Study of glare evaluation methods for application in traffic

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1. INTRODUCTION

Topic of disability and discomfort glare on the roads has long been a topic of research. The first problem was the precise definition of terms. Disability glare concept is well defined at present but discomfort glare is problematic term. Discomfort glare is dependent on many factors such as mood or fatigue, and does not depend directly from the lamp. There are many possible sources of glare in traffic situations. Glare can be caused by street lightning, direct glare from the vehicle headlamps or indirect glare via inside and outside mirrors. There is several different methods for assessment of glare. The aim of this article is a comparison of methods for assessment of glare in outdoor (mainly caused by road lighting and vehicle headlight), rating systems and assessment of suitability for use in various situations. Emphasis is placed primarily on Holladay`s method, Threshold Increment (TI), Cumulative Brightness Evaluation (CBE) Schmidt-Clausen and Bindels` method and Glare Mark evaluation. For the evaluation of glare, there is a relatively large number of systems, but not everyone is suitable for every application.

2. DEFFINIOTION OF GLARE

In International Lighting Vocabulary is the concept of glare divided into two groups. First group is Disability glare, defined as “glare that impairs the vision of objects without necessarily causing discomfort”. Second group is Discomfort glare, defined as “glare that causes discomfort without necessarily impairing the vision of objects”.[1] Disability is well defined term but definition of discomfort glare is problematic one. This topic will be mentioned later in next sections.

3. DISABILITY GLARE

When we want to make precise definition of disability glare, we have to use other definition as in International Lighting Vocabulary. Disability glare can be defined as the masking effect caused by light scattered in the ocular media which produces a veiling luminance over the field of view. This kind of glare is absolutely unacceptable for the situations in traffic because of speed of cars and relatively long recovery time of the human eye after exposure to a glare source.[1]

3.1. The Holladay formula

First measurements of disability glare were made by Holladay in the middle 1920s by using the then recently introduced equivalent veil technique. Holladay`s research was later modified by Stiles and Crawford and by Adrian and Bhanju.[9]

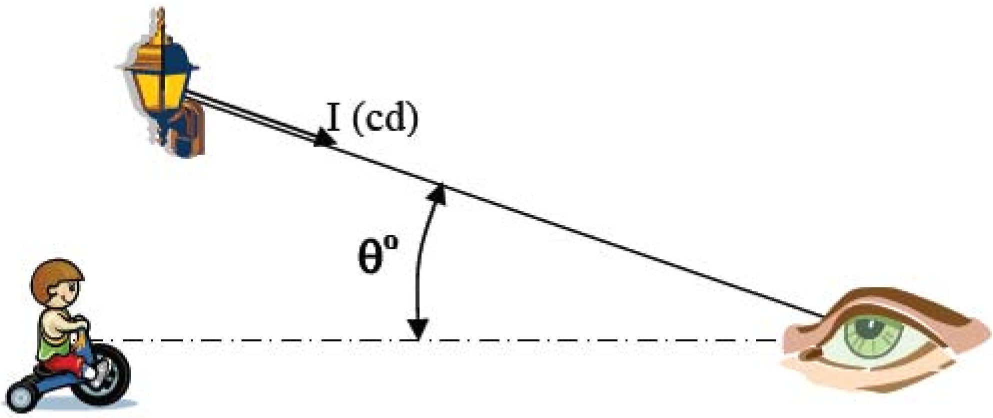

Figure 1: The equivalent veiling luminance caused by one light source[9]

$$L_V = k * E_{gl}/\theta^n$$

Equation 1: Standard form of disability glare veiling luminance

k age dependent multiplayer

$$k = 9{,}05*(1+(Age/66{,}4)^4)$$

Equation 2: Calculation of age dependent multiplayer

n exponent that can vary with the angle of glare source

$n = 2{,}3 - 0{,}7*\log(\theta)$ (for angles from 0,2° to 2°)

$n = 2$ (for angler greater then 2°)

Equation 3: Calculation of exponent n

E_{gl} illuminance of the source of glare, in lux

Θ angle of the glare source from the line of sight, in degrees

3.2. Threshold Increment

Threshold increment evaluation method is related to road safety. Relationship between TI and road safety is unknown but there is a known relationship between visual performance and road safety. TI represents the impact of the glare source on the threshold of an object. In other words, it represents how much brighter, in percent, an object must be in order to be seen in the same conditions with a glare source present as compared to one without a glare source present.[2]

$$TI = \frac{(65 * MF^{0,8} * L_V)}{L_{AV}^{0,8}}$$

Equation 4: Calculation of TI for $L_{AV} \leq 5$

$$TI = \frac{(95 * MF^{1,05} * L_V)}{L_{AV}^{1,05}}$$

Equation 5: Calculation of TI for $L_{AV} > 5$

MF maintenance factor used for calculation of average luminance

L_v veiling luminance, in cd/m^2

L_{AV} average maintained road luminance, in cd/m^2

The longitudinal position of the observer at which the TI will be maximum, is dependent upon the screening angle of the vehicle`s roof. This angle has been standardized by the CEN at 20 degrees above the horizontal. Threshold increment is evaluated only for luminaries within this angle.[4]

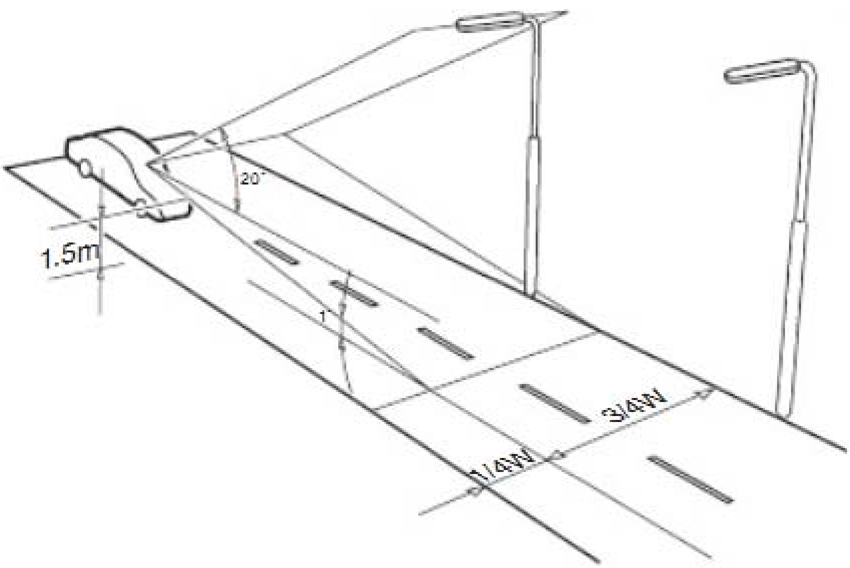

Figure 2: Standardized position of the observer[3]

The Threshold Increment method is evaluated as a percentage. For the better visibility we need lower level of Threshold Increment. For each type of road are different requirements for TI. CIE states that threshold increments lower than 2 can be neglected. For the illustration we can use following table[3].

TI (%)	Verbal assessment
> 20	Bad
10	Moderate
< 10	Good

Table 1: Verbal assessment of the various levels TI

4. DISCOMFORT GLARE

Nowadays we use many different definitions of discomfort glare but there is no precise one. In general we can say that this kind of glare doesn't causes decreased vision, but just makes us to feel uncomfortable. Discomfort glare has the same physical configuration as disability glare, but it produces another type of effect. Discomfort glare can by generally associated with bright light sources (road lighting), which attack our attention and catch our gaze. Sometimes we can divide discomfort glare into two specific groups (discomfort glare and dazzling glare). CIE International Lighting Vocabulary ranks dazzling glare under Discomfort glare but reason for its creation is different. Here we are concerned with a bright field of view (a sunlit book, the sky, or a sandy desert).[1]

Discomfort glare is the subjective impression of discomfort and is a function of several factors: the observer`s line-of-sight angle with respect to the glare source, the amount of illumination from the glare source and the brightness of the surrounding field to which the subject is adapted. Some research has shown that this kind of glare is based more on emotional state of the observer than on the light source itself. It depends on the mood, age, emotions and fatigue of driver.[5]

There are several methods for evaluation of discomfort glare. We can divide these methods in terms of the use in two categories. The first group involves evaluation of glare caused by roadway lighting. This includes Glare Control Mark (renamed from Glare Mark Evaluation) and Cumulative brightness Evaluation (CBE). The second group involves evaluation of glare caused by vehicle headlight by Schmidt-Clausen and Bindels`s Equation. Most of these models are derived from model created by deBoer.

4.1. De Boer method

The principle of de Boer method was the fact, that when we want to prevent disability glare cannot occur even discomfort glare. It was found, that discomfort glare arises if glare source affects the eye of observer with illuminance E_a and this illuminance is higher as illuminance of the eye E_b.[6]

$$\frac{E_a}{E_b} \leq 1$$

Equation 6: Calculation of de Boer method

Value factor E_a depends on the distance of the lamp from the eye and on the luminous intensity in the direction of the eye.

$$E_A = \frac{I_a}{r^2} = \frac{I_a}{a^2 + h^2 + l^2}$$

Equation 7: Illuminance of the observer`s eye (caused by glare source)[6]

Value factor E_b depends on average luminance of the road, cone angle of view glare source and elevation angle of view glare source.

$$E_B = 7{,}5 \cdot \sqrt[3]{{L_V}^4 \cdot \varepsilon^4 \cdot \omega^2}$$

Equation 8: Illuminance of the eye[6]

I_a luminous intensity in the direction of the eye, in candela

ε elevation angle of view glare source, in sr

ω cone angle of view glare source, in sr

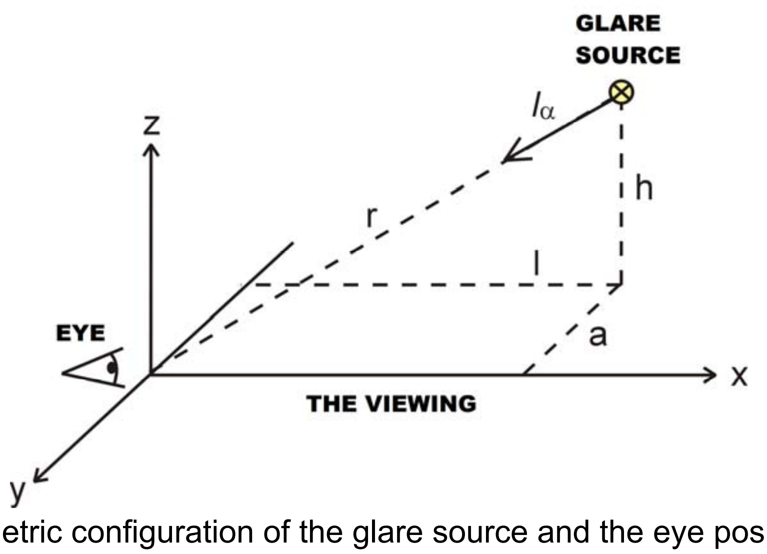

Figure 3: Geometric configuration of the glare source and the eye position of observer[7]

For the evaluation of glare by de Boer`s method was introduced scale rating. This rating is typically known as the deBoer scale. The scale is usually a nine point counterintuitive scale (higher number represents a better condition). The problem is that the scale is very dependent on the field of use. For this reason, scale has been amended many times by different scientists (Schmitd-Clausen & Bindels, Becker & Mortimer, Olson & Mortimer, Bhise et al., Olson & Sivak).[8] In table 2 we can see original deBoer scale.

W	Verbal assessment
1	Unbearable
2	
3	Disturbing
4	
5	Just Admissible
6	
7	Satisfactory
8	
9	Unnoticeable

Table 2: deBoer scale by de Boer & Schreuder, 1967

4.2. Glare Control Mark (GCM)

This method for evaluation glare is primarily used for evaluation of glare caused by street lighting. I should be emphasized that this kind of glare is not static but dynamic experience. Construction of street lighting, masts height and wattage of used lamps can affects human mood and ultimately affects the driver`s reaction time.[2]

Glare evaluation method Glare Control Mark is described in CIE technical report No. 31-1976 “Glare and Uniformity in Road Lighting Installations”. GCM expresses on an ordinal scale the subjective appraisal of the degree of discomfort experienced. Verbal assessment for evaluation of GCM is identical with original deBoer scale (table 2). It should be noted that values G<1 and G>9 have no practical meaning.[4]

$$G = 13.84 - 3.31*\log I_{80} + 1.3\left(\log\frac{I_{80}}{I_{88}}\right)^{0.5} - 0.08*\log\frac{I_{80}}{I_{88}} + 1.29*\log F + 0.97*\log L_b + 4.41*\log h' - 1.45*\log p$$

Equation 9: Glare Control Mark Evaluation[2]

G	glare evaluated on a 9 point scale
I_{80}	intensity of the luminaire at 80° to vertical
I_{88}	intensity of the luminaire at 88° to vertical
F	luminous area of luminaire seen at 80° from vertical
L_b	background luminance
h'	adjusted luminaire height
p	number of luminaries per kilometer

Since introduction of this method in practice scientists made a relatively large amount of practical measurements. Kaiser et al. and Keck and Odle discovered that in some situations GCM model works fine, in some situations needs small changes and sometimes there is no relationship between the predictive GCM and the experience of the driver.
The relationship between G and subjective feeling of glare is based on great number of laboratory experiments. There is also small influence of the color of the light in the value G, but this influence has been neglected.[2]

4.3. Cumulative Brightness Evaluation (CBE)

This method was found by Bennett and is also primarily used for evaluation of glare caused by street lighting. In the dynamic evaluation of the roadway, Bennet found that the experience of discomfort was related with the driver speed and developed the Cumulative Brightness Evaluation. CBE method evaluates impact of each of the luminaires in the visual scene.[2]

$$CBE_{Tol} = \frac{67{,}1}{L_b^{0,5}} \sum_n \left(\frac{L_i^{1,67} * \omega_i}{8{,}8 * 10^{-3} * \theta_i^2 + 1{,}35} \right)$$

Equation 10: Cumulative Brightness Evaluation

ω solid angle of the i_{th} glare source

Θ_i glare angle of the i_{th} glare source

L_i luminance of the i_{th} glare source

L_b luminance of the background

n number of glare sources

4.4. Schmidt-Clausen and Bindels`s Equation

Schmidt-Clausen made laboratory research where vehicle headlamps were rated for discomfort using DeBoer scale. They developed formula based on position of the light source, the luminance of the background, and the illuminance of the glare source.
It should be noted that this formula was developed in the seventies just in laboratory areas. American scientists from The University of Michigan made in the nineties several practical experiments and on the basis of these experiments, they modified assessment for U.S. roads. They found that the rating in North America would typically be 1 to 2 de Boer levels higher than that in Europe. It was also found that levels in real situations are typically higher than in the laboratory settings.[5]

$$W = 5 - 2LOG_{10}\frac{Ei}{C_{poo} * (1 + \sqrt{\frac{La}{C_{pL}}}) * \theta_{\max}^{0,46}}$$

Equation 11: Schmidt-Clausen and Bindels`s Equation[2]

W	mean value on deBoer`s scale
E_i	average level of illumination directed towards the observer`s eye from the headlamp, in lux
θ_{max}	glare angle between observer`s line of site and the headlamps at location where maximum illumination occurs, in minutes
L_a	adaptation luminance, in $cd.m^{-2}$
C_{poo}	constant value equal 0.003, in $lux.min^{-0.46}$
C_{pl}	constant value equal 0.04, in $cd.m^{-2}$

5. CONCLUSION

As we can see, problematic of glare in traffic is serious and not well explored area. In the past, there was a lot of different research in this field. These studies have a lot of mistakes. First problem is, that glare (especially discomfort glare) is subjective feeling. Every human being can perceives this feeling other way. It depends on the mood, age, emotions and fatigue of driver. Perception and evaluation of glare is also dependent on the state or country which the observer comes from.

Second problem is that high amount of methods for evaluation of glare (also all methods based on de Boer`s model) were created in laboratory conditions and there have been just small amount of practical tests. Tests, which were made after establishment of a model, showed often that the model is inappropriate or absolutely useless for certain situations. There has been never created the model with high amount of participants.

Third problem is the huge amount of different situations arising in the road. It can be for example an influence of weather, type of roadway, speed of vehicle, luminous intensity curve and luminance curve of luminaire and lamp used, recovery time of the human eye after several exposures to a glare source and many more.

Next problem is inconsistent of assessment scale. There are different variants of original deBoer scale and also many of scientists create their own. This inconsistency causes that one value on deBoer scale can be interpreted in many ways.

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