Laboratory based study on the effects of CCT on visibility using ADRIAN model

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SUBMITTED BY
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All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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CHAPTER- 1

Abstract
Road lighting is primarily used to improve visibility for drivers and other road users. Age and visual features of the observer, duration of the observation, target size, luminance of the target, luminance of the backdrop, contrast polarity, exposure time, intensity of the impairment glare, and adaptation all affect a target's visibility. Adrian first described a visibility formula in 1989, and visibility levels were used as a quality criterion in North America. When the target luminance, background luminance, and veiling luminance are provided in the calculation techniques, it is possible to compute the visibility of the target in accordance with the protocols outlined in ANSI/IESNA RP-8-00: American National Standard Practice for Roadway Lighting. This criterion is still being researched as a novel idea in European nations.

1.1. Introduction

Road lighting is the use of illumination systems along various types of roadways, initially with the goal of promoting safety by making roadside hazards more visible and by lessening the impact of glare from other light sources, such as car headlamps.

Designing street lighting so that people may safely use the roads is known as "road lighting design". Although street lighting schemes can never replicate the appearance of sunshine, they can offer enough light for pedestrians to see crucial obstacles in the road. Road lighting plays an important role in:

- Reducing the risk of night-time accidents
- Assisting in the protection of buildings/property (discouraging vandalism)
- Discouraging crime
- Creating a secure environment for habitation

Under ideal circumstances, theoretical methods are often employed to calculate luminance and illuminance, but in actuality, a number of design restrictions must be taken into account.
In a perfect world, background and target brightness are also taken into account when determining the visibility level. When designing lighting, there are many factors that are difficult to anticipate and take into account in execution. A complicated apparatus like the human eye makes it challenging to accurately design an outdoor lighting system based only on various theoretical presumptions. For theoretical calculations of light distribution on pavement, RP-8 is used. This calculating approach has to incorporate a correction factor for variables such uneven ground, maintenance for cleaning or deteriorating lighting.

It is now possible to estimate the small target visibility thanks to the development of computer design and computer modelling of lighting systems (STV).

The Illumination Engineering Society of North America (IESNA) and the American National Standard Institute are recommending STV as the preferred design method (ANSI).

Assume that ambient light is ignored in the design any light that is added to the area under design will merely increase the level of lumination and illumination and make the area brighter than it was designed to be. Ignoring the ambient light is would constitute a conservative and hence desirable design methodology.

1.2. Visibility of targets in illuminated roads

The visibility level (VL), a quality index in road lighting design. The VL establishes a connection between lighting design and driving performance as compared to illuminance levels. Only when the object's contrast with the background (the road or its background) is greater than the contrast threshold value may a driver see an object in the road or in its background. Contrast is positive if the luminance of the object is greater than the luminance of the background.
The following elements affect how difficult it is to spot obstacles:

- The difference between the object's luminance and the background in which it is immediately visible
- the general amount of adaptation of the eye's retinal area focused on the object
- observer time on the road
- size and shape of the object
- disability glare - the amount of veiling luminance entering the eye
- the intricacy of the background and the dynamics of traffic
- drivers' ability to see

Over the past 70 years, many research initiatives have sought to determine the criterion for evaluation of visibility of obstacles in the road. The International Commission on Illumination (CIE) introduced the Visibility Level (VL) in 1972 based on Blackwell's laboratory studies

$$\mathrm{VL} = \frac{C}{C_{th}} = \frac{\Delta L}{\nabla L_{th}}$$

Where: C is the actual contrast and C_{th} is threshold contrast and ΔL is the actual luminance difference in cd/m^2, ΔL_{th} is threshold luminance difference in cd/m^2.
A calculation model for visibility level on the road was developed as a result of Adrian's research at the end of the 1970s.
Currently, the Small Target Visibility (STV) criterion is based on Adrian's formula.

STV is the third criterion used in the United States for constructing road lighting, after luminance and illuminance. Small Target Visibility Criteria is still being researched as a revolutionary idea in European nations.

1.3. Energy Efficient lamp for Road Lighting

A good designed, an energy-efficient street lighting system should improve the aesthetic of the area while allowing users to travel at night with high visibility, in safety and comfort. Poorly constructed lighting systems can cause light pollution, poor visibility, or perhaps both. In average cities globally, lighting may account for 10–38% of the entire energy expenditure (NYCGP 2009). Because of its strategic significance for societal and economic stability, street lighting is a particularly concerning issue for public authorities in developing countries. Each year, enormous financial resources are lost due to inefficient lighting, and harmful situations are created. Street lighting expenses can be significantly reduced (typically by 25–60 %) by using energy-efficient technology and designs. These cost savings can eliminate or decrease the need for new power plants and offer funding for alternative energy options for people living in remote places.

The following are the main causes of municipal street lighting systems that are inefficient:

- Selection of inefficient luminaires
- Poor design and installation
- Poor power quality
- Poor operation and maintenance practices

A rapidly developing technology with tremendous energy-saving potential is light-emitting diode (LED) technology. LEDs give a nice spectrum of light and may last up to 13 years when used for an average of 10 hours each day (Masthead LED Lighting, 2009). The lifespan and performance are influenced by the LED's build quality, system design, operating environment, and other elements like the lumen depreciation factor over time. Although the initial cost of an LED is more than that of the majority of HID lamps, the energy it uses is half that of the lamp (or less), and since LEDs live longer than traditional lamps, there are considerable savings can be made.

Instead of capital costs, maintenance and operating costs make up the majority of the cost of street lighting (hardware costs). For illustration, the total cost of installing standard street lighting over a 25-year period is divided as follows: 15% for construction costs, 85% for maintenance/operation (including power supply). Reduced energy usage and reduced maintenance costs are now the major factors to be taken into account when designing a street lighting system. In this system, the use of energy-efficient LED lighting and the adaptive control of illumination level by Pulse Width Modulation (PWM) signal ensures energy efficiency. The LED light source is used to ensure maximum energy efficiency in lighting to maximise energy-saving.

The types of lamps commonly used for street lighting are listed in Table. Even though the initial cost of an LED is more than the cost of the majority of HID lamps, the energy used by an LED is half that of the lamp (or less), and LEDs live longer than traditional lamps, leading to considerable savings.

Type of Lamp	Luminous Efficacy (lm/W)	Color Rendering properties	Lamp life in hrs	Remarks
Metal Halide (MH)	70-130 lm/W	Excellent	8,000-12,000	High luminous efficacy, poor lamp life
High Pressure Sodium Vapor (HPSV)	50-150 lm/W	Fair	15,000-24,000	Energy-efficient, poor color rendering
Low Pressure Sodium Vapor	100-190 lm/W	Very poor	18,000-24,000	Energy-efficient, very poor color rendering
Light Emitting Diode (LED)	70-160 lm/W	good	40,000-90,000	High energy savings, low maintenance, long life, no mercury. High investment cost

Table 1: The types of lamps commonly used for street lighting

Recent developments in lighting technology have produced energy-efficient lighting systems that include one or more of the elements listed below

- Low loss ballasts
- Constant wattage high intensity electronic ballasts
- Energy-efficient luminaires
- Better monitoring and control mechanisms

Energy-efficient Street lighting projects have several stages that are shown in figure 1

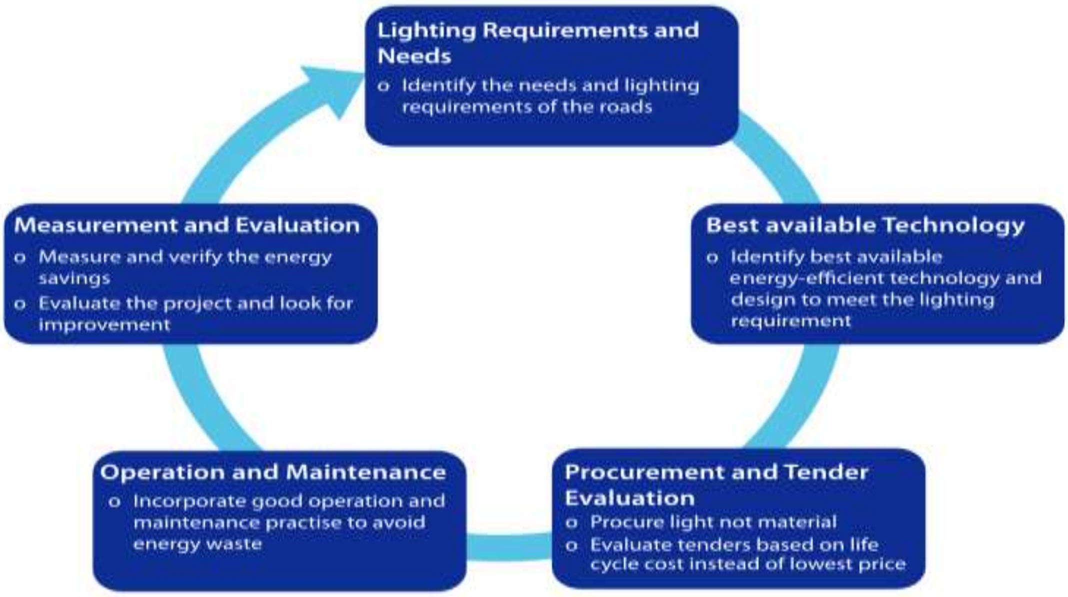


Figure 1: Energy-efficient Street Lighting Project Cycle

1.4. Human Centric lighting

A phrase used to describe lighting solutions that take into account the traditional aspects of lighting quality that are based on human vision while also taking into account new knowledge about the non-visual impacts of light is called "human-centric lighting."

Houser et al. recently discussed the development of human-centric lighting and its state in modern lighting.

According to research, integrated lighting, also known as human-centric lighting, is not a commercial feature, and lighting products that promise to boost productivity or sleep quality should be viewed with caution.

Instead, human-centric lighting is the result of sound decision-making at each stage of the lighting design process and starts with an effective prioritisation of design goals.

Project conceptualization, prioritising of design objectives, architectural design (including day lighting design), stipulation of lighting equipment, commissioning, and system operation are all steps in the process of human-centric lighting. All parties involved in the design, construction, and operation of the building, including the tenants, must support the execution for it to be successful.

The biological effectiveness of a light stimulus can be changed at any time by changing the light level and then the light spectrum.

Brighter light that coincides with the melanising action spectrum and emits a proportionally greater amount of short-wavelength radiation has greater biological potency than dimmer light that emits a lesser amount of short-wavelength radiation and corresponds with the same spectrum. Broadband sources with a higher CCT are frequently more physiologically potent than those with a lower CCT at constant illumination, though this depends on how biological potency is measured. However, because CCT is a one-dimensional reduction of a light source SPD, it is unable to accurately forecast biological potency. This shortcoming is particularly obvious for color-mixed LEDs and other SPDs with distinct peaks and valleys.

Visual and non-visual demands are typically synced in people who are active during the day. While the cycle and light/dark ratio necessary for circadian health are naturally provided by the sun's and the sky's light, electric lighting plays a crucial role because most of us spend the majority of our time indoors. It is possible to deliver biologically effective light during the day and reduce light exposure at night by combining architecture, glazing, lighting technology, and lighting control solutions, all while balancing conventional factors like colour quality, flicker, glare, psychological reinforcement, and visibility. Providing high biological potency light during the day and low biological potency light at night may be the simplest advice to promote the health of those who are day-active.

1.5. The factors responsible for the lighting scheme for roads are:

i. Luminance Level
ii. Luminance Uniformity.
iii. Degree of Glare limitation.
iv. Lamp Spectra and
v. Effectiveness of visual guidance

1.5.1. Luminance Level

Because a road's luminance affects how sensitively drivers' eyes perceive contrast and how well obstacles stand out against the background. Thus, it influences how well road users perform. Brightness of the environment has an impact on how the human eye adapts. Bright surroundings reduce contrast sensitivity, necessitating a greater road surface brightness. Darker conditions help the motorist adjust to the road (assuming road is brighter). Roads with gloomy surroundings must be illuminated by the environment. Drivers would not be able to see nearby things otherwise. According to CIE 12, 5 metres on either side of the road should have lighting that is at least 50% as bright as that on the road.

1.5.2. Luminance Uniformity

For optimal visual performance and user comfort, uniformity must be sufficient. U_0 = Lmin / Lavg is the definition of uniformity ratio from the perspective of visual performance. U_0 must not be less than 0.4. From the perspective of visual comfort, the uniformity ratio is calculated as U1 = Lmin / Lmax along the line that passes through the observer standing in the centre of the road and looking in the direction of traffic. This is also known as longitudinal uniformity ratio.

1.5.3. Degree of Glare limitation

Glare can impair vision due to physical limitations or other causes. Visual comfort is impacted by psychological or uncomfortable glare. At all costs, avoidance of glare is advised.

1.5.4. Lamp Spectra

The lamp's spectral composition determines its colour effect. The spectrum should be such that there is a rapid perception, less discomfort from glare and a quick recovery from glare. The way lamp is going to render color to objects Low pressure sodium vapour lamps give greater visual acuity.

Visual guidance directs the driver and is therefore necessary for the user to immediately capture a familiar image of the course.

1.5.5. Effectiveness of visual guidance

A lamp configuration that follows the course of the road helps with this. More so if there are turns and intersections. A lighting plan must offer visual cues. The lighting columns are situated on the separator on roadways with distinct lanes. This is typical in broad avenues in metro areas. The lighting column is situated along the outer column of a curve. This makes the flow of the road on the curvature quite visible. Traffic is guided by visual cues through various coloured lights along various routes.

CHAPTER- 2

2.1. Background of the research work

lluminance, or the quantity of light from luminaires incident upon a specific surface of interest, and luminance, or the amount of reflected light back to the driver's eye from the surface of interest, have historically been used as two complementary measurements of road lighting system performance.

Prior to 1940, the primary basis for road lighting design requirements was lighting levels represented in terms of illuminance units.

Design ideas based on physiology began to replace photometric and geometric considerations from 1940.

Target luminance, road surface luminance, road surface luminance uniformities, and glare are now considered when designing road lighting installations [1].

The fundamental principles of vision in road lighting have been the subject of numerous studies and investigations; the most thorough work was probably done by Waldram [2], Weston [3], and Blackwell [4].

The "silhouette concept" of road lighting was established by Waldram's work, which states that most targets on illuminated highways appear as black silhouettes against the bright road surface. In their research on visual performance, Blackwell and Weston found that the capacity to complete a certain visual task depended on the size, luminance, and luminance contrast of the target in relation to its background.

The luminance concept of road lighting, which is still in use today, was developed using these fundamental concepts of visual performance [5, 6].

Landolt rings and other stationary targets were put along the road surface in early road lighting tests conducted in the 1940s and 1950s as visual targets to assess the quality of the illumination [7, 8].

Following the testing of several other visual tasks, the 20 cm × 20 cm square target with a contrast of C = 0.33 with regard to the road surface, positioned on the road 100 m in front of the vehicle, was the one most frequently chosen by the road lighting research communities.

The creation of recommendations for the existing levels of road lighting was based on this visual work [6].

Road lighting studies began to include visual comfort considerations after the Second World War and shifted away from focusing solely on the visibility of targets on illuminated roads.

De Boer was one of the pioneering researchers in the 1950s and 1960s to expand on the pure visibility component of road lighting [7].

The statistical analysis of accident data became popular in the 1960s as a result of increases in the severity and frequency of traffic accidents.

Many researches were done to see if there were any relationships between the quantity of accidents and the standard of road illumination.

A thorough investigation on how lighting affects road accidents was conducted in the UK in the late 1970s by Green and Hargroves [9]. All of the road illumination quality factors that were then known were considered in the study. The average road

surface brightness was the factor having the highest correlation to the night time accident ratio [5].
The construction of road lighting is reported to generally lower at night time accidents by 20–40%, according to studies. The average reduction in accidents throughout the night is determined to be roughly 30% for all injury accidents, 60% for all death accidents, 45% for accidents involving pedestrians, 35% for accidents involving injuries at rural intersections, and 50% for accidents involving injuries on highways.
Road lighting has been demonstrated to have a much smaller impact on preventing accidents in wet and snowy weather than in dry weather [10].
Because there is little association between changes in road lighting quality parameter values and accident rates, accident studies have never been a decisive factor in determining the quality parameters of road lighting (lighting level, luminance, uniformities, disability glare).
However, decisions about whether or not to illuminate certain roadways were influenced by these investigations. In this context, whether or not to illuminate roads today is heavily influenced by a thorough review of 62 research from 15 countries published by CIE in 1992 [11].
Studies on road lighting in the 1970s focused on the potential for driver anticipation.
As a result, the field of road illumination research started to place a significant emphasis on a more or less structural examination of the driving task.
Studying the visibility of targets merely 100 metres in front of the driver, in the middle of a straight, largely empty road, was no longer sufficient [5].
The visibility index (VI), which Gallagher developed in the 1970s and can be determined from the photometric data of the lighting installation [12], is a measurement for supra-threshold visibility. Numerous other scholars, mostly in North America, have improved the visibility index since Gallagher first proposed it. In order to provide more acceptable solutions for actual visibility circumstances on the road, a significant effort has been undertaken over the past 40 years to incorporate the visual performance of the essential objectives on the road into the design of road lighting. As a result, the American National Standard Practice for Roadway Lighting RP-8-00 [13] included the Small Target Visibility (STV) idea as one of the three criteria for constructing continuous lighting systems for roadways. To change RP-8 by eliminating STV as a design measure, the IESNA's Roadway Lighting Committee (RLC) passed a resolution in August 2006. The decision was made due to the on-going challenges in linking safety to the STV metric [5].
Road lighting was mostly associated with motorised vehicles up until the late 1970s. However, organised efforts to light up the streets and reduce on night time crime have been done since the late 1970s. Caminada and van Bommel conducted one of the earliest thorough investigations of the needs of pedestrians and residential neighbourhoods in 1980 [14], with a focus on personal protection. The study's key finding was that semi cylindrical illuminance was the measurement most appropriate for use in residential environments to achieve a specific recognition distance [5]

2.2. Visibility of targets: Adrian Model for calculation

Visual information and visual performance are significantly connected. This model was created to explain the differences in colour between the target and background luminance in mesopic vision (cone and rod vision), such as in the visibility of street lighting. The technique described here is an improved version of Adrian's 1960 model, which merely allowed luminance differences to be calculated.
This enhanced version includes the ability to calculate luminance differences thresholds L for negative contrast targets (targets that appear darker than their surroundings) as well as the effect of age on threshold perception. The model is limited to positive target contrast at lower Luminance levels.

2.2.1. Model development

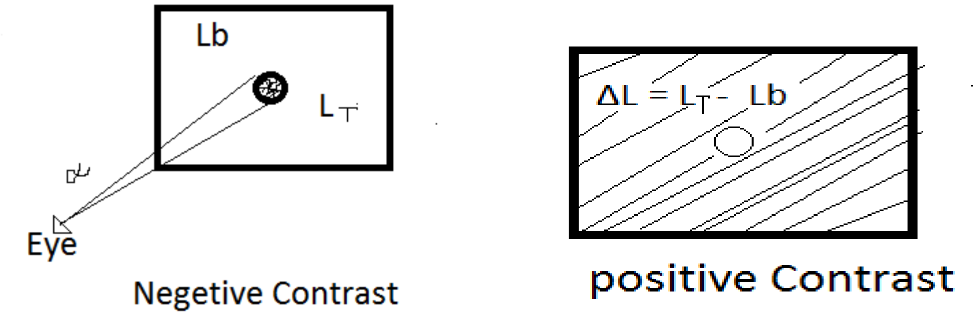


Fig.2 **Target with angular size e can have positive or negative contrast to background luminance Lb . LT is Target Luminance**

Figure 1 shows a target subtending the angular size α seen against a background luminance L_b The target can have a higher luminance than the background (positive contrast) or it appears darker than L_b (negative contrast). For both cases we need a minimal luminance difference

$\Delta L = L_T - L_b$ (where L_T is the target luminance) to perceive the target with a certain probability level P — 99.93%.

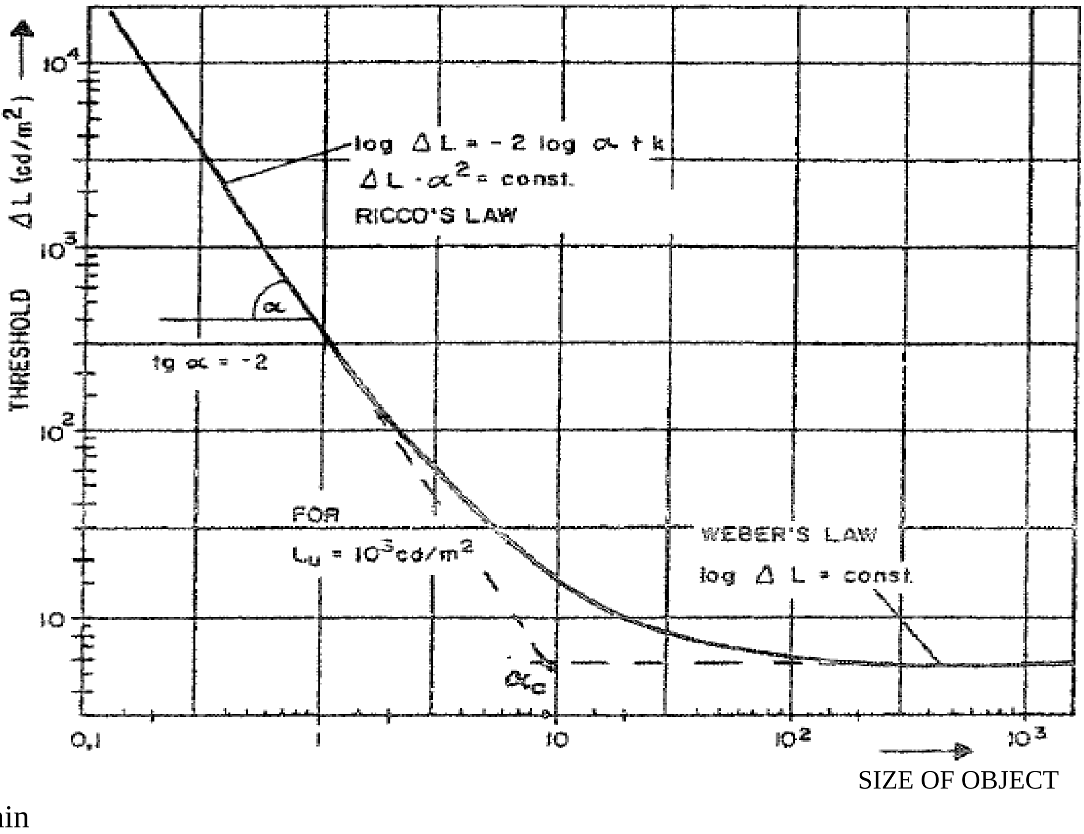


Figure 3: ΔL threshold as a function of o at a constant background luminance $L_b = 10^3$ cd m^{-2}. The intersection of die Ricco and Weber functions is often taken as indicator of the critical angle α_0 over which spanal summation occurs.

Figure 3 contains experimental results of the necessary *ΔL* for positive contrast as a function of the target size on a background of $L_b = 10^3$ cd m-2. This graph shows for small targets function

$$\textbf{Log } \Delta L = -2\log\alpha + k \mid \alpha \to 0$$

For larger target sizes a the threshold *ΔL* assumes a constant value and becomes independent from the target size

$$\textbf{Log } \Delta L = const. \mid \alpha \to \infty$$

This expresses Weber's law indicating that for larger objects the threshold is dependent only on the background luminance bi the ratio finally assumes the value unity

$$\frac{\Delta L}{\Delta L\text{b}} = const$$

The calculation of ΔL is based on a composite of these two laws. Introducing two auxiliary functions: Ø the luminous flux function, characteristics for the Ricco-process, in which the luminous flux determines perception and L, the luminance function, reflecting Weber's law.

Berek suggested the geometric summation for getting ΔL

Ricco:

$$\Delta L = K\alpha^{-2}|_{\alpha \to 0}$$

Weber:

$$\Delta L = \text{const.}|_{\alpha \to \infty}$$

Ricco:

$$\Delta L_{\alpha \to 0} = \Phi(L_b)\alpha^{-2}$$

Weber:

$$\Delta L_{\alpha \to \infty} = L(L_b)$$

$$\Delta L = k\left(\frac{\emptyset^{1/2}}{\alpha} + L^{1/2}\right)^2 \quad \text{cd m}^{-2} \quad \text{------------ (i)}$$

From Adrian's, Aulhorn's and Blackwell's data the $\emptyset^{1/2}$ and $L^{1/2}$ funcñons have been derived and can be calculated from the following equations:

$Lb \geq 0.6\ cd\ m^{-2}$

$\emptyset^{1/2} = log\ (401925\ L_b^{0.1556}) + 0.1684\ L_b^{0.5867}$ ------------(ii)

$L^{1/2} = 0.05946\ L_b^{0.466}$

$L_b \leq 0.00418\ cd\ m^{-2}$

$\log \emptyset^{1/2} = 0.028 + 0.173 \log L_b$ -------------------- (iii)

$\log L^{1/2} = -0.891 + 0.5275 \log Lb + 0.0227(\log L_b)^2$

0.00418 cd m -2 $< Lb < 0.6$ cd m -2

$\log \emptyset^{1/2} = -0.072 + 0.3372 \log L_b + 0.0866(\log L_b)^2$ ------------(iv)

$\log L^{1/2} = -1.256 + 0.319 \log L_b$

The functions have to be subdivided into three ranges of background luminance for the optimum fit. $\emptyset^{1/2}$ And $L^{1/2}$ may be computed using the set of equations, allowing ΔL to be obtained.

2.2.2. Influence of exposure time:

The model's data were gathered over a period of 2 seconds or an indefinite amount of observation time. In order to perceive the target, ΔL must grow for shorter exposure times.

A term is used to describe this influence:

$$\frac{a\ (\alpha, Lb) + t}{t}$$

in which $\boldsymbol{a}$ is a function of target size and luminance level L_b , The following equations to calculate $\boldsymbol{a}\ (\boldsymbol{\alpha}, \boldsymbol{L}\mathbf{b})$ are derived on the basis of experimental data of Schmidt-Claussen ' and Blackwell ".

$$a(\alpha) = 0.36 - 0.0972 * \frac{(\log\alpha+0.523)^2}{(\log\alpha+0.523)^2-2.513(\log\alpha+0.523)+2.7895} \quad \text{--(v)}$$

$$\mathbf{a(L_b) = 0.355 - 0.972} * \frac{(\log \mathrm{Lb}+6)^2}{(\log \mathrm{Lb}+6)^2 - 10.4(\log Lb+6\ )+52.28} \quad \text{----------(vi)}$$

For target sizes with (a < 60') the value of a (α , L_b) can best be approximated by the expression:

$$\mathbf{a}(\boldsymbol{\alpha}, \boldsymbol{L_b}\ ) = \frac{(a(\propto)^2 + a(Lb)^2)^{\frac{1}{2}}}{2.1} \quad \text{-----(vii)}$$

In consequence the threshold ΔL following from equation
4 valid for 2 s observation time have to be multiplied by equation 8 to account for shorter durations:

$$\Delta L_t = \Delta L_{t=2sec}$$

2.2.3. Difference between ΔL thresholds for positive and negative target contrast:

So far, only positive contrast targets have been evaluated. Only good contrast targets were used in Adrian's and Blackwell's measurements. 'We meet this problem whichever visual function we evaluate,' Aulhorn stated, referring to a target in negative contrast (Figure 2) that could always be seen better at the same AL than in positive contrast. She looked into luminance difference sensitivity and its relationship to visual acuity, and she came up with a lot of data for both positive and negative contrast targets. The threshold differences between negative and positive targets are therefore dependent on the background luminance L_b as well as the target size in CIE. It's helpful to look at the outcomes to get a better understanding of the data. The inhibitory zones have varying widths, and the ratio between them fluctuates depending on the luminance level, which explains the dependence on ∝ and L_b.

To obtain the difference between ΔL for positive and negative contrast, a factor Fcp (contrast polarity factor) was derived from Aulhorn's data. The luminance difference threshold ΔLneg for a target in negative contrast can be computed with the term:

$$Lneg\ =\ Lpos * \ Fcp$$

In which L_{neg} has to be the value for the exposure time t = 2 s. Fcp which is dependent on the background and target size can be calculated according to the equation:

$$\mathbf{Fcp}(\boldsymbol{\alpha}, \boldsymbol{L_b}) = \mathbf{1} - \frac{m\propto^{-\beta}}{2.4\nabla Lpos\ t=0}$$

In that equation for $L_b\ \geq 0.1\ cd\ m^{-2}$:

$$m = 10^{-10^{-(0.125(logLb+1)^2 + 0.0245)}} \quad \text{--- (viii)}$$

For all L_b

$$\beta = 0.6L^{-0.1488} \quad \text{------------------ (ix)}$$

In the case that a target of negative contrast is observed for duration shorter than 2 s, ΔL_{neg} has to be multiplied by the time factor following from equation 8.

2.2.4. The influence of Age on ΔL

Ocular transmittance has been measured by Mortenson-Blackwell and Weale, who discovered that it declines with age. According to Reference 6, this causes elderly adults to have greater M thresholds, which can be shown in Figure 3. 234 participants, ranging in age from 20 to 80, have been grouped into 10 year age groups.

234 OBSERVER

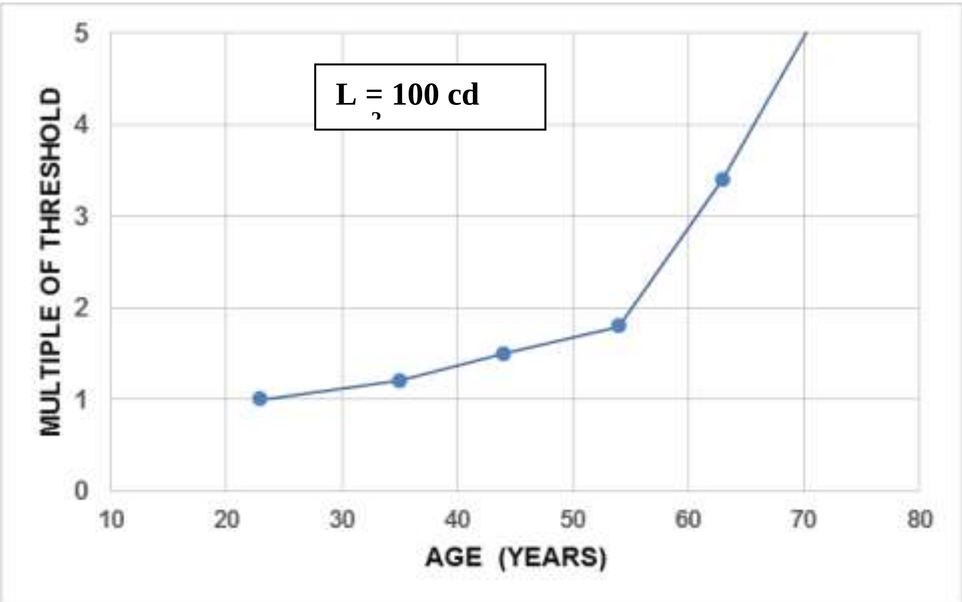


Figure 4: Multiple of the threshold contrast required for observer of age in relation to the base group with an average of 23 years

The ΔL for subjects older than 23 years, the age at which the function assumes unity, can be found from the following equation:

$\Delta L_{AGE} = \Delta L_{23} AF$

The age factor AF for 23y < Age < 64y

$$\mathbf{AF} = \frac{(Age-19)^2}{2160} + 0.99 \quad \text{----------------(x)}$$

For 64y < Age < 75y

$$\mathbf{AF} = \frac{(Age-56.6)^2}{116.3} + 1.43 \quad \text{----------- (xi)}$$

AF takes account of the age related threshold increase. ΔL as in equation holds for young persons and has to be multiplied by the age factor AF to get the threshold for older subjects ΔL_{AGE}.

2.2.5. Calculation of ΔL

Equation (xii) can be used to get the final ΔL threshold value for luminance difference perception, one of the fundamental visual functions.

It takes into account the observation duration, since we need bigger luminance differences with shorter exposure times, the factor accounting for contrast polarity, so that ΔL can be estimated for targets, darker and brighter than their background, and the impact of age on the ΔL threshold.

$$\Delta L = 2.6\left(\frac{\phi^{1/2}}{\alpha} + L^{1/2}\right)^2 F_{cp} \frac{a(\alpha, Lb) + t}{t} AF \quad \text{-------- (xii)}$$

$F_{cp} = 1$ for positive target contrast; AF = 1 for young observer group with an average age of 23years;

ΔL is practically constant for exposure time $\geq 2\ s$.

2.2.6. ΔL calculation and disability Glare

Glare sources in the visual field impair vision and force an increase in ΔL to maintain target visibility.

The initial suggestion made by Hollada was to describe the impact of straylight on target visibility Lt in terms of an additional uniform brightness to the background luminance L_b .

It is called L_{seq}, a veiling luminance equivalent to the glare and is given in general form by:

$$L_{seq} = K \sum_{i=1}^{n} \frac{E_{GIi}}{\theta_i^2} \quad (\text{cdm}^{-2}) \text{ --------(xiii)}$$

Where E_{GIi} is the illumination in flux at at the eye from glare source I; θi is the glare angle in degrees between the centre of the glare source and the fixation line valid for

$1.5° < \theta < 30°$ k is an age dependent constant. For the 20-30 years age group k = 9.2

So in calculation of ΔL, L_b is replaced by $L_b + L_{seq}$

2.2.7. Influence of age on the constant K in equation (xiii)

The average of the influence of age on the constant K can be expressed as:

$K = (0.0752\ Age - 1.883)^2 + 9.2$ ---------------- (xiv)

This equation is valid for $25y < Age < 80y$

The whole impact of disability glare is included in equations (xiii) and (xiv) and is given as the comparable veiling luminance. The following illustration illustrates how stray light reduces contrast. The difference is described as:

$$C = \frac{\Delta L}{Lb} = \frac{LT - Lb}{Lb}$$

The stray light superimposes on retinal image. So we get for reduced contrast C_{red}:

$$C_{red} = \frac{(Lb+Lseq)-(Lb+Lseq)}{(Lb+Lseq)} = \frac{LT-Lb}{(Lb+Lseq)}$$

$$= \frac{\Delta L}{(Lb+Lseq)} \text{ -------- (xv)}$$

If $L_b >> L_{seq}$, then $C_{red} = \frac{C}{2}$

2.2.8. Visibility Level (VL) of Adrian's model

On the basis of experimental data, the numerical description of the luminance difference threshold ΔL has thus far been addressed. ΔL designates a number where, given the observational conditions utilised in the laboratory studies, a target of defined size becomes visible with about 100% probability. These were open viewings conducted with binoculars (in Aulhorn's investigation, monocular). If the threshold values are lowered by a factor of 0.84, the generated functions also suit the data provided by Siedentopf quite well.

However, in actual observation conditions, a multiple of ΔL is required depending on the demand of the visual task. In the CIE Report 19.2 Blackwell introduced the very descriptive term visibility level VL:

$VL = \Delta L_{actual} / \Delta L_{threshold}$

The visibility level is obtained by the ratio of the actual luminance difference the target displays to its threshold value from equation (xii). It expresses how much a target is above the level of threshold perception.

CHAPTER- 3

3.1. Experimental Procedure and setup:

The experiment is conducted in the laboratory using the Adrian's model. Three different sizes of objects are taken with different colour. Varying the CCT values of LED, appears various colour for measurement. With the help of luminance meter, different luminance values are taken.

3.1.1. For calculation of visibility level in the laboratory, following steps are taken into account

- The observer is situated on a line that runs across the calculation locations and is perpendicular to the midline of the calculation plane.
- Three different sizes (square, prismatic & cylindrical) of object with three different colours (yellow, green & violet) are considered.
- The observer was situated on the line 9.94 meters away from the location.
- The reference line meets the calculation plane at 9.94 meters and 1.10 meters eye position from the road, with a 6.33° downward view from the horizontal as the defined observation geometry.
- Background luminance (Lb1) is calculated at a point on the pavement adjacent to the centre of the bottom of the target, that is, the target's position on the roadway.
- Background luminance (Lb2) is calculated at a point on the pavement 1.048m beyond the target, at a point on a line projected from the observer's point of view through the point at the centre of the top of the target.
- The target is situated where two grid lines meet.
- The target's surface is fully diffuse, vertical, and perpendicular to a line between the observer and the grid point. Additionally, it is assumed that light will reflect in a Lambertian manner.
- Using 12-watt LED (Haloneix prizm) lamp with different values of CCT (Correlated Colour Temperature), which is used to illuminate the target.
- With the help of luminance meter, readings are taken at the middle of the target.

3.1.2. Experimental set-up

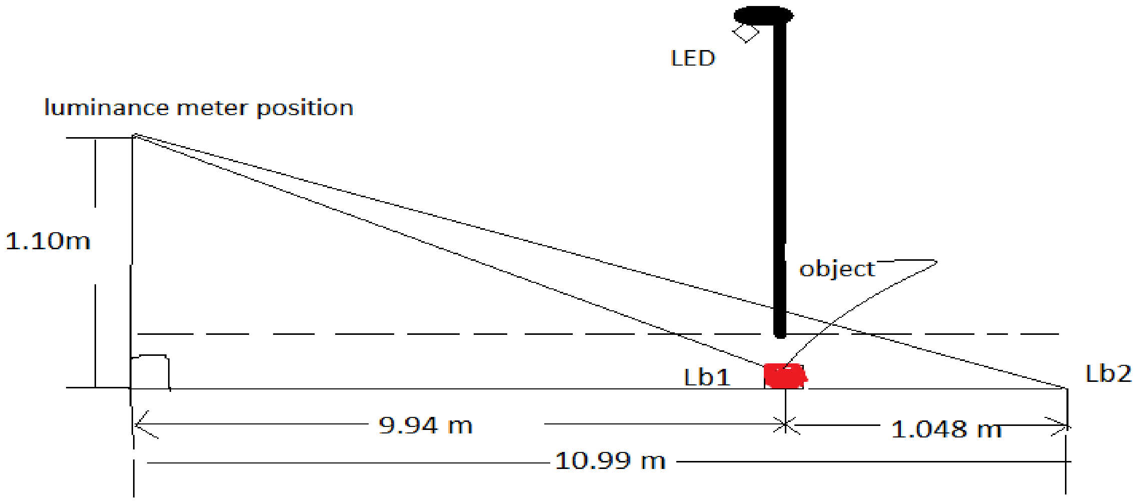


Figure 5. experimental set-up for measurement

3.1.3. Experimental Equipment:

The following equipments are used to measure the data

i. Luminance meter

Photometric brightness is measured by single element detectors called luminance metres. Luminance meter measures the amount of emitted or reflected light from a surface. These portable, lightweight instruments can show brightness in either cd/m2 or foot-lambert (ft-L).

Figure 6. Luminance meter

ii. Distance Meter

The distance meter uses a laser to precisely measure an object's distance without making touch. In the industrial sector, especially in occupations related to construction like architecture, surveying, carpentry, masonry, locksmiths, etc., the distance metre is commonly employed. The distance meter may come with a Leica lens, which is the industry standard for optical distance metres, depending on the model.

Figure 7. Distance meter

iii. Different shape & size of object:

Three different shape and size of objects are considered with different colour for calculation of Visibility Level (VL) under the variable CCT.

Prismatic (green) **Square (yellow)** **Cylindrical (violet)**

Figure 8. Different size of object with different colour

iv. LED

Wattage 12-watt smart LED, Base B22, input voltage: AC 220-240V, 50Hz
Requires a secured 2.4 GHz WI-Fi network connection. With the change in atmosphere, CCT of the lamp can be changed with the help of smartphone or tablet.

Figure 9. LED lamp

3.2. Experimental data

The experimental data and measurements which has been taken for the visibility calculation are given below

Distance of the object from the Observer = 9.94m
Distance at a point on the pavement beyond the target, at a point on a line projected from the observer's point of view through the point at the centre of the top of the target = 1.048m
Height of the observer = 1.10 m
Angle (θ) = $\tan^{-1}(1.10 / 9.94) = 6.33°$
Targeted luminance = L_T
Background luminance1 = L_{b1}
Background luminance2 = L_{b2}
Different types of Object size
Different types of object colour (Yellow, Green & Violet)
Variable CCT = 3000k, 4000k, 5000k & 6000k
Time of observation T = 0.4 sec
Age of the observer TA (23 year to 30 year)
Background luminance L_{b1} and L_{b2} are taken by the luminance meter for different objects with corresponding CCT values.

3.3. Programming for data calculation

For calculation of data Python program is used. The programming is as follows-

```
import math
Lt=float(input("Enter target luminance: "))
Lb1=float(input("Enter background luminance 1: "))
Lb2=float(input("Enter background luminance 2: "))
x=float(input("Enter size of the object: "))
d=float(input("distance from object: "))
T=float(input("time of observation: "))
TA=float(input("age of the observer: "))

Lb = (Lb1+Lb2)/2
print("Lb : ", Lb)
α=math.atan2(x, d)*180* 60 /math.pi
print("α :",α)
LL=math.log10(Lb)

if Lb  >= 0.6 :
   F= (math.log10(4.2841*math.pow(Lb, .1556)) + (.1684 * math.pow(Lb, .5867)))**2
   L=(.05946*math.pow(Lb, .466))**2
elif Lb > 0.00418 and Lb < 0.6 :
   F= math.pow(10, (2*((.0866*(LL**2))+ (.3372*LL)-.072)))
   L= math.pow(10, (2*(.319*LL-1.256)))
else:
   F=math.pow(10, ((.346*LL)+.056))
   L=math.pow(10, ((.0454*(LL**2))+(1.055*LL)-1.782))

l= 2.6*((((F**(1/2))/α)+(L**(1/2)))**2)
print("l:",l)

def b(α):
   return (.36-((.0972*(((math.log10(α))+.523)**2))/(((math.log10(α))+.523)**2-
2.513*((math.log10(α))+.523)+2.7895)))

def c(Lb):
   return (.355-((.1217*(((math.log10(Lb))+6)**2))/(((math.log10(Lb))+6)**2-
10.4*((math.log10(Lb))+6)+52.28)))

def a(α,Lb):
   return ((((b(α))**2)+((c(Lb))**2)**(1/2))/2.1)
TF= (a(α,Lb) +T)/T
print("TF :", TF)
```

```
B= math.log10(α)+.523
print("B :",B)
C= LL+6
AA = .360 - ((.0972*(B**2))/(B**2-(2.513*B)+2.789))
AL = .355 - (.1217*(C**2/(C**2-(10.4*C)+52.28)))
print("AL :" ,AL)
AZ= math.sqrt((AA**2+ AL**2)/2.1)
DL1=2.6*(((math.sqrt(F)/α)+math.sqrt(L))**2)

if  LL > -2.4 and LL < -1 :
   m=math.pow(10,-1* math.pow(10, -((.075*((LL+1)**2))+.0245)))
   β=.6*(math.pow(Lb, (-.1488)))
   FCP=1-((m*math.pow(α, -β))/((1.2*DL1*(AZ+2))))
elif LL>= -1:
   m=math.pow(10,-1* math.pow(10, -((.125*((LL+1)**2))+.0245)))
   β=.6*(math.pow(Lb, (-.1488)))
   FCP=1-((m*math.pow(α, -β))/((1.2*DL1*(AZ+2))))
else:
   FCP=0.5
if TA <= 64 :
   AF= ((TA -19)**2/2160)+.99
else:
   AF= ((TA -56.5)**2/116.3)+1.43

if Lt<Lb:
   Lo= l*FCP*TF*AF
else:
   Lo=l*TF*AF

VL=(Lt-Lb)/Lo
print("VL is:",VL)
```

3.4. Experimental Result

VL calculation for different objects with variable CCT values using Adrian's Model are tabulated below

object size	colour	dimension	CCT	target luminance(Lt) (cd m-2)	Background luminance 1 (Lb1) (cd m-2)	Background luminance 2 (Lb2) (cd m-2)	visibility (VL)
Square	**Yellow**	8cm X 8cm	3000k	1.001	0.65	0.298	**18.3**
			4000k	1.121	0.521	0.327	**26**
			5000k	1.097	0.557	0.35	**23**
			6000k	1.129	0.418	0.252	**33.6**
Prismatic	**Green**	H =8 cm B= 10 cm	3000k	0.63	0.434	0.117	**16.7**
			4000k	0.73	0.445	0.221	**16.86**
			5000k	0.795	0.432	0.118	**21.4**
			6000k	0.745	0.396	0.178	**21.1**
Cylindrical	**Violet**	H=10cm D=9cm	3000k	0.246	0.569	0.11	**6.6**
			4000k	0.296	0.565	0.098	**2.6**
			5000k	0.252	0.466	0.084	**3.6**
			6000k	0.245	0.503	0.112	**9.37**

CHAPTER- 4

4.1. Simplifications and assumptions employed in Adrian's formula and for calculation of STV as adopted in the work

Despite having a clear method of evaluation, the Small Target Visibility criterion, which is mostly based on Adrian's model, includes extensive simplifications for the computation of the Visibility Level. The road segment taken into account during the calculation is clear of other traffic participants, and vehicles are approaching from the opposite direction, so there is no glare from these vehicles' headlights. The driver's visual task is straightforward and consists of identifying an object in a predetermined space that is squarely in line with the driver's field of vision.
The intricacy and dynamism of real-world traffic situations, along with other traffic participants, severely restrict the vision of oncoming objects. When examining the visibility requirement, the following questions regarding the backdrop luminance computation and the driving environment arise.

Road and Pedestrian Conflict Area		**STV Criteria**	**Luminance Criteria**		
Road	**Pedestrian Conflict Area**	**Weighting Average VL**	**Lavg [cd/m²] Median <7.3m**	**Lavg [cd/m²] Median ≥7.3m**	**Uniformity Ratio Lmax/Lmin (Maximum Allowed)**
Freeway "A"	-	3.2	0.5	0.4	6.0
Freeway "B"	-	2.6	0.4	0.3	6.0
Expressway	-	3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

Table 3: Lighting requirements based on small target visibility

Luminance concept for motorised traffic

The uniformity of the roadway and brightness level serve as the determining factors for how roads are illuminated for motorised vehicles. The variables that determine how well-lit a road is for motorised vehicles are the luminance level and uniformity of the carriageway. The lighting requirements listed for each class in Table.4 serve as the definition for the lighting classes M1 to M6. For the determination of the M lighting class defined by the CIE (CIE 132-1999 and CIE 144:2001). The proper lighting class is defined according the purpose of the road, the intended speed, the general design, the volume and composition of the traffic, and the surrounding environment.

LIGHTING CLASS	VISIBILITY LEVEL Minimum Maintained	Lavg [cd/m^2] Minimum Maintained	Lmin/Lmax Minimum Maintained	TI [%] Initial
M1	7.5	2.0	0.2	10
M2	7.0	1.5	0.2	10
M3	6.0	1.0	0.2	15
M4	5.5	0.75	0.2	15
M5	5.0	0.5	0.2	15
M6	5.0	0.3	0.2	20

Table 4: CIE lighting requirements based on visibility concept

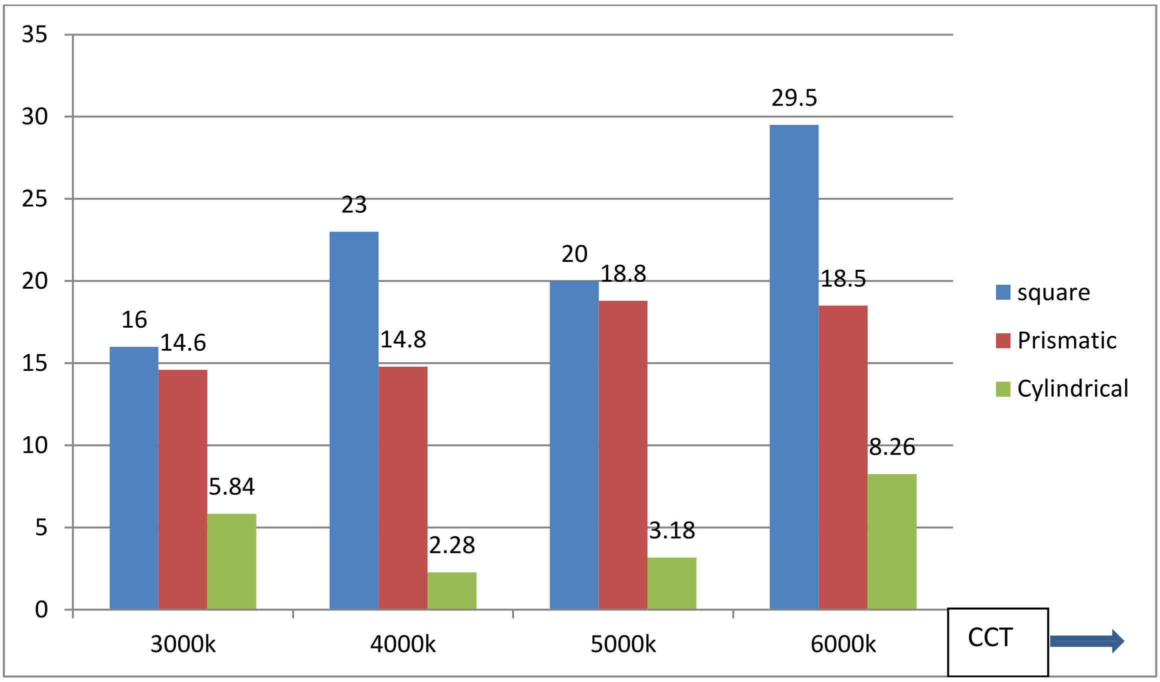
4.2. Comparison the Visibility Level (VL) of Adrian's & STV model data

The Illuminating Engineering Society's American National Standard Practice for Roadway Lighting(IES 2000) has approved Adrian's Visibility Model as the Small Target Visibility (STV) design criterion as a valuable tool for determining an object's visibility at night. STV is the modified version to calculate the VL that includes the CIE disability glare equations (CIE, 2002). The different values of VL have been shown below for these two models with variations of CCT.

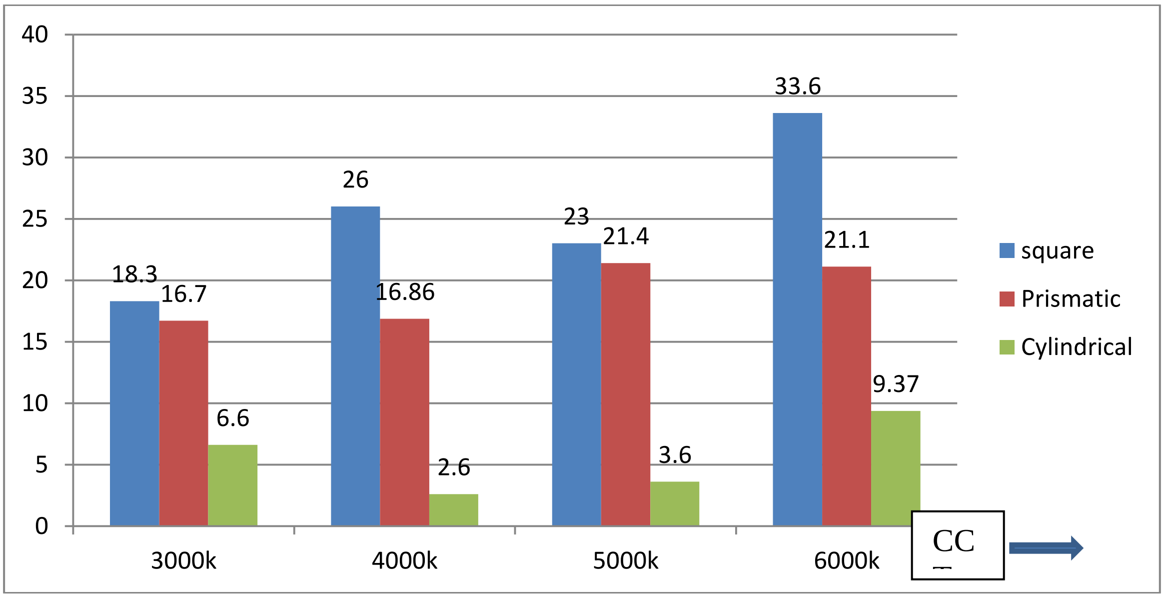
Object Dimension	CCT	VL of STV model	VL of Adrian model
Square 8cm X 8cm (Yellow)	3000k	16	18.3
	4000k	23	26
	5000k	20	23
	6000k	29.5	33.6
Prismatic H=8cm B =10cm (Green)	3000k	14.6	16.7
	4000k	14.8	16.86
	5000k	18.8	21.4
	6000k	18.5	21.1
Cylindrical H=10cm D=9cm (Violet)	3000k	5.84	6.6
	4000k	2.28	2.6
	5000k	3.18	3.6
	6000k	8.26	9.37

4.3. Graphical representation of different values of VL for STV Model & Adrian Model

By conducting the experiment it has conclude that, the values of Visibility Level (VL) of road surface are varying with the object colour and CCT values of luminaires. How the VL values are changing with objects size and colour with respect to corresponding CCT values, which are shown by graphical representation.



VL values of STV model



VL values for Adrian Model

CHAPTER- 5

5.1. Results and Analysis

Target-background luminance contrast can be used to provide a meaningful initial estimate of target salience and visibility if it is measured in a precise recreation of an event's lighting conditions and site layout.
The modified Adrian/CIE VL model offers a more accurate estimate of a target's visibility by taking into account additional variables known to affect target contrast (such as glare intensity and location) and observer contrast detection thresholds (such as target size, viewing duration, contrast polarity, observer age, and eye colour).
An easy-to-use tool that automates the calculation of VL based on the model is the VLC described here.
Although Adrian suggested VLs between 10 and 20 for acceptable night-time visibility, subsequent research has advised VL numbers outside of this range. When the results of a research on pedestrian visibility were applied to the modified Adrian/CIE model, Ising reported VLs for alerted drivers ranging from 0.1 to 18 and for unaltered drivers from 14 to 89. According to a driving simulator study on visibility in mesopic settings, a VL of 7.5 would be sufficient under static conditions, whereas a VL of 21 might be required for performance at the 85th percentile under dynamic situations. Green claimed that a VL of 10 to 12 would be comparable to the visibility demands for an 85th percentile driver and that a VL of 50 should fit nearly all drivers because, overall, visibility studies show diminishing improvement for VLs above 10 to 15. The results of a recent simulation of a night-time motor vehicle/pedestrian collision in which one of the authors took part are consistent with Green's suggested VL levels of 10 to 12.Despite receiving location and timing cues. Both of the two adult observers failed to notice a darkly dressed pedestrian substitute in the roadway illuminated by car headlights in the presence of headlight glare from an approaching truck when VLs dropped below 9.4. In that visibility is affected by several target and observer variables not included in the Adrian model, it is unsurprising that detection VLs vary significantly across observers and between different studies.
In the laboratory three different colour objects are being used with different CCT value while taking the readings. So the certain range of VLs are taken . Given the uncertainty of VL data, caution should be exercised when utilising it as a measure of road visibility.
Furthermore, a number of factors, such as scene complexity, light adaptation, expectation, attention distraction, and placement in the visual field, have an impact on the likelihood that a "visible" target will really be "seen". The measurement of VL might be improved, and its application for forecasting target visibility and detection distance could be honed through future field and high-fidelity simulation study. Here are some ideas for such target-parameter and observer-factor studies.

5.2. Conclusion

A properly planned and installed road lighting system should offer adequate visual conditions for all of its users by achieving the fundamental lighting requirements throughout its operation. All participants in traffic, including those in vehicles, bicycles, and on foot, should have eyesight that enables them to perform their respective visual tasks. However, drivers' visual duties are much more difficult than those of other traffic participants, and because they have less time to think things through and act on them, it is these actions that are actually taken into account when assessing how visible road impediments are.

Instead of limiting the driver's visual tasks to detecting a stationary object at a specific location on the road, the visibility of an object should be evaluated on three different levels: position, circumstance, and navigation. Adrian's VL mathematical model needs to be expanded, but it still offers a strong foundation for further study. It is very challenging and calls for the conduct of numerous scientific tests to find an answer to the author's questions. Unquestionably, the results of this research will make a substantial contribution to the creation of approaches for the design of regional road lighting systems.

A road lighting installation's effectiveness is influenced by a variety of intricate factors, such as the mesopic visual performance and windshield transmittance of moving vehicles, both of which have an impact on the driver's vision conditions. Road lighting design and calculation systems that are significantly more advanced than that currently in use (like DIALux and Calculux) will likely be developed in the near future in order to replicate the actual visibility conditions of drivers in certain circumstances. These algorithms can be used to compute the attributes of high-quality road lighting based on the various intricately interwoven parts that make up the environment of the road lighting.

CHAPTER- 6

6.1. FUTURE SCOPE OF WORK

In conclusion, the precise viewing circumstances will determine the necessary VL for pedestrian detection. The Adrian threshold model is an excellent place to start when figuring out VL, but it has certain restrictions and needs to be modified periodically.

6.1.1. Target parameters

a. Contrast detection thresholds for extended targets are somewhat lower for comparable-sized circular targets. The model's accuracy could be increased through research by providing a suitable target shape adjustment factor.
b. Despite the model's underlying assumption that targets are fixed with respect to the observer, contrast sensitivity is known to vary with temporal modulation, target size, and observer age. An angular target's size also grows exponentially for an approaching observer as a function of approach velocity. It has also been observed that when identifying novel objects, drivers prefer to focus more on motion than on expectation. There is evidence that in low light, "biological motion" by pedestrians is more obvious. According to one study, people wearing biological motion configurations were visible even in the presence of visual congestion more frequently and farther away than people wearing luminous vests. Research on VL as a function of target size, visual field position and spatial context, motion rate and motion type for observers of different ages is expected to improve predictions of visibility on dynamic tasks.
c. The current VL model presupposes that targets are viewed in the fovea, where contrast sensitivity and acuity are optimal, but that peripheral target detection declines as a function of retinal eccentricity. It is also decreased by complex backgrounds and internal motion. It has been suggested that location and context factors could be generally addressed by creating reference driving scenarios with existing road classification data in which pertinent variables like workload, scene complexity, speed, and retinal eccentricity are assessed with the aim of defining scenario-specific VL recommendations.

6.1.2. Observer factors

a. Age-related vision decline makes night-time visibility problems for older drivers worse. The assertion that the model's age adjustment understates the detrimental effect of age-related visual impairments on VL may be put to the test by closely evaluating age-related variations on VL.
b. The model is built on threshold data from very sensitive, dark-adapted observers, yet there are wide variations in observer adaptation levels for actual activities. For instance, since they usually fixate on the ends of their headlamp beams, drivers might not be well-suited to detect objects in darker off-road areas. According to studies, it would be more common to determine VL using a light adaptation factor based on observer age.
c. The detection distances for small targets are substantially larger in a field study when the same observers are passengers as opposed to drivers. The authors' conclusion was that even relatively low information-processing needs can make it difficult to see targets. Additionally, it has been shown that more experienced drivers are more adept at dividing their visual attention across different objects than less experienced ones. The significance of considering cognitive load and driver/observer experience for determining task-specific VLs is highlighted by these findings.

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