Glare at tunnel entrances

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Introduction and discussion

This note is written after a Nordic tunnel lighting meeting on 30/31 October 2012 in order to express some matters more clearly.

The L_{20} value was introduced in CIE 88: 1990 ”Guide for the lighting of road tunnels and underpasses” and thereafter introduced in national regulations for tunnel lighting. It appears as well in NVF report 4: 1995 ”Belysning af vejtunneler – Fælles nordiske vejledende retningslinier. This report is being used directly in Denmark and has formed the basis for regulations in the other Nordic countries.

The L_{20} value is considered in section 1, where it is concluded that L_{20} is intended as an approximated and un-scaled value of the veiling luminance caused by glare L_{seq} and that the correct scaling is given by $0{,}055\times L_{20}$.

It is a further conclusion that the problem in tunnel entrance lighting is reduction of the contrast of objects in the threshold zone, because of the addition of L_{seq} to the adaptation luminance.

The problem is not that drivers need time to adapt his vision from the daylight level outside of the tunnel to the lower level in the entrance zone. He might need some time, but probably not much. Adaptation is at high levels, where only cones are active, it concerns a reduction of the lighting level of only approximately a factor of 20 and occurs probably with the fast mechanisms of pupil reaction and network adaptation.

CIE 88: 1990 also introduced a diagram for the determination of L_{seq}, which became central in the CIE 88 edition of 2004, replacing the L_{20}.

The methods of evaluating glare, L_{20}, the diagram and a basic equation are compared in section 2. It is concluded that the use of L_{20} can cause large uncertainties depending on the lay-out of the tunnel and the circumstances of daylight and that it is best to base tunnel entrance lighting on more accurate evaluation of L_{seq}. The diagram may be applicable, but other techniques using the basic equation are probably available. Such techniques include computer simulations and digital cameras.

Finally, in section 3, it is pointed out that a convention based on a 20° cut-off by the car roof is used in glare calculation in road lighting and could be used for tunnel entrance lighting as well. This, however, would not reduce L_{seq} significantly.

1. The L_{20} value

CIE 88:1990 introduces L_{20} as the average luminance in a ±10° field about the viewing direction towards a tunnel entrance, and indicates that the road surface luminance in the entrance zone L_{th} can be determined as a fraction of L_{20}. Recommended values of the fraction, which is labelled k, are in the range of 0,04 to 0,1.

CIE 88:1990 also contains an annex with a polar diagram intended for the determination of the veiling luminance L_{seq}. The field of the L_{20} value is shown in figure 1, while the diagram is shown in figure 2.

Figure 1: The ±20° field used to determine L_{20}.

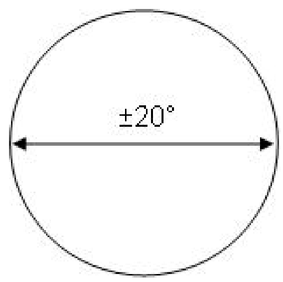
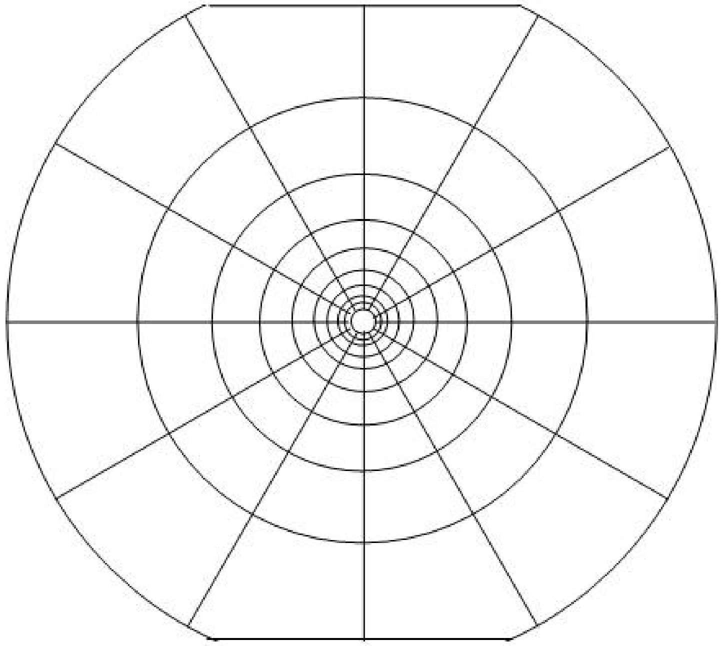


Figure 2: Polar diagram for the determination of the veiling luminance L_{seq}.



The inner zone in the diagram has a diameter of 2° and is not included in the determination of the veiling luminance.

The other zones are found in 9 rings limited by circles with diammeters of respectively 3,0°; 4,0°; 5,8°; 8,0°; 11,6°; 16,6°; 24,0°; 36,0° and 56,8°. Each ring has 12 zones limited by radial lines with mutual angles of 30°. The total number of zones is 9×12 = 108.

The diagram is to be placed over a tunnel scene, either a drawing or a photograph, with the centre coinciding with the viewing direction. The average luminance within each zone is to be determined or estimated, and this is followed by determination of the veiling luminance by:

$L_{seq} = 0{,}513\times10^{-3}\times\Sigma L_i$
where Σ means summation over the zones
and L_i is the average luminance in a zone.

As the number of zones is 108, the equation can be simplified:

$L_{seq} = 108*0{,}513\times10^{-3}\times(\Sigma L_i/108) = 0{,}055\times L_{average}$
where $L_{average}$ is the average of the L_i values.

CIE 88:1990 does not explain the purpose of L_{seq} or how to use it. However, the NVF report 4: 1995 proposes that $L_{average}$ can replace L_{20}. This implies that L_{20} is intended as an approximated and un-scaled value of the veiling luminance and that the correct scaling is given by $0{,}055\times L_{20}$.

This is supported by CIE 88:2004, which is based on the determination of the veiling luminance by means of the diagram. The value of L_{seq} is used in calculations of the visibility of objects to determine the value of L_{th}.

The above-mentioned methods to determine the L_{th} all result in L_{th} values that are about the same as the value of the veiling luminance. This is reasonable as the luminance in the threshold zone obviously needs to be approximately the same as the veiling luminance. If much lower, contrasts are washed out to the degree that visibility is lost. If much higher, the illumination of the threshold zone becomes too expensive.

The conclusion is that the problem in tunnel entrance lighting is glare by scattering of light in the eye. This scattering is described by the veiling luminance, which adds to the level of adaptation. CIE 88: 2004 goes a step further by also including veils by scattering of light in the wind screen and in the atmosphere in front of the tunnel entrance.

2. Comparison of methods to determine glare

As the veiling luminance L_{seq} is the fundamental value and the L_{20} value is in reality used as an un-scaled approximation to L_{seq}, it is worthwhile to consider the uncertainty of the approximation. For this purpose the relative weights for summing up L_{20} and of L_{seq} in accordance with the diagram are shown in figures 3 and 4 respectively.

Figure 3: Constant weight in the ±10° field used to determine L_{20}.

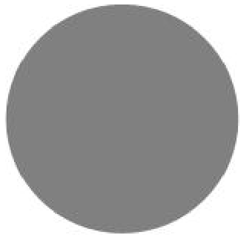


Figure 4: Varying weights in the polar diagram for the determination of L_{seq}.

The weight in the ±10° field used to determine L_{20} is constant, because L_{20} is the average luminance within the field.

The weight is also constant within each zone of the diagram, as the luminance of a zone is the average luminance within the field of the zone. The weight is also constant among zones within the same ring as such zones have the same area. However, the weight decreases from ring to ring from the innermost ring and outwards, because the areas increase.

This shows that L_{20} and L_{seq} are summed up with widely different weights to areas about the viewing direction. This is further illustrated in figure 5, where the relative weights are shown in scales that would result in the same value for a large field of uniform luminance.

Figure 5: Relative weights for the L_{20} and L_{seq} values.

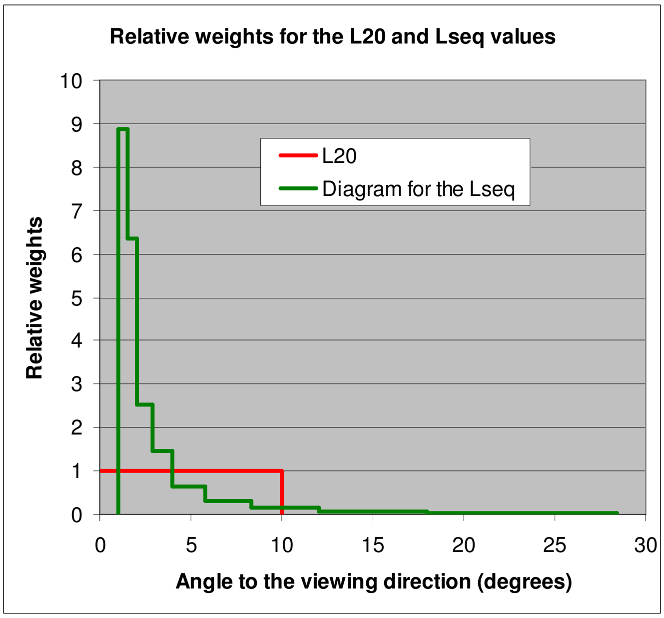


Figure 5 shows that the closest surrounds to the viewing direction, say at 1° - 2°, are given much more weight to L_{seq} than to L_{20}, while the opposite is the case for more distant surrounds, say at 5° - 10°.

For this reason, it is concluded that the use of L_{20} can cause large uncertainties depending on the lay-out of the tunnel and the circumstances of daylight, and that it is best to base tunnel entrance lighting on L_{seq}.

L_{seq} could for instance be used together with k factor values in the same way as for L_{20} with however k factors brought into scale by division with 0,055. A k factor value of for instance 0,04 would become 0,04/0,055 = 0,73 after rescaling.

This does not necessarily mean to use the diagram for the determination of L_{seq}. It is inconvenient to place the diagram over drawings or photographs followed by hand calculation, and other techniques should be available.

NOTE: As the diagram is in the scale of degrees (°), it does not match perspectives in neither drawings nor photographs. It would first have to be redrawn in the scale of tangent to degrees.

Other techniques would include computer simulations and digital cameras. The basis is the equation for L_{seq}:

$$L_{seq} = C \times \Sigma(E/\theta^2)\ \text{cd/m}^2$$

where C is a constant

E is the illuminance at the eye produced by a glare source in lx

and θ is the angle between the observation direction and the direction towards the glare source in degrees (°).

The value of 9,2 for C is provided in CIE 88: 1990. However, the value of 10 is normally used in road lighting calculations. Higher values are sometimes considered for older people.

The value of E can be obtained by:

$$E = \omega \times L \times \cos\theta$$

where	ω is the solid angle occupied by the glare source in steradian (sr)
and	L is the luminance of the glare source.

In a digital image, whether computed or taken with a camera, each pixel can be assigned a fixed value of the solid angle ω and the pixel value can represent the luminance L. Further, the angle θ can be calculated for a given pixel from its location in the image relative to the centre pixel of the image.

The smoothly running weight of the glare equation is illustrated in figure 6.

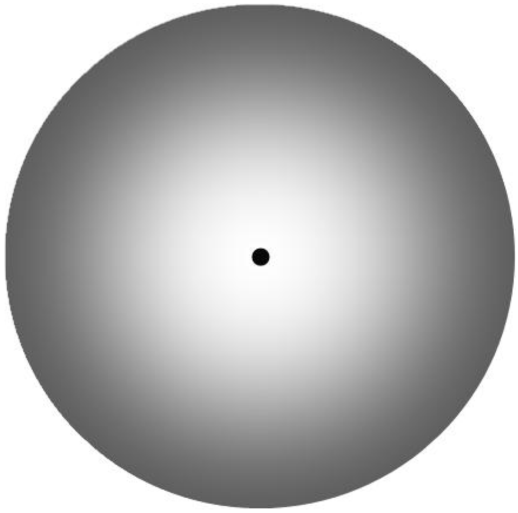


Figure 6: Weights in the equation for the determination of L_{seq}.

3. Car roof and other glare protection

In road lighting, it is a convention that luminaires above a plane tilted 20° upwards are excluded from glare calculations. The underlying assumption is that the car roof prevents a view above this angle.

A similar convention should probably be introduced in tunnel entrance lighting, when evaluating glare with either the diagram or the glare equation. The L_{20} methods avoids such a need by restricting the field to 20° above the viewing direction, but the diagram includes a view up to 56,8° above the viewing direction and it would be natural to do the same, when using the glare equation.

A cut-off at 20° is illustrated in figure 7. It looks like a some, but corresponds to elimination of only approximately 2 zones of the total of 108 zones of the diagram. Even if the sky is seen in these 2 zones with a luminance of 3 000 cd/m^2, the reduction of L_{seq} is only 3 cd/m^2.

It is, therefore, a question if it is worthwhile to introduce the convention. Additionallt, it might be necessary to consider a range of cars, in particular large vehicles, before introducing the convention.

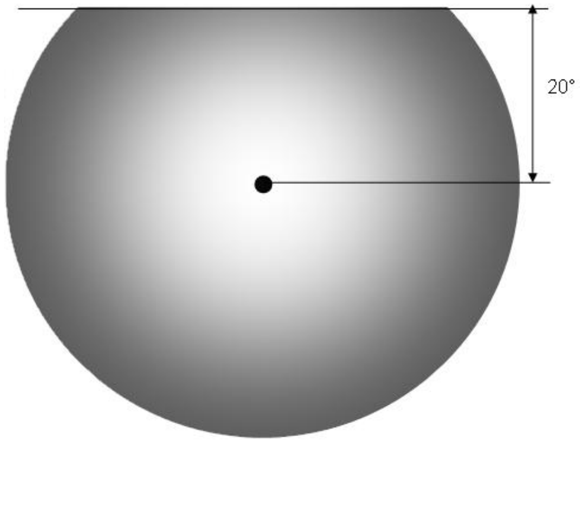


Figure 7: Weights in the equation for the determination of L_{seq} with a cut-off at 20°.

It is noted, on the other hand, that a driver might help his view into a tunnel entrance by setting the screen of the car to reduce the view to even lower angles. At an angle of 5° the glare will typically be reduced to half.