Glare Modeling Formulae

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Glare Calculations

- Disability Glare
- Discomfort Glare

  - In German, these two phenomena are know as Physiological Glare and Pyschological Glare

Disability Glare

- The generally accepted metric for disability glare is L_{seq}, the equivalent veiling luminance.

- L_{seq} provides a measure of the luminance that is equivalent of the veil of light a person experiences due to the scatter of light passing through the eye.

Impact of Disability Glare

- Disability Glare effectively reduces the contrast of the object you are trying to see.

$$C = \frac{\left(L_{Background} + L_{seq}\right) - \left(L_{Object} + L_{seq}\right)}{L_{Background} + L_{seq}}$$

$$C = \frac{L_{Background} + L_{Object}}{L_{Background} + L_{seq}}$$

Disability Glare

- Several Different computations for L_{seq} exist:
  - Holladay
  - Stiles/Crawford
  - Fry
  - Adrian
  - Hartman
  - Meskov
  - Vos

- All of these formulations have the same basic format:

$$L_{SEQ} = \frac{k \cdot E_{gl}}{\theta^n}$$

L_{seq} – Adrian and Bhanji (1991)

$$L_{SEQ} = \frac{k \cdot E_{gl}}{\theta^n}$$

- k is a multiplier that is age dependent
  - For a 25 year old k = 9.2
- E_{gl} is the illuminance of the glare source
- θ is the angle of the glare source from the line of sight
- n is an exponent that can vary with the angle of the glare source
  - $n=2.3-0.07*\log(\theta)$ for $0.2^{\circ} < \theta \leq 2^{\circ}$
  - $n=2$ when $\theta > 2^{\circ}$

Age Factor

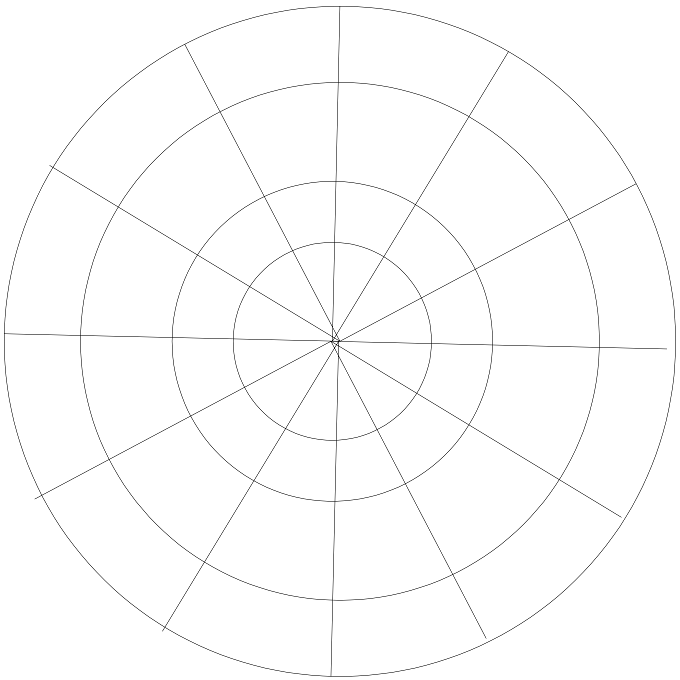
- The factor k is adjusted to account for the change in L_{seq} with age.

- Based on two data sets of over 2200 participants, the following relationship was developed:

$$k = 9.05 \cdot \left(1 + \left(\frac{Age}{(66.4)} \right)^4 \right)$$

Adaptation Luminance

- The adaptation luminance is the sum of the veiling luminance from the scene and the background luminance

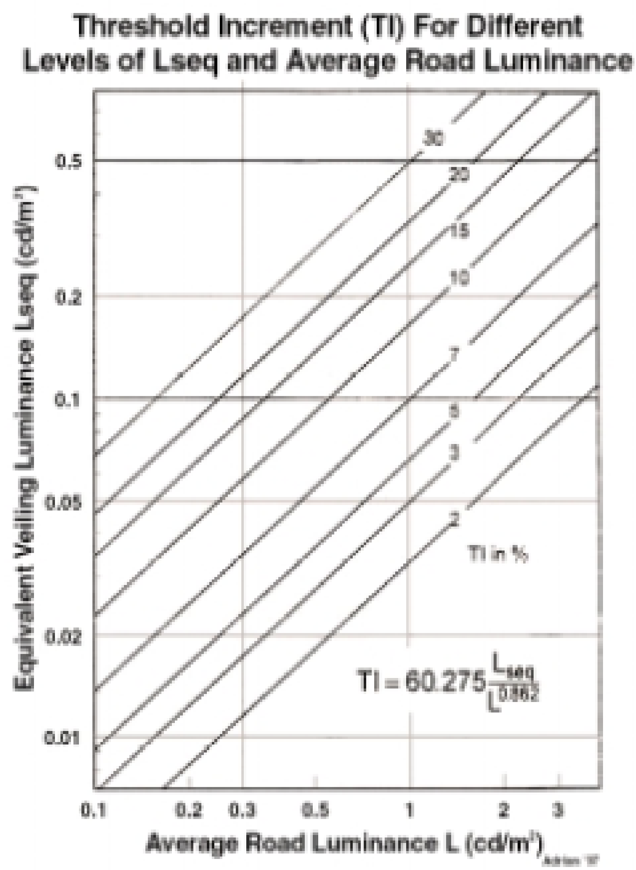


$$L_{Adaptation} = L_{Background} + \sum_{\pi} L_{seq(i)}$$

Threshold Increment

- Another method for expressing the impact of the glare is the Threshold Increment.
- It describes the percentage increase in the threshold luminance due to the addition of a glare source.

$$TI = 60.275 \cdot \frac{L_{seq}}{L^{0.862}}$$



Discomfort Glare

- For calculations, Discomfort Glare is dependent on:
  - The Luminance of the Luminaire
  - The Observers Adaptation Level
  - The Luminaire Position
  - Size and Number of Glare Sources
  - Other factors are significant but are not typically included in the models
- Most Models are based on these or some derivation of these factors.

deBoer's Scale

- Typically, the subjective evaluation of discomfort glare is performed using the deBoer Scale.
- It is a nine point scale where the participant rates the glare impression from (1-Unbearable to 9-Just Noticeable).

1	Unbearable
2	
3	Disturbing
4	
5	Just Acceptable
6	
7	Satisfactory
8	
9	Just Noticeable

BCD – Borderline Between Comfort and Discomfort

- A quantitative method evaluation of Discomfort Glare is the BCD.
  - The participants are allowed to adjust the luminance of a glare source until they feel that the if the luminance was brighter, the source would cause discomfort.
    - A bracketing method is typically used for the adjustment.
  - This is often used as a screening method for participants in other studies.

Discomfort Glare Modeling

- There are several different metrics for Disability Glare.
- Interior Lighting:
  - UGR – Unified Glare Rating
  - VCP – Visual Comfort Probability
- Exterior Lighting:
  - CBE – Cumulative Brightness Evaluation
  - Glare Control mark
  - Schmidt-Clausen and Bindels

Interior Lighting

- UGR – Unified Glare Rating
  - An amalgamation of the European Glare Index and Luminance Limiting Curve methods.
- VCP – Visual Comfort Probability
  - Defines the percentage of people who would be comfortable in the lit environment.
  - Used in North America only.

$$UGR = 8 \cdot \log\left(\frac{0.25}{L_{Background}}\right)\sum_n\left(\frac{L^2\omega}{p^2}\right)$$

where

$L = Luminance\ of\ the\ luminous\ area$

$\omega = size\ of\ the\ luminous\ area$

$p = Guth\ position\ index$

$L_{Background} = Background\ Luminance$

$n = number\ of\ luminaires$

Exterior Lighting

- Exteriors provide a much different type of glare and require different models than interiors:
  - The exterior typically has lower adaptation levels
- For Roadway Lighting:
  - There is a pulsating action as you travel underneath a fixed lighting system.
  - There is often high intensity light sources close to the line of sight (oncoming headlamps).

CBE – Cumulative Brightness Effect

- Bennett developed the Cumulative Brightness Effect to evaluate the effect of several luminaires and vehicle motion as compared to the BCD
  - Experiments were performed in a simulator which could model the light impression of a driver under a fixed lighting system
- The tolerable CBE is defined by:

$$CBE_{Tol} = \frac{67.1}{L_b^{0.5}} \sum_n \left(\frac{L_i^{1.67} \cdot \omega_i}{8.8 \cdot 10^{-3} \cdot \theta_i^{\,2} + 1.35} \right)$$

where

$\omega_i = solid\ angle\ of\ the\ i_{th}\ glare\ source$

$\theta_i = glare\ angle\ of\ the\ i_{th}\ glare\ source$

$L_i = luminance\ of\ the\ i_{th}\ glare\ source$

$L_b = luminance\ of\ the\ background$

$n = number\ of\ glare\ sources$

Glare Control Mark

- Glare Control Mark is a model which uses the luminaire run back and the number of luminaires per kilometer to establish the apparent glare condition
- GCM is based on a nine point scale similar to the deBoer scale
- GCM was adopted by the CIE

GCM Model

$$G = 13.84 - 3.31 \cdot \log I_{80} + 1.3\left(\log \frac{I_{80}}{I_{88}}\right)^{0.5} - 0.08 \log \frac{I_{80}}{I_{88}} + 1.29 \cdot \log F$$

$$+ 0.97 \cdot \log L_b + 4.41 \cdot \log h' - 1.45 \cdot \log p$$

- G – Glare Evaluated on a 9 point Scale
- I_{80} – Light Intensity of the luminaire at 80º to the vertical
- I_{88} – Light Intensity of the luminaire at 88º to the vertical
- F – Luminous area of the luminaire seen at 80º from vertical
- L_b – Background Luminance
- h′ – Adjusted Luminaire Height
- p – Number of luminaires per kilometer

Combination of CBE and GCM

- Adrian (1991) has combined the formulations of the CBE and the GCM models into a single model
  - An adjustment had to be made to allow for the number of luminaires per kilometer and the luminaire runback
    - α is added to the formula to allow for this factor
- This model has not been experimental verified

$$CBE = 10^{-0.5045(GCM-1)+\alpha}$$

$$\alpha = 1.808 \cdot 10^{-4}(p)^2 - 0.0205p - 2.2485 \cdot 10^{-3}\left(\frac{I_{80}}{I_{88}}\right)^2 + 0.051\left(\frac{I_{80}}{I_{88}}\right) - 2.296 \cdot 10^{-4}h^2 + 0.0216h + 3.842$$

Schmidt-Clausen and Bindels

- Schmidt-Clausen and Bindels developed a formula to calculate the deBoer ratings based on position of the light source, the luminance of the background, and the illuminance of the glare source.
- It was later found that the rating in North America would typically be 1 to 2 deBoer levels higher than that in Europe (Olsen and Sivak, 1983).

Schmidt-Clausen and Bindels

$$W = 5.0 - 2.0 LOG_{10} \frac{E\max}{0.003 * \left(1 + \sqrt{\frac{La}{0.04}}\right) * \theta_{\max}^{0.46}}$$

where:

W = mean value on deBoer's scale

Ei = Average level of illumination directed towards the observer's eye from the headlamps (lux)

θmax = glare angle between observer's line of site and the headlamps at location where maximum illumination occurs (minutes)

La = adaptation luminance (cd/m2)

Summary

- Disability Glare is a well defined Physiological Phenomenon and has a model which has a very simple and common format
- Discomfort Glare has many tools for evaluation with many different models
  - Boyce (1991) calls it a "Subject in a Swamp"