Application of Energy Saving Methodology

for Road Lighting in Expressways - Sri Lanka

By Eng Gehan Bandarigodage, MSc Eng, CEng, MIE(SL), MIET

Brief Outline:

Roadway lighting standards are based almost exclusively on vehicular traffic safety considerations. Benefits of road illumination for drivers include easing of flow of traffic, reduction of night time accidents, visibility of adjacent users, and general way of finding assistance. Road lighting is used specially to highlight hazards despite the glare of headlight beams and reveal signage, in riskier environments, such as urban streets and interchanges where there are exits and entries from local roads.

Energy saving on road lighting is not only good for the environment; it is good for the per capita income of people as well, because the expenditure on energy directly relates to the cost of goods produced. High expenditure on energy decreases profit margins and raises price of goods and services. Therefore reducing the cost of energy through energysaving methodologywill benefit the people directly.

Finding methods and switching to more energy efficient methods to save energy without affecting the final product or outcome can be difficult, but possible. Being professionals, focusing on this aspect is very vital asit will result in tremendous savings in cost of energy. Therefore it is our duty to take measures to save energy in all aspects as it's a national requirement.

The present Government is highly focused on the Development of National Road Network in Sri Lanka under Infrastructure development, as it plays a key role in the development of the country. As a result of this, Southern Expressway up to Galle has been already completed and Colombo - Katunayake Expressway is just completed. Therefore the dream of having a developed road network and transport system in Sri Lanka will become a reality in the near future.

During the construction stage of these roads I had the opportunity of providing consultancy services on road lighting systems

In the road lighting design of Southern Expressway, the average illumination level in interchange areas was considered as 1 cd/m^2.

I tried as much as possible to adopt energy saving methodologies and maintenance aspects during the design stage of road lighting systems. On that basis I thought to analyze the consumption of electrical energy of Colombo - Katunayaka Expressway and Southern Expressway as the lighting levels adopted is same i.e, Class "ME3a" as per the CIE classifications and my report on the detailed analysis is given below.

General Design Criteria of Road Lighting:

The general design criteria for road lighting are visibility, safety, energy consumption and economics. All of these must be considered when designing the lighting system.

The criterion of visibility describes how well the lighting system performs in revealing the roadway objects within the roadway and the surroundings of the roadway to the driver.

- **When designing road lighting, following factors were taken in to considerations;**

a) Energy saving through selection of efficient lamp technologies & design practices.

b) Safety of motorist and cyclists, security of pedestrians, improved traffic guidance and providingof a pleasant environment.

c) Capital cost saving using proper spacing & placement.

d) Maintenance cost saving using lamps with longer life. Proper spacing placement can reduce the maintenance cost

e) Reduced glareand improved visibility by careful selection of luminaries that enhances visibility can improve the detection of pedestrians by drivers and increase signal distance

f) Improved sense of security by selection of efficient systems and incorporating proper design can make an area appear safer and more secure.

- **Further when designing road lighting from the Road Users point of view following factors were taken in to account;**

Requirement of Road Users:

a) Visibility of the road and its surroundings.

b) Visual guidance of the shape of the road. The motorist should be clearly able to identify bends and curves and change in road widths achieved by well designed Road Lighting System.

c) Identification of obstacles.

d) Entire road stretch should be without any obstacles. The appearance of the road should be such that the driver is certain that the road is clear. In other words it should provide “visual comfort” to the driver.

e) Appearance of lighting of the street should be uniform and continuous.

f) The visual field of the driver comprises:i) The carriagewayii)The surrounds to the road, including signs,iii) The sky, including the bright luminaries.

Analyzing of Lightning Needs :

Warrants for highways, freeways, interchanges and bridges may be undertaken using the American Association of State Highway and Transportation Officials(AASHTO) Roadway Lighting Design Guide Warranting System. AASHTO defines warrants for Continuous Freeway Lighting (CFL), Complete Interchange Lighting (CIL) and Partial Interchange Lighting (PIL) based on warrant conditions including:

- Traffic volumes
- Spacing of freeway interchanges
- Lighting in adjacent areas
- Night-to-day crash ratio

AASHTO believes it is desirable to provide lighting on long bridges in urban and suburban areas even if the approaches are not lighted. On bridges without full shoulders, lighting can enhance both safety and utility of the bridges, and is therefore recommended. Where bridges are provided with sidewalks for pedestrian movements, lighting is recommended for pedestrian safety and guidance.

The following terminology is used with respect to the amount of lighting, as determined by the warrant system:

- Full Lighting – Denotes lighting covering an intersection in a uniform manner over the traveled portion of the roadway.
- Partial Lighting – Denotes lighting of key decision areas, potential conflict points, and/or hazards in and on the approach to an intersection. Partial lighting may also guide a driver from one key point to the next, and (if sufficient luminaires are used) place the road user on a safe heading after leaving the lighted area.
- Delineation Lighting – Denotes lighting that marks an intersection location for approaching traffic, lights vehicles on a cross street or lights a median crossing.
- Based on the warrant analysis the following conditions define the need for full, partial or delineation lighting:
- If the intersection is signalized, full lighting is warranted.
- If the intersection is not signalized, the need for and the amount of lighting is indicated by comparing the point-score obtained from the warrant form categories to the following criteria:
    - Full Lighting – Is warranted where a total point-score of 240 or more points.
    - Partial Lightning – Is warranted where the point-score is between 151 and 239 points.
    - Delineation Lighting – Is warranted where the point-score is between 120 and 150.
    - No Lighting – Generally, a point-score under 120 indicates that lighting is not warranted. This score indicates that neither the critical operational warranting factor (substantial traffic volumes) nor the critical crash warranting factor (repeated nighttime crashes) is present.

Lighting may be prioritized solely on the basis of the point-scores, or in conjunction with a benefit/cost analysis. Benefits would typically be based on the potential reduction in crash frequency and severity at the intersection.

Depending on the road authority practice, costs would typically include the initial cost of the lighting system, its ongoing (electricity) costs, and its maintenance costs. Initial costs may be substantial if a power source is not present at the intersection.

Design Codes and Standards of road lighting used:

Based on above factors the following Design Codes and Standard established on Road Lighting were used for the designing.

BS 5489:1992 Road Lighting

Part 1 : Guide to general principles

Part 2 : Code of practice for lighting for traffic routes

BSEN 60598-2-3:1994 Road Lighting Luminaires

BS 5649 Lighting Columns

BSEN 60529: 1992 Degree of protection provided by enclosures.

BSEN 60662 High Pressure Sodium Vapour Lamp

CIE 23: 1973 International Recommendations for Motorway lighting

CIE 30.2:1983 Calculation & Measurement of Luminance and Illuminance in Road Lighting

CIE 31:1976 Glare and uniformity in road lighting installations

CIE 47:1976 Road Lighting for Wet conditions

CIE 66:1981 Road surfaces and lighting

ME Series of Lighting Classes, established for Different Road Types under CIE Classification:

Apart from above, the design code BS EN 13201 : 2004) which was established **under CIE Classification** in 2004 defining several types of Lighting Classes for Motorways and Traffic routes was also used during the design.. These classes were defined as ME1, ME2, ME3a, ME3b and ME4a. The lighting classes against the relevant Motorways and Traffic routes are tabulated in the Table 01, as follows;

Table:01: Lighting Classes for Motorways and Traffic routes (As per the BS EN 13201 : 2004):

Nr	Hierarchy description	Type of Roads	Detail description	Traffic flow vehicles per day	Lighting Class
1	Motorway	Limited access	Routes for long distance traffic, Main carriageway		
			a) Complex interchanges	< 40,000	ME1
				➢ 40,000	ME1
			b) with interchanges < 3kM	< 40,000	ME2
				➢ 40,000	ME1

			c) with interchange > 3kM d) Emergency lane	< 40,000 ➢ 40,000 -	ME2 ME2 ME4a
2	Strategic route	Trunk and principal roads	Route for fast moving long distance traffic, speed limits are more than 40mph **a)** Single carriageways **b)** Dual carriageways	 < 15,000 ➢ 15,000 < 15,000 ➢ 15,000	 ME3a ME2 ME3a ME2
3	Main Distributor	Major urban network	Route linking to urban network, speed limits are less than 40mph a) Single carriageways b) Dual carriageways	 < 15,000 ➢ 15,000 < 15,000 ➢ 15,000	 ME3a ME2 ME3a ME2
4	Secondary Distributor	Classified roads B and C	Route linking to urban network, speed limits are less than 40mph a) Rural areas b) Urban areas	 < 15,000 ➢ 15,000 < 15,000 ➢ 15,000	 ME3b ME3a ME3b ME2

Each ME class conclude definite values for average road surface luminance (L), Overall uniformity of the luminance (U_0), Longitudinal uniformity of the luminance (U_1),Threshold increment (T1) and Surround ratio (SR) as tabulated in the Table No.02 as follows;

Table 02: Ratings of ME series Lighting classes (As per the BS EN 13201 : 2004):

Class	Luminance of the road surface of the carriageway for the dry road surface condition			Disability glare	Lighting of surrounding
	L in cd/m^2 (average maintained)	U_O (minimum)	U_I (minimum)	TI in % (maximum)	SR (minimum)
ME1	2,0	0,4	0,7	10	0,5
ME2	1,5	0,4	0,7	10	0,5
ME3a	1,0	0,4	0,7	15	0,5
ME3b	1,0	0,4	0,6	15	0,5
ME4a	0,75	0,4	0,6	15	0,5
ME4b	0,75	0,4	0,5	15	0,5

The **importance** of these factors are illustrated as follows;

a)Luminance-

The most generally used approach to selecting quality criteria for lighting roads for motor traffic is based on the luminance concept. This is the minimum value to be maintained throughout the life of the installation. It is dependent on the light distribution of the luminaries, the luminous flux of the lamps, the geometry of the installation and on the reflection properties of the road surface (See Fig.1).

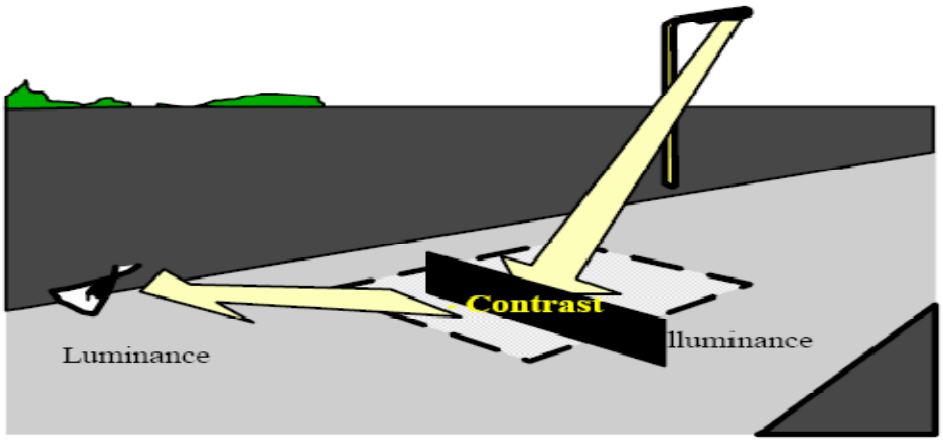


Figure 1

The road surface is a very important criterion in Road Lighting. Same illuminance may result in different visual scene because of difference in Road Surface. It is obvious that road surface luminance rather than illuminance should be the accurate measure of the effective light in a road surface. In the present state of technique and the knowledge of reflection properties of road surface, calculation and measurement of luminance is difficult. Thus illuminance values are taken as standards for road lighting. However, it shall be kept in mind, the visual appearance of a road is solely determined by the luminance values and uniformity. Same illuminance may result in different Visual Scene because of difference in Road Surface Reflectance and Uniformity.

b)Uniformity

A good overall uniformity ensures that all spots on the road are sufficiently visible.
Overall uniformity (Uo): It is the ratio of the minimum to the average road illuminance. A good overall uniformity ensures that all spots on the road are sufficiently visible.
Longitudinal uniformity (UL): It is the lowest ratio of the minimum to the maximum road illuminance in the middle of each lane.

c) Glare

It is caused due to the sudden presence of very bright source in the visual field. Glare in Public Lighting is caused by luminaries.
a) Disability glare impairs vision
b) Discomfort glare of lighting cause visual discomfort.

Glare depends on the illumination produced by the luminaire on the eye of the observer.

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 in front of the observer.

d)Threshold Increment

The percentage increase in the luminance level required to make an object equally visible as in the absence of glare. Glare Control Mark is a measure for discomfort glare in Road Lighting designs. It is calculated from certain luminaire and installation characteristics.

e)Surround ratio

It is the ratio that measures the amount of light falling on the surrounds as a proportion ofthat falling on the road. Surround ratio is defined as the ratio of the average illumination on street, 5m wide or lesser if space does not permit, which are adjacent to the edge of the both sides of the carriageway to the average illumination on the adjacent streets, 5m wide or half the width of the carriageway whichever is the smaller in the carriageway.

Road illumination levels recommended by International Commission on Illumination(CIE 180) are given in Table 03 below;

Table 03

S nr	Category	Average Level	U_0	U_1	T1
1	Residential areas and pedestrians	1 – 2 lux	0,2	n/a	n/a
2	Largely residential, but some motorized vehicles	4 -5 lux	0,2	n/a	n/a
3	Major access roads, distributors and minor main roads	0,5 cd/m^2 (~ 8 lux)	0,4	0,5	n/a
4	Important rural and urban traffic routes	0,5 cd/m^2 (~ 15 lux)	0,4	0,6	20%
5	High-speed roads, dual carriageways	0,5 cd/m^2 (~ 25 lux)	0,4	0,7	15%

The Other important factor of road lighting is selection of Road Lantern and it is elaborated as follows;

Selection of Road Lantern:

The most important element of the illumination system is light source. The selection of light source was based on luminous flux, service life, Colour Rendering Index(CRI), color temperature, light intensity, and light efficiency. High pressure sodium lamps of 250Watt have been used in all theexpressway as a road lanterns. High pressure sodium lamps have higher light efficiency, longer working life, strongerpenetrability.

A so called 'semi cut off' (SCO) light distribution has been considered. SCO lighting has a lower level of beam angle and it limits the high angle light towards the driver, caused due to glare.

According to the comparative life cycle assessment of available street light technologies for sustainable Innovation it was found that LED technologies were comparable in terms of the environmental impacts of their manufacture, lower energy use, and lower maintenance costs due to long-lasting bulbs. However the efficiency of high pressure sodium technology appears to be in the maximum level, while that of LED lighting is increasing rapidly. LED lighting is increasingly emerging as a way to capture energy efficiency savings around the world.This will provide a significant cost saving for the energy consumption on expressway street lighting in near future.

LEDs are becoming a promising alternative for road lighting in near future and still reaching noteworthy improvements in their luminous efficacy. With the recent development in LED technology, the efficiency of commercial LEDs has been increased to around 100 lumens per watt, and even more efficient LEDs may developed in the future. Nevertheless, HPS lamps still outperform LEDs efficiency wise. Further, LEDs usually involve higher initial cost and still not proven for expressways. Because of low energy consumption and low cost of maintenance, definitely there should be a conservative approach towards LED road lighting in future for all road lighting installations.

Although the power consumption of LED lamps are very low, , still not being widely used and proved for illumination of expressways since there are technical issues on efficacy, glare and thermal management ofLED lamps. Comparison of road lantern with 250Watt HPS Lamp and 150Watt LED are given in **Table** 04 below;

Table 04

	Type of Lamp	**250Watt HPS**	**150Watt LED**
1	Wattage	250	150
2	Initial Lantern Lumens	25,000	13,500
3	Efficacy (Lm/W)	100	90
4	Life time (Hours)	12,000	50,000
5	Correlated Colour Temperature (K)	2700	4000 to 6000
6	Cost	100X	300X

Under these circumstances we may have to still depend on HPS lamps in road lighting as installed in Colombo - Katunayaka Expressway and being used in Southern Expressway.

Lighting arrangements used in Sri Lankan Expressways:

For the Southern expressway, road Lighting has been provided only for the interchanges. Additional outside lighting was provided for about 300m beyond the expressway–ends of the ramps. The other side lighting was terminated at the end of ramp. All the interchanges were provided with transition lighting arrangement along both sides of the expressway.

But in Colombo - Katunayaka Expressway, road Lighting has been installed for the entire road stretch including interchanges compared to Southern Expressway. The Colombo - Katunayake Expressway lighting arrangement has been installed not merely to provide road lighting but also to maintain the country image

and the standard at a higher level similar to other developed countries aiming the panoramic attraction on foreign delegates and tourists at the first glance of visiting Sri Lanka.

Comparison of lighting designs of Colombo Katunayaka Expressway by using "Dialux" lighting design software:

Determining an acceptable lighting system design requires numerous iterations of calculation based on numerous variables. In this context I used the computer software called "Dialux" for lighting design analysis. From Dialux software, it is possible to generate templates for the design and to check the luminance, uniformity and other parameters by fixing the wattage of road lantern, distance between lamp post and road width.

a).Application of "Dialux" Software for lighting class ME3a:

Data applied: 1) Road Width – 7.5m

2) Distance between 02 lamp post - 45m

3) Power of Road Lantern proposed - 250W

By applying those data ,i.e .width of the road (7.5m), distance between 02 lamp post (45m) and road lantern (250W), I was able to get following technical details in accordance with ME Series Lighting Class on Colombo Katunayaka Expressway.

1. Average maintained Luminance
2. Overall Uniformity
3. Longitudinal uniformity
4. Maximum Threshold increment

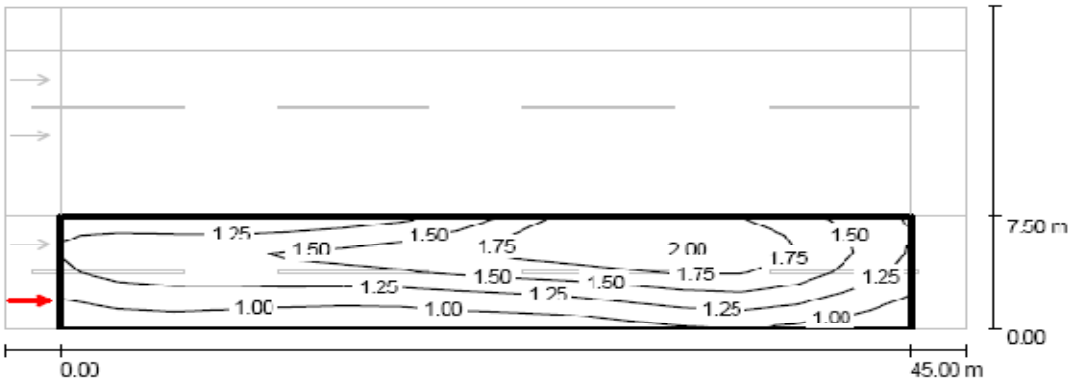
Test Details on Dialux:

COLOMBO -KATUNAYAKE EXPRESSWAY PROJECT

DIALux
14.00.2012

Operator Gehan Bandangodage
Telephone
Fax
e-Mail gehancb@yahoo.com

Colombo-Katunayake Expressway Project / Valuation Field Roadway 1 / Observer 1 / Isolines (L)



Values in Candela/m², Scale 1 : 365

Grid: 15 x 6 Points
Observer Position: (-60.000 m, 1.875 m, 1.500 m)
tarmac: R3, q0: 0.070

	L_{av} [cd/m²]	U0	UI	TI [%]
Calculated values:	1.38	0.61	0.74	7
Required values according to class ME3a.	≥ 1.00	≥ 0.40	≥ 0.70	≤ 15
Fulfilled/Not fulfilled:	✓	✓	✓	✓

The results obtained are tabulated as follows:

1. Average maintained Luminance: 1.38 cd/m^2
2. Overall Uniformity Uo-0.61
3. Longitudinal uniformity UI – 0.74
4. Maximum Threshold increment TI %- 7

Comparison of the above results with ME Series:

Assumptions : Road width-7.5m, Distance between 02 lamp post – 45m and road lantern-250W

		Results obtained	**Relevant values of ME3a series (Ref. Table 2)**	**Equivalent ME Class**
1	Average maintained Luminance	1.38 cd/m^2	1.00 cd/m^2 Average	ME3a
2	Overall Uniformity **(Uo)**	0.61	0.40 (Minimum)	ME3a
3	Longitudinal uniformity **(UI)**	0.74	0.70 (Minimum)	ME3a
4	Maximum Threshold increment TI %	7	15 (Maximum)	ME3a
5	Minimum Surrounds Ratio SR – 0.5	5	5 (Minimum)	ME3a

b). Application of "Dialux" Software for Colombo - Katunayaka Expressway:

The Illumination requirement in the original Contract requirement of the Colombo - Katunayake Expressway was specified as 1.5 cd/m^2.

Therefore to match the above condition the required lighting class was ME2 and according to the **International Commission on llumination** (CIE) standards, the illumination levels and other factors specified on ME2 class were used as follows;

1. Average maintained Luminance: 1.5 cd/m^2
2. Overall Uniformity Uo-0.4
3. Longitudinal uniformity UI – 0.7
4. Maximum Threshold increment TI %- 10
5. Minimum Surrounds Ratio SR – 0.5

Therefore the selected lighting class was ME2 and by applying all these data to "Dialux" following results were achieved inversely;

1) Road Width -7.5m

2) Distance between 02 lamp post - 35m

3) Power of Road Lantern proposed - 250W

Comparison of ME3a and ME2 lighting classes on economical aspects:

Since there were no complaints, about road lighting so far from the users in Southern Expressway, it can be proved that the lighting Class ME3a which is the lighting class selected, is acceptable for Expressway's in Sri Lanka. This design criteria can be considered as a uniform lighting design standard acceptable for all expressway projects in Sri Lanka, which ensures driver safety and low cost of maintenance when compared with lighting class of ME2. This will provide significant cost saving on energy consumption.

As per the lighting Class ME2, the distance between 2 lamp post in "Colombo -Katunayaka Expressway" will have to be 35m and this is 10m closer than the "Southern Expressway". In other wards no. of road lights /Km & No.of lamp post/Km are higher in "Colombo - Katunayaka Expressway" than in "Southern Expressway".

By comparing the No. of lighting columns and No. of lanterns in different Luminance levels, i.e; 1.5 cd/m^2 & 1.0 cd/m^2 the results can be summarized for the" Colombo-Katunayake Expressway " as follows;

Total length of Colombo Katunayake Expressway is 25.517km.

	Feature	Average Luminance 1.5 cd/m^2 (Class ME2)	Average Luminance 1.0 cd/m^2 (Class ME3a)
1	No of Road lighting columns	729	567
2	No of 250Watt HPS Lanterns	1458	1134

From above, the energy consumption/ can be tabulated as follows:

	Road	Average Luminance 1.5 cd/m^2			Average Luminance 1.0 cd/m^2		
		Total kWatt	kWh per day	Cost per day, Rs	Total kWatt	kWh	Cost per day, Rs
1	CKE	364.5	4009	70,804,00	283.5	3118	55,070.00

- Operation time assumed for lights from 6.30 pm to 5.00 am(10.30 hrs)
- Assumed tariff is as follows:
    - Peak time 6.30PM to 10.30PM - 25.00 Rs per 1kWh.
    - Off peak 10.30PM to 5.00AM – 14.50 Rs per 1kWh

If the design conditions of “Southern Expressway” is adopted in “Colombo -Katunayaka Expressway” the total annual energy saving for total road length is 320,760.kWh and it is approximately equal to 5.66 Million Rupees per year.

Please note that, here the maximum demand (kVA) tariff factor and fuel adjustment changes have not been considered for the comparison.

Summary:

As the summary of the abstract, I may propose followings to consider in future, when designing and implementation ofRoad Lighting in Sri Lanka.

1. In general,being Engineers we always should select the best suitable and most appropriate design methodologies when practicing Engineering in the society targeting optimum benefits out of minimum energy.

2. In future there should be a standardization on lighting levels on road lighting of Expressways in Sri Lanka. In my experience, lighting level 1cd/m^2 for Expressways in Sri Lanka is more appropriate as it saves more electricity

3. Provisions has to be made to replace HPS with LEDs in future for saving electricity without changing the Road Lighting columns, once the LEDs are being introduced and when the HPS luminaries are to be replaced.

4. Introduction of the intelligent lighting control module for the road lighting distribution panels to reduce the voltage levels at late night in order to achieve less power consumption in HPS road lanterns.

5. There should be a policy of standardization on Road Lighting of Expressways in Sri Lanka, in future

6. The amount of Energy saving depends on the Luminance value and the lighting class.
