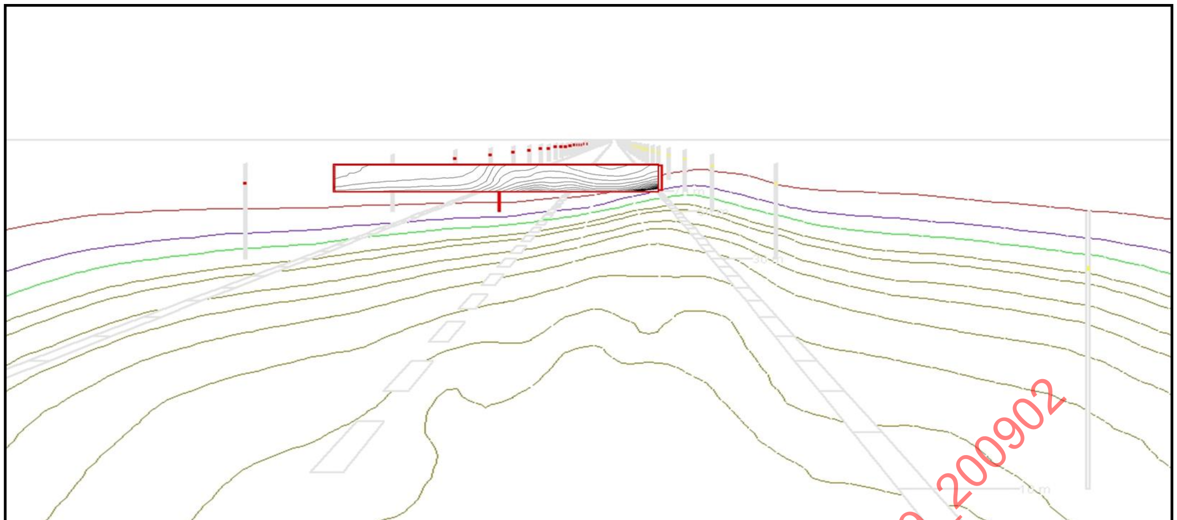


FIGURE 6 - PERSPECTIVE VIEW OF THE ROAD SCENE SHOWING THE LOCATION OF THE GLARE ZONE DESCRIBED IN FIGURE 5

Figure 7 shows the result of the glare evaluation for the 22 sets of headlamps assessed throughout this report. For the purposes of establishing a threshold for the maximum acceptable glare level it was decided to discount the results for samples USA2, USA3 and USA6 on the basis that these exhibited the highest values and acknowledging the growing pressures from government agencies to reduce glare of headlamps.

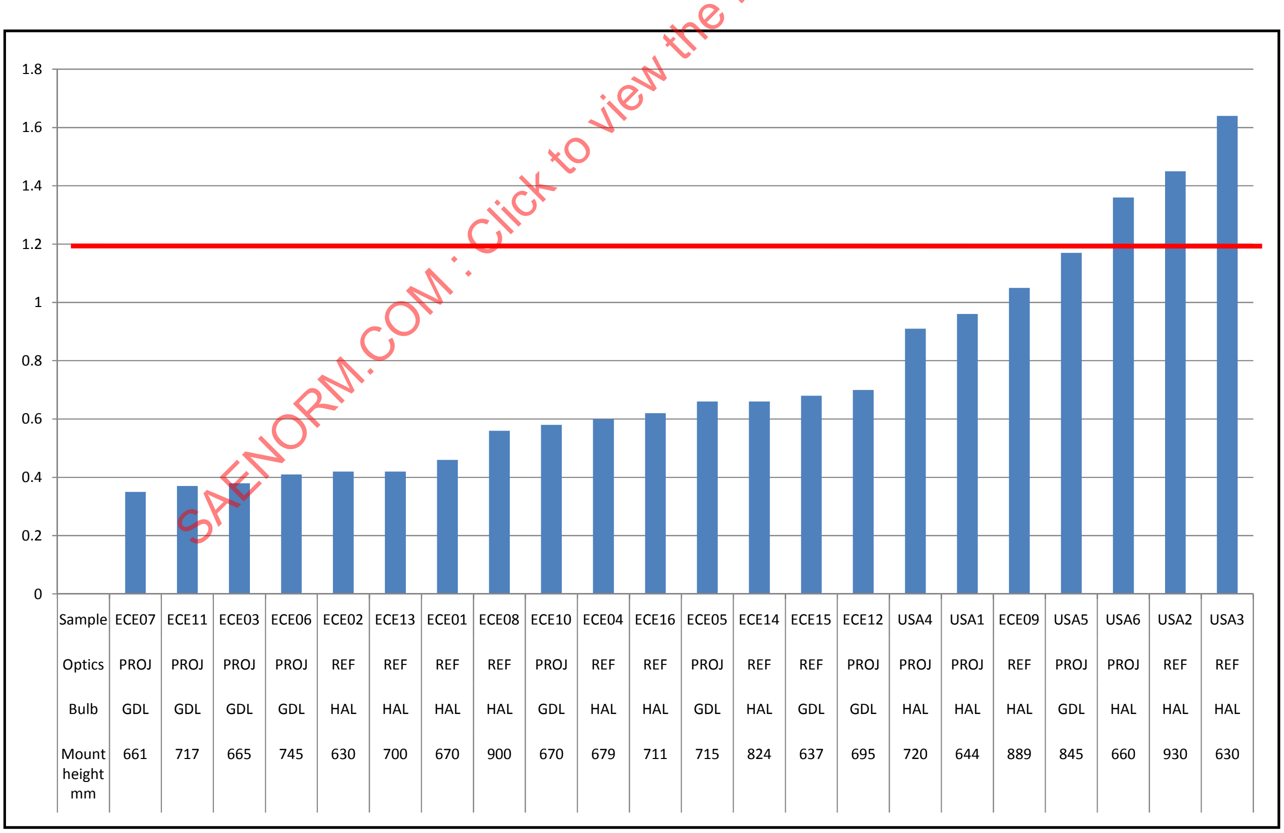


FIGURE 7 - GLARE RANKING BASED UPON THE CIE TC4-45 METHOD
- WEIGHTED LUMINOUS FLUX IN THE GLARE ZONE - LUMENS
THE THRESHOLD ADOPTED FOR THE MAXIMUM ACCEPTABLE GLARE VALUE IS SHOWN AS 1.2 LUMEN

6.3 Effects of Mounting Height and Low-Beam Aim

The acceptability of a low beam system will be determined by its ability to provide adequate forward illumination while maintaining acceptable glare levels as discussed in the preceding paragraphs. For a given headlamp, however, the optimum aim will depend upon its mounting height as installed on the vehicle. To attempt to show an example of the effects of this mounting height and low beam aim relationship, a sensitivity analysis has been carried out using a typical halogen headlamp employing reflector optics. The luminous intensity distribution of this headlamp is shown in Figure 8.

The performance of this headlamp system has been calculated in terms of pedestrian visibility and glare as defined in 6.1 and 6.2 and an explanation of the calculation method and the results based upon the combination of the pair of headlamps is shown in Figures 9 to 16 below. The headlamps were assumed to be installed at a separation of 1250 mm and calculation were based upon mounting heights of 590 mm, 700 mm, 830 mm and 1100 mm above the road surface.

Figure 17 presents a graphical summary of the result of the calculations. The separation between the lines representing the visibility and glare boundaries provides an indication of the sensitivity of the low beam to a change in aiming angle. It can be concluded that a low beam having a sharp cutoff, low glare and high visibility rankings will achieve a greater separation between these boundaries. The importance of correct initial aim and the adoption of automatic leveling systems is also emphasized by these results.

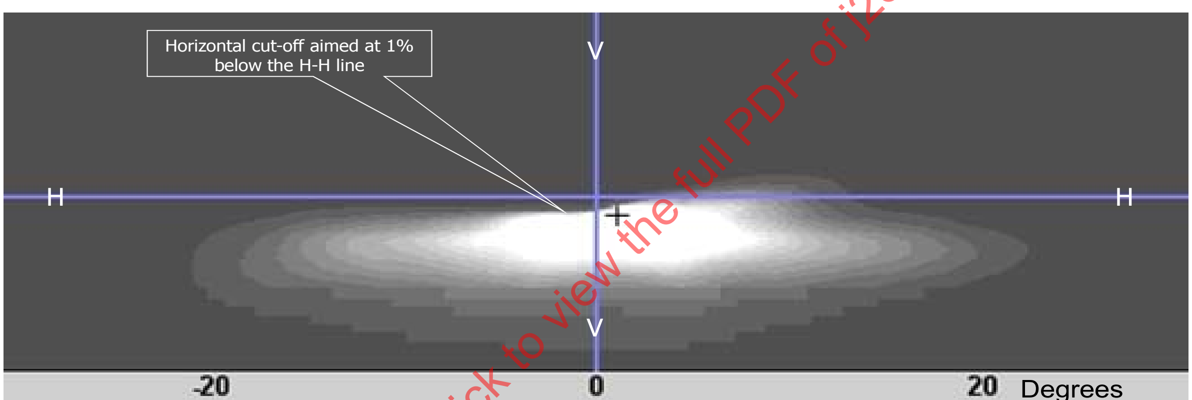


FIGURE 8 - INTENSITY DISTRIBUTION PROJECTED ONTO A SCREEN LOCATED AT 25 m DISTANCE
HALOGEN REFLECTOR SYSTEM (ONE HEADLAMP OF THE TWO HEADLAMP SYSTEM SHOWN)
AIM: 1% DOWN FROM H-V, H7 LAMP OPERATED AT 13.2 v, TOTAL LUMINOUS FLUX = 368 LUMEN

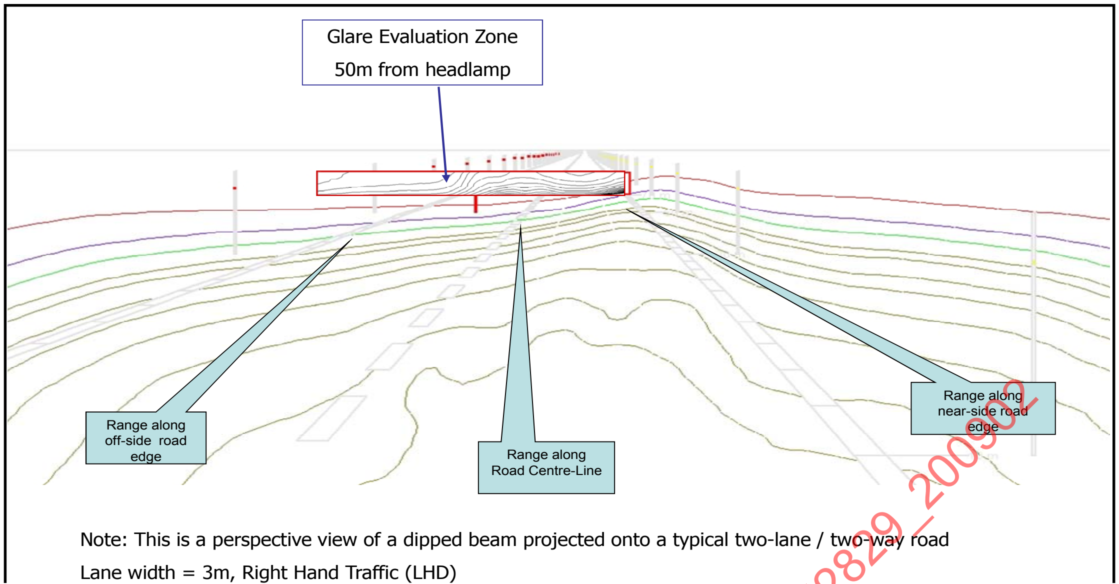


FIGURE 9 - ASPECTS OF THE LOW BEAM EVALUATED FOR THE AIMING SENSITIVITY STUDY

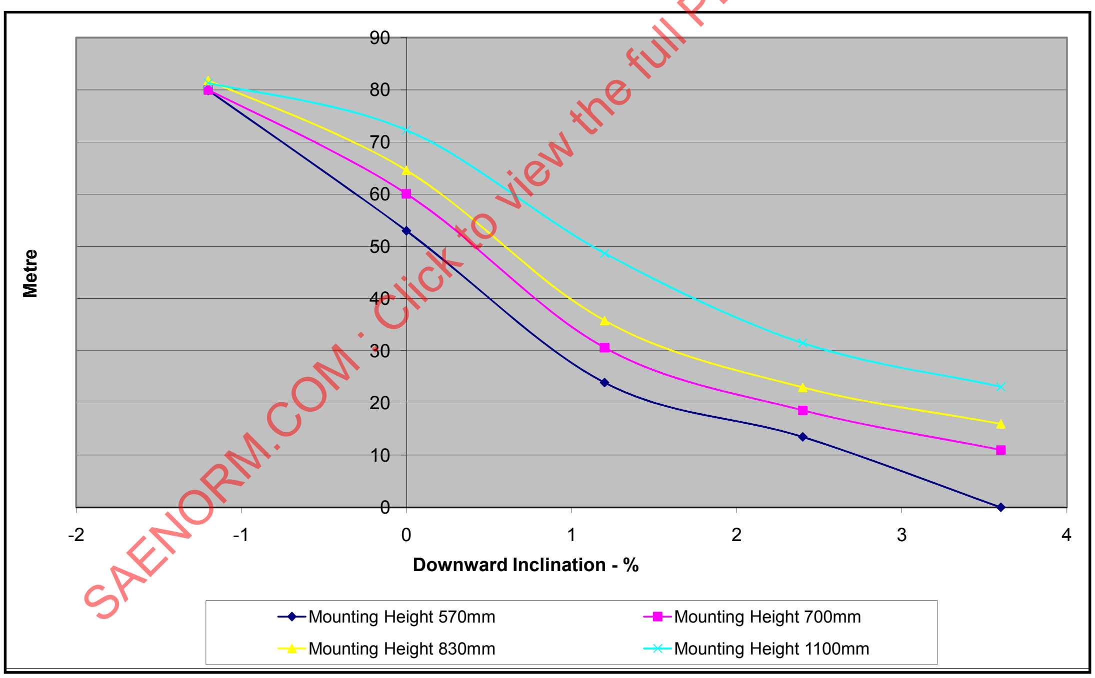


FIGURE 10 - RANGE OF THE 3 LUX LINE AT 250 mm ABOVE THE ROAD SURFACE AT THE LEFT SIDE (OFFSIDE) CURB RELATIVE TO MOUNTING HEIGHT AND DOWNWARD INCLINATION

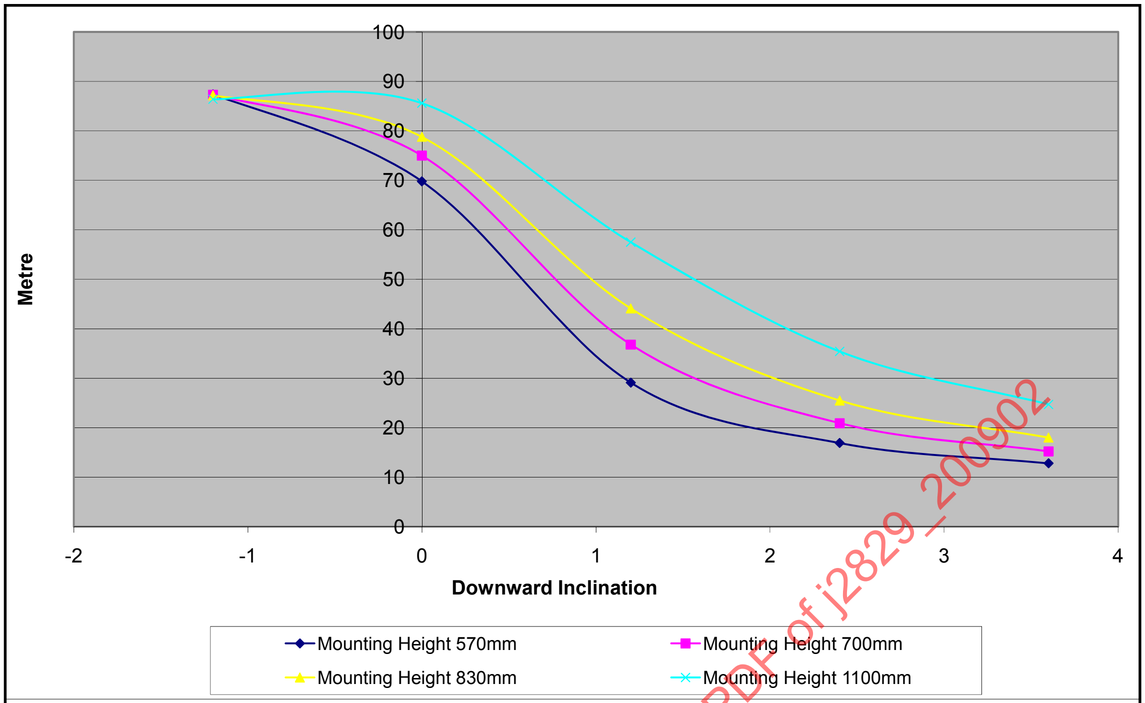


FIGURE 11 - RANGE OF THE 3 LUX LINE AT 250 mm ABOVE THE ROAD SURFACE AT THE ROAD CENTRE-LINE RELATIVE TO MOUNTING HEIGHT AND DOWNWARD INCLINATION

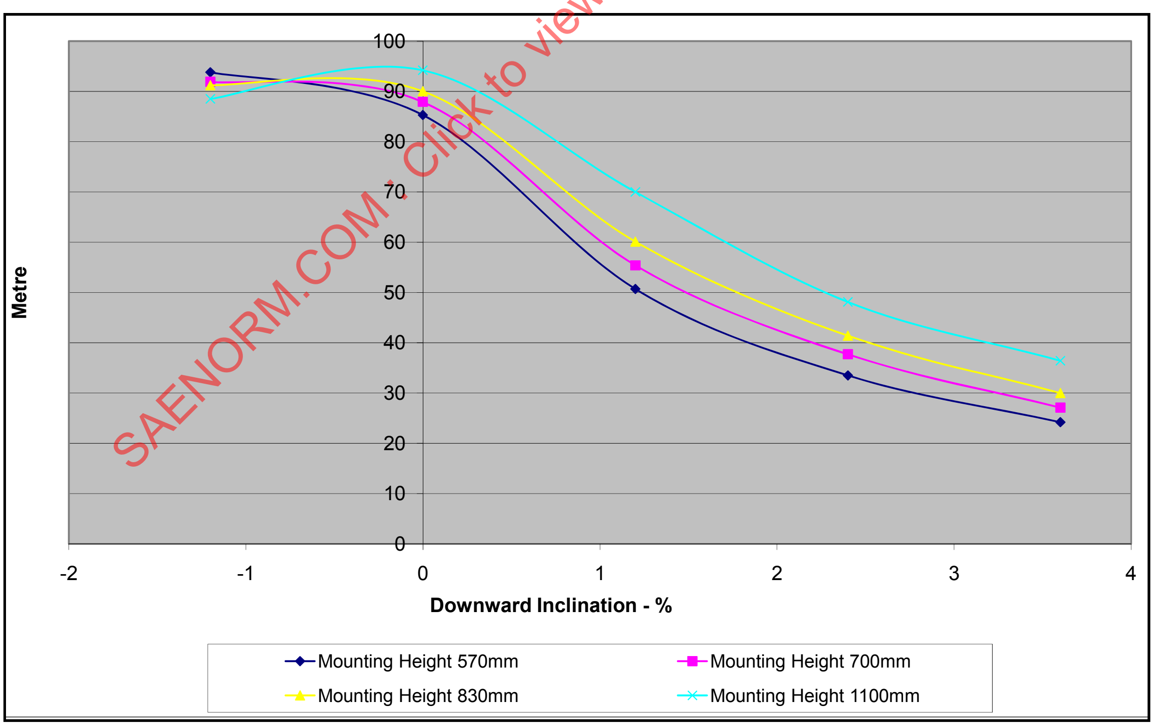


FIGURE12 - RANGE OF THE 3 LUX LINE AT 250 mm ABOVE THE ROAD SURFACE AT THE RIGHT SIDE (NEARSIDE) CURB RELATIVE TO MOUNTING HEIGHT AND DOWNWARD INCLINATION

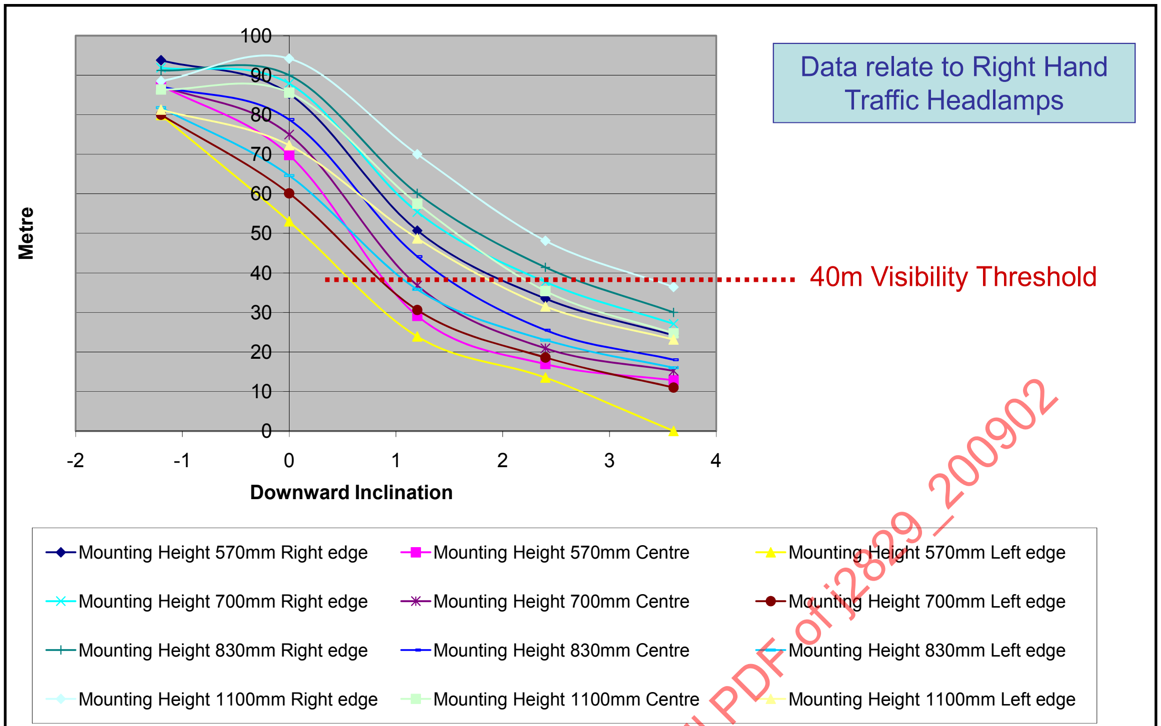


FIGURE13 - COMBINATION OF DATA SHOWN IN FIGURES 10, 11 AND 12

THIS IS USED TO DETERMINE THE CORRESPONDING DOWNWARD AIM TO ACHIEVE A RANGE OF 40 m FOR EACH CURVE

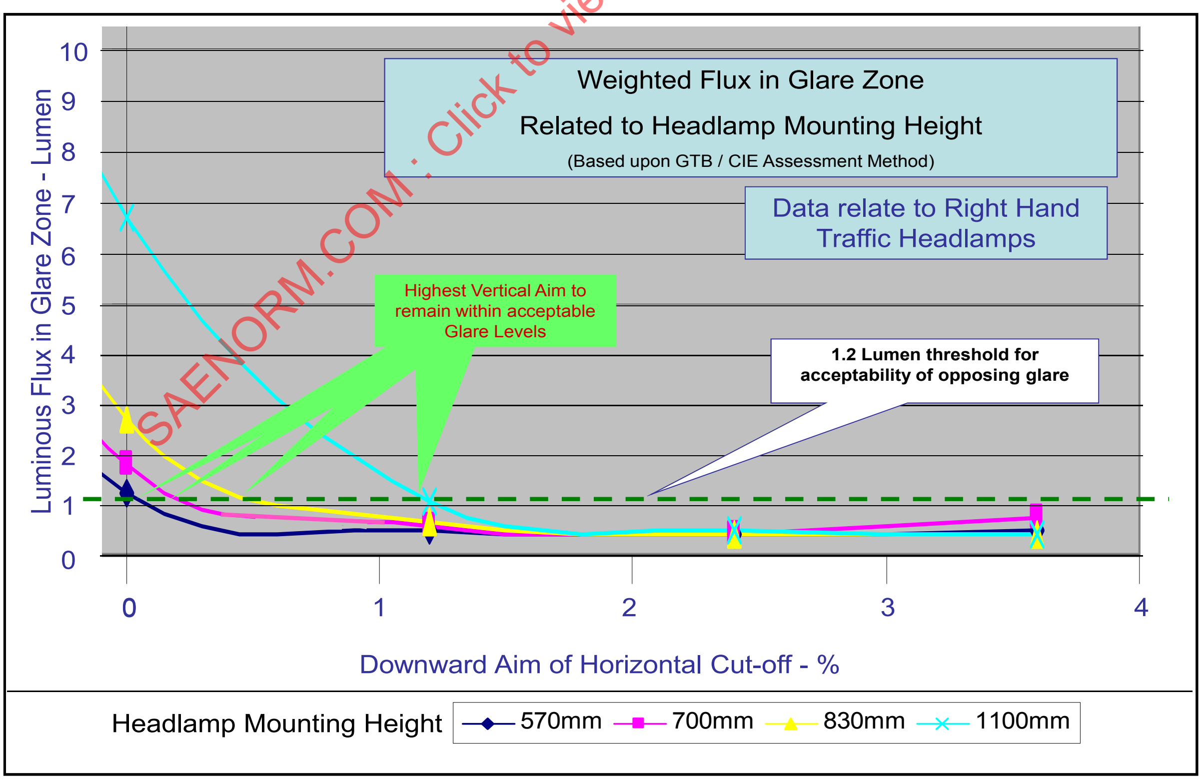


FIGURE14 - WEIGHTED LUMINOUS FLUX IN THE GLARE ZONE RELATED TO DOWNWARD AIM FOR EACH MOUNTING HEIGHT

FROM THESE GRAPHS THE HIGHEST VERTICAL AIM RELATED TO MOUNTING HEIGHT TO REMAIN WITHIN THE 1.2 LUMEN THRESHOLD (CHOSEN AS THE LIMIT OF ACCEPTABLE GLARE) IS DETERMINED

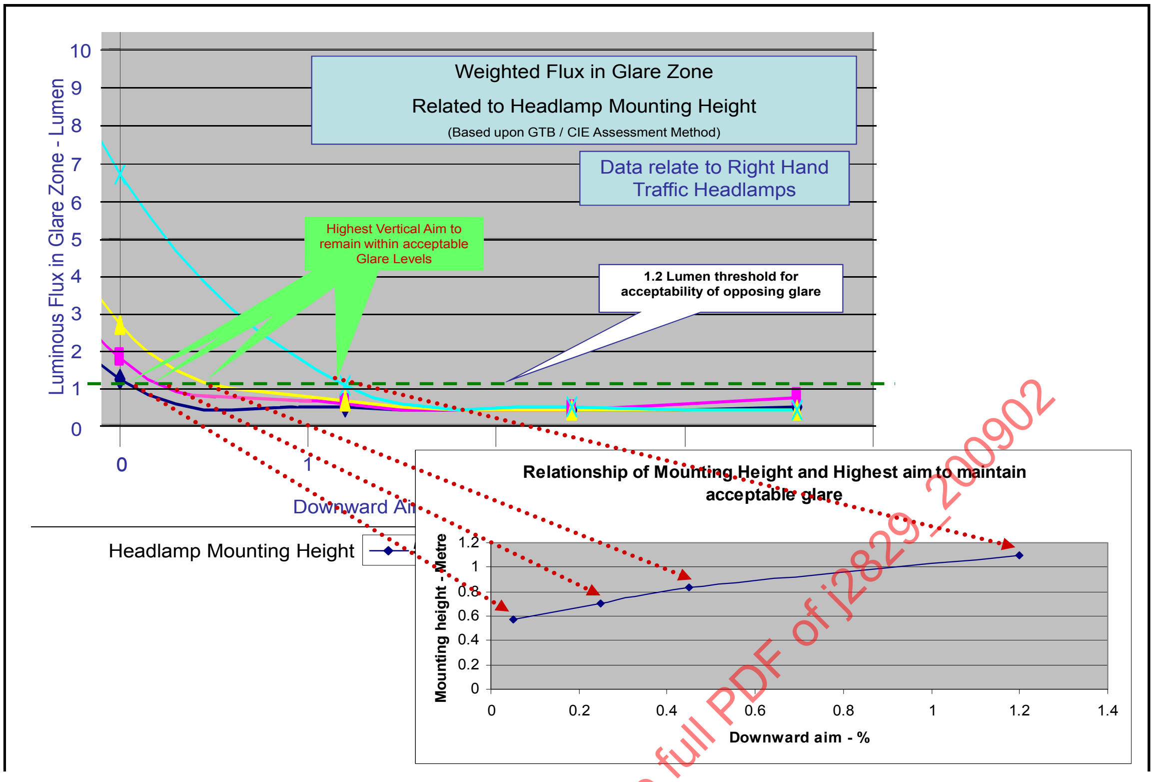


FIGURE15 - METHOD USED TO DETERMINE THE RELATIONSHIP OF MOUNTING HEIGHT AND DOWNWARD AIM BASED UPON A 1.2 LUMEN THRESHOLD CHOSEN BY THE TASKFORCE AS AN INDICATION OF ACCEPTABILITY OF OPPOSING GLARE

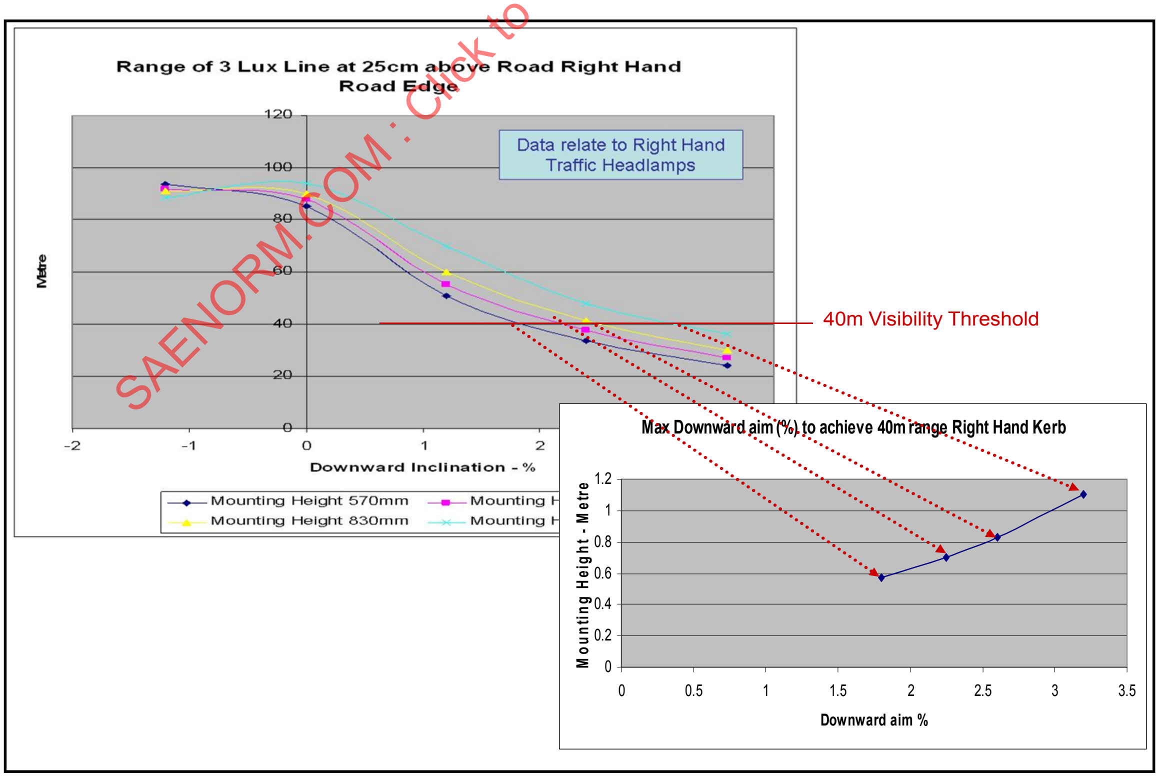


FIGURE16 - METHOD USED TO DETERMINE THE RELATIONSHIP OF MOUNTING HEIGHT AND DOWNWARD AIM TO ACHIEVE 40 m VISIBILITY

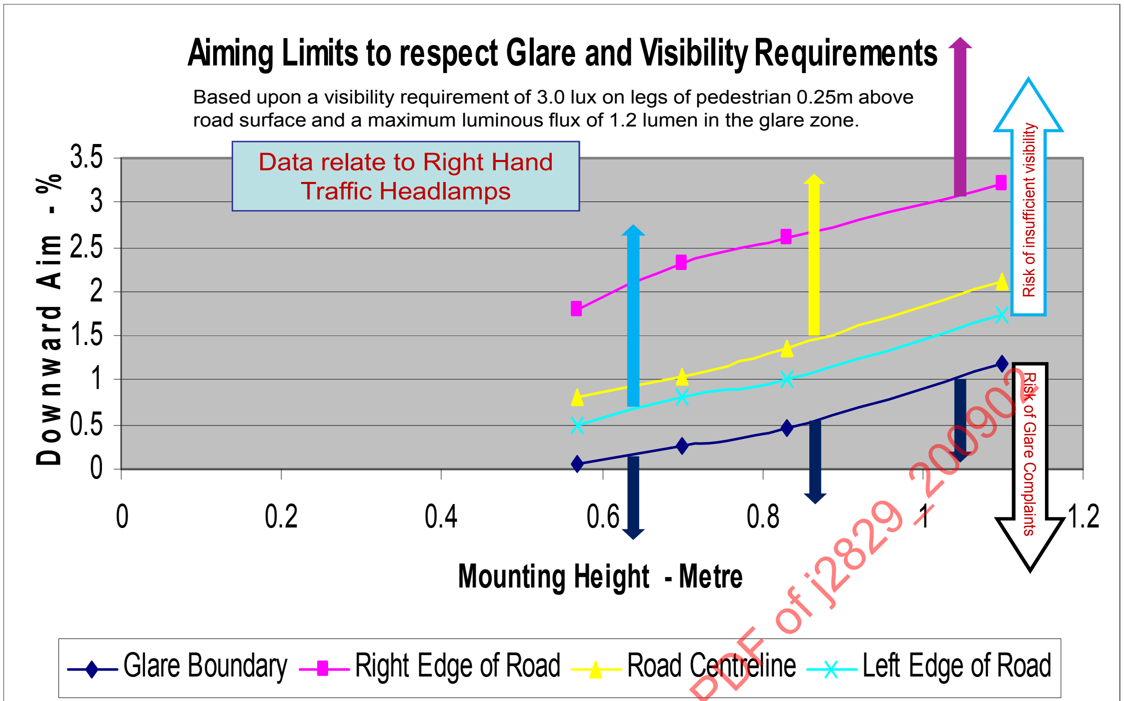


FIGURE17 - COMBINATION OF THE GRAPHS DERIVED FROM FIGURES 15 AND 16 SHOWING THE VISIBILITY / GLARE SENSITIVITY BASED UPON AIM AND MOUNTING HEIGHT
(THE GAP BETWEEN THE PURPLE, YELLOW AND BLUE LINES AND THE DARK BLUE LINE INDICATES THE RANGE OF AIMING ANGLE THAT WILL SATISFY THE GLARE AND VISIBILITY CRITERIA DEFINED BY THE TASKFORCE)

7. EVALUATION OF THE CAPABILITY OF EXISTING HEADLAMP SYSTEMS

7.1 Illuminance on the LH and RH Road Edges

16 sets of current ECE type approved headlamps and 6 sets of US headlamps were assessed with regard their ability to produce an illuminance of 3.0 lux along the line of the offside and nearside curbs at a height of 0.25 m above the surface. A graphical method was used, following the procedure outlined below, to represent the performance of the headlamp system as installed on the car to provide an overall impression of the beam distribution and the glare levels.

Each headlamp was operated at the vehicle system voltage declared by the manufacturer and the luminous intensity was measured using an LMT photometer. The measurements were carried out using horizontal scans within the range from 60° L to 60° R with 0.2° increments and at vertical increments from 10° D to 45° U having the following resolution:

Within the range 10° D to 5° D:	0.5° steps
Within the range 5° D to 3° U:	0.1° steps
Within the range 3° U to 45° U:	0.5° steps

The low beam was aimed using the SAE photometric method.

Using the matrix of low beam data for the individual headlamps, calculations of the illuminance pattern on the road surface and at 0.25 m above the road were made using the LMT LIMES Software.

These calculations were carried out by combining the photometric data of the left and right-hand headlamps and taking account of the separation, mounting height and aiming angle as declared by the car manufacturer.

The headlighting system performance is represented as a perspective view of a standard two lane 6 m wide road with the glare zone at 50 m distance and a "birds-eye view of the plane 0.25 m above the road surface with the 3.0 isolux line superimposed. Results for both US and ECE systems are shown in Appendix A, Figures A1 to A22.

7.2 Calculation of the Uniform Detection Characteristic (UDC) Locus

Using the software tool made available by LMT, the task force determined the UDC locus for both US and ECE headlamp systems. The results are shown in Appendix A, Figures A1 to A22.

7.3 Luminous Flux in the Glare Zone

The method as described in 6.2 was used to evaluate the weighted luminous flux in the glare zone. Results are shown in Appendix A, Figures A1 to A22, for both US and ECE Headlamp systems.

7.4 Analysis of the Evaluation Results

Figure 18 shows:

a. The visibility along the left (offside) and the right (nearside) curbs on a plane 0.25 m above the road surface.

b. The weighted luminous flux in the glare zone (multiplied by 100 to improve the diagram)

These results are shown in order of headlamp number

Figure 19 shows the overall ranking in order of increasing value and calculated using the formula:

$$Visibility_{Left} + Visibility_{Right} - Glare/2 \quad \text{(Eq. 1)}$$

It should be noted that the above formula has been chosen based upon an assumption that the importance of detecting a pedestrian relative to the glaring effect on other drivers is a factor of two. However, further consideration would be required to verify the relevance of such a relationship before it can be used as the basis of a rating system.

Figure 20 provides a comparison of the performance of the headlamps that achieve a visibility of more than 40 m on a plane 0.25 m above the road on the left hand (Offside) curb. The headlamps are shown in order of increasing rank value.

Figures 21 to 23 provide comparisons of the performance of the highest and lowest ranked headlamps according to the light source and reflector technologies employed.

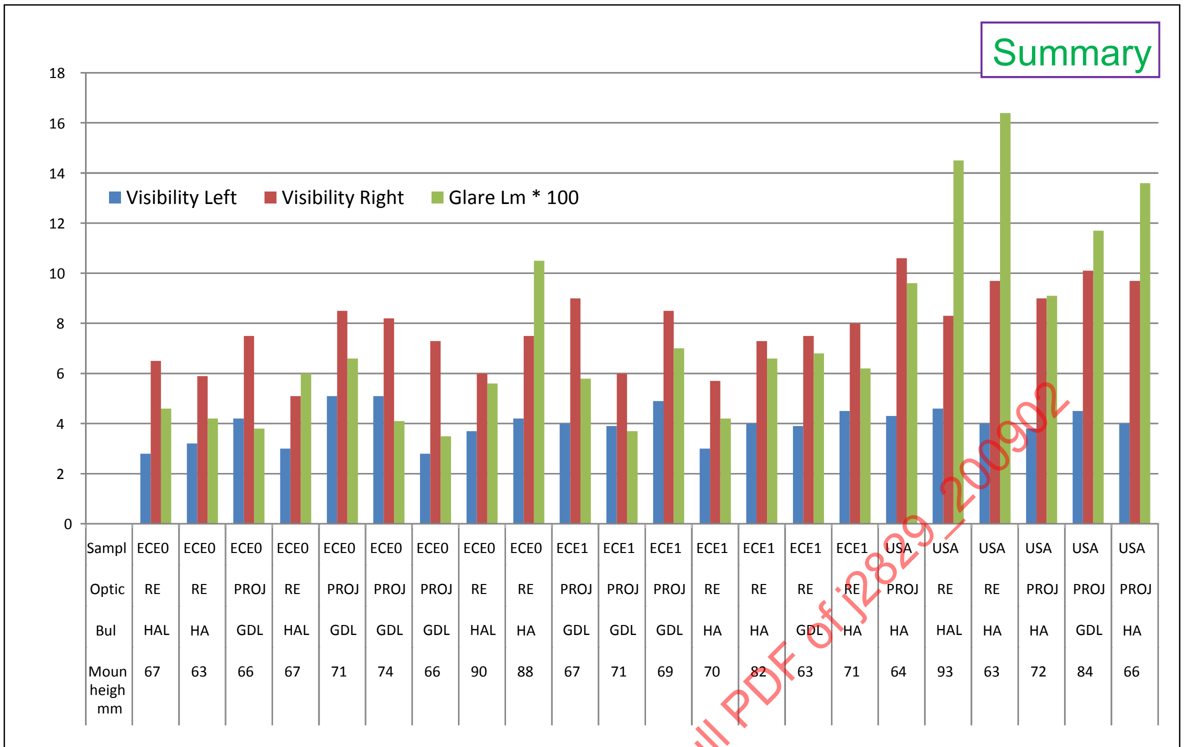


FIGURE 18 - RELATIVE RANK SUMMARY OF ALL 22 SYSTEMS EVALUATED

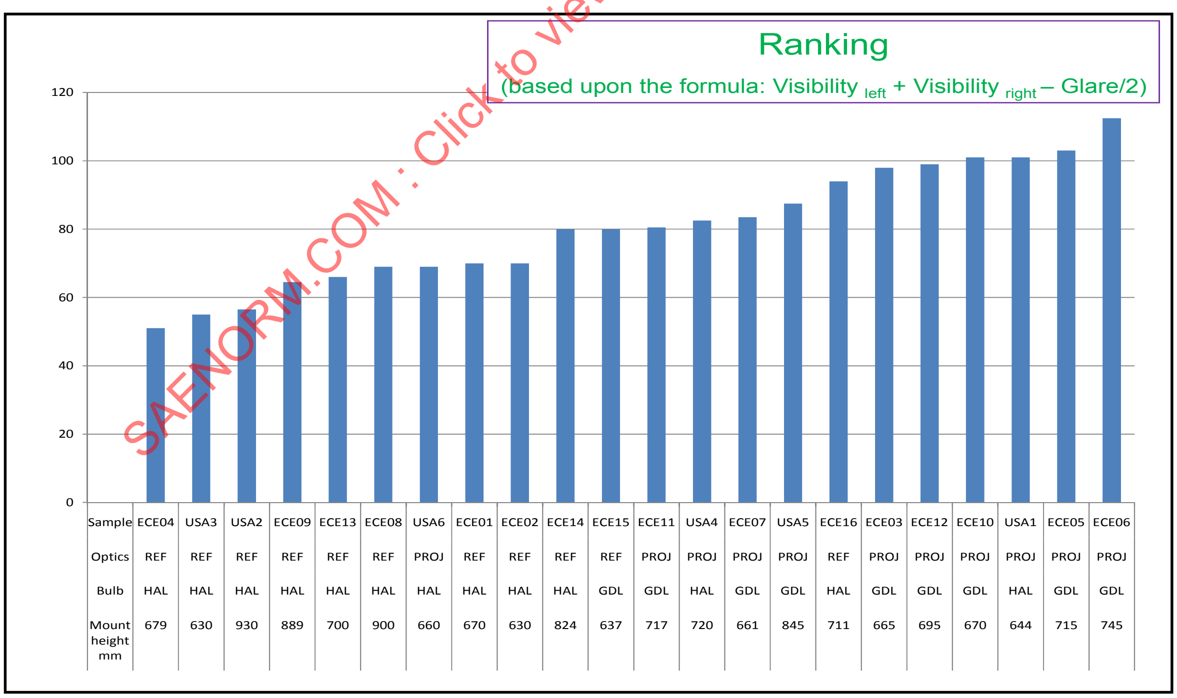


FIGURE 19 - OVERALL PERFORMANCE SUMMARY - SORTED ACCORDING TO RANK VALUE

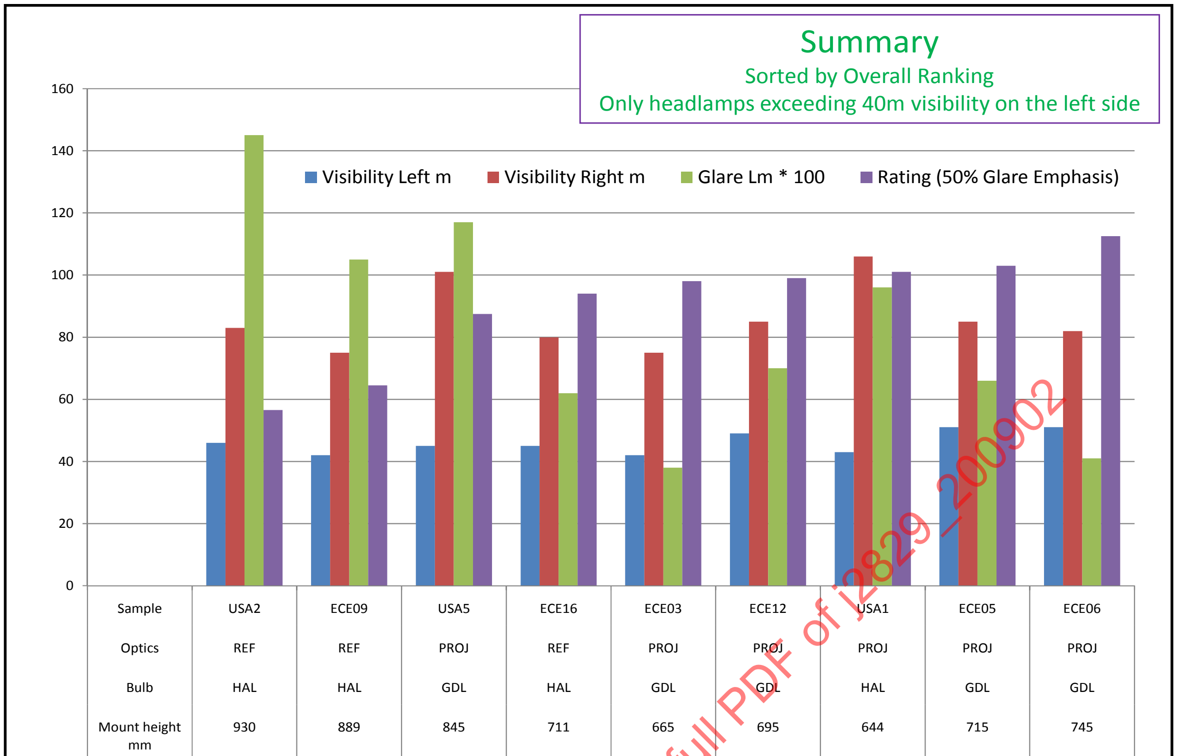


FIGURE 20 - RELATIVE PERFORMANCE SUMMARY SORTED BY OVERALL RANK

ONLY SYSTEMS ACHIEVING MORE THAN 40 m VISIBILITY ON THE LEFT SIDE (OFFSIDE) ARE SHOWN

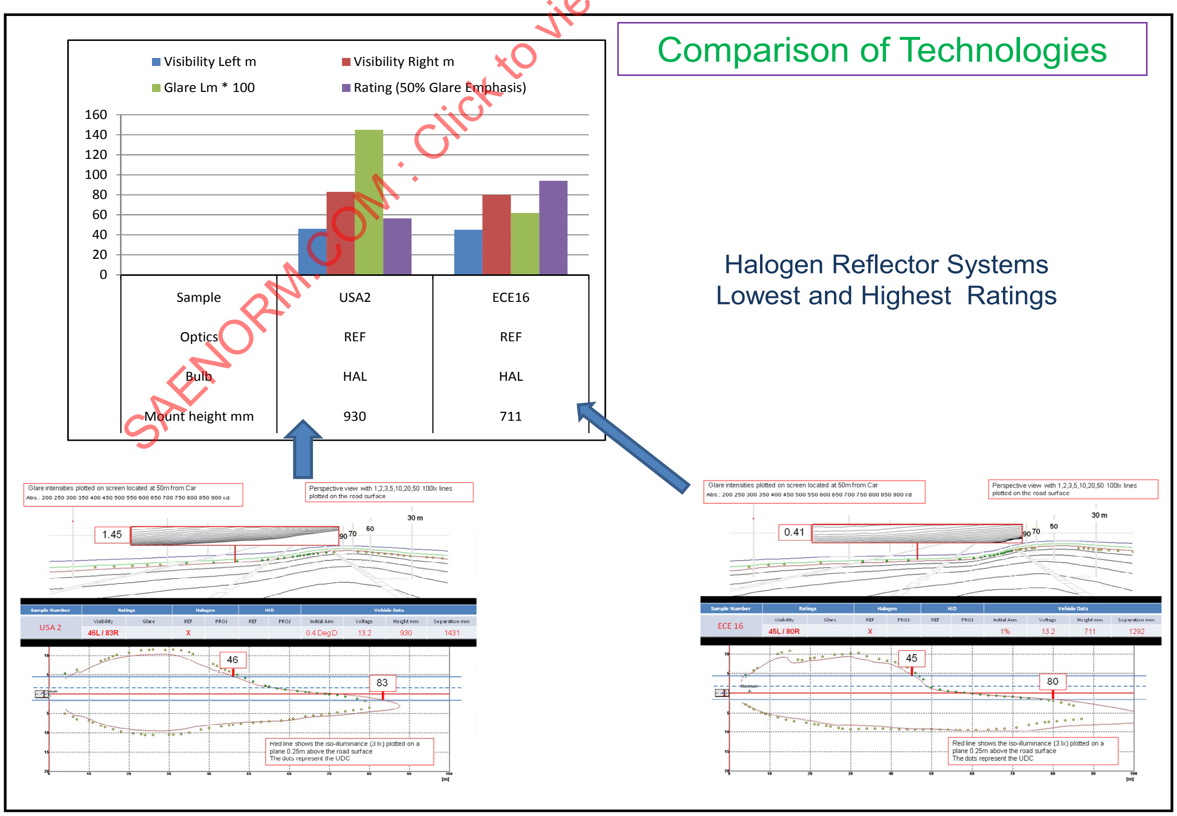


FIGURE 21 - COMPARISON OF TECHNOLOGIES - HALOGEN REFLECTOR SYSTEMS

WHILE THE VISIBILITY DISTANCES ACHIEVED BY THE TWO SYSTEMS ARE SIMILAR, THE USA2 SYSTEM DEMONSTRATES A DIFFUSE CUTOFF AND A HIGHER GLARE VALUE

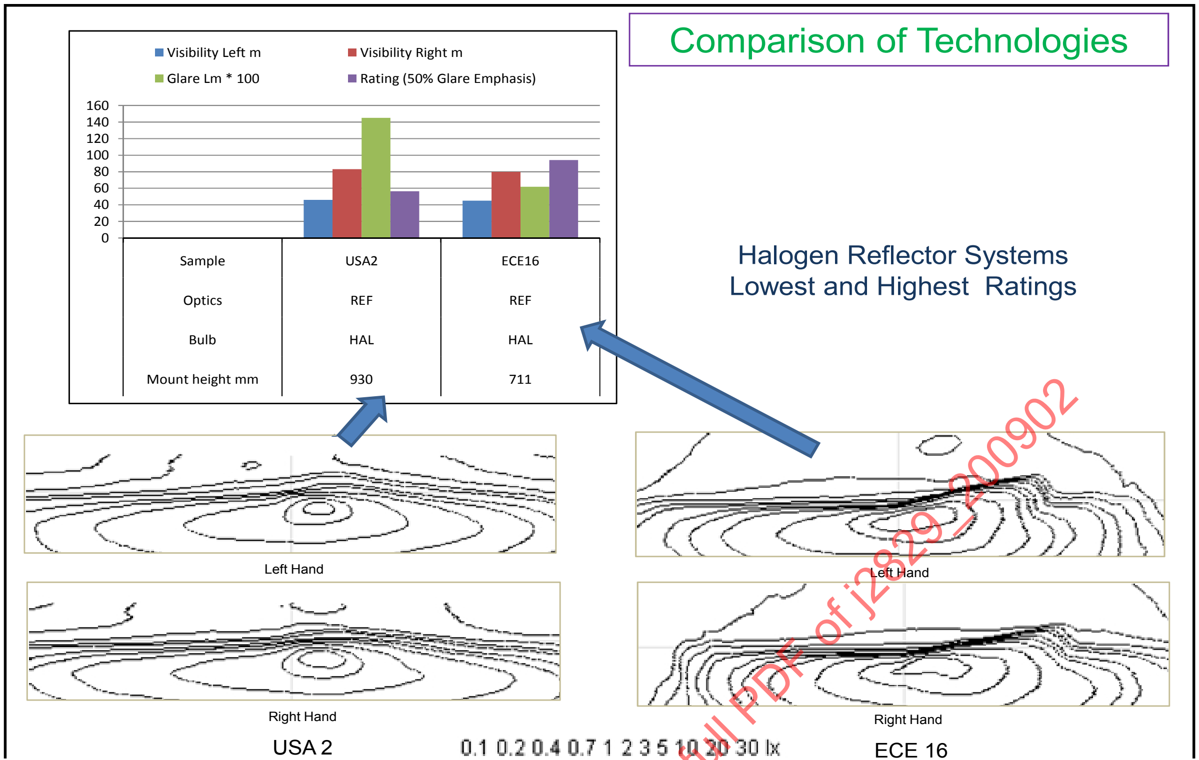


FIGURE 22 - COMPARISON OF TECHNOLOGIES - HALOGEN REFLECTOR SYSTEMS
THE DIFFERENCES IN THE CUTOFF CHARACTERISTICS OF USA2 AND ECE16 ARE CLEARLY DEMONSTRATED BY THESE DIAGRAMS

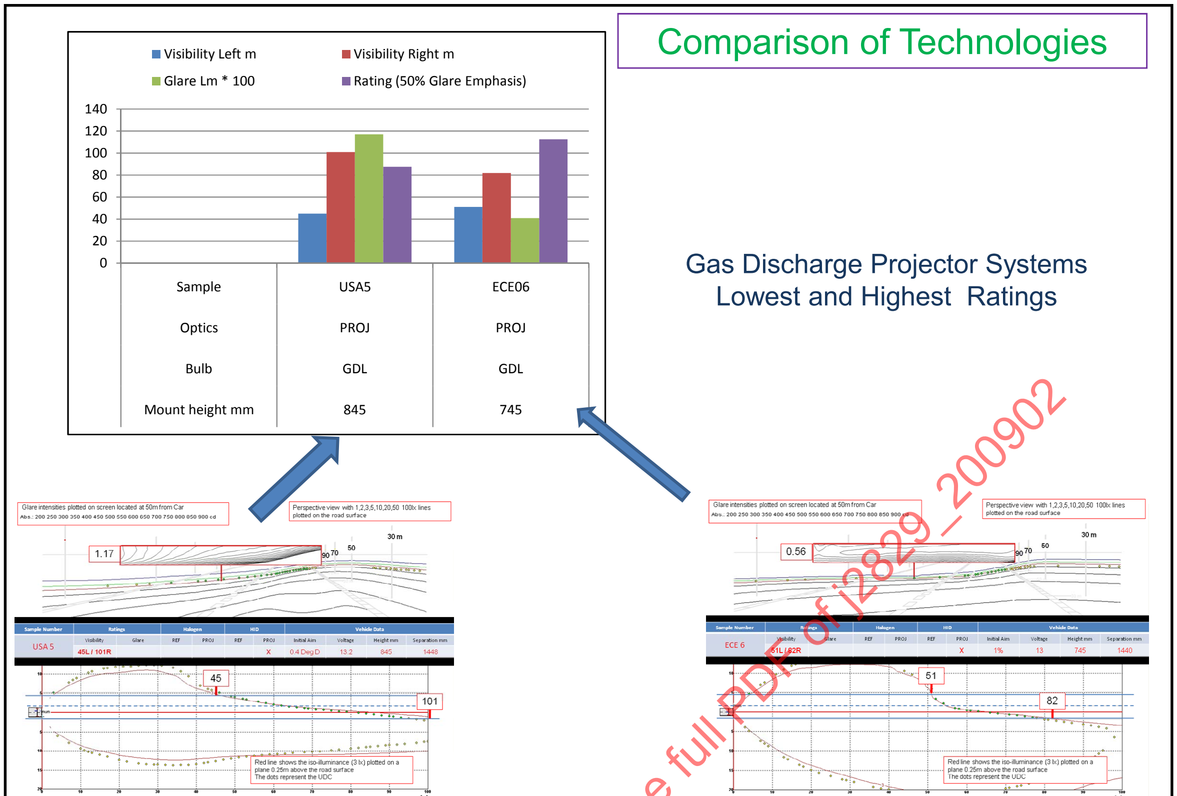


FIGURE 23 - COMPARISON OF TECHNOLOGIES - GAS DISCHARGE PROJECTOR SYSTEMS

THE USA5 SYSTEM ACHIEVES A GREATER VISIBILITY ON THE RH (NEARSIDE) BUT AT THE EXPENSE OF A DIFFUSE CUTOFF AND SIGNIFICANTLY HIGHER GLARE VALUE

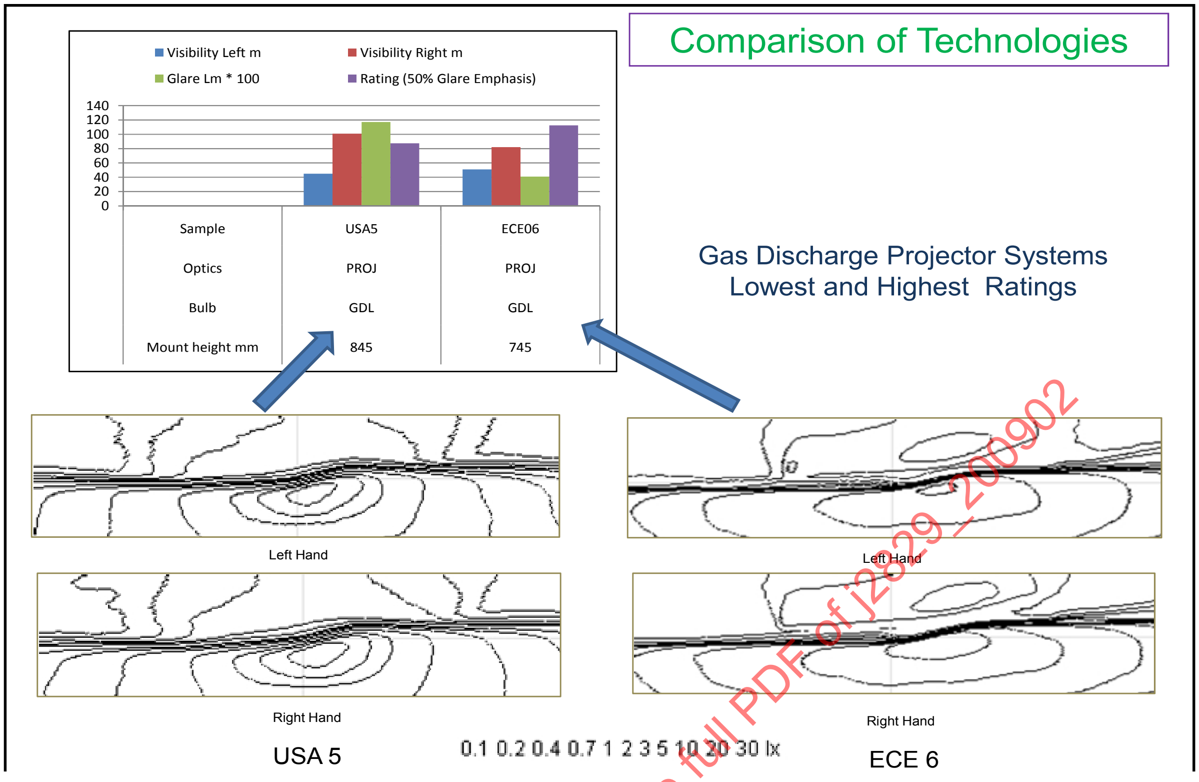


FIGURE 24 - COMPARISON OF TECHNOLOGIES - GAS DISCHARGE PROJECTOR SYSTEMS
THE DIFFERENCES IN THE CUTOFF CHARACTERISTICS OF USA2 AND ECE16
ARE CLEARLY DEMONSTRATED BY THESE DIAGRAMS

7.5 Conclusions Derived from the Ranking Formulae Adopted by the Taskforce

From the comparison of the 22 headlamp systems detailed in this report the following conclusions can be drawn:

a. The Uniform Detection Characteristic UDC calculated on the basis of a target of 10% reflectance and located 250 mm above the road surface yields similar visibility distances to those derived from the 3.0 lux illuminance contour used in the CIE TC4-45 procedure. This is a particularly interesting outcome as these two methodologies are based upon essentially different approaches of independent lighting / human factors experts. One references twilight illumination while the other interpolates experimental data from many engineers and scientists. The difference in the two methodologies is that the UDC can accommodate changes in key parameters such as expectancy, size and visual centroid while the use of the 3.0 lux parameter is a generic approach.

b. No clear relationship between mounting height, visibility and glare was found amongst the 22 headlamp systems evaluated.. The aim of the low beam cutoff and the actual light distribution in the low beam has more impact upon visibility and glare than the mounting height. It should be noted that the highest mounting height of the 22 headlamp systems was 940 mm. Higher mounting heights may result in higher glare values and in this case further study would be required although the method described in paragraph 6.3 provides some good indication of the consequences.

c. Halogen systems can give a good pedestrian visibility performance at the expense of higher glare values

d. Gas Discharge systems employing projector optics offer the best overall performance with higher visibility and lower glare.

e. There is no clear benefit from US or ECE systems. This is particularly interesting in the context of discussions relating to harmonization of US and ECE requirements.

f. The US systems demonstrate higher glare values associated with diffuse cut-offs. This is the main feature that distinguishes the US and ECE systems.

The optimization of pedestrian visibility performance and “low” glare levels is a matter of beam design preference. It is likely that the best balance of these features will be based upon a system employing gas discharge light sources, projector optics and a mounting height of approx 750 mm.

8. AN APPROACH TOWARD A REVISED PHOTOMETRIC SPECIFICATION

Achievement of the required illuminance levels related to pedestrian visibility is dependent upon the luminous intensity distribution of each headlamp *and the vehicle installation*. This means that only a system based approach will provide a means to specify and verify the performance required for adequate pedestrian visibility.

Some existing headlamp systems, currently in service and complying with either US or ECE requirements, are able to meet the requirements chosen by the taskforce for pedestrian visibility and glare. This is demonstrated by the results of calculations shown in appendices A and B.

The contents of this report are *intended to serve as a guide* for further work in the SAE Lighting Committees to define new standards and in addition may also provide useful input into considerations regarding NCAP rating systems.

9. CONCLUSIONS

The work described in this report demonstrates that lighting improvements can address at least the “expectant” driver’s needs. Not surprisingly HID headlamp systems provide the best opportunities to achieve the required improvements but even where HID light sources are employed, changes to the ways in which minimum requirements for photometric performance are specified will be required. To adequately incorporate the requirements of pedestrian visibility, a new approach to the specification of beam pattern requirements based upon a vehicle system installation will have to be introduced. The requirements cannot be adequately defined using the conventional approach of specifying values in a beam pattern assessed at fixed points related to angular positions relative to the optical axis, as mounting height, separation, system voltage, and beam aim are significant influencing factors.

The minimum criteria to determine acceptability of a low beam performance in terms of pedestrian visibility should be the attainment of a visibility of a target having 10% reflectance and located at 250 mm above the road surface. This report has examined two methods to assess this and any further work to develop requirements for a new low beam specification will have to decide which approach to adopt. The two methods are:

a. Calculating the range where an illuminance of 3.0 lux is attained on a generic pedestrian target situated on the left (offside) verge or

b. Calculating the UDC (Uniform Detection Characteristic) for a set of parameters selected to represent a pedestrian’s leg with 10% reflectivity.

To achieve the minimum illuminance requirements for pedestrian visibility it is necessary to provide more light close to the h-h line. One possible approach is shown in Figure 25 and is derived from the work of the EUREKA AFS Group that resulted in the new ECE AFS Regulation (ECE R123).The consequences of this sharper gradient low beam cutoff gradient in terms of increased glare and the effects due to vehicle motion and beam alignment, possibly leading to automatic headlamp leveling and headlamp cleaning systems, will require more careful study.

While it has been demonstrated that some existing headlamp technologies and systems are capable of satisfying the requirements in terms of pedestrian visibility and glare, the new emerging technologies such as adaptive forward lighting and LED systems will provide further opportunities. Reference has been made to the “expectant driver” in the calculations summarized in this report and here, the technologies associated with infrared assisted systems can provide early detection of unlighted warm bodies can be usefully combined with the improved headlamp systems.

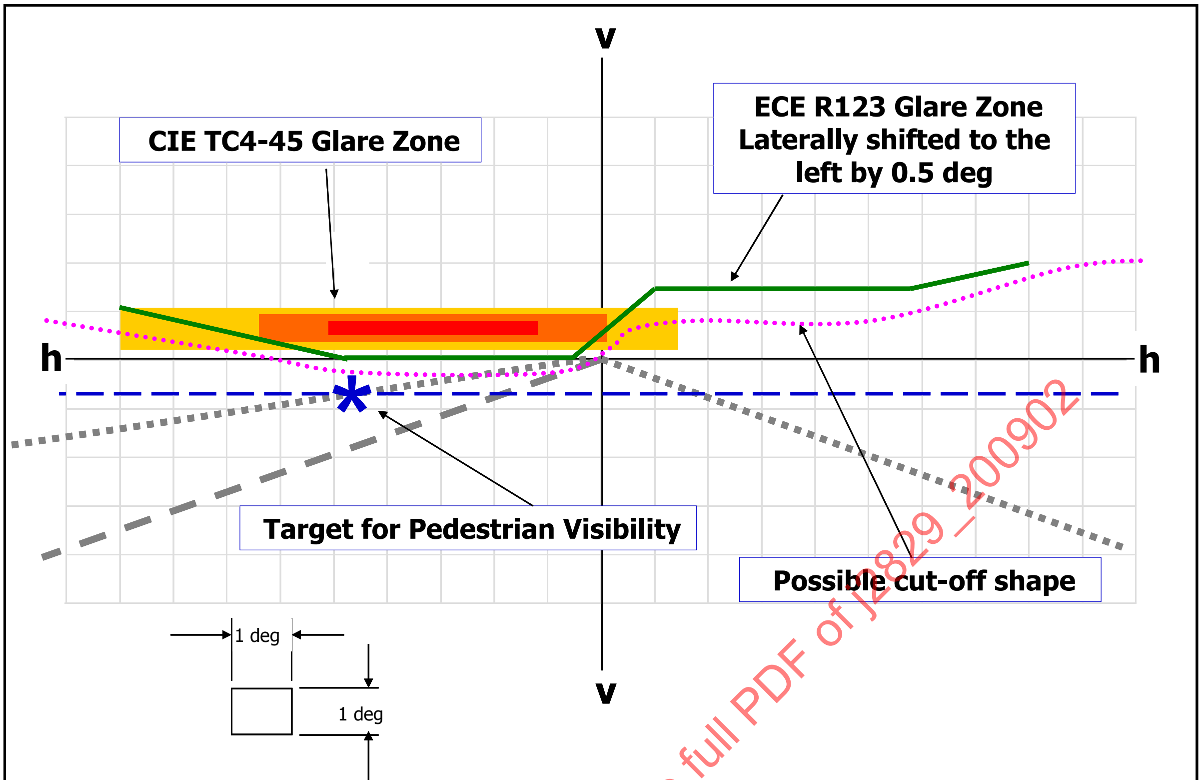


FIGURE 25 - A POSSIBLE APPROACH TO THE DEFINITION OF AN IMPROVED LOW BEAM PATTERN

The downsides and arguments remain the same mature and timeless issues of glare-averse public reaction, governments' regulatory issues, and cost/benefit/effort-related concerns among manufacturers of vehicles and lighting. These will have to be seriously taken into account during the work in the SAE Lighting Committees. In particular, decisions will have to be reached concerning the limiting value of glare to the oncoming driver. Based upon the glare model developed by CIE TC4-45, the taskforce concludes that a value of 1.2 lumens should be adopted for the weighted luminous flux in glare zone. This would imply that future US low beams would exhibit a sharper cutoff than that currently adopted.

Finally, it is interesting to note that the ranking of the 22 headlamp systems (including 6 US systems) reveals no evidence to support the frequently used arguments concerning the relative superiority of the ECE or US beam patterns. From the point of view of pedestrian visibility both patterns are capable of meeting the minimum requirements identified in this report with a mounting height of the order of 750 mm. However, when the requirement for good pedestrian visibility and lowest possible glare effects are combined, the sharper cutoff gradient associated with the ECE system provides the best results. This however does not mean that such headlamps cannot meet the FMVSS108 requirements; it is more a question of design philosophy to achieve sharper cutoffs and the associated lower glare levels.

10. RECOMMENDATIONS

Having demonstrated the feasibility of producing low beams capable of providing the required illuminance pattern to satisfy the pedestrian visibility requirements, the task of translating these requirements into the lighting standards should be assigned to the respective SAE lighting committees.

The question of low beam cut-off characteristics in relation to glare effects to the oncoming driver will need very careful consideration and possibly further investigation. There is a clear correlation between sharper cutoffs, lower glare and improved pedestrian visibility performance.

Consideration must be given to associated technologies such as auto-leveling and headlamp cleaning as these will be required to mitigate the potential effects upon perceived glare that could result from the adoption of sharper low beam cutoffs

The opportunity should be taken to develop improved requirements for low cost solutions in addition to taking advantage of new technologies such as adaptive lighting and increased efficiency light sources.

From a technical stance it is clear that it is feasible to harmonize the US and ECE requirements while meeting the pedestrian visibility and glare requirements necessary for safe night-time driving. Although there are significant political barriers to be overcome, the SAE lighting committee should continue to strive towards harmonization that will result in a single globally acceptable headlamp system standard.

11. NOTES

11.1 Marginal Indicia

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE ROAD ILLUMINATION DEVICES STANDARDS COMMITTEE

APPENDIX A - EVALUATION OF EXISTING HEADLAMP SYSTEMS - ILLUMINANCE AND GLARE

The CIE TC4-45 Technical Committee working to define a method of assessing headlamp performance has compiled a database of the performance of 16 sets of headlamps selected to provide a representative sample of current ECE headlamps. The opportunity was taken to use part of this database to support the work of the SAE Pedestrian Visibility taskforce and the results are shown below. Additionally, 6 sets of US headlamps were submitted to the same procedure to provide a total of 22 headlighting systems that form the basis of this report.

The following figures show the relative performance of the 22 sets of headlamps using iso-illuminance curves on a perspective view of the road scene and also as a “bird’s eye” view. Additionally, the glare levels are represented as iso-candela lines on the screen located at 50 m from the car to give an impression of the light distribution and the effects of the cut-off sharpness. On each figure the range along the nearside and offside curbs and the weighted luminous flux in the glare zone are indicated. The Uniform Detection Curves (UDT) for each system are also represented by the dotted lines.

The results show a wide diversity of beam distributions. It is particularly interesting to compare the relative performances along the left side of the road in the region sensitive to collisions with pedestrians. It should be noted that in each diagram the upper image represents the illuminance on the road surface whereas the lower image shows the illuminance plotted on a plane 0.25 m above the road surface to coincide with a point on the pedestrian’s legs. As is obviously the case, the range at which a low beam is able to produce the required 3.0 lux on the pedestrian’s legs is considerably shorter than a corresponding point on the road surface.

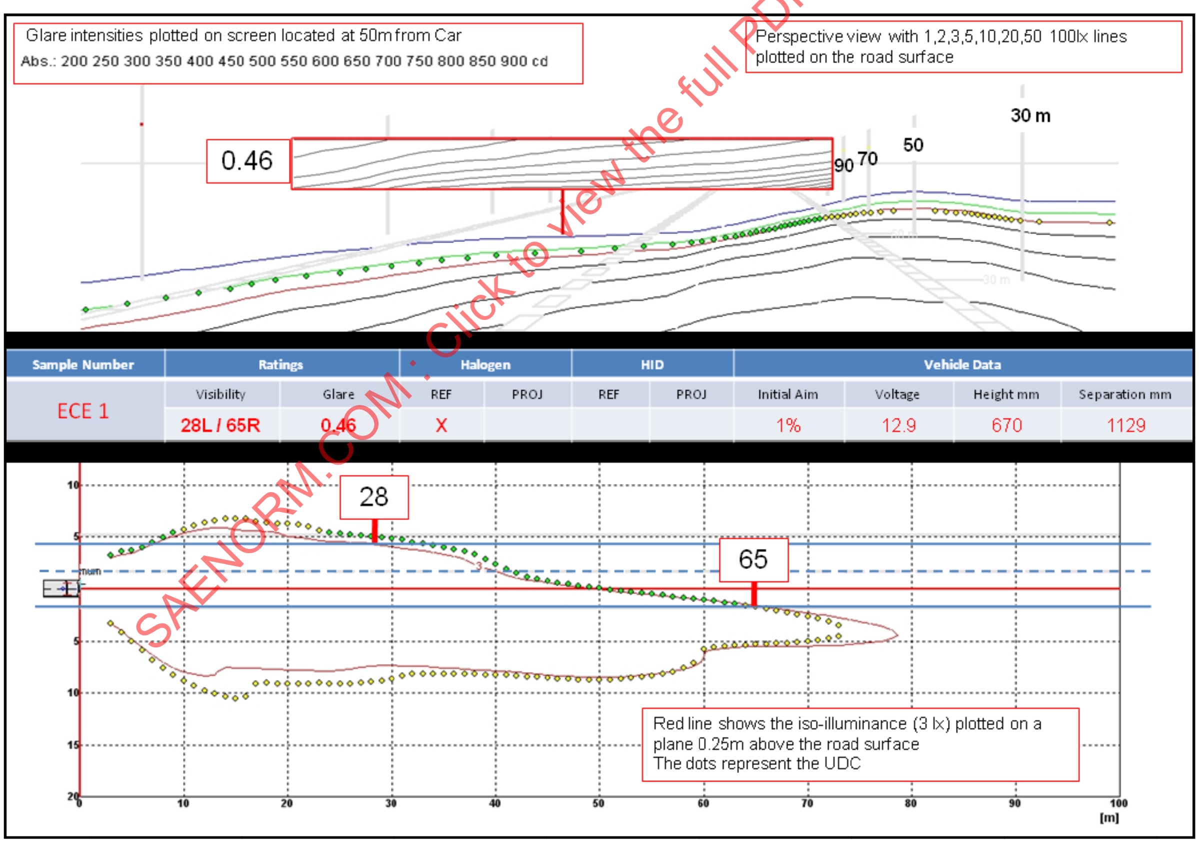


FIGURE A1

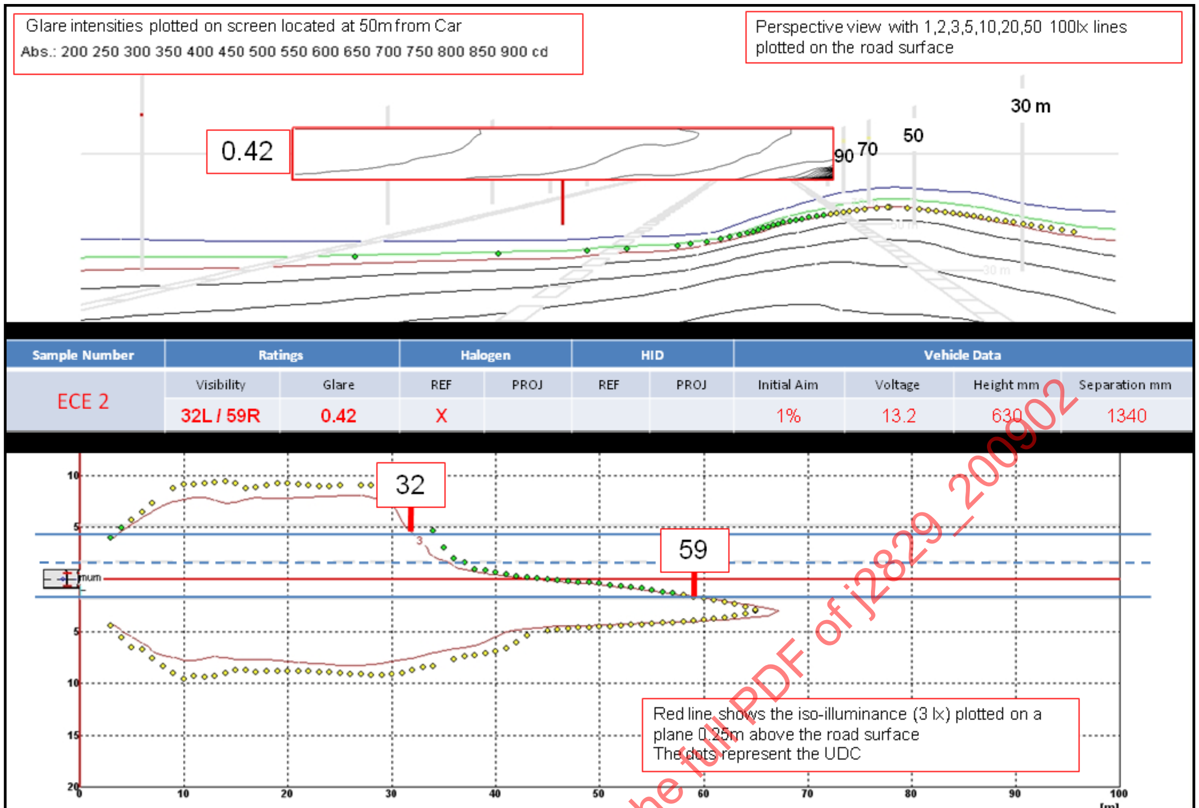


FIGURE A2

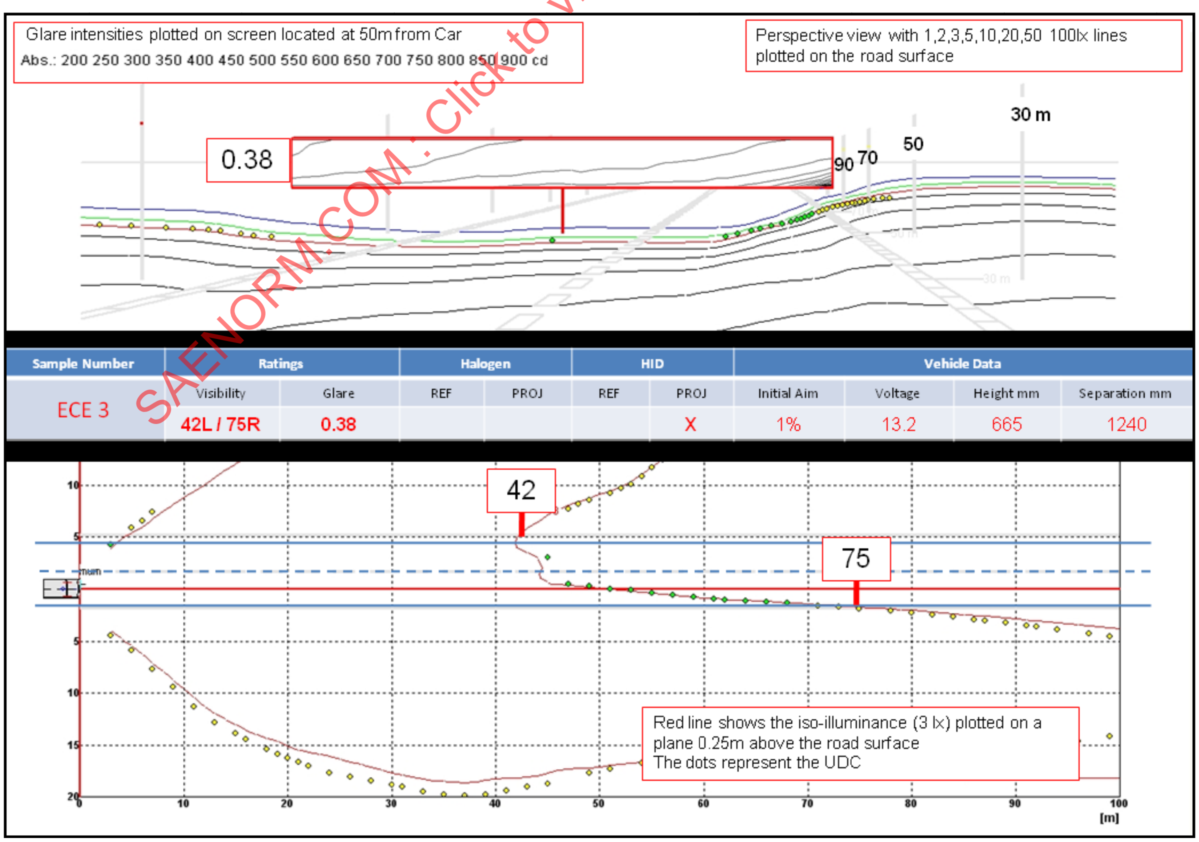


FIGURE A3

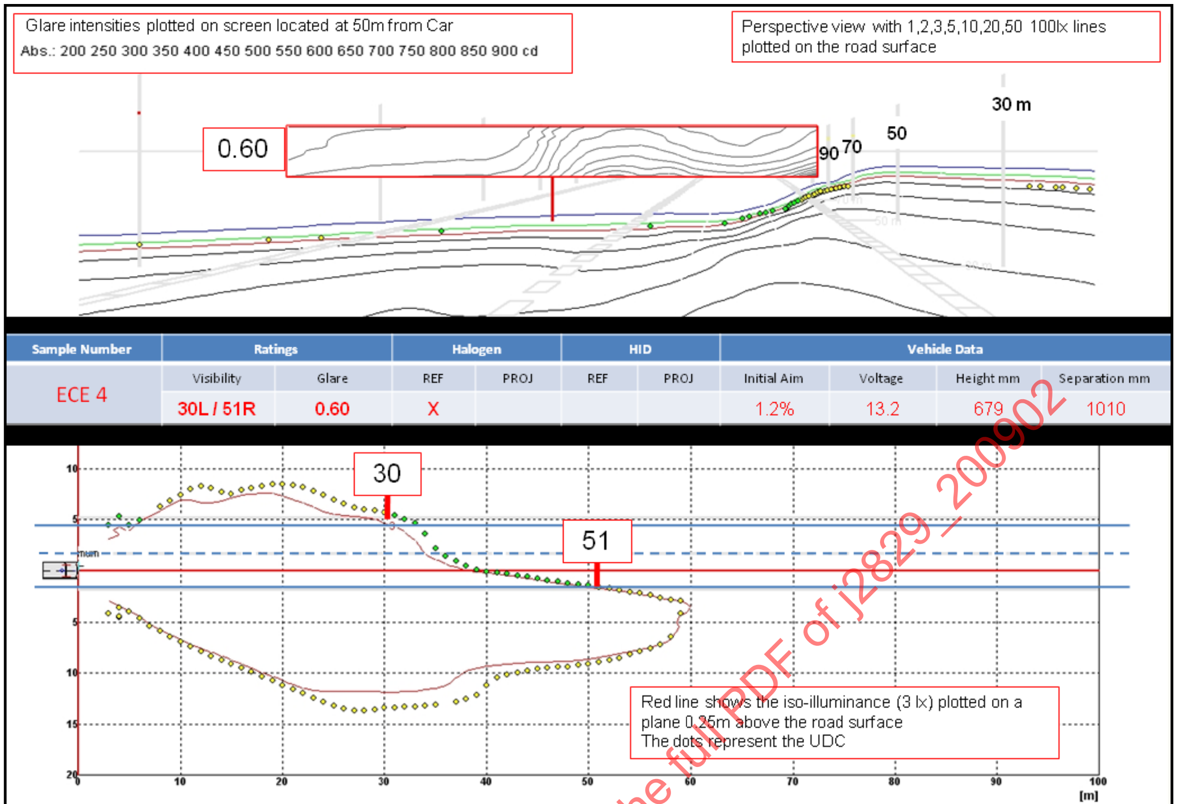


FIGURE A4

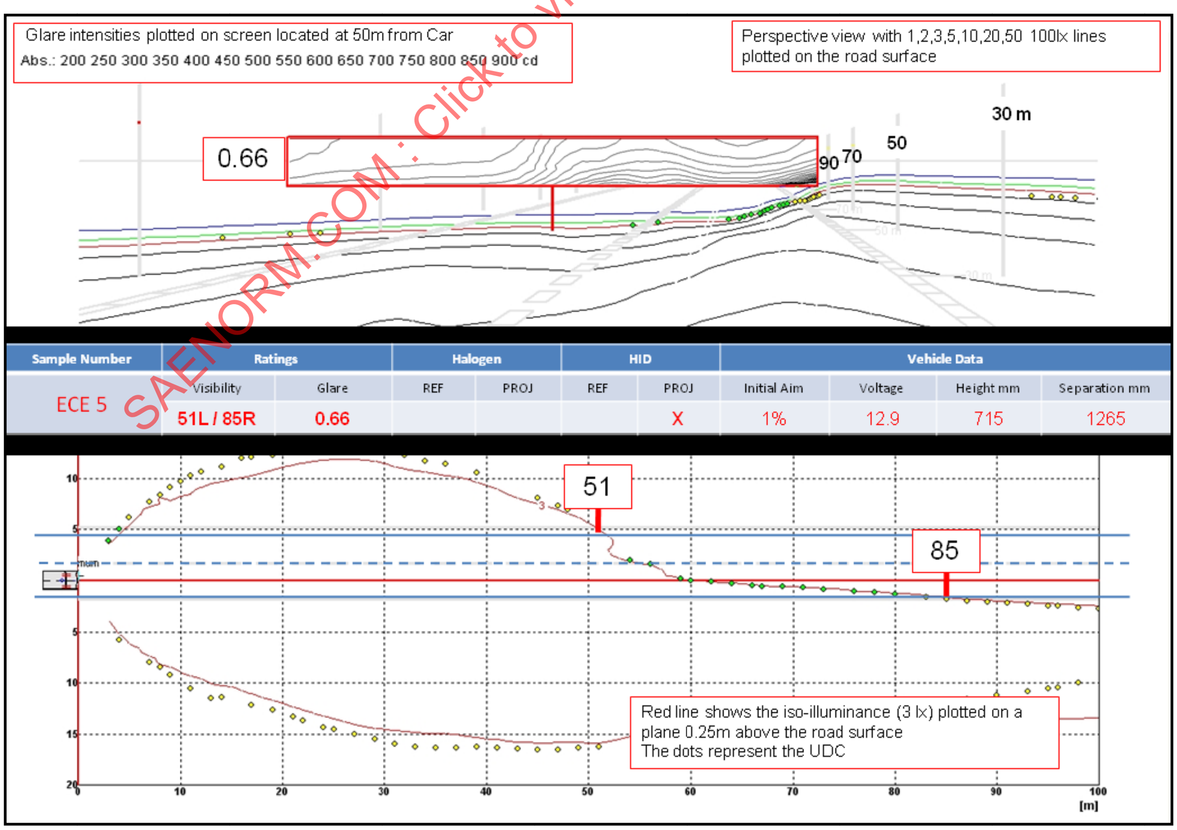
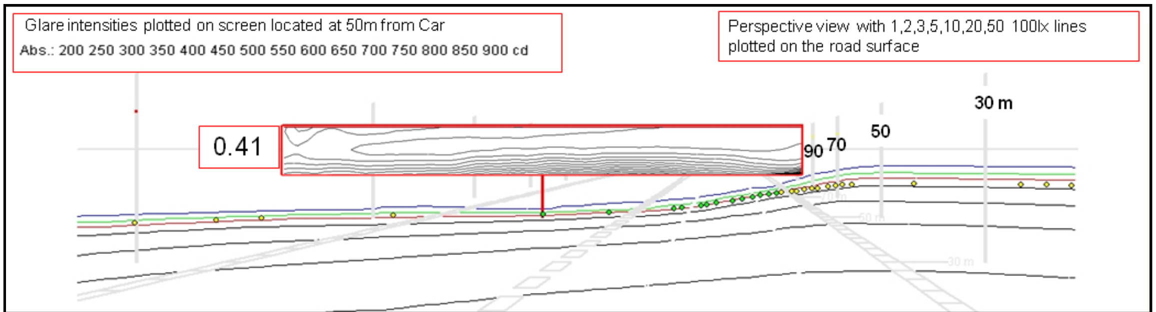


FIGURE A5



Sample Number	Ratings		Halogen		HID		Vehicle Data			
	Visibility	Glare	REF	PROJ	REF	PROJ	Initial Aim	Voltage	Height mm	Separation mm
ECE 6	51L / 82R	0.41				X	1%	13	745	1440

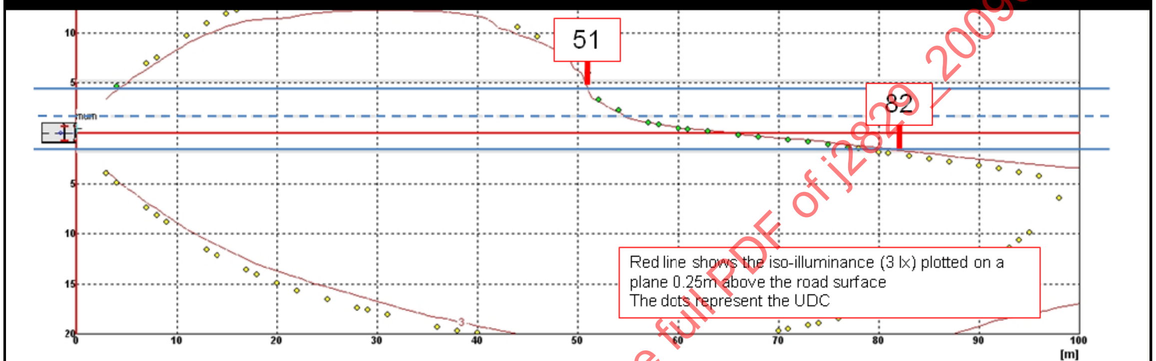
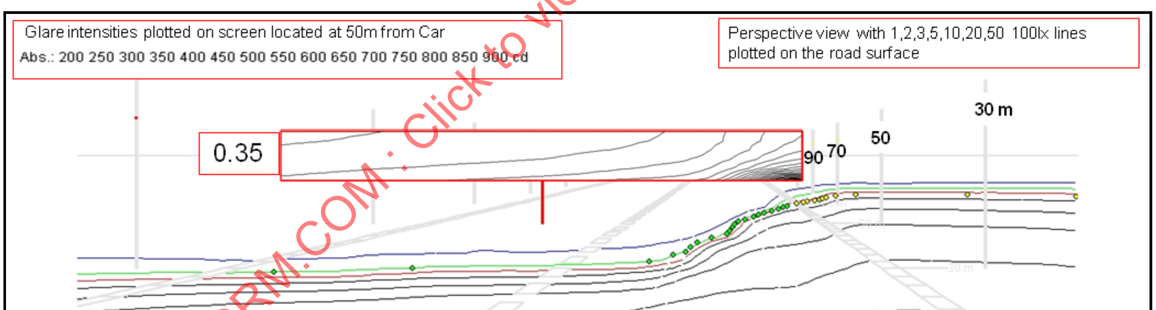


FIGURE A6



Sample Number	Ratings		Halogen		HID		Vehicle Data			
	Visibility	Glare	REF	PROJ	REF	PROJ	Initial Aim	Voltage	Height mm	Separation mm
ECE 7	28L / 73R	0.35				X	1.3%	13.7	661	1301

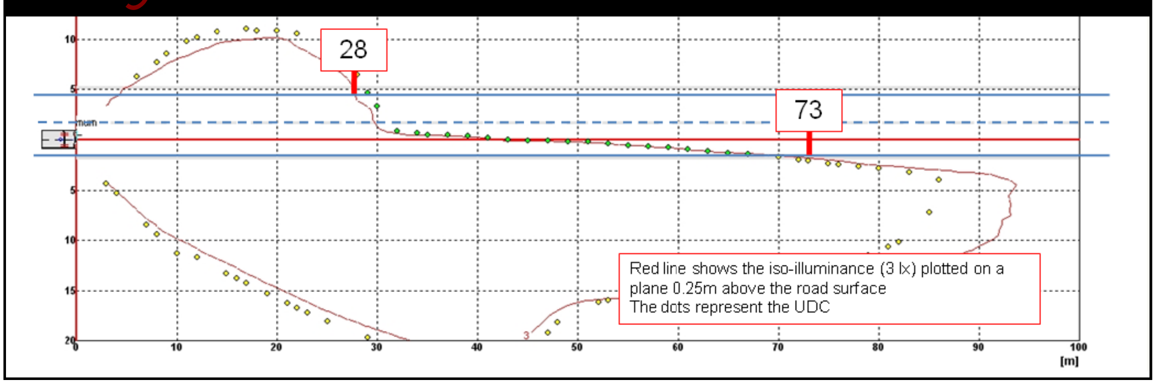


FIGURE A7