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

A THESIS
SUBMITTED TOWARDS PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY
IN
ILLUMINATION TECHNOLOGY AND DESIGN

SUBMITTED BY
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EXAM ROLL NO: M6ILT22005
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ACKNOWLEDGEMENT

I would like to acknowledge everyone who played a role in my academic accomplishments .I take this opportunity to express my deep sense of gratitude and indebtedness to **Dr. Suddhasatwa Chakraborty**, Assistant Professor, Electrical Engineering Department, Jadavpur University, for his constant guidance and supervision. I would also like to thank him for providing me his valuable time and helpful suggestions.

Again I would like to thank my parents, who supported me with love and understanding. Without you, I could never have reached this current level of success. Finally, this thesis would not have been possible without the confidence, endurance and support of my Class mates with whom I share tons of fond memories. They are always been a source of inspiration and encouragement.

Dated: 17.08.2022

MRINMOY PODDER

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CHAPTER-1

1.1 INTRODUCTION:

Roadway lighting design initially focused on the output of the lighting fixtures, hereafter referred to as luminaires, and used illuminance was the key design factor for the objects. Later, it was discovered that drivers actually respond to luminance, or the amount of light reflected off of roadway objects and the pavement itself. Therefore, luminance became the standard for lighting design. When the connection between luminance and the driver's eye was made, lighting experts took the issue to a new level of logical complexity and started looking for a way to design roadway lighting based on some aspect of visibility.STV is effectively the first attempt to link the biology of the human eye to the physics of roadway lighting performance. From a physics standpoint, contrast affects visibility. Simply said, contrast is the relationship between the amount of light reflected off a target and the amount of light reflected off its background (i.e. the pavement).This is simple to calculate in a static mode, but as roads are used in highly dynamic environments, the static calculation of contrast provides little to connect the design to the appropriate operating environment. When we incorporate human vision into the calculation,it becomes more complicated. Visibility is infinitely random and varied. Therefore, the best an engineer can hope for is to construct a close approximation to account for the wide range of human vision that will pass over the illuminated area in issue. The fact that many of the physical characteristics employed in the procedure are changing over time further calls into doubt the validity of the design calculations. With time, the reflective properties of the pavement will deteriorate. The luminaries output characteristics will change as they gather dust and deteriorate. The amount of off-road lighting that contributes to visibility on the road changes as development along the lighted area changes. Final point: Because rain and ice change the pavement's reflected properties from diffuse to specular, they completely invalidate the design calculations.Lighting engineers have therefore set themselves the challenging task of being able to precisely and mathematically represent an illuminated section of highway.

1.2 BACKGROUND OF THE WORK:

According to research, lighting streets with lots of nighttime traffic will cut down on accidents. When creating continuous lighting systems for roads, three conditions must be met. These are illuminance, luminance, and Small Target Visibility (STV). Roadway lighting has traditionally employed illumination-based design, a straight forward design methodology. The amount of light falling on the road surface is calculated. The quantity of light directed toward the driver is calculated, and the luminance of the road is predicted, using luminance-based design. Target and background luminance, adaption level, and disability glare are all calculated as part of the visibility measure known as STV, which is used to assess the visibility of a variety of targets on the road.

The visibility index (VI), created by Gallagher in 1970 and based on Blackwell's research, was the first successful attempt to create a visibility criterion. Gallagher et al. demonstrated that the calculated visibility of an object was a very accurate prediction of the distance at which the drivers recognized this target using the bottom section of an 18 inch traffic cone that was 6 percent grey or 29% white reflectant. Later in 1977, a research by Janoff shown that the VI was superior to all other photometric measurements they tested as a predictor of nighttime accident rates.

A new visibility matrix was presented in 1989 by Adrian from the University of Waterloo in Canada and was based on the writings of Blackwell (1946), Aulthorn (1964), and himself.Simply put, his visibility level (VL) is the difference between real and threshold brightness. Small Target Visibility is a recognized term for the standard target that has been proposed (STV).Using photometers to measure target brightness, pavement luminance, and veiling luminance, the VL can be calculated. Then, a computer programme that predicts the future plays a crucial role in the design of a road lighting system.The most recent programme on the market is STV by Keck (1990), which is updated as needed. Janoff (1993) conducted a study to compare the target, pavement, and veiling brightness to really measured values. Two separate targets made up this experiment. Each target measured 7 inches square and was positioned upstream and downstream of the nearest brightness. The three targets had varying reflectance of 5, 30, and 80%.The findings showed that the measured values and the projected values did not agree. The luminance of the target, pavement, and veiling varied significantly. Janoff came to the conclusion that a stronger correlation between measured and predicted values might be possible with an accurate r-table for the surfaces under study, accurate reflectance values for the targets, accurate candle power distribution (including depreciation factors), and some derived field factors to account for light reflected from the pavement onto the target.

Adrian, Gibbons, and Laura Thomas revised the STV formula in 1997 after researching how light reflected from the road surface affected the target brightness. Each target brightness calculation used the reflected light from a total of 72 pavement portions. Based on the computation, it was determined that road segments that were more than six multiples of the target's size away from it did not need to be taken into account because they contributed less than 5% of the target's overall brightness.The calculation shows that the amount of light that is reflected from the pavement onto the target can reach 15% of the target's overall brightness. This quantity will alter the target's VL, which might be cut in half if pavement reflections are not taken into account.

Illuminance, 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].

Following World War II, studies on road lighting began to consider factors of visual comfort in addition to the visibility of targets on illuminated highways.De Boer was one of the pioneering researchers in the 1950s and 1960s to expand on the pure visibility component of road lighting [7].Given that high-speed road users favoured relatively comfortable roads for relatively long rides, this was thought to be crucial.However, it was also significant because at that time, traffic composition and density were already shifting significantly [5].

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 research were done to determine if there were any relationships between the quantity of accidents and the standard of road lighting. A thorough investigation on how lighting affects traffic 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 luminance was the factor having the strongest correlation to the nighttime accident ratio[5].

According to studies, installing road illumination generally results in a 20–40% reduction in nighttime accidents. Researchers have discovered that the average accident-reducing effect in the dark is roughly 30% for all injury accidents, 60% for all fatal accidents, 45% for pedestrian accidents, 35% for injury accidents at rural intersections, and 50% for injury accidents on highways. When compared to dry weather, it has been discovered that road lighting has a much smaller impact on preventing accidents during snowy and rainy 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. Regarding the decision to illuminate roads now, a thorough study of 62 studies from 15 countries that CIE published in 1992 [11] has a lot of value.

Studies on road lighting in the 1970s focused on the potential for driver anticipation. As a result, a more or less structural examination of the driving task started to be significant in the field of road illumination research. 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 which can be determined from the photometric data of the lighting installation [12], is a measurement for supra-threshold visibility. Numerous studies have improved the visibility index since it was first introduced by Gallagher, particularly in North America. 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. However, the IESNA's Roadway Lighting Committee (RLC) approved a resolution in August 2006 to change RP-8-00[13] by eliminating the use of STV as a design metric. The decision was made due to the ongoing challenges in connecting safety to the STV metric [5].

Road illumination wasn't widely used outside of motorised vehicles until the late 1970s.However, organized efforts to light up the streets and cut down on nighttime 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. Semi-cylindrical illuminance was shown to be the metric best suited for use in residential areas in order to achieve a specified recognition distance, which was the study's most significant discovery [5]. The 1990s saw a rise in traffic congestion, which prompted researchers to examine how road illumination can improve traffic flow [5].

The present standards for road lighting design, calculations, and measurements are largely based on knowledge, research, practical experience, and agreement among specialists in various international lighting communities. These guidelines are widely accepted and have been incorporated into numerous lighting design standards, studies, and suggestions. To develop and improve road lighting principles, there are new trends and directions in research and practise related to road lighting.The continued development of road lighting is being impacted by recent advancements in light sources, new tools for measuring and controlling road illumination, and mesopic photometry. The direction that road lighting will change in the future is also heavily influenced by Directive No. 2006/32/EC [15] of the European Parliament regarding energy efficiency among end users and energy suppliers and Commission Regulation (EC) No. 245/2009 [16] of the Commission of the European Communities regarding lamp efficacy in public lighting.

CHAPTER-2

2.1 ROAD LIGHTING:

Promoting a city has always been effective with road lights. In addition to serving a practical purpose by ensuring the safety and security of residents, drivers, and pedestrians, it also contributes to the development of a community's identity and image.

A nighttime environment where people can see comfortably and recognize items on the road they are travelling on can be created by fixed illumination of public ways for both automobiles and pedestrians. Roadway lighting can increase traffic safety, facilitate efficient traffic flow, and encourage the facility's broad use at night and in a variety of weather situations.

The volume of traffic on the roads keeps increasing as a result of technical advancements and the greater dependency of emerging societies on the automobile. Although the majority of this traffic happens during the day, there is still a considerable amount of traffic during the night. About 25% of travel, on average, takes place at night in various nations. However, fatal traffic accident rates are roughly three times higher at night than they are during the day, primarily because of the decreased visibility at this time.

Some of the visual signals needed at night are provided by headlights, but as speed, vehicle density, or scene complexity rise, headlights become progressively less useful. Additionally, they glare at approaching traffic, especially in areas without established road lights. On two-way roads with close-proximity traffic going the opposite direction, this issue is made worse. The reduction of headlight glare is achieved by high-quality road lighting, which also enhances comfort and enables drivers to see details clearly and identify them in time for a timely reaction.

2.1.1 Purpose Of Road Lighting:

It is only possible to make wise decisions about investing in road lighting systems if one has a thorough understanding of its benefits. Road lighting for motorised traffic should offer visual performance, visual comfort, and support driver alertness. Good road lighting has been proved in numerous studies to prevent nighttime accidents. Road lighting can boost a motorway's capacity in nations where peak travel times are after dark. Road lighting in populated and residential areas should also provide visual cues for slow-moving traffic, such as pedestrians, cyclists, and moped riders, to help them find their way without running the risk of running into or tripping over potentially hazardous obstacles. Road lighting in these regions should also be designed to prevent crime, violence, and vandalism. In fact, according to crime statistics, there is a link between improved road lighting and decreased crime. Residents' sense of security can also be enhanced by well-lit streets. This is crucial in preventing social isolation, particularly for young girls and the elderly. Finally, well-designed road lighting can contribute to the attractiveness of an area.

In road and street lighting the following aspects are considered:

a) Energy conservation through the use of effective lighting, technologies, and design concepts.
b) Utilizing bulbs with a longer lifespan and the right spacing to save maintenance costs
c) By carefully choosing luminaires and bulbs, reduced glare and increased visibility
d) Capital cost savings by using right spacing and location
e) Enhanced sense of security through the use of effective methods and suitable design. This can give the impression that a place is secure and safe.
f) Enhanced sense of economic sustainability;
g) Enhanced safety for drivers, cyclists, and pedestrians; enhanced traffic direction; and better perception of a pleasant environment.

2.1.2 Design Parameters (Illuminance Based) :

Maintained average illuminance:

Illuminance to be calculated at each grid point,and then some of all illumination value divided by total number of grid point,gives average illuminance.

Overall uniformity :

It is defined as $\frac{E_{\min}}{E_{avg}}$. So out of total grid points there must be one or two points where minimum illumination observed, that minimum value divided by average illumination which calculated prior,gives overall uniformity.

Longitudinal uniformity:

For the central grid line the ratio of minimum to maximum illuminance is a measure of uniformity.A good longitudinal uniformity ensures comfortable driving conditions without the ‘zebra’ effect.

Lateral uniformity:

For the grid line just below the luminaire, the ratio of minmum to maximum illuminance is a measure of lateral uniformity.

In case of **luminance** based design, beside the above parameters designer have to consider some other parameters

Veiling luminance:

the light from the glare source scattered in the direction of the retina will cause a bright veil to be superimposed on the sharp image of the scene infront of the observer,this veil can be considered as having certain luminance,called veiling luminance.

$$L_{veiling} = k\sum_{i=1}^{n}\frac{E_{eye}i}{\theta_i^2}$$

Threshold increment:

The percentage increase in brightness level needed to make an object as observable as when there is no glare is known as the threshold increment.

$TI = 65\times\frac{L_{veiling}}{L_{avg}^{0.8}}$;L_{avg}=average luminance of the object or road surface

2.1.3 Classification Of Installations :

A street's amount and kind of lighting are mostly determined by how important it is for both vehicular and pedestrian traffic. Aesthetic considerations, the characteristics of the street (whether a shopping area or a ring road in non-built-up area), aesthetic considerations, the properties of the carriageway surface, the existence of humps, bends or long straight stretches, and overhanging trees are all relevant factors that should be taken into account when designing the lighting system.

The classification is one of lighting andnot of roads, but is linked with traffic density.The choice of the lighting category for a particular route is left up to the local engineer.

Street lighting is divided into the following categories:

Group A- For main roads. This is sub-divided into two categories:

> Group A1- For very important routes with rapid and dense traffic where the only considerations are the safety and speed of the traffic and the comfort of the drivers.
>
> Group A2 - Other main roads carrying mixed traffic like main city streets, arterial road and throughway roads.

Group B- For secondary roads which do not require lighting up to Group A standard. This is also divided into two categories:

> Group B1- Secondary roads with considerable traffic like principle local traffic routes and shopping.
>
> Group B2 - Secondary roads with light traffic.

Group C- Lighting for residential and unclassified roads not includedin the previous groups.

Group D- Lighting for bridges and flyovers.

Group E- Lighting for town and city centers.

Group F- Lighting for roads with special requirements, such as roads near airfields, railways and docks.

TABLE 1 : CLASSIFICATION OF LIGHTING INSTALLATION AND LEVELS OF ILLUMINATION[3]:

Classification of Lighting Installation	Type of Road	Average Illuminance on Road Surface	Uniformity Ratio (E_{min}/E_{avg})	Transverse Uniformity (E_{min}/E_{max})
Group A1	Important traffic routes carrying fast traffic	30	0.4	0.33
Group A2	other main roads carrying mixed traffic like main city streets,arterial road and throughway roads	15	0.4	0.33
Group B1	Secondary roads with considerable traffic like principle local traffic routes and shopping	8	0.3	0.2
Group B2	Secondary roads with light traffic	4	0.3	0.2

2.1.4 Types of Arrangement:

Different types of luminaire arrangements as a function of the effective road width, w. There are four basic types of street lighting layout arrangements used for streets or highways illumination.

Single sided pole arrangement-

located on one side, if width of the road less than or equal to mounting height. $W \approx h_m$

Fig 1 : Single sided pole arrangement

Both sided opposite pole arrangement-

located opposite one another. When width is 2-2.5 times the mounting height. $W \approx 2h_m$

Fig 2: Both sided opposite pole arrangement

Both Side Staggered pole arrangement-

located on either side of the road in a staggered or zigzag fashion when width is 1.5 times the mounting height. $W \approx 1.5h_m$

Fig 3: Both Sided Staggered Pole Arrangement

Twin central pole arrangement-

In Twin central arrangement, the luminaries are mounted on a T-shaped in the middle of the center island of the road. The central reserve is not too wide, both luminaires can contribute to the luminance of the road surface on either lane. The installation height of the lamp be equal to the effective width of the road.

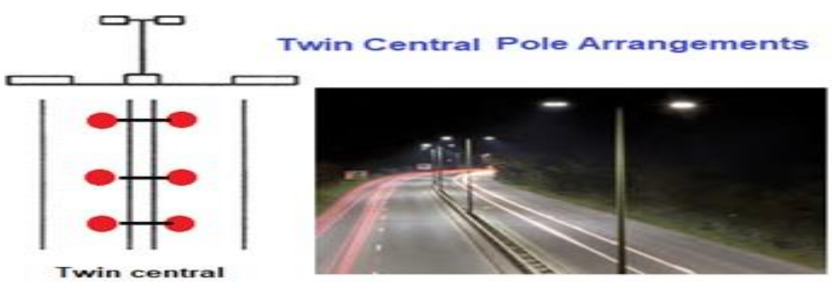

Fig 4: Twin central Pole Arrangements

2.2 VISIBILITY OF TARGETS IN ILLUMINATED ROADS :

An object will be visible on the road only if the contrast of the object with the background is above the threshold value of contrast. Basically there are two types of contrast. One is positive contrast; creates when the object's luminance is higher than the luminance of the background. And the another one is negative contrast; mostly visible at the time of road lighting.

The obstruction while spotting the objects on the road surface are:

i) the contrast between the luminance of the object and its immediate visual background.
ii) the general level of adaptation of that portion of the retina of the eye concerned with the object.
iii) observer duration on road
iv) the size, shape of the object
v) disability glare - the amount of veiling luminance entering the eye
vi) transient adaptation - the difference in eye adaptation between successive eye movements
vii) the background complexity and the dynamics of traffic
viii) visual capability of drivers.

The designers assumed that both the object (target) and the background luminance are uniformly distributed. And it is assumed that:

- Increasing luminance increases visibility
- Increasing contrast increases visibility. Given a dark object on a bright background or a bright object on a dark background, seeing improves.
- Increasing visual size of any object increases visibility.
- Given the more time to see a target, likelihood of target acquisition becomes better.

Numerious experiment has been carried on over last 70 years to find out visibility criterion on the road surface.On the basis of Blackwell's laboratory research, the International Commission on Illumination (CIE) introduced in 1972 the Visibility Level (VL) of the critical object on the road surface is defined as

$$\text{VL} = \frac{\Delta L_{\text{actual}}}{\Delta L_{threshold}}$$

Where, ΔL_{actual} is the luminance difference between the target and its background in the real conditions

$\Delta L_{threshold}$ is the luminance difference needed for minimal visibility, between a target of certain angular size and its background.

At the end of 1970s, Adrian finally led to a calculation model of VL in the road. Currently, Adrian's formula is the basis for Small Target Visibility (STV) criterion.

In United States, STV is the third criterion while designing road lighting apart from illuminance and luminance.

2.3 ENERGY SAVING:

A city's responsibility to provide street lighting is of paramount importance. In typical cities throughout the world, street lighting consumes between 15-40 % of all electricity. The cost of street lighting can be reduced by 35-70% with energy-efficient findings and design. With such savings, the requirement for new power plants will be reduced or eliminated. Savings like these enable the provision of alternate energy options for residents of remote places. Municipalities may be able to increase the availability of lighting in low-income and other sub-urban areas by expanding street lighting in additional locations thanks to these cost savings. Additionally, better lighting can raise the level of safety for pedestrians and vehicular traffic.

Users should be able to travel at night with good visibility thanks to a well-designed, cost and energy-efficient lighting system. Inadequate lighting is frequently underestimated and improperly assessed, resulting in the waste of priceless energy resources. Therefore, energy management in street lighting is crucial today in order to use only the minimum amount of energy necessary and prevent the creation of extra energy.

Today, a number of innovative methods are being explored to reduce the amount of energy consumed for street lighting. Every nation has its own set of rules governing street lighting. Every technique used across the globe complies with the standards set forth and varies slightly from one country to the next while still aiming to reduce energy usage.

The first approach entails turning on the lights when necessary and turning them off when not in use. Street lights already use a huge amount of electricity since they automatically turn on as dusk approaches and turn off as dawn gets closer. This is a significant energy waste, and the plan for execution needs to be changed. This intelligent street lighting system consists of an LED light, brightness and motion sensors, as well as a local area network for data transmission. Just before pedestrians and cars pass, the lights turn on, and they turn off or dim when they do.

Cost-effective and energy-efficient street lighting lowers the need for electricity. We can save our lives from danger by increasing lighting's energy efficiency, and we can provide drivers and pedestrians a sense of security and hope on the roads by installing adequate lighting.These are some of the techniques for energy efficient street lighting:

i) Replace existing sodium and incandescent lamp with LED lamps which take 75 percent less power than the ordinary bulb. They provide equivalent illumination as of incandescent lamps while consuming less than 80 percent electricity of the same lamp. LED lamps last longer as their life span is around 50000hr.
ii) When installing a CFL light, we provide the chokes and ballasts that are necessary. Utilizing them lowers the amount of energy required and the power factor, increasing the effectiveness of the bulbs being utilized.
iii) The height at which the luminaries are present, matters as improper mounting leads to wastage of lumens.
iv) Light level can be automatically controlled according to a surrounding light intensity.
v) Control of the light intensity based on the movements of people or vehicles.
vi) Remote management possibility in case of breakdown.
vii) Maintain the proper poll height and use proper reflector to reduce the wastage of light and minimal level of light pollution.

Every time a new technique is used, a gradual increase can be seen. Everyone is concerned about energy conservation. It is essential to preserve the quality of the environment. The major goal of this project is to install automatic street lights that use less energy and produce sustainable results. In this instance, standard sodium vapour lamps are replaced with LEDs made by Crompton, and IR sensors are utilized to monitor vehicle movement and manage lamp lighting. This, in our opinion, will contribute to significant energy savings and extend the lifespan of lighting systems.

2.4 HUMAN CENTRIC LIGHTING:

Traditionally the lighting industry has designed products to enable and support our vision. Recent scientific insights, however have shown that life does a lot more than enabling us to see and be seen. Human biology is directly linked with the daily rhythm of the sun. with the discovery of the third photo receptor (Ganglion cells containing melanopsin called “Intrinsically Photosensitive Retinal Ganglion cells”, ipRGC) in the human eye , we now know and understand how light affects our hormone system to make us awake when the sun rises and absence of light makes us feel sleepy after sunset.

HCL is intended to go beyond illumination. It’s intentionally designed to promote a person’s well being, mood and health. We defined it as evidence based lighting solutions for improved vision, well-being and performance. A simple way to how it works and easiest to remember is that blue light with intensity level activates our body by increasing the level of Cortisolhormone in our blood and reduces the secretion of the sleep hormone Melatonin. In darkness or low light level of red light this secretion is not suppressed. This explains the so called circadian rhythm (body’s sleep/wake cycle) or how we have evolved in sync with the sun. when the sun rises, light levels increases, the cortisol level in our blood increases, and we became active. Variation with the highest rate of rise in the early morning, peaks at noon and lower levels in the evening. After sunset in absence of artificial light the body will increase the melatonin levels in our blood as a result of which we become sleepy.

These insights can be used in various ways.

I. It can support us to live a more natural life even when spending most of our time indoors, this can be done by increasing light level during the day, yet avoid high level of blue light in the evening that could otherwise disturb our sleep.
II. It increases the concentration level of students, resulting in improved school performance.
III. In healthcare it supports patient’s recovery and enhanced drug efficacy.
IV. In industry better vision will result in less rejects and higher productivity. Dynamic lighting strategies can support night shift worker to reduce the impact of shift work on their biorhythm.

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CHAPTER-3

3.1 SMALL TARGET VISIBILITY (STV) CALCULATION METHOD:

STV value is based on Adrian's visibility model with all of its simplifications.In the draft RP-8 (1998), the *Small Target Visibility* (*STV*) concept has been proposed for roadway lighting design. This came from the assumption that only pavement luminance is not sufficient to see an object. It is necessary to have a difference in luminance of object and background for the object to be visible. This difference in luminance has to be above a certain minimum value for visibility. This difference with respect to a threshold luminance value is termed *Visibility Level* (*VL*).

Small Target Visibility (STV) is a weighted average of the values of target Visibility Level over a grid of points on an area of roadway for one direction of traffic flow.

Theoretical STV calculations were made using the Keck software for a specific lighting scenario, and the approach is documented in the RP-8-00[13].By assuming perfect circumstances on the road, the program(Keck program) determines the theoretical visibility level distribution between the luminaires. Only fixed highway lighting luminaires are taken into account when calculating visibility level in order to provide roadway and pedestrian lights.

The ratio of actual to threshold contrast represents VL. VL is just the actual contrast in comparison to the contrast required by the reference job when defined in this fashion. With a VL of 5, a target's luminance contrast is 5 times more than what is required for threshold perception for the particular observer. VL varies inversely with observer age and directly with target size and contrast. VL at a specific location has no significance and cannot adequately describe a driving condition, but the typical VL of a section of road in front of the driver may be an indicator of the effectiveness of the lighting system.

Road luminance, luminance uniformity, and glare restriction were three technical lighting factors that Hall and Fisher (1978) used to study the design of a roadway lighting system. Within the constrained range of contrast, a target of 20 × 20 cm is employed in the calculation. They discovered that lighting design based on a visibility matrix needs to be simplified. A conventional 20 x 20 cm target with an 18% diffuse reflecting surface (Kodak grey card) was utilised by Jug and Titishov (1987) for their studies. They discovered that fixed lighting has an excessive number of transient quantities that are challenging to define. The luminance design standard is used in the study as reflected light, while the illuminance design standard is used as an incident light alone design. Marsden (1976) conducted numerical and experimental study on road lighting, visibility, and accident reduction. They measured the amount of vertical, horizontal, and veiling brightness that caused handicap glare. On the type, they captured all the data as well as the driver's field of vision. The same field is also the subject of a calculation.

Small target 18 x 18 cm square with 20% diffuse reflective surface as required by RP-8 (IES, 1990). This target size is allowed because it is the largest dimension a car can pass on it without any collision. According to Freedman et al. (1993), older drivers generally displayed a much decreased likelihood of target detection. They also demonstrated that the probability of recognising a target substantially relies on the type of target.so that the Size, shape, and reflective surface of the target cannot be chosen at random. Some researchers employed targets of a different size than STV targets.Roper (1953) examined the visibility matrix using a 40.64 cm2 square target with a 7.5% reflecting surface. A sizable target with a mean linear dimension of 91.4 cm and a 15% reflecting surface was employed by Haber (1955). A target made of a Landholt ring with a stroke width of 8.7 cm and a height of 43.5 cm was utilized by Waetjen et al. in 1993. Zwahlen and Schnell (1994) employed a target that was 60.96 cm square, positioned 30.48 cm above the road's surface, and had different reflecting surfaces.

For a roadway lighting installation meets the criteria of RP-8-00[13], and the following conditions are assumed and published in RP-8-00[13].

The observer is located on a line parallel to the centerline of the roadway that passes through thecalculation points .The observer located on the line at the distance 83.07 meters from the point.With a 1° downward view from the horizontal, as the defined observation geometry, the fixationline meets the road at 83.07 meters at 1.45 meters eye position from the road. The target is located at the intersection of two grid lines.
The pavement’s surface is assumed level, uniform, homogeneous dry and to have directional light reflectance characteristics, which are expressed in terms of a reduced luminance coefficient. The target’s surface is assumed to be perfectly diffuse, vertical and perpendicular to a line fromthe observer to the grid point, and the light is reflect in a Lambertian manner. Only fixed lighting luminaires installed for the purpose of providing roadway and pedestrian lighting are considered in the calculations. The distribution of those luminaires is assumed to be representing by a table of luminous intensities.
The accuracy of calculations for pavement luminance, and STV not only depends on the above assumptions, but also depends upon the following conditions:

The lighting design calculation must include a Light Loss Factor (LLF).Whether or not the photometric data used to determine the candle power intensity at a particular angle correctly represents the output of the lamp and luminaire. Whether or not the directional reflectance tables (r-tables) provides accurately directional reflectance coefficients of the actual surface.

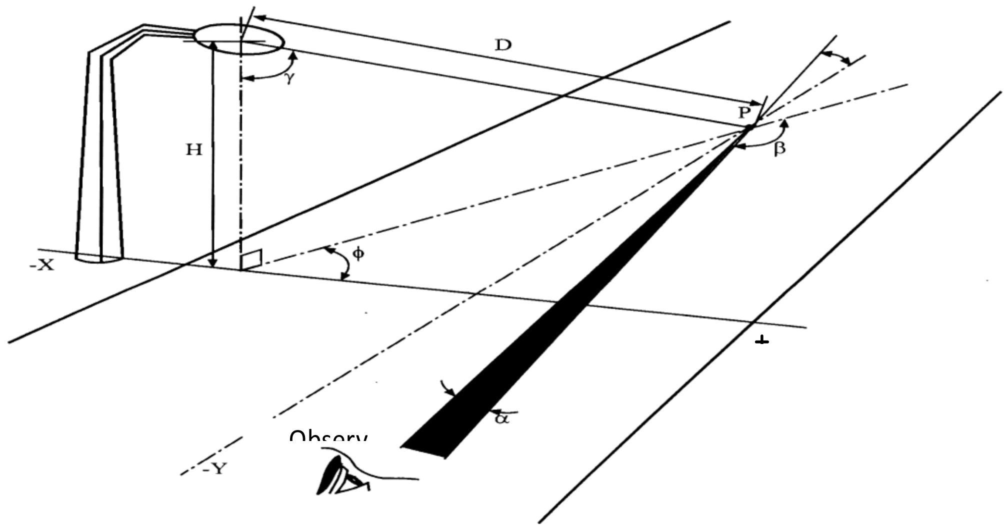


Fig 5: Single luminaire

The visibility level formula is defined in RP-8-00[13] and elsewhere, as shown in the following equation:

$$VL = \frac{L_t - L_b}{DL_4}$$

Target Luminance, $L_t = \dfrac{I(\phi,\gamma)\times(\cos\gamma)^2 \times \sin(\gamma)\times[\cos(90-\phi)]\times 0.5\times LLF}{[H-(0.5\times TH)]^2\times\pi}$

I = Intensity at angles gamma and phi

H = Luminaire mounting height above the pavement surface (meters)

LLF= Light Loss Factor

0.5 = Reflectance Factor (diffuse)

TH = Target Height (typically, 0.18 m)

3.1.1 Veiling Luminance Calculation Method :

The light from the glare source scattered in the direction of the retina will cause a bright veil to be superimposed on the sharp image of the scene infront of the observer. This veil can be considered as having certain luminance,L_v. L_v can be calculated by using the following empirical formula derived for one single luminaire.

$$L_v = \frac{K}{\theta^n} = \frac{10 \times E_v}{\theta^n}$$

$$n = 2.3 - 0.7 \times Log_{10}(\theta) \qquad , \text{for } \theta < 2$$

$$n = 2 \qquad , \text{for } \theta \geq 2$$

where:
L_v = Veiling Luminance from one individual luminaire
K = 10 (Vertical illuminance at the plane of a 25-year-old observer's eye)
θ = Angle in degrees

on the footway surrounding to the center of the bottom of the target the background luminance (L_{b1}) is calculated. Background luminance (L_{b2}) is calculated on the footway which is 11.77 meters from from away from the target, at a point on a line projected from the observer's point of view through the point at the center of the top of the target. We can say $L_{b1}$is background luminance at the upper boundary of the target and L_{b2} is background luminance at the lower boundary of the target.
Background luminance (L_b) is calculated by taking arithmetic average of $L_{b1}$and L_{b2}as $(L_b = (L_{b1} + L_{b2})/2)$

3.1.2 Adaptation luminance Calculation :

$$L_a = L_b + L_v$$

$$LL_a = Log_{10}(L_a)$$

$$A = \arctan\left(\frac{\text{Target size}}{\text{Distance observer t o target}}\right)$$

Where, L_a is adaptation luminance and A is visual angle in minutes

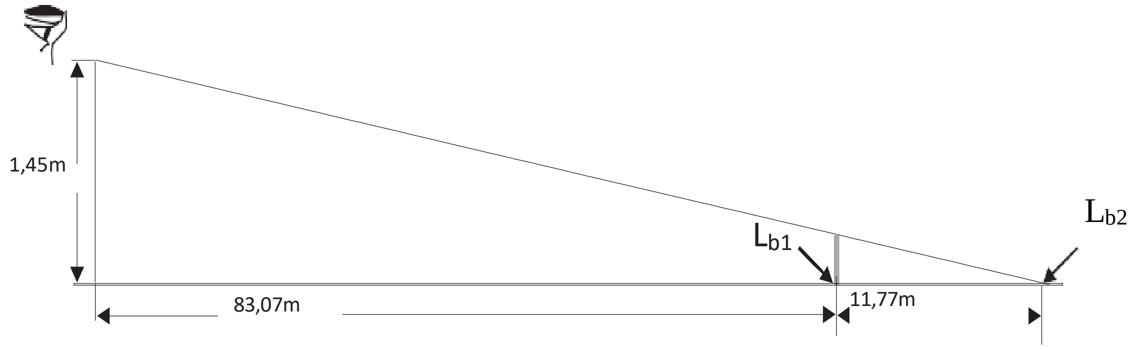


Fig 6: Luminance of target and background location on the pavement

The luminous flux function (*F*) and the luminance function (L) reflecting Weber's law are used in the model to estimate the sensitivity of the visual system.

Where L_a is greater than or equal to 0.6 cd/m^2, the functions are calculated as per following equations:

$$F = \left[Log_{10}\left(4.284 \times L_a^{0.1556}\right) + \left(.1684 \times L_a^{0.5687}\right)\right]^2$$

$$L = \left(0.05946 \times L_a^{0.466}\right)^2$$

If L_a greater than or equal to 0.00418 and less than 0.6

then $F = 10^{\left\{2\left[\left((0.0866 \times \mathrm{LL}_a^2) + (0.3372 \times \mathrm{LL}_a) - 0.072\right)\right]\right\}}$

and $L = 10^{[2(0.319 \times \mathrm{LL}_a - 1.256)]}$

If L_a less than or equal to 0.00418

then $F = 10^{(0.346 \times LL_a + 0.056)}$

and $L = 10^{\left[\left(0.0454 \times LL_a^2\right) + \left(1.055 \times LL_a\right) - 1.782\right]}$

Calculate some constant to obtain DL_1 using the following equation

$$B = Log_{10}(A) + 0.523$$

$$C = LL_a + 6$$

$$AA = 0.360 - \frac{\left(.0972 \times B^2\right)}{\left\{B^2 - \left(2.513 \times B\right) + 2.789\right\}}$$

$$AL = 0.355 - \frac{\left(.1217 \times C^2\right)}{\left\{C^2 - \left(10.40 \times C\right) + 52.28\right\}}$$

$$AZ = \frac{\sqrt{AA^2 + AL^2}}{2.1}$$

$$DL_1 = 2.6 \times \left[\frac{\sqrt{F}}{A} + \sqrt{L}\right]^2$$

The value of a negative contrast adjustment factor (FCP).
not accurate when LL_a is less than -2.4.
If LL_a greater than -2.4 and less than -1

then $M = 10^{-10^{-\left\{\left[0.075 \times (LL_a + 1)^2\right] + .0245\right\}}}$

if LL_a greater than or equal to -1

then $M = 10^{-10^{-\left\{\left[0.125 \times (LL_a + 1)^2\right] + .0245\right\}}}$

The value of TGB will be $-0.6L_a^{-.1488}$

And FCP will be $1 - \left[\frac{(M) \times (A)^{TGB}}{1.2 \times (DL_1) \times (AZ + 2)}\right]$

Otherwise if the value of LL_a is less than or equal to -2.4 ,

Then the value of FCP will be considered as 0.5(TGB and FCP need not be calculated)

With the change in observation time we can adjust DL_1 accordingly, Where T is the observation time

$$DL_2 = DL_1 \times \left[\frac{(AZ + T)}{T}\right]$$

The value of DL will also change in accordance with the observer age (TA)
If the age of the observer is less than or equal to 64,

then $FA = \frac{[(TA - 19)^2]}{216} + 0.99$

otherwise, $FA = \frac{\left[(\text{TA} - 56.5)^2\right]}{116.3} + 1.43$

$DL_3 = DL_2 \times FA$

Calculate the adjustment if the target is darker than the background (negative contrast)

If $L_t < L_b \Leftrightarrow DL_4 = DL_3 \times FCP$

Otherwise, $DL_4 = DL_3$

Visibility Level (VL) $= \frac{L_t - L_b}{DL_4}$

3.2 EXPERIMENTAL PROCEDURE AND SETUP :

The main purpose of the experiment is to observe the change in visibility level under different CCT for different object size. So it has been conclude, which size of object is less visible and which one is more visible. And reasonable idea will deduce about the dependency of visibility on CCT.

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 size(square, prismatic & cylindrical) of object with three different colour(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 1.048 m 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 Tempareature), which is used to illuminate the target.

- With the help of luminance meter, readings are taken at the middle of the target.

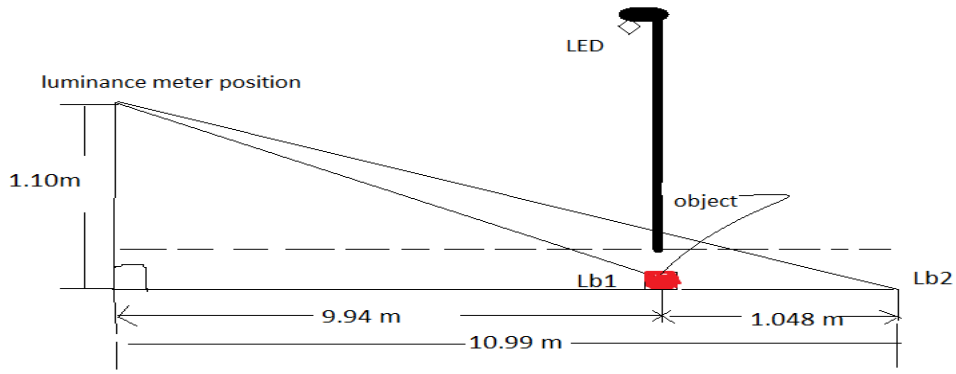


Fig 7: Experimental Setup

3.3 EXPERIMENTAL EQUIPMENT:

The following equipments are used to measure the data :

3.3.1 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/m^2 or foot-lambert (ft-L).

Fig 8: Luminance meter

3.3.2 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.

Fig 8: Distance meter

3.3.3 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)**

Fig 9: Different size of object with different colour

3.3.4 Halonix Prizm Smart 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.

Fig 10: Halonix Prizm Smart LED

3.4 **EXPERIMENTAL DATA :**

With the help of luminance meter and distance meter, target luminance and background luminance has been measured for different size and shape of objects. CCT of the lamp has been varied with the help of mobile app. Data's of the experiment are tabulated below.

Table 2: Experimental Data

object size	**colour**	**dimension**	**CCT**	**target luminance (Lt) (cd/m²)**	**Background luminance1 (Lb1) (cd/m²)**	**Background luminance2 (Lb2) (cd/m²)**
Square	**Yellow**	8cm X 8cm	3000 k	1.001	0.65	0.298
			4000 k	1.121	0.521	0.327
			5000 k	1.097	0.557	0.35
			6000 k	1.129	0.418	0.252
Prismatic	**Green**	H =8 cm B= 10 cm	3000 k	0.63	0.434	0.117
			4000 k	0.73	0.445	0.221
			5000 k	0.795	0.432	0.118
			6000 k	0.745	0.396	0.178
Cylindrical	**Violet**	H=10cm D=9cm	3000 k	0.246	0.569	0.11
			4000 k	0.296	0.565	0.098
			5000 k	0.252	0.466	0.084
			6000 k	0.245	0.503	0.112

CHAPTER-4

4.1 VISIBILITY LEVEL CALCULATION (Using Python):

Python programming has been used for calculation of Visibility level under different CCT condition, Which is based on STV model. Steps of the programming are shown below.

```
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)
A=math.atan2(x, d)*180* 60 /math.pi
print("A :",A)
LL=math.log10(Lb)
print("LL :", LL)

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
elifLb> 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))

print("F :", F)
print(" L :", L)
B= math.log10(A)+.523
print("B :",B)
C= LL+6
print("C :",C)
```

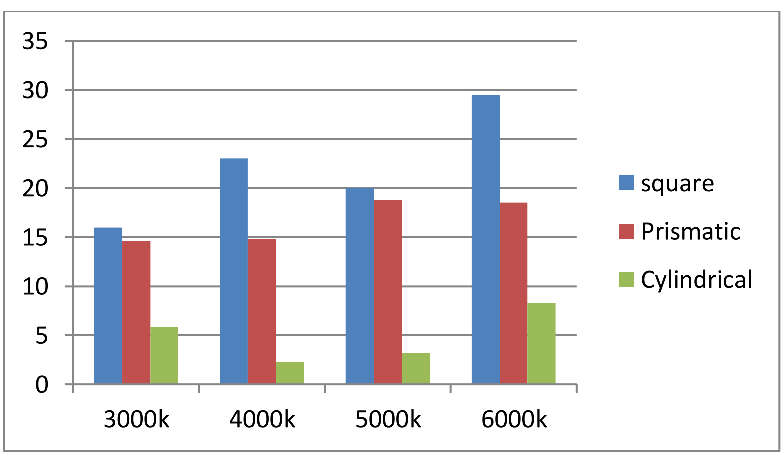
```
AA = .360 - ((.0972*(B**2))/(B**2-(2.513*B)+2.789))
print("AA :",AA)
AL = .355 - (.1217*(C**2/(C**2-(10.4*C)+52.28)))
print("AL :" ,AL)
AZ= math.sqrt((AA**2+ AL**2)/2.1)
DL1=2.6*(((math.sqrt(F)/A)+math.sqrt(L))**2)

if  LL> -2.4 and LL < -1 :
    M=math.pow(10,-1* math.pow(10, -((.075*((LL+1)**2))+.0245)))
    TGB=-.6*(math.pow(Lb, (-.1488)))
    FCP=1-((M*math.pow(A, TGB))/((1.2*DL1*(AZ+2))))
elif LL>= -1:
    M=math.pow(10,-1* math.pow(10, -((.125*((LL+1)**2))+.0245)))
    TGB=-.6*(math.pow(Lb, (-.1488)))
    FCP=1-((M*math.pow(A, TGB))/((1.2*DL1*(AZ+2))))
else:
    FCP=0.5

DL2=DL1*((AZ + T)/T)
if TA <= 64 :
    FA= ((TA -19)**2/2160)+.99
else:
    FA= ((TA -56.5)**2/116.3)+1.43

DL3=DL2*FA

if Lt< Lb :
    DL4=DL3*FCP
else:
    DL4=DL3
VL= (Lt-Lb)/DL4
print("VL is:",VL)
```

4.2 RESULTS & COMPARISON:

Adrian first described a visibility formula in 1989, and visibility levels were used as a quality criterion in North America. Currently, the Small Target Visibility (STV)[13] criterion is based on Adrian's formula[4].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 new concept in European nations. Therefore, a comparison of visibility level using the Adrian model and the STV model under various CCTs for various object sizes is presented below.

Table 3: Comparison of Visibility Level Using STV Model & Adrian Model under different CCT

Size & colour of the object	CCT	VL using STV model	VL using 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



Plot 1: Visibility Level vs CCT

4.3 DATA 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 STV 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 STV model, using 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 our laboratory three different colour objects are being used with different CCT value while taking the readings. So we have got a certain range of VLs . 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.
Here three different size of objects have been taken with three different colour. And calculate the visibility under different color temperature. It is observable that object will be highly visible under higher CCT compare to lower CCT. In case square type objects visibility level increases and cylindrical objects are less visible under artificial light. Visibility level of prismatic type object lies in between square and cylindrical type objects.

CHAPTER-5

5.1 CONCLUSION:

By meeting the basic lighting requirements throughout its operation, a properly planned and implemented road lighting system should provide adequate visual conditions for all of its users. All traffic participants, including cars, bikers, and pedestrians, should have vision that allows them to fulfil their respective visual jobs. However, because drivers' visual tasks are considerably more challenging than those of other traffic participants, and because they have less time to make a decision and execute any movement, it is these activities that are truly considered when evaluating the visibility of road obstacles.The driver's visual tasks should not be restricted to identifying a stationary object at a given area on the road; instead, the visibility of an object should be assessed on three levels: position, situation, and navigation.Despite the fact that Adrian's mathematical model of the VL needs to be extended, it provides a solid platform for future research. Finding a solution to the author's queries is extremely difficult and requires the conduct of multiple scientific experiments. The findings of such research will undoubtedly contribute significantly to the development of methodologies for planning local road lighting systems.

A number of complicated variables, including as the mesopic visual performance and windshield transmittance of moving vehicles, which have an impact on the driver's vision conditions, affect how well a road lighting installation performs. It is highly expected that in the near future, road lighting design and calculation systems that are substantially more sophisticated than those currently in use (such as DIALux and Calculux) will be created in order to simulate the actual visibility conditions of drivers in those situations. On the basis of the numerous intricately interconnected components that make up the road lighting environment, these algorithms can be used to compute the features of high-quality road lighting.

5.2 FUTURE SCOPE OF WORK:

Target parameters

a. For circular targets of comparable size, contrast detection thresholds are slightly lower for extended targets. Research could be used to improve the model's precision by offering a suitable target shape adjustment factor.
b. Contrast sensitivity is known to vary with temporal modulation, target size, and observer age, despite the model's assumption that targets are stationary with respect to the observer. Additionally, as a function of approach velocity, the size of an angular target increases exponentially for an approaching observer.

Additionally, it has been noted that drivers prefer to pay more attention to motion than to expectation when detecting new objects. There is proof that in low light pedestrian "biological motion" is more noticeable. According to one study, even in the face of visual clutter, individuals wearing a biological motion configuration were seen more frequently and farther away than those wearing luminous vests. It is likely that the prediction of visibility on dynamic tasks could beenhanced by research on VL as a function of target size, visual field location and spatial context, motion rate and motion type for observers of different age.

c. The present VL model assumes that targets are viewed on the fovea, where contrast sensitivity and acuity are at their best, but that the detection of peripheral targets degrades as a function of retinal eccentricity. Complex backdrops and apparent motion within also decrease it. It has been proposed that location and context factors could be addressed generally by using existing road classification data to create reference driving scenarios in which relevant parameters like workload, scene complexity, speed, and retinal eccentricity are assessed with the goal of defining scenario-specific VL recommendations.

Observer factors:

a. Visibility issues for senior drivers at night are made worse by age-related vision degradation. By carefully examining age-related variations on VL, the claim that the model's age adjustment understates the negative impact of age-related visual deficiencies on VL might be tested.
b. The model is based on threshold data from extremely sensitive, dark-adapted observers, however observer adaptation levels on real-world activities vary greatly. For instance, drivers may not be well suited to locate targets in darker off-road regions since they frequently focus on the end of their headlamp beams.It would be more universal to calculate VL using a light adaption factor based on observer age, according to research.
c. According to a field research, when the identical observers are passengers rather than drivers, detection distances for small targets are noticeably longer. The authors came to the conclusion that target visibility is hampered by even very low information-processing demands. It has also been demonstrated that more seasoned drivers are better at allocating their visual attention than less seasoned ones.These results highlight the importance of taking into account cognitive load and driver/observer experience when determining task-specific VLs.

CHAPTER-6

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