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Illuminance Range for AEB Night Test in Malaysia Based on Selected Road Lights Illuminance Data

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ABSTRACT – *The study involves a case study on road lighting in Perak, Malaysia, focusing on Seri Iskandar, Taman Botani, and Meru Impian, to propose a suitable range of illumination for Autonomous Emergency Braking (AEB) night conditions in Malaysia. The selected sites, representing different configurations of two-lane carriageways under Road Type R3, exhibit variations in distances between luminaires and lamp heights. The study underscores the importance of lumen efficacy in LED lighting, explaining its relation to the lifespan of LEDs. The correlation of color temperature (CCT) with human perception is discussed, emphasizing the flexibility of LED lights to adjust CCT based on environmental settings. The Ingress Protection (IP) ratings are introduced to evaluate the resistance of luminaires against dust and liquid intrusion. The methodology involves a reference grid light measurement using EURO NCAP grid calculation at the sites. The lux meter measures illuminance at evenly spaced points between road lights along the x-axis, and uniformity metrics (U_o and U_l) are calculated. Results of lux measurement testing for each site indicate illuminance levels and uniformities variations. The discussion compares these results with Malaysian standards, highlighting potential maintenance issues and environmental factors affecting street lighting performance. The paper concludes by proposing a range for AEB night test illumination based on average values from the sites and literature, considering luminaire duration and road class. The study provides valuable insights into LED road lighting performance in Malaysia and suggests considerations for enhancing standards and testing protocols for AEB night conditions.*

KEYWORDS: Illumination, ASEAN NCAP, street lighting, Autonomous Emergency Braking (AEB)

1. INTRODUCTION

ASEAN countries have achieved a significant milestone in road safety through the introduction of the ASEAN New Car Assessment Program for Southern Asian Countries (NCAP) (Kassim et al., 2017). Launched in December 2011 in alignment with the United Nations Decade of Action for Road Safety 2011-2020, the ASEAN NCAP aims to enhance vehicle safety standards, foster consumer awareness, and stimulate a market for safer vehicles within the region (Ishak & Rahim, 2020). Within the realm of vehicle safety standards, the luminance and illuminance of surrounding lighting emerge as pivotal factors for both drivers and pedestrians (Fitri et al., 2021). The correlation between road lighting and road crash casualties is underscored by the findings of Sari and Yudhistira (2021), who demonstrated a 4.2% increase in road crash casualties associated with poor road lighting. Significantly, they argued that improving road lighting is three times more cost-effective than road infrastructure enhancement. Recent Autonomous Emergency Braking (AEB) tests conducted by the Insurance Institute for Highway Safety (IIHS) in the United States revealed the ineffectiveness of AEB systems in low-light situations, prompting attention to the absence of night conditions in the current AEB Test Protocol 2021-2025 (ASEAN NCAP, 2020; Collision Repair Magazine, 2022).

In Malaysia, High-Pressure Sodium Vapor (HPSV) dominates street lighting over high-power Light Emitting Diode (LED) technology. A 2012 technical report evaluating the suitability of LED road lighting in Malaysia concluded that, at that time, LED adoption was not advisable due to factors such as initial and maintenance costs (TEEAM, 2012). However, advancements in LED technology since 2012 have prompted the Malaysian government to incorporate LED lighting into new projects, albeit it remains a minority compared to HPSV road lighting. LED streetlamps offer advantages in energy efficiency, light quality, durability, and cost over HPSV lighting (Zin & Abdullah, 2015). A survey by Zin and Abdullah (2015) indicated that LED street lighting could yield energy savings of 40% to 60%. Furthermore, LED lighting exhibits superior Ingress Protection (IP) ratings and Color Rendering Index (CRI) compared to HPSV streetlights.

As of 2021, Malaysia boasts a road network spanning 339,886 km, encompassing federal roads (FedR), Federal Land Development Authority roads (FELR), federal institutional roads (FIR), industrial roads (IR), federal territory roads (FTR), and expressways (Ex) (JKR, 2022). Road pavement in Malaysia is categorized into asphalt and concrete (75.37%), gravel (16.17%), and soil/laterite (8.46%), further differentiated into R1 (Portland-cement concrete), R2 (asphalt with a minimum of 60% gravel passing 3/8-in. sieve), R3 (asphalt with rough texture typical for highways), and R4 (asphalt with smooth texture).

This study employs the illuminance method due to its practicality in measurement compared to the costlier luminance method. Illuminance refers to the light volume falling onto a surface and is measured based on the grid reference method used in Euro NCAP. This study is motivated by the imperative to assess the compliance of street lighting in Malaysia with established standards and to scrutinize the testing protocols for AEB systems in the ASEAN NCAP (ASEAN NCAP, 2020; Amrun et al., 2023). While illuminance provides a straightforward assessment, the luminance method offers greater detail, considering the surface and angle from which observers perceive light. Carlucci et al. (2015) posit that uniformity in lighting, measured through luminance, defines the field's quality with a single value, an essential parameter with an ideal value of 1. Achieving uniformity in lighting design is crucial to minimizing eye strain and adapting to lighting conditions (Burton et al., 2012; Inan, 2013; Carlucci et al., 2015; Galatioto & Beccali, 2016; Kayakuş & Üncü, 2020).

The only protocol relating to AEB for night conditions is the Euro NCAP AEB VRU System. Inside this protocol, there is a detailed explanation of the standard of illumination of every point during the AEB Test. Hence, this study is looking into how this standard can be applied to Malaysia as the standard for road lighting in Malaysia is different from Europe. Specifically, we will look into changing the range of illumination permitted by the AEB night condition set by the Europe standard to fit to Malaysian standard. Thus, the study involves collecting selected illumination data and from these, illumination ranges that are suitable for the AEB night test, are proposed.

FIGURE 1: Literature for illumination measurements in Malaysia

Source	Location	Average Illuminations (Lux)
Prasetijo et al. (2021)	FT 050 Jalan Batu Pahat – Ayer Hitam – Kluang	26.3
Prasetijo et al. (2021)	FT 001 Johor Bahru – Segamat	18.3
Nor et al. (2013)	Karak Highway (Eastbound)	27.8
Nor et al. (2013)	Karak Highway (Westbound)	29.6
JKR (2023)	Kuala Terong, Perak	26.3

2. SITES AND LUMINAIRE DESCRIPTION

For this case study, the sites chosen are located in Perak which are Seri Iskandar, Taman Botani, and Meru Impian. The specifications for sites have been detailed in Table 2. Locations are selected due to focusing on the R3 road type with different distances between luminaires and lamp heights.

TABLE 2: Site description

	Seri Iskandar	Meru Impian	Taman Botani
Carriageway Type	Two-lane dual carriageways	Two-lane single carriageway	Two-lane single carriageway
Lane Width (m)	3.3	3.35	3.74
Lamp Position	center of the carriageway	left side of the carriageway	left side of the carriageway
Luminaire Type	LED	LED	LED
Lamp Height, *H* (m)	10	7.1	8
Distance between adjacent luminaires, *D* (m)	35	25	39
Luminaire Tilt Angle (Degree)	0	10	5
Overhang (m)	1.5	0.5	1.5
Road Type	R3	R3	R3

There is some difference between Malaysia Standard and the suggested LED luminaire used for road lighting for Euro NCAP, LED Series 48 2403 from Schuch (JKR, 2013; Euro NCAP, 2018). Table 3 below lists some of the differences:

TABLE 3: Comparison between Malaysia standard and suggested LED from Euro NCAP

Parameter	Malaysia	Schuch 48 2403 LED Lighting
Lumen efficacy	> 90 lm/W	141 lm/W
Usable lifetime	L80 ≤ 36000h	L90 > 100,000h
Correlated Color Temperature (CCT)	2500K - 3500K	4000K (For Euro standard, the range is from 3500K - 5500K)
Ingress Protection Index (IP)	IP65 (min)	IP66

The measure of lumen efficacy indicates the amount of light produced in lumens for each watt of electrical energy consumed. Unlike conventional lighting technologies that stop producing light altogether at the end of their lifespan, the lifespan of LEDs is determined by the point at which their lumen output decreases to a level where it is no longer sufficient to meet the required lighting standard. The industry defines the lifespans of LEDs as the point at which their lumen output diminishes to 70% of their original level. The usable lifetime from the Malaysian Standard and European Standard refers to 80% and 90% of LED lifespans, respectively (METREL, 2002; DOSM, 2007).

The Correlated Color Temperature (CCT) is the temperature of the Planckian radiator whose perceived color most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. The Correlated Color Temperature (CCT) describes the color of the light source, and it is determined by comparing the light's color to that of the Plankian radiator when heated to a specific temperature, measured in Kelvin (K). The CCT score is a general indicator of the 'warmth' and 'coolness' of the light's appearance, but it is worth noting that, in contrast to the temperature scale, lights with a CCT score below 3200K are typically classified as 'warm', whereas these with a CCT score above 4000K are typically considered to have a 'cool' appearance (METREL, 2002).

Throughout the day, the color temperature of natural daylight changes, with a CCT of approximately 3000K during sunrise and sunset and reaching the highest level of around 5000K or higher at noon. The color temperature of light plays a significant role in impacting humans, and it is essential to consider it in different settings. Warm light with a color temperature of 3000K is preferred in places such as coffee shops, restaurants, and hotel lobbies where people gather, as it promotes relaxation. In contrast, cooler light with a color temperature of around 4000K is more suitable for areas such as classrooms, offices, and conference rooms, where individuals need to be more focused on their jobs. LED lights offer the best options to adjust the CCT to meet the desired requirements (METREL, 2002).

When water or dust enters electric or electronic equipment, it can cause damage and malfunction. Thus, to assess the resistance of an enclosure against the intrusion of dust or liquids, the International Electrotechnical Commission (IEC) has introduced a grading system known as the Ingress Protection (IP) ratings. These ratings are widely used across various industries. The IEC Technical Committee has developed a standard that utilizes the IP code to evaluate the degree of protection provided by the enclosure of electrical equipment with a rated voltage of up to 72.5 kV. This standard also outlines the tests that must be conducted to confirm that the enclosure meets these requirements. The IP code consists of two digits where the first digit represents the protection against solid objects and ranges from 0 (no protection) to 6 (complete protection against dust ingress). While the second digit denotes the enclosure's defense against liquid and is graded on a scale of 0 (no protection) to 9(protection against high-pressure hot eater from different angles) (METREL, 2002).

3. METHODOLOGY - REFERENCE GRID LIGHT MEASUREMENT

Grid calculation from Euro NCAP (2018) is used as the grid measurement method at the site. The distance between two luminaires first must be decided. For the proposed protocol, the measuring points of 10 evenly spaced between two adjacent road lights of the x-axis are considered, as shown in Figure 1.

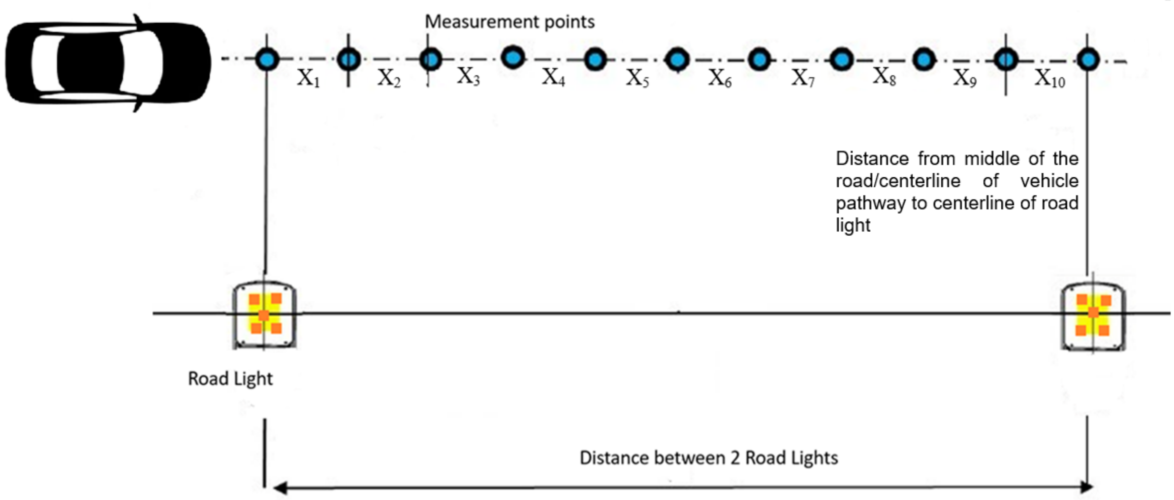

FIGURE 1: Grid measurement proposed and used in site testing

The lux meter was placed on ground level to measure the actual illuminance level for each point. Then, the data is recorded and used to calculate the overall uniformity, U_o and longitudinal uniformity, U_l using Eq. 1, 2, and 3.

$$U_o = \frac{E_h \text{ min}}{E_h \text{ avg}} \tag{1}$$

$$E_h \text{ avg} = \frac{1}{M} \sum E_h\ i \tag{2}$$

$$U_l = \frac{E_h \text{ min}}{E_h \text{ max}} \tag{3}$$

Where U_o is the overall uniformity of horizontal illuminance, E_h is illuminance in lux, E_h min, E_h max and E_h avg is the minimum, maximum, and average of illuminance, $E_h\ i$ is the illuminance of i testing point, M is of the number of tested point grids on road.

4. RESULTS AND DISCUSSION

4.1 Road Lights Illumination Data

The illumination data involving grid measurements as described in the previous section are presented. Tables 4, 5, and 6 show the data of lux measurement testing for the selected sites at Perak. The measurement started at 8 pm. Pole heights and distances between the two selected road lights were also recorded and have been presented in Table 2.

TABLE 4: The results for measuring point along the x-axis trajectory for site Seri Iskandar

Measuring Points	On-site Illuminance (Lux)
X_1	28
X_2	29
X_3	24
X_4	18
X_5	13
X_6	12
X_7	12
X_8	16
X_9	22
X_{10}	28
X_{11}	34

By using Equation (1) and Equation (2), the results for the Seri Iskandar site are E_h avg = 21.5 lux, E_h min = 12 lux, E_h max = 34 lux, U_l = 0.35 and U_o = 0.56.

TABLE 5: The results for measuring point along the x-axis trajectory for site Taman Botani

Measuring Points	On-site Illuminance (Lux)
X_1	16
X_2	12
X_3	8
X_4	5
X_5	4
X_6	4
X_7	6
X_8	8
X_9	14
X_{10}	19
X_{11}	21

By using Equation (1) and Equation (2), the results for the Taman Botani site are E_h avg = 10.6 lux, E_h min = 4 lux, E_h max = 21 lux, U_l = 0.19 and U_o = 0.38. The results for U_l and U_o is compared with Malaysia Standard [19] in Table 6 below.

TABLE 6: Comparison between site lux measurement and Malaysian standard for road lighting

	Road Class	Malaysia Standard [19]		On-site measurement	
Sites		U_l min	U_o min	U_l	U_o
Seri Iskandar	M3	0.7	0.4	0.35	0.56
Taman Meru Impian	M5	0.4	0.35	0.4	0.55
Taman Botani	M5	0.4	0.35	0.19	0.38

Good street lighting illuminance level dictated in literature, on average is 20 lux [20]. From the number, only 1 site has a good streetlight which is Seri Iskandar while the other sites are below the average. It should be noted that the street lighting in Seri Iskandar is newly built compared to the others. The other sites illuminance performance could be because of lack of proper maintenance. The second reason could be due to the illuminance is deteriorating because it approaches the limits of useful life for LED lighting. From on-site measurements of U_l and U_o, there are measurements below the minimum requirement dictated by Malaysia Standard. Other reasons for the difference in value may be caused by external factors such as the surroundings of the road lamp. Especially in the Taman Botani site where there are quite a lot of huge trees behind the road lamp. So, the measurement for the site could be said influenced by the trees' shadow.

4.2 Deduction of Proposed AEB Night Test Illumination Range

Based on the illumination measurement data of road lights in the three sites and also several selected data from the literature, the AEB night test illumination range is proposed based on the average values and lumping all the illumination values. The range of the proposed pole heights and distance between poles are also presented. Table 7 shows the proposed of proposed AEB night test illumination range and current AEB night pedestrian night test range.

TABLE 7: Range values of proposed AEB night test illumination range and current AEB night pedestrian night test range

Parameter	Proposed Range	Current Euro NCAP AEB VRU Protocol Range (Euro NCAP, 2018)
Illumination, E_v	$22.3\ \pm 6.5\ lx$	$19\ \pm 3\ lx$
Height, H	$10.4\ \pm 2\ m$	Unspecified
Distance between poles, D	$33.8\ \pm 4.5\ m$	Unspecified

As can be seen, the value of average in illumination has a very large tolerance. This is caused by the varied duration of the luminaire installed at the sites from the newly installed (Kuala Terong) and the longest period in the authors' knowledge which is 10 years (Taman Botani). As mentioned before, the useful lifetime for luminaire in JKR standard stands for L80 ≤ 36000 hours. If the luminaire is working 10 hours per day, which makes the 36,000 hours equal to 9.86 years. The other factor is the difference in lighting road class. Hence, the average values concluded from the survey and past pieces of literature could be determined as working illumination for many levels of road lighting class starting from M1 (highway) to M5 (residential area).

5. CONCLUSION

The results for the selected sites indicated variations in illuminance levels and uniformities, with Seri Iskandar meeting the recommended standards while others fell below, potentially due to maintenance issues or environmental factors. The article proposed a range for Autonomous Emergency Braking (AEB) night test illumination based on average values from the sites and literature, highlighting the impact of luminaire duration and road class on illumination levels. Overall, the study provided insights into the performance of LED road lighting in the selected sites and suggested considerations for improving standards and testing protocols.

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