Chapter 7
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An Elite Roadway Illuminance Calculation (ERIC) Method Provides Optimum Performance and Cost-saving without Compromising Safety

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ABSTRACT

This paper addresses the difficulties and consequences of the luminance calculation method for roadway lighting applications and recommends a novel illuminance calculation method as the best fit for Roadway Lighting Applications. This change would lower the costs of roadway lighting design while increasing safety, benefiting both society and the profession. Luminance calculations are complex, taking approximately five times as long as the new illuminance calculation method, providing no additional insight, and yielding the same design outcome. This paper conducts a comparative study and analyzes both methods using regular comparative analysis, quantitative and qualitative assessments, and offers a solution to the over-50-year-old challenge. The quantitative evaluation uses a sample case study and examines its corresponding benefit-cost ratio. The qualitative approach entails conducting a survey of peers and lighting designers. This is the first paper to address all of the parameters of roadway lighting in a comprehensive manner. This paper will be helpful for academics, researchers, scientists, engineers, consultants, architects, lighting designers, contractors, developers, financial institutions, and government agencies funding outdoor lighting.

Keywords: Roadway lighting; illuminance; luminance; visibility; pavement; reflectance.

1. INTRODUCTION

The luminance method was created in the 1970s, documented by the Commission International de l'Éclairage (CIE) in 1982 [1,2], and adopted by the Illuminating Engineering Society of North America (IESNA) in 1983 [2,3]. Illuminance is the amount of luminous flux that falls on a surface, whereas

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luminance is the amount of luminous flux that leaves a surface [4]. The luminance of any point on a road surface is determined by the reflection properties of the pavement material. The luminance value can be calculated using the typical R3-type asphalt road surface property. As a result, IESNA converted existing illuminance values to luminance values based on roadway pavement classification [5]. It was assumed that the first step in developing a metric based on human vision. The use of luminance represents the luminous intensity per unit area in a given direction. It has been realized that the reflected light from the road surface toward the driver is better, more reliable measure than illuminance [5]. Therefore, IESNA has adopted luminance (cd/m2) as the primary metric for assessing lighting in straight roadways and tunnels and illuminance (lux) metric for all other applications [6]. Of the two metrics, luminance represents the driver's perception of the roadway surface or what the driver sees under certain conditions. Therefore, IES adopted luminance calculations for straight roadways as an established software calculation method [6]. Luminance calculations assume that the observer (driver) is in a fixed location at 83m and 1.45m elevation from the calculation points [6]. The calculation grid configuration for one luminaire cycle assumes a consistent number of lanes, luminaire, mounting height(s), arm length(s), and pole setback(s) are constant along the roadway.

2. BACKGROUND

The accuracy of the pavement luminance calculation depends on the appropriate light loss factor, photometric data, and directional reflectance table [5]. The lighting calculation can be accurate based on theory, but it does not correspond with reality. The luminance calculation for the roadway is more complex than the illuminance calculation. Achieving results that reflect reality is challenging, given that assumptions about observer position and lighting are rarely accurate. The road often curves and changes the number of lanes (road width), poles usually spaced unevenly with different mounting heights, the change of luminaire type, wattage, and distribution make it more complicated to achieve the acceptable luminance calculation results. The illuminance calculation applications include intersections, crosswalks, curved roadways and hills, roundabout, parking lot, and more [6]. These areas need more critical attention than straight roads for a driver. The luminance calculation method does not work for these vital areas due to the software limitation to set the variable observer positions.

Further, drivers seldom look 83m ahead at an angle 1 degree below the horizontal sightline, as is assumed with the luminance calculation method [6]. This assumption is even less accurate for pedestrians, who do not fix their attention that far down the road. Therefore, the luminance calculation values do not correlate with the perception of the driver. The purpose of the luminance calculation is to see the roadway's surface but achieving the actual luminance of the pavement is not possible because many variables influence the visual environment. One addition to this difference is a variation in road surface reflectance [7,8]. The luminance calculation method is also limited in unfavorable weather and wet road surface conditions due to changes in surface reflection [9].

The reflectance value of the pavement changes due to physical conditions such as ice, snow, wet, damp condition, and the pavement is not homogeneous and degrades over time. Therefore, the actual luminance varies based on pavement conditions, but this variation is not reflected in luminance calculations. The following Fig. 1 shows the typical illuminance and the luminance calculation method [10,11].

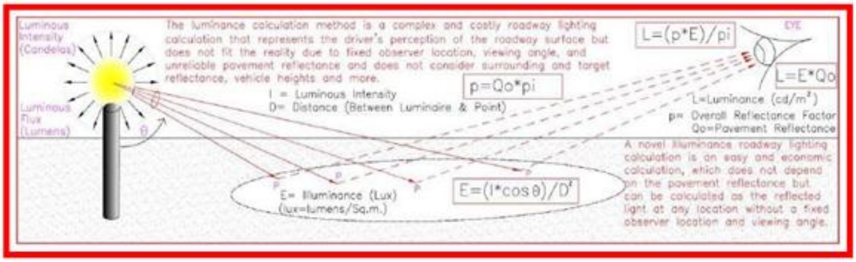

Fig. 1. Illuminance and Luminance calculations
Source: Compiled and Designed by the Author [10]

Horizontal (pavement) illuminance (E) is calculated as [10,11]:

$$\text{Horizontal Illuminance [E]} = \frac{\text{Intensity * Cosine angle [I cos}\theta\text{]}}{\text{Distance Square [D2]}} \quad (1)$$

Where: E = horizontal illuminance (lux), I = luminous intensity of a light source (cd), θ = the angle measured from the vertical to the incident ray, and D = distance between the source and point P (m).

Horizontal (Pavement) luminance (L) is calculated as the product of horizontal illuminance (E) and pavement reflectance (Qo) [10,11]. This is the direct conversion from illuminance. The directional reflectivity values slightly vary based on the observer's location and viewing angle.

$$\text{Luminance [L]= Illuminance * Reflectance [E * Qo]} \quad (2)$$

Where: L= luminance (cd/m2), Qo= pavement reflectance under the corresponding geometry (cd/m2/lux). The two different calculation methods and two different units of measurement create cumbersome in the same projects.

3. METHODOLOGY

A comparative study to evaluate the roadway lighting calculation approaches using illuminance and luminance methods is challenging since many lighting variables influence the calculation method. Therefore, the following concurrent triangulation assessments are expected to fill these gaps successfully. The comparative, quantitative, and qualitative concurrent triangulation method is the robust mixed method of research that will examine to find the solution to this complex issue. The researcher used hypothesis testing, a calculation case study, and a qualitative survey among colleagues and peers to validate the assessment. Fig. 2 below shows the Concurrent Triangulation Method.

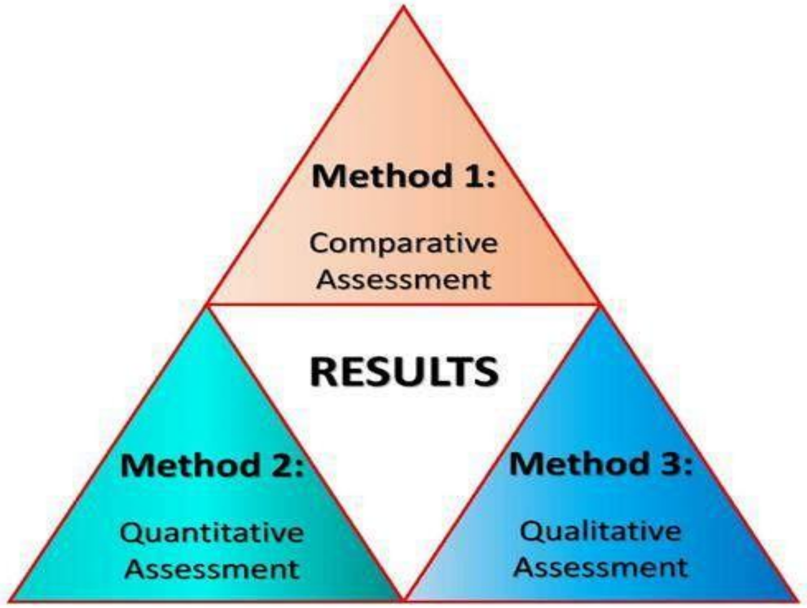

Fig. 2. Concurrent triangulation method
Source: by the Author

3.1 Comparative Assessment

The average pavement luminance is determined by three factors, the observer's location, the quantity and direction of light, and the reflective characteristics of the roadway pavement. On the other hand, illuminance measures the light incident on the roadway surface despite roadway reflectance or the oobserver's direction. Illuminance and Luminance design criteria are broadly used, but there is a strong correlation between the two metrics. RP-8-18's standards are luminance based, except for curve or hill roads and intersections where the requirement is illuminance based. Illuminance measures the light incident on the surface; observer direction and pavement reflectance are disregarded. There may be a growing interest in the role of pavement luminance in roadway lighting design, but it is a costly exercise, and the results do not fit reality. The comparative analysis is divided into four categories. Each section has its objectives and comparative analysis. We may have to pay attention to the following four main areas, as shown in Table 1, to identify the luminance lighting calculation deficiencies.

Table 1. The comparative analysis for lighting calculations methods

No	Categories	Description - Hypothesis Testing
1.1	Area Assumptions	Road Geometry, Pole Spacing, Mounting Heights, and Luminaire Types are not uniform
1.2	Calculation Assumptions	Observer position, Pavement Condition, Pavement Level, Users, and Luminance Value do not resemble reality.
1.3	Surrounding Area Lighting	Vehicle Headlight, Oncoming vehicle headlight, Off- roadway lighting, Moon, Star & Sky lighting, and area lighting are not included in the calculation
1.4	Visibility and Roadway Lighting	Luminance calculation does not resemble visual reality.

Source: by the Author

3.1.1 Area assumptions

The luminance calculation for the roadway lighting application is a time-consuming and expensive practice, but it does not seem to reflect the driver's visual reality in the Roadway. The designer may have to perform several lighting calculations between each pair of lighting poles for the following reasons:

a. **Road Geometry:** Most of the time road width is not uniform due to right & left-turn lanes and median island.
b. **Pole Spacing:** Pole spacing, and setback are not uniform due to several underground and overhead physical constraints.
c. **Mounting Height:** Pole mounting height and arm length are not uniform due to hydro or other types of poles.
d. **Luminaire Type:** The wattage, type, and distribution of the luminaires are sometimes different.
e. The Lighting and Geometric controlled variables for both calculations are listed below. Table 2 gives the relative complexity of the Illuminance vs. Luminance Calculations:

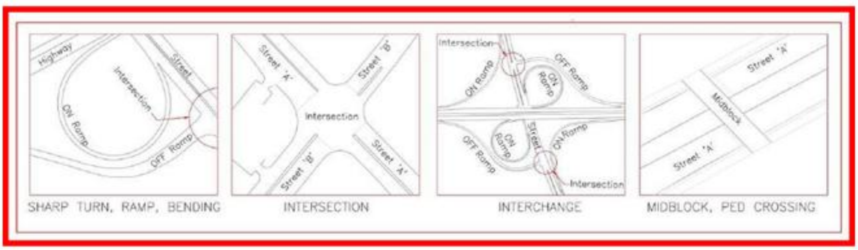

Fig. 3. The luminance calculation cannot be accomplished in the above critical areas
Source: by the Author

Table 2. The controlled variables

No.	Lighting and geometric variables	Horizontal illuminance	Horizontal luminance
2.1	Road Geometry (Number of lanes, Median, Sidewalk \ & Shoulder width,driver's eye)	YES (No Obsever eye)	YES
2.2	Pole spacing (Pole anrangement)	YES	YES
2.3	Mounting height (based on Type and length of arm and attachment height)	YES	YES
2.4	Luminaire Type (Wattage,Distribution, Luminaire optic type)	YES	YES
2.5	Observer Location (Fixed)	N/A	YES
2.6	Pavement reflectance	N/A	YES
2.7	Surrounding reflectance	N/A	N/A
2.8	Target reflectance	N/A	N/A
2.9	Car headlights	N/A	N/A
2.10	Sky Light (moon & Star)	N/A	N/A

Source: by the Author

The road geometry and the lighting equipment are used to calculate both illuminance and luminance measures. Lighting equipment and the geometric variable affect both illuminance and luminance calculations. From Table 2, the only difference is that luminance incorporates observer location and pavement reflectance. The fixed observer location does not resemble reality. The driver needs to observe signage, traffic signals, pedestrians, other vehicles, and more. Therefore, it does not serve the purpose. If the pavement reflection is constant, the illuminance value can be converted to the luminance value or vice versa. The lighting engineer needs to calculate multiple pairs of lights for luminance calculation, which is time-consuming. The lighting designer tries to avoid so many calculations assuming that the rest of the straight roadways will yield similar results. In reality, this is not the case, and it is considered incomplete work. After all, drivers and pedestrians do not observe only the area between two poles while driving. It is a full field of view, and the driver's foveal vision is based on the head position. It is more important to see all the roadways. From Table 1 and Fig. 1, we can conclude that the luminance calculation for the straight roadway does not produce any useful results. Further, it is easy to drive straight sections of the road but not in critical areas such as bends, intersections, midblock, interchange ramps, and pedestrian crossings. Therefore, the luminance calculation required for the driver to see the pavement luminance for the critical areas is more essential than the straight roadway. The luminance calculation cannot be performed in the Critical regions (as shown in Fig. 3) due to the software limitation.

Generally, a driver at nighttime gets proper guidance from the headlight, pavement markings, and the front vehicle's backlight than roadway lighting. Further, a driver observes the traffic signal heads, regulatory and warning signs, street names, and changeable message signs and pavement markings than the pavement surface. It is essential to see the critical areas of the roadway than the straight road. The driver and pedestrian need to see the luminance of these vital areas of the roadway. Unfortunately, we cannot accurately calculate the luminance in the critical areas. Therefore, the designer can only perform illuminance calculations for the roadway sharp turn, ramp and bending areas, intersection, midblock, interchange areas; and vertical illuminance in the pedestrian crossing area.

3.1.2 Calculation assumptions

The luminance calculation is built on many assumptions, and it applies only to a straight road. The following unrealistic assumptions (refer to Fig. 4) are the foundation of the luminance calculation:

Observer position: The lighting calculation software is assumed that the observer position and the direction of view are fixed. It is a very minimum chance for the driver to focus on the roadway's specific point or location when driving. Therefore, the calculation does not resemble reality. A driver needs a full field of view for safe driving. Driver observing angle changes all the time, including the different speeds of driving. Therefore, the Observer position and viewing angle are not fixed.

Pavement Condition: The lighting calculation software is assumed that the Pavement surface is dry and has directional light reflectance. Pavement reflectance characteristic changes over the period, including various weather conditions or wet, damp, snow, and dry condition. It leads to different reflectance/luminance values based on the condition of the pavement.

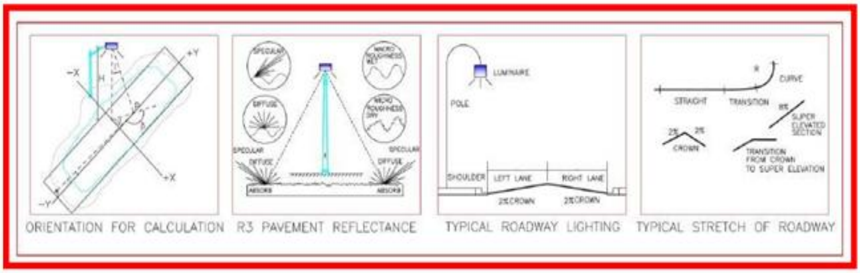

Fig. 4. Calculations, reflectance, typical lighting, and roadway
Source: by the Author

Pavement Level: The lighting calculation software is assumed that the pavement level or surface is homogeneous. A typical roadway has a 2% crown and an 8% superelevation [12]. Therefore, the reflectance value of the pavement at the calculated point different than reality. According to Sabey's report, the reflectance of the road surface can vary as much as 3: 1. Waldram verbally reported that the reflectance variation could be even higher than the ratios suggested by Sabey (1991). The changes in the surface characteristics will change the luminance as well. Therefore, the luminance calculation will not be an efficient and reliable tool for the roadway lighting calculation method, and it does not serve the purpose.

Users: The lighting calculation software is assumed that design lighting for the young person only. Drivers are not young people only. Therefore, an aging population with various eye sensitivity has a different perception of the roadway.

Luminance Value: The luminance values used do not backed by scientific justification or do not correlate with the complex human visual system and process, which varies from person to person.

The luminance of the roadway surface depends on the relative positions of the light source, the driver, and the directional reflectance characteristics of the pavement surface. The computer program calculates the pavement luminance using typical calculation techniques. Pavement luminance patterns, as viewed by the moving driver, are continually changing. Therefore, it may be practically impossible to achieve complete uniformity of pavement luminance. It is complex and only gives the luminance value of the moving Driver looks 83m away and 1 degree down the road. Therefore, it is missing 99% of other optional luminance values and does not reflect the real perception of the driver most of the time.

3.1.3 Surrounding area lighting

The surrounding area influences roadway lighting and visibility (refer to Fig. 5). The lighting calculation does not consider the surrounding area. Therefore, the lighting calculation does not fit reality for the following reasons.

Vehicle Headlight: Vehicle Headlighting provides illumination on the roadway. There is no interaction between vehicle-mounted lighting and fixed roadway lighting.

Oncoming vehicle headlight: Other factors, such as surrounding object reflectance and the interaction of oncoming vehicle headlight lighting, should also be considered, but it is difficult to quantify and is a large variable due to the changes in traffic volume at night.

Off-roadway lighting: There is surrounding or off roadway lighting, but there is no interaction between the off-roadway lighting and fixed roadway lighting. There is a legal consideration here to include such values if they can be calculated.

Moon, Star & Sky lighting: There are certain days of each month, especially full moon and stars contribute lighting, but there is no interaction between the sky lighting and fixed roadway lighting.

A lighting system designer always thinks of what the road will look like when the lighting system is energized. Unfortunately, the method based on horizontal luminance does not provide such information correctly. Further, 93% of the incident light is absorbed by the pavement, and only 7% is reflected from the surface. Therefore, we cannot rely on the luminance of the roadway for safe driving. People drive safely in the unlit area using vehicle headlight, pavement markings, and signage. Therefore, a driver needs a guide to drive safely, and having additional lighting provides more safe and comfortable driving.

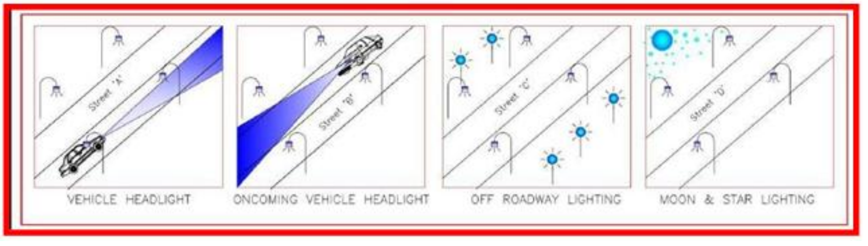

Fig. 5. Surrounding area Lighting are not included in the lighting calculations
Source: by the Author

3.1.4 Visibility for roadway lighting

Visibility is the capacity to extract information from the visual environment. Vision is a critical factor in the driving task as most of the information the driver receives comes through the visual sense. The driver can turn both eyes and head to gain a more extensive field of view and use peripheral vision to see objects or movements even without turning their eyes. Fig. 6 shows the foveal and peripheral view under the mesopic lighting condition of roadway lighting. The view ahead through the windshield has to be sufficient and open for the driver. It enables the driver to stop in an emergency and under necessary conditions. Similarly, rear and side views are essential for maintaining speed, taking turns, exerting a break, or parking [13].

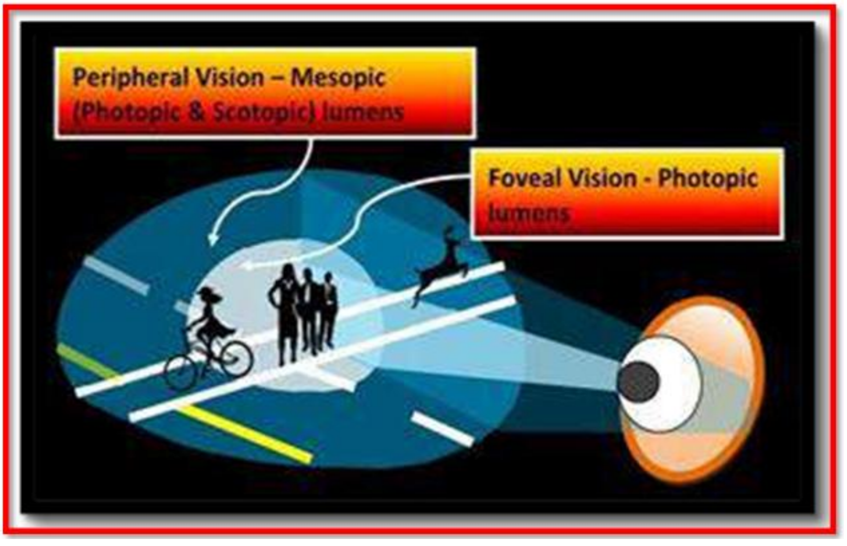

Fig. 6. The foveal and peripheral view under the mesopic lighting condition
Source: by the Author

Views close to the vehicle are necessary when turning left or right and maintaining proper distance to avoid accidents. The headlight and surrounding pavement marking, signage, and other illuminance from the vehicle and surrounding area lighting are sufficient to handle. Safe driving was possible in the unlighted area because of the headlight and the contrast and retro-reflectivity created by the pavement marking and signage.

The view of the driver can be represented in two-dimensional geometry by considering an unreal sightline (Horizon) passing through the driver's eye. The traffic signals and signage can be viewed angle above the horizon [12]. Therefore, the driver must concentrate on the direct way on the road for a longer view. The driver needs a much longer view to anticipate and prepare for avoiding accidents. It is where roadway lighting is going to play a role. The optimal roadway lighting may not be the one with the most uniform pavement luminance. Object contrast is necessary. The higher contrast and retro-reflectivity of the pavement marking, and signage create a distinct contrast to discern the information from the visual field to guide the driver than average luminance on the asphalt pavement [14]. The luminance values also do not have any meaning in our heads. It does not matter even if there is no reflected light from the black/grey asphalt. The light is reflected from the pavement markings, and signage is more important. A driver needs to observe the Pavement Markings, signage, Traffic Signals, pedestrians, and more in the field of view for safe straight driving, making turns or lane changing (Fig. 7). In this case, luminance calculation for the observer point at 83m away and one degree down in an obsolete practice and does serve it purpose.

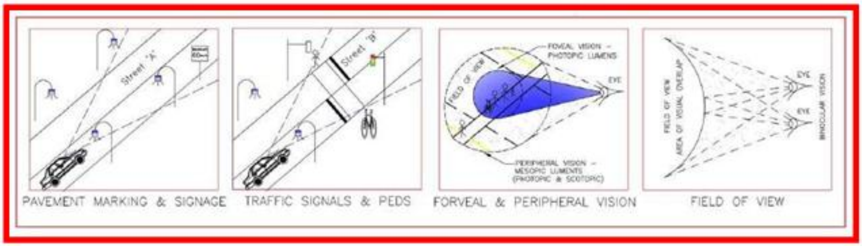

Fig. 7. Driver Observe the Pavement Marking, Signage, Traffic Signals & Pedestrian
Source: by the Author

The lighting calculation and light meter reading would show brighter for some light sources, but the human eye would object. The human eye responds to the Scotopic and photopic as well and would see the difference. Some light sources appear dimmer on a light meter and the calculation, but it would give better lighting. It would mean better visibility for the same number of watts used. It spreads a little light on why the meter and the calculation appear to be wrong. The nighttime roadway environment is flooded with photons from various directions, including fixed roadway lighting, adjacent lighting, environmental lighting, reflected light from the pavement, and vehicle headlighting. All these lightings provide visibility to the driver. Therefore, it is not correct to evaluate the visibility at a point 83m away from the observer only for the reflected light contribution from the fixed roadway lighting. It may be a conflict between theory, professional practice, and reality. Further, the R-3 table is a typical table that does not provide the absolute reflectance for a point since it is a combined reflection. We also do not know whether specular or diffuse reflection or combined one towards the driver or observer. Therefore, illuminance lighting calculation provides an objective assessment and the amount of light falling on the road surface.

The traditional calculation method emphasizes the two transverse points per lane, a minimum of 10 points between luminaires, no grid under luminaire, the observer keeps a fixed distance and direction of view, and more [6]. This calculation method is complex, time-consuming, and does not correlate with reality. A driver needs to see the entire field of view in each direction of the roadway for safe driving and the safety of others. Therefore, this calculation method can be called an Elite Roadway Illuminance Calculation (ERIC) method or Uthayan's ERIC Method for each roadway direction using a 2m-by-2m grid to get the required average and uniformity light levels for the entire street or road or highway. This method correlates with reality and provides a whole field of view calculation without any viewing restriction. The calculation result difference between the traditional method and the ERIC method is the decimal place. Therefore, the ERIC method offers a solution to the over-50-year-old challenge in roadway lighting calculation.

3.1.5 Veiling Luminance Calculation

The luminaire emits lighting to the eye of the observer, as a result, produces a reduction in the visual performance. Veiling Luminance (Lv) - A measure of disability glare, veiling luminance is a luminance superimposed over the eye's retinal image produced by stray light within the eye [6]. When we introduce a full-cut-off luminaire for the roadway application, veiling luminance may not be an issue for verification. The current roadway lighting design typically uses full-cut-off luminaires. The luminous intensity (in candelas) at or above an angle of 90° (above nadir) is zero, and the light intensity (in candelas) at or above a vertical angle of 80° (above nadir) does not numerically exceed 10% of the luminous flux (in lumens) of the luminaire [15].

It is not necessary to do a veiling luminance calculation for the current luminaire with a full cut-off angle. However, it is not hard to do a standard optimization calculation to see the veiling luminance ratio. Now, the Maximum level of veiling luminance is caused by opposing traffic only. The Veiling luminance calculation is related to luminaire to observer performance. There is no issue in performing a typical veiling luminance calculation to see the observer’s performance to the corresponding luminaire. Therefore, there is no need for calculating veiling luminance for each luminance calculation.

3.2 Quantitative Assessment

A Typical hypothetical section of the street has been taken for quantitative assessment for both illuminance and luminance methods. The same typical street needs to be used to compare both methods. The following Fig. 8 shows the standard luminance and illuminance calculation method. The regular street has hydro poles on the north side and steel poles on the south side. As you can see, the pole spacing and mounting heights are different for both hydro pole and steel pole. Road width and lane making are changing throughout the street. Therefore, luminance calculation needs to be performed between each section of poles. Thus, eight (8) calculations need to be completed. The average luminance of eastbound and westbound are shown on the drawing.

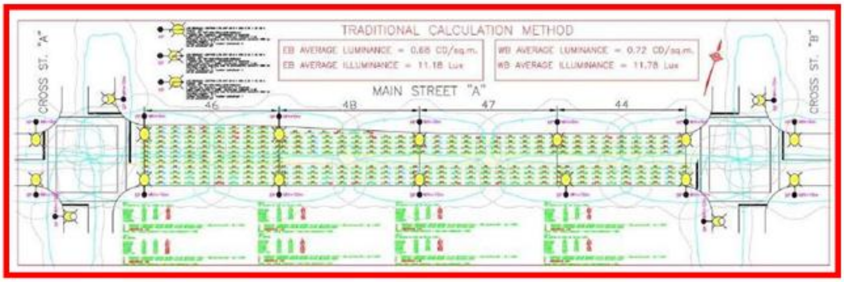

Fig. 8. Standard calculation method for a typical section of roadway
Source: by the Author

The following Tables 3 and 4 provide the Luminance and Illuminance Calculation Results for West Bound and East Bound of the above-noted typical section of Roadway shown in Fig. 6.

Fig. 9 shows the same typical street, poles, and luminaire in the exact location, but the calculation is illuminance. The illuminance calculation shows the amount of light that falls on the surface of the road and does not need to have an observer position. Therefore, Illuminance calculation needs to be performed in each direction of the street instead of between each section of the poles. Thus, two (2) calculations need to be completed. The average luminance conversation for eastbound and westbound are shown on the drawing.

The following Table 5 provides the Illuminance Method Calculation Results for West Bound and East Bound of the above-noted typical section of the Roadway shown in Fig. 7.

The following Table 6 compares the standard illuminance calculation method versus the new ERIC illuminance method and the differences.

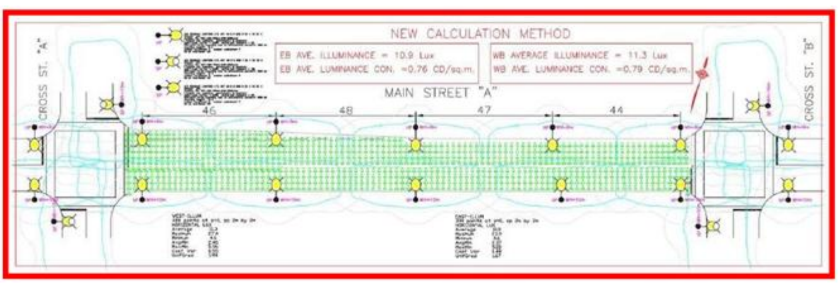

Fig. 9. The new ERIC (illuminance calculation) method for a typical section of Roadway
Source: by the Author

Table 3. The luminance and illuminance calculation results for west bound

No.	Categories	WB-1	WB-2	WB-3	WB-4	West Bound	Required
3.1	Average Luminance	0.64	0.66	0.75	0.81	0.72CD/Sq.m.	0.6 CD/Sq. m.
3.2	Average Illuminance	10.7	11.1	12.4	12.9	11.78 Lux	8.5 Lux
3.3	Uniformity (Ave./Min.)	2.01	2.42	2.39	2.16	2.24:1	3:1
3.4	Uniformity (Max./Min.)	5.04	5.72	5.08	4.40	5.06:1	6:1

Source: by the Author

Table 4. The Luminance and Illuminance Calculation Results for East Bound

No.	Categories	EB-1	EB-2	EB-3	EB-4	East Bound	Required
4.1	Average Luminance	0.66	0.64	0.64	0.77	0.68 CD/Sq. m.	0.6 CD/Sq. m.
4.2	Average Illuminance	11.2	10.5	10.1	12.9	11.18 Lux	8.5 Lux
4.3	Uniformity (Ave./Min.)	1.99	2.07	2.14	1.82	2.01:1	3:1
4.4	Uniformity (Max./Min.)	3.84	4.20	4.51	3.11	3.92:1	6:1

Source: by the Author

Table 5. The ERIC method of illuminance calculation results

No	Categories	West Bound	East Bound	Required
5.1	Average Illuminance	11.3 Lux	10.9 Lux	8.5 Lux
5.2	Uniformity (Ave./Min.)	2.46:1	2.37:1	3:1
5.3	Uniformity (Max./Min.)	5.96:1	5.20:1	6:1
5.4	Luminance Conversion	0.79 CD/Sq. m.	0.76 CD/Sq. m. CD/Sq. m.	0.6

Source: by the Author

Table 6. The comparative analysis for lighting calculation methods

No	Categories	Standard	ERIC	Difference
6.1	EB Average Illuminance	11.18 Lux	10.9 Lux	-0.28
6.2	WB Average Illuminance	11.78 Lux	11.3 Lux	-0.48
6.3	EB Ave./Min.	2.01:1	2.37:1	0.37
6.4	WB Ave./Min.	2.24:1	2.46:1	0.22
6.5	EB Max./Min.	3.92:1	5.20:1	1.28
6.6	WB Max./Min.	5.06:1	5.96:1	0.90
6.7	EB Average Luminance	0.68 CD/sq. m.	0.76 CD/sq. m.	0.08
6.8	WB Average Luminance	0.72 CD/sq. m.	0.79 CD/sq. m.	0.07

Source: by the Author

The following Figs. 10 and 11 show the traditional illuminance and luminance calculation methods versus the new ERIC method and conversion to luminance values.

ERIC method is more accurate because it takes the entire field of view in the direction of travel and provides uniformity for a complete area. The average light level is less than 0.5 lux for the ERIC method. As expected, the average light level will be less, and uniformity will be high because it takes the entire roadway and reflects reality (refer to Fig. 9). The difference between the traditional luminance calculation and converted luminance from the ERIC method is negligible and less than 0.09 CD/Sq. m. (refer to Fig. 10). The ERIC method covers the entire field of view. Therefore, this verification confirmed that the ERIC method is more accurate than the traditional luminance calculation method.

3.3 Qualitative Assessment

A subjective oral assessment from nine (9) colleagues and peers was completed to determine the benefits and professional satisfaction of the luminance versus illuminance calculation methods (refer to Table 7). Satisfaction is a feeling that the lighting design calculations cover all areas within the project limit using the objective assessment to meet the requirement and resemble reality. The results of the survey are shown in Fig. 9.

4. RESULTS

The concurrent triangulation method is a robust way to find a solution to challenging issues. Therefore, the comparative, quantitative, and qualitative assessments were conducted, and the corresponding results are shown below.

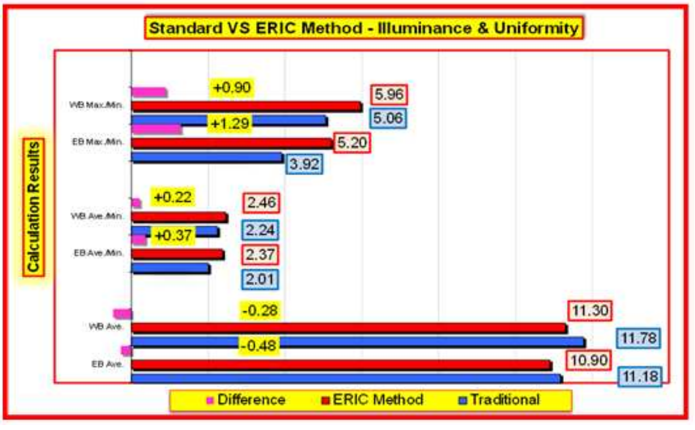

Fig. 10. Traditional illuminance method versus new ERIC method
Source: by the Author

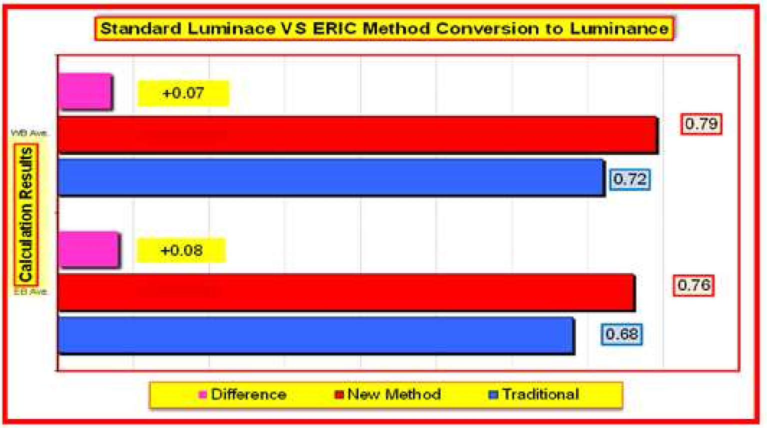

Fig. 11. Traditional luminance method versus new ERIC method conversion to luminance
Source: by the Author

4.1 Comparative Assessment

The following Table 8 provides the results of the comparative assessment for Lighting Calculation methods, for which the calculation method offers accurate results.

Visual sensitivity varies from person to person, and the human eye is a complex and sophisticated organ that can adapt almost to any situation. Therefore, the luminance calculation does not produce additional benefits since the analysis aims to reflect the visibility correctly. The luminance calculation has many assumptions, and the results did not correlate with reality.

4.2 Quantitative Assessment

The following Table 9 provides the quantitative assessment results for luminance and ERIC methods from Figs. 6 and 7 and provides the corresponding benefit-cost ratios (BCRs). BCRs are most often used in budgeting to analyze the overall value for money of undertaking a new project. The BCR is calculated by dividing the proposed total cash benefit of a project by the proposed total cash cost of the project. For example, If the cash benefit for performing the lighting calculation is $300, the proposed total cost of the illuminance calculation is $150, and the luminance calculation is $750. Therefore, BCR for the illuminance calculation method is 2, and the luminance calculation is 0.4.

BCR indicates the relationship between a proposed project's relative costs and benefits, expressed in qualitative terms. If a project has a BCR greater than 1.0, it is expected to deliver a positive net present value to a firm and its investors. If a project's BCR is less than 1.0, its costs outweigh the benefits, and it should not be considered. Therefore, the ERIC method is the preferred method for quantitative analysis.

Table 7. The qualitative assessment survey

No	Questions	Luminance	ERIC	NC*
7.1	Which calculation requires less time?	-	7	2
7.2	Which calculation covers the entire area of the project?	-	8	1
7.3	Which calculation is more authentic or objective?	1	7	1
7.4	Which calculation has fewer assumptions?	-	9	-
7.5	Which calculation is easy to achieve the required light level?	-	9	-
7.6	Which is the preferred unit of measurement Lux or cd/sq. m.?	1	7	1
7.7	Which calculation takes less time to review?	2	7	-
7.8	Which calculation makes QC/QA process easier?	1	7	1
7.9	Which calculation provides higher professional satisfaction?	1	6	2
7.10	Which calculation provides higher client satisfaction?	1	5	3

Source: by the Author

*Note: The numbers refer to the number of people who responded. *NC – No Comments*

Table 8. The comparative assessment

No.	Categories	Luminance Method	ERIC Method
7.1	Area Assumptions (Refer to subsection 3.1.1)	Impact	No Impact
7.2	Calculation Assumptions (Refer to subsection 3.1.2)	Impact	No Impact
7.3	Surrounding Area Lighting (Refer to subsection 3.1.3)	Not Used	Not Used
7.4	Visibility for Roadway Lighting (Refer to subsection 3.1.4)	Not Accurate	No Impact
7.5	Veiling Luminance Calculation (Refer to subsection 3.1.5)	Impact	No Impact

Source: by the Author

Table 9. The Quantitative Assessment

No.	Description	Luminance Method	ERIC method
8.1	Calculation Hours*	5 Hours	1 Hour
8.2	Cost ($150/hr.)	$750	$150
8.3	BCR if benefit is $300	0.4	2
	Results	Not Preferred	Preferred

Source: by the Author

**The time spent is shown only for the preparation of calculation grids for both calculations.*

4.3 Qualitative Assessment

The following Fig. 12 provides the survey results achieved among nine (9) professional people. These subjective assessment results indicate that the new calculation method is best, including cost-effectiveness and overall professional satisfaction.

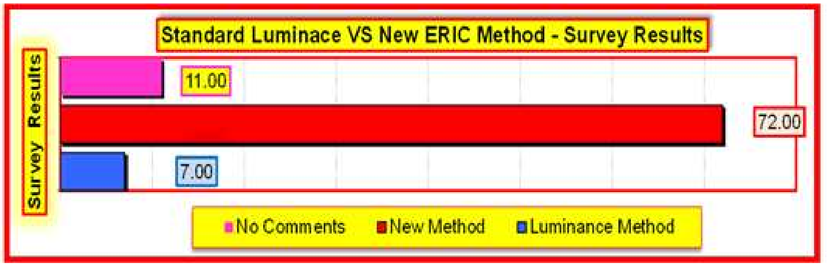

Fig. 12. The survey evaluation results
Source: by the Author

5. DISCUSSION AND CONCLUSION

Luminance is a measurable quantity with so many shortcomings. Brightness is the human sensation of luminance, which varies from person to person [16]. Therefore, having luminance as a calculation method for straight roadway lighting does not produce any objective results, nor is there a perception that it produces superior results. The current approach makes it complicated and increases the work time and review time without achieving its purpose or satisfaction. A proposed design should be an excellent method to include actual data from the field without many assumptions. The new ERIC method matches reality and is a little more challenging than the standard illuminance or luminance method to fulfill the requirement. Therefore, the ERIC method will not compromise but is better than the standard illuminance or luminance method. If all the roadway lighting calculations change to the ERIC method of illuminance calculation, anyone can save approximately 80% of the lighting calculation cost. Therefore, the ERIC method of illuminance calculations gives objective results to cover all the road areas within or beyond the project limit to client satisfaction.

Typically, the same type of asphalt (R3) has been used for roadway application, and there is a correlation between luminance and illuminance values. Therefore, we can find out the approximate luminance value for the corresponding illuminance value if necessary. Further, luminance values from the roadway lighting calculations do not have any justification for the human sensation. All in all, the ERIC method of illuminance calculation is easy to perform and achieve, clear to understand, cost-effective, and satisfactory to the designer and the client.

Further, based on assumptions and conflicting reality, a mock-up visual evaluation can be completed as part of the lighting design process. It gives the actual field condition where a lighting designer can assess the perception and visibility, glare, veiling reflection, overlighting, clutter, trespass lighting, and sky glow. Therefore, the author strongly recommends the ERIC method of illuminance calculation for all roadway lighting applications.

COMPETING INTERESTS

The author has declared that no competing interests exist.

REFERENCES

1. Commission international de l'éclairage calculation and measurement of luminance and illuminance in road lighting. Vienna: CIE. [cited Feb 28 2023]. 1982;30(2).
Available: http://cie.co.at/publications/calculation-and-measurement-luminance-and-illuminance-road-lighting (Note: superseded by CIE.
2. Thurairajah U. A comparative study: the benefits of a novel illuminance calculation method over luminance calculation method for optimal roadway lighting design applications, U Thurairajah 2022 J. Phys Conf Ser. 2022;2224:012117.
3. Illuminating Engineering Society of North America. ANSI IESNA RP-8 recommended practice on roadway lighting. New York: IESNA; [cited Feb 28, 2023]; 1983.
Available: https://www.ies.org/product-category/recommended-practices-and-ansi-standards/.
4. Cuttle C. A new direction for general lighting practice. Lighting Research & Technology. 2013;45(1):22-39.
5. Fortios S, Gibbons R. Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations. [accessed: Feb 28, 2023]; 2018.
6. IES roadway lighting 2021, recommended practice for lighting roadway and parking facilities, ANSI/IES RP-8-21 [cited Feb 28, 2023].
Available: https://store.ies.org/product/rp-8-21-lighting-roadway-and-parking-facilities/.
7. Bodmann HW, Schmidt HJ. Road surface reflection and road lighting: Field investigations. Lighting Res Technol. 1989;21(4):159-70.
8. Fotios SA, Boyce PR, Ellis CE. The effect of pavement material on road lighting performance. Lighting J. 2006; 71:35-40.
9. Frederiksen E, Gudum J. The quality of street lighting installations under changing weather conditions. Lighting Res Technol. 1972;4(2):90-6.
10. Aktan F, Schnell T, Aktan M. Development of a model to calculate roadway luminance induced by fixed roadway lighting. Transportation Research Record. 2006;1973(1):130-41.
11. Thurairajah U. A novel method to prove the visibility distance of candlelight and the milky way's Vega Star and apply dis knowledge to outdoor lighting applications, SCIREA. J Phys. 2023;8(1):1-18.
12. Sabey BE. Road surface reflection characteristics [cited Feb 28 2023]; 1991.

Available: https://trl.co.uk/reports/LR490. Paper presented at conference on Illuminating Engineering. Barcelona
13. Karmarkar S. Basic Ergonomics in Automotive design, The Fundamentals of Human-System Interactions; 2018 [cited Feb 28 2023]. Available: http://www.dsource.in/course/basic-ergonomics-automotive-design/module-2/visual-field-and-visual-obstruction.
14. Green M. Determining visibility; 2018 [cited Feb 28 2023]. Available:https://www.visualexpert.com/Resources/contrastfundamental.html.
15. Hiscocks P. Measuring light. Ontario, Canada: Ryerson University. [cited Feb 28, 2023]; 2011. Available: https://studylib.net/doc/18128884/measuring-light---ryerson-university
16. IESNA luminaire cutoff classifications. What are the IESNA cutoff classifications? [cited Feb 28, 2023]; 2019. Available:https://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/cutoffClassifications.asp.

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