AN ANALYSIS OF ROAD LIGHT INTENSITY ON SINGLE LANE ROAD WITH LAMP POLE ON KERB SIDE EDGE

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This report is submitted
in fulfilment of the requirement for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JULY 2024

DECLARATION

I declare that this project report entitled “” is the result of my own work except as cited in the references

Signature : Saufi ....

Name : MUHAMAD SAUFI BIN ISHAK

Date : 13/7/2024 ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Name of Supervisor : IR. TS. DR MOHD ZAID BIN AKOP

Date : 13/7/2024

DEDICATION

To my beloved mother and father

ABSTRACT

This thesis provides an in-depth analysis of light intensity on a single-lane road, where lamp poles are positioned at the curb’s edge. The objective is to assess the distribution of light across the road. The study involves measuring light intensity at various heights and angles from the road surface, utilizing advanced photometric equipment to collect precise data. For this purpose, a portable streetlamp was specially designed to measure the light intensity on double lanes. Several factors were considered, including the road’s length and width, the lamp’s height, and the angle at which the light is projected. Based on these parameters, light intensity readings were obtained along a grid line on the road. The findings reveal that light intensity is higher at the beginning and end of the lamp's reach, with lower intensity levels observed in the middle of the road between lamp posts. This research provides a valuable foundation for city planners and engineers to improve road lighting systems, thereby enhancing safety and efficiency in transportation networks. Additionally, the study evaluates the potential effectiveness of Autonomous Emergency Braking Systems (AEB) in vehicles.

ABSTRAK

Kajian ini mempersembahkan analisis komprehensif terhadap intensiti cahaya di jalan satu lorong dengan tiang lampu yang diposisikan di tepi bahu jalan. Kajian ini bertujuan untuk menilai pengagihan cahaya di jalan dua lorong. Penyelidikan ini melibatkan pengukuran intensiti cahaya pada pelbagai ketinggian dan sudut dari permukaan jalan, menggunakan peralatan fotometrik canggih untuk mengumpulkan data yang tepat. Sebuah lampu jalan mudah alih telah direka khas untuk kajian ini bagi mengukur intensiti cahaya di jalan dua lorong. Pelbagai aspek telah dipertimbangkan, seperti panjang jalan, ketinggian lampu, lebar jalan, dan sudut cahaya lampu. Berdasarkan faktor yang dikira, bacaan intensiti cahaya akan diperoleh sepanjang garis grid jalan. Hasil kajian menunjukkan tahap intensiti cahaya yang lebih tinggi pada permulaan dan akhir lampu, dengan intensiti cahaya yang lebih rendah di bahagian tengah jalan antara tiang lampu. Kajian ini menawarkan asas yang bernilai untuk perancang bandar dan jurutera dalam meningkatkan sistem pencahayaan jalan untuk rangkaian pengangkutan yang lebih selamat dan berkesan. Selain itu, kajian ini berpotensi menilai keberkesanan Sistem Pembrekan Kecemasan Autonomi (AEB) kereta.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my supervisor, Ir. Ts. Dr. Mohd Zaid bin Akop, for giving me the opportunity to work on this final year project under his guidance. His unwavering support, advice, and readiness to assist whenever I encountered challenges have been invaluable. I am truly grateful for his patience and insights throughout the course of this project.

I also extend my heartfelt gratitude to my family for their unwavering love, patience, and encouragement. Their constant support has strengthened and motivated me throughout my academic journey. To my mom, thank you for your steadfast belief in me and for always supporting my dreams.

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LIST OF ABBEREVATIONS

AEB	Autonomous Emergency Braking
LDR	Light Depends Resistors
MIROS	Malaysian Institute of Road Safety Research
RTCs	Road Traffic Crashes
LED	Light-Emitting Diode
UDS	Ultrasonic Distance Sensors
ADAS	Advanced Driver Assistance System
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
LCA	Lane Change Assistance
LiDAR	Light Detection and Ranging
NCAP	New Car Assessment Programme
Euro NCAP	European New Car Assessment Programme
JNCAP	Japanese New Car Assessment Program
CNCAP	Chinese New Car Assessment Program
VUT	Vehicle under test
EPT	Euro NCAP Pedestrian Target

CHAPTER 1

INTRODUCTION

1.1 Background

The illumination of roadways is a critical component of rural infrastructure. It ensures safety and visibility for both pedestrians and motorists during nighttime hours. Among the various aspects of road lighting, the placement and intensity of lamp poles play a significant role in determining the overall quality of illumination and, by extension, road safety. This study focuses on the analysis of road light intensity on a single-lane road with lamp poles installed on the kerb side edge. Proper road lighting is essential for several reasons in enhancing the safety of road users by providing improved visibility. It significantly reduces the risk of accidents and improves traffic flow, providing a safer and more comfortable environment for road users. Adequate lighting ensures that the road and its surroundings are well-illuminated, allowing drivers to see the road ahead, potential obstacles, other vehicles, and pedestrians more clearly.

The rapid advancements in autonomous driving technologies, particularly Autonomous Emergency Braking (AEB) systems, have paved the way for a safer and more efficient road transportation system. A critical aspect of the AEB system's performance is its ability to accurately detect and respond to potential hazards, such as obstacles or pedestrians, in various lighting conditions. One crucial factor influencing the effectiveness of AEB systems is road light intensity. This study is aims to experimentally validate of road light intensity on different road light heights and angles to evaluate the AEB system performance protocol under varying lighting conditions.

To attain this goal, a comprehensive strategy will be utilized. The study will encompass in-person site visits and measurements to appraise the lamp posts' placement, elevation, and orientation. Light intensity will be evaluated at particular locations to gauge the overall brightness and its even distribution on lanes.

1.2 Problem Statement

Analysing road light intensity on a single-lane road with lamp poles on the kerb side edge presents a multifaceted challenge, especially when considering its relevance to Autonomous Emergency Braking (AEB) systems. One of the primary problems stems from uneven illumination caused by the positioning of lamp poles. Irregular distribution of light on the road surface can create shadows and bright spots, which may impact the accuracy of AEB sensors in detecting obstacles. For instance, if an AEB system relies heavily on cameras, harsh shadows and glares due to improperly placed lamp poles can hinder the system's object recognition capabilities. Furthermore, glare from misaligned lighting can confuse AEB sensors, making it difficult for the system to assess distances and react to potential hazards accurately.

The optimal positioning of lamp poles, considering their height and angle, is another crucial problem. Lamp poles that are too tall or have an incorrect angle can result in light spillage into oncoming lanes, which can cause glare for drivers. AEB systems rely on sensors that capture data in real-time, and any hindrance due to glare can significantly impact their ability to respond to emergencies effectively. Moreover, incorrect pole placement may lead to over-illumination, that affect the energy-efficient and confuse AEB systems by generating excessive reflections and shadows.

Analyzing road light intensity on single lane roads with lamp poles on the kerb side edge has direct implications for AEB systems. Addressing problems related to lamp pole positioning, even illumination, adaptation to changing light conditions, and energy efficiency is crucial to ensure that AEB systems can accurately detect and respond to potential hazards while operating under varying lighting conditions. The successful integration of AEB technology with well-designed road lighting systems is essential to enhance road safety and mitigate single-lane road accidents.

1.3 Objective

The objectives of this project are as follows:

1. To analyze light intensity variations based on different heights from road surfaces and various angles of lamp poles.
2. To correlate the effect of height and angle on light intensity.

1.4 Scope of Project

The scopes of this project are:

1. To develop and setup on road AEB test capabilities subjected to road with varying light conditions.
2. Collecting and analysing data through an onboard system for measurement and data acquisition.
3. Verify the light intensity generated by a specially designed road light intensity simulation testing apparatus.
4. Report writing, journal publications and project presentation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Road Light Intensity

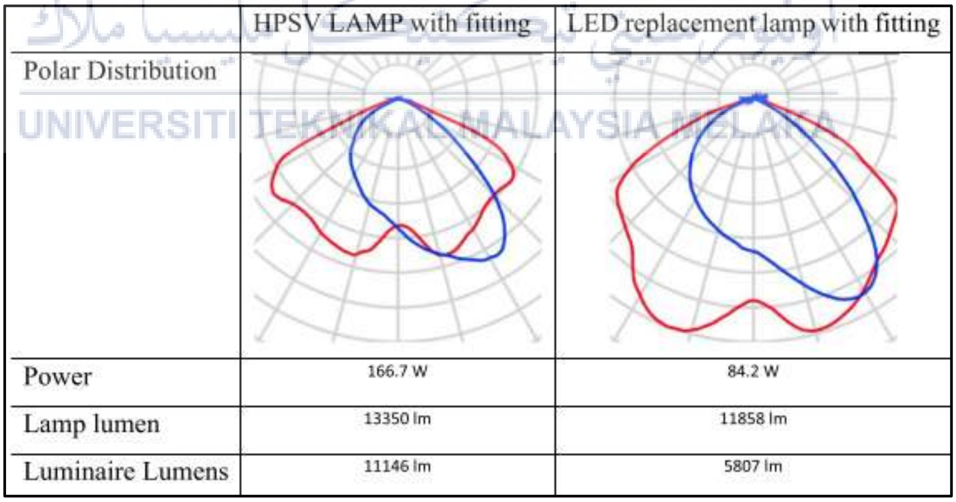
The intensity of road lights, measured in lux, is an important feature of road infrastructure that improves safety, visibility, and overall road user experience. Adequate lighting on highways and streets ensures that drivers can easily see the road, potential obstructions, and other cars, lowering the chance of accidents, especially at night and in bad weather. It also improves pedestrian and cyclist visibility, which contributes to their safety. Proper road illumination not only makes driving more comfortable by minimizing eyestrain and tiredness, but it also helps with traffic flow management by clearly delineating lanes, signs, and signals, making it simpler for drivers to follow traffic laws.

2.1.1 Road with Lighting and Without Lighting

The primary objective of road lighting is to ensure human safety by illuminating objects on the road and around cars, as well as to offer optimal visibility conditions and reduce potential hazards. Furthermore, good road lighting is required to estimate the automobile speed, monitor dangerous items beside the car, and maintain the spacing between the cars. As a result, the primary aim of road illumination is to assist road users in rapidly, accurately, and pleasantly recognizing objects around them (Setyaningsih *et al.*, 2018).

2.1.2 Consideration of Road Light Specification

The intensity of road illumination influences visibility and sensing distances as well. Road lighting intensity levels of 100% and 49% without glare give equivalent detection distances, whereas visibility is lowest at 71% of road lighting intensity (Bozorg Chenani *et al.*, 2016). However, a balance must be struck between delivering enough light intensity and limiting light pollution, which can have negative environmental and health consequences also ensuring optimal visibility for road users. Modern technology, such as energy-efficient LED streetlights, has made it possible to meet these objectives while lowering energy consumption and maintenance costs. In most situations, the intensity of road illumination is determined by specific road lighting classes, with different static road surface brightness levels applied to different types of roads. Furthermore, the brightness levels of road surfaces are often dynamic and greatly depend on the current weather conditions.



	HPSV LAMP with fitting	LED replacement lamp with fitting
Polar Distribution		
Power	166.7 W	84.2 W
Lamp lumen	13350 lm	11858 lm
Luminaire Lumens	11146 lm	5807 lm

Figure 2.1 HPSV Lamp vs LED Lamp (Jamaludin *et al.*, 2023)

2.1.3 Intensity From the Colors of The Road Light

The effects of lights colors on visual safety perception and clarity are different. Road illumination with white light is judged to be more secure and pleasant than yellowish light (Setyaningsih *et al.*, 2018). Besides, the production of white light commonly involves the combination of blue and yellow light, as discussed by Lee et al. (2015). The incorporation of yellow phosphors in white light-emitting diodes (LEDs) has the potential to improve both the brightness and color rendering of the emitted light, as highlighted in the study by Haranath et al. (2006). Furthermore, short-wavelength yellow oxynitride phosphors have been explored to generate vivid daylight emissions from white LEDs, as elucidated by Xie et al. (2006).

Regarding road safety, it has been suggested that white road lighting reduces road traffic crashes (RTCs) (Marchant & Norman, 2023). The hue of road illumination can also influence visibility and detection distances. Chenani et al. (2017) discovered that target identification was impaired in almost half of road lighting settings, implying that visibility may be impaired. On the other hand, Buyukkinaci et al. (2017) demonstrated that visibility levels for road lights with different color temperatures were sufficient for fully detection of essential objects.

2.1.4 Smart Street Lighting

A project known as Ambient Street Illumination has been developed, which uses an embedded-based microcontroller to govern illumination in accordance with the circumstances existing in the region surrounding the road (Mohamed *et al.*, 2018). Ambient Street Lighting reduces the amount of electricity required by the street lighting system while simultaneously increasing its efficiency. This is a working prototype of a system that can automatically modify the illumination intensity based on the brightness of the surroundings and the number of cars passing by. It can detect the ambient intensity condition by utilizing LDR Sensors, which stand for "Light Depends Resistors," and UDS Sensors, which stand for "Ultrasonic Distance Sensors," and can identify the number of automobiles. The number of automobiles is used to simulate an increase in brightness caused by car lights.

2.1.5 Motion Sensors for Adaptive Road Lighting

The use of motion sensors for adaptive road lighting has gained significant attention in the field of urban infrastructure management. Motion sensors, in combination with other types of sensors, have been proposed for adaptive road lighting systems to improve energy efficiency and enhance safety. For instance, Chiradeja et al. (2020) highlighted the use of LDR sensors to control road lighting based on the availability of natural light, demonstrating the potential for adaptive lighting control (Chiradeja, Yoomak and Ngaopitakkul, 2020). Additionally, emphasized the utilization of vehicle motion sensors and inertial sensors to detect various road surface types and anomalies, indicating the diverse applications of motion sensors in road infrastructure (Institute of Electrical and Electronics Engineers, 2018). Furthermore, Collotta et al. (2014) proposed an adaptive traffic light control algorithm that adjusts the sequence and length of traffic lights in real-time based on the traffic detected, showcasing the adaptability of sensor-based systems in managing road traffic (Collotta *et al.*, 2014).

2.1.6 Performance of Automated Road Light Intensity Control

Automated road light intensity performance can be evaluated through sensor-based systems and control algorithms. proposed sensor solutions that can detect road users and determine their movement direction and speed, enabling dynamic lighting control and traffic intensity prediction (Adrian *et al.*, 2021). Additionally, energy-efficient smart light controlling system was developed using motion and light sensors for automatic lighting control (Saidul Islam *et al.*, 2021). introduced a technique for controlling LED street light intensity based on vehicle movement detection, to achieve power savings (Prof. Sagar Bhaisare, 2022) and evaluated the energy efficiency of LED road lighting using normalized power density, providing insights into the performance of lighting systems (Jägerbrand, 2016). Furthermore, presented an IoT-enabled light intensity-controlled seamless highway lighting system, demonstrating the potential for advanced control mechanisms in road lighting (Rahman *et al.*, 2021). conducted a study on target detection distances under different road lighting intensities, highlighting the impact of lighting intensity on visibility and detection (Bozorg Chenani *et al.*, 2017). Moreover, explored road lighting automation scenarios based on traffic speed and volume, emphasizing the importance of analyzing vehicle speeds and numbers for effective automation algorithms (Buyukkinaci *et al.*, 2019).

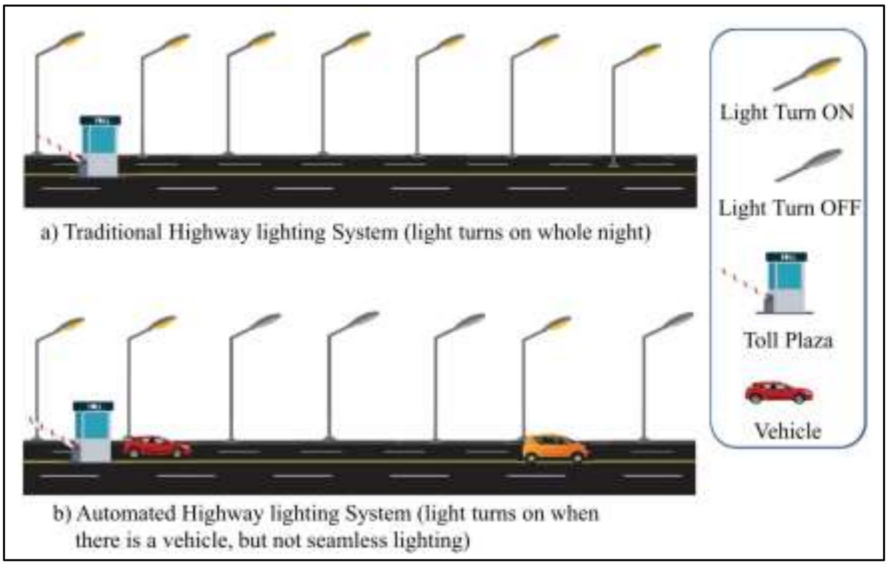


Figure 2.2 Two unfit-for-purpose highway lighting systems (Rahman *et al.*, 2021)

2.2 Height and Angle Influencing the Intensity of Road Lighting

Several factors need to be considered to investigate the effect of the height and angle of road lamps on the intensity of the road lamp. Emphasized the significance of lamp type, pole distance, pole height, and proper lighting angles in redesigning street lighting, as these factors can affect the illumination value on both the main road and the sidewalks (Abdullah, Aziz and Huda, 2021). Additionally the luminaire mounting height, street light spacing, luminaire inclination angle, and road surface properties are essential for ensuring the desired street lighting performance (Lee *et al.*, 2020). Furthermore, demonstrated that illuminance affects obstacle detection, with the height needed for 50% detection probability increasing as illuminance decreases (Fotios and Cheal, 2013). These findings collectively underscore the importance of considering the lamp type, pole height, and lighting angles in determining the intensity of road lamps.

Moreover, the study also revealed that obstacle detection was influenced by illuminance, with detection performance increasing with illuminance, reaching a plateau at 2.0 lux (Uttley, Fotios and Cheal, 2017). This suggests that the height and angle of road lamps can impact obstacle detection, which is crucial for road safety. Additionally, highlighted that lighting intensity, profile, and architecture influence the performance of road users (Prasetijo *et al.*, 2021). This further emphasizes the need to consider the height and angle of road lamps to ensure optimal lighting intensity for road users.

2.3 Advanced Driver Assistance System (ADAS)

In the intricate landscape of automotive technology, sensors stand as the cornerstone, transforming vehicles from mechanical entities into intelligent, data-driven systems. These sophisticated devices are designed to perceive and interpret the dynamic environment surrounding a vehicle, providing a wealth of real-time data that is fundamental to its functionality, safety, and overall performance.

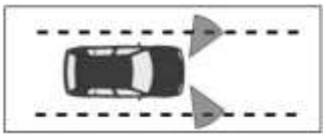
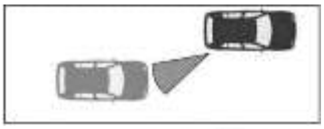
Advanced Driver Assistance Systems (ADAS) represent a comprehensive suite of technologies integrated into vehicles to enhance safety, improve driver experience, and mitigate the risk of accidents. ADAS utilizes sensors, cameras, radar, and other sophisticated devices to monitor the vehicle's surroundings in real-time. ADAS system, such as emergency braking systems, adaptive cruise control, and lane-keeping system, support the driver in driving tasks by detecting other vehicles behavior (Athanasas et al., 2017). By leveraging sensor data and employing automated responses, ADAS aims to assist drivers in various aspects of driving, such as maintaining safe distances from other vehicles, staying within designated lanes, and reacting to potential hazards.

ADAS harnesses the power of sensors to usher in a new era of safety and convenience. Peiris et al. (2022) investigate how insufficient road infrastructure affects the safety advantages provided by Advanced Driver Assistance Systems (ADAS), encompassing systems like AEB (Peiris et al., 2022). Although the study does not specifically discuss into road lighting conditions, it underscores the significance of well-designed road networks and infrastructure in facilitating the effectiveness of ADAS technologies. This implies that the state of road lighting, being an integral component of the broader road infrastructure, might impact the functionality of AEB systems. These systems encompass a spectrum of functionalities, ranging from collision avoidance and lane departure warnings to the critically important Autonomous Emergency Braking (AEB) systems.

An example of Advanced Driver Assistance Systems (ADAS) is the Lane Departure Warning (LDW) system. This technology uses cameras or sensors to monitor a vehicle's position in its lane. Some advanced versions, like Lane Keeping Assist (LKA), can even help steer the vehicle back into its lane to prevent potential collisions. There is also Lane Change Assistance (LCA), which is aware of hits for driver before changing lane.

Table 2.1 ADAS System Description

ADAS System	Description
Lane Departure Warning (LDW)	Lane Departure Warning (LDW) serves as a crucial safety feature by verifying that a vehicle maintains secure travel within lane boundaries, as exemplified by road markings. Employing cameras and computer systems, LDW detects and analyzes roadside obstructions and lane markers, issuing warnings to the driver when necessary. However, as the computer assumes full control of the vehicle and the potential for erroneous alerts persists, the widespread acceptance of LDW is expected to encounter challenges.

Lane Keeping Assist (LKA) 	The Lane Keeping System (LKS) represents a more sophisticated iteration of the Lane Departure Warning (LDW) system. In contrast to merely issuing alerts for unintentional lane departures, LKS employs steering wheel actuators to intervene in the driver's steering tasks actively. Remarkably, LKS can completely assume the driver's responsibility for steering, signifying a heightened level of automation in vehicle control.
Lane Change Assistance (LCA) 	A compilation of technologies designed to tackle challenges related to rear visibility and blind spots constitutes this system. Using sensors, it identifies objects and vehicles that might escape the driver's notice due to obstructions. Moreover, it enables the anticipation of vehicles approaching from behind, with timely alerts to inform the driver

2.3.1 Autonomous Emergency Braking (AEB)

Autonomous Emergency Braking (AEB) is a safety technology integrated into vehicles to mitigate or prevent collisions by autonomously applying the brakes when an imminent collision is detected. Autonomous Emergency Braking (AEB) systems represent active safety technologies engineered that autonomously engage the brakes during emergency scenarios (Veneroso *et al.*, 2023). The primary purpose of AEB is to enhance vehicle safety by utilizing advanced sensor systems, such as radar, LiDAR, or cameras, to monitor the vehicle's surroundings constantly. In critical situations where the system detects an impending collision with an obstacle, pedestrian, or another vehicle, AEB intervenes swiftly and automatically engages the brakes, either slowing down the vehicle or bringing it to a complete stop. Research indicates their effectiveness in lowering rear-end collision rates, with data pointing to a potential reduction of up to 43% in rear-end crashes reported to the police (Graci et al., 2019). Particularly advantageous in vehicle-pedestrian collisions, AEB systems hold the capacity to prevent or minimize the severity of such incidents (Haus, Sherony and Gabler, 2019). This technology is a crucial component of Advanced Driver Assistance Systems (ADAS), contributing significantly to accident prevention and reducing the severity of collisions.

Enhancing the functionality of Autonomous Emergency Braking (AEB) systems has been a focal point of research, with investigations delving into multiple dimensions. One facet of inquiry involves scrutinizing driver braking patterns in diverse situations, such as conflicts between vehicles and bicycles, to provide insights for refining AEB system development (Duan et al., 2017).

2.3.2 Impact of Road Lighting Condition on AEB System Performance

Considering the influence of road lighting conditions on the efficacy of Automatic Emergency Braking (AEB) systems is a crucial aspect of road safety. Although the references provided do not explicitly delve into this precise subject, certain sources touch upon related facets that can offer valuable insights into the broader implications of road conditions on the performance of AEB systems.

The study by Yang et al. (2020) focuses is on the influence of pavement conditions on the performance of Automatic Emergency Braking (AEB) systems. Although the discussion doesn't explicitly touch upon road lighting conditions, it implies that variations in road surface conditions may impact the effectiveness of AEB systems (Yang *et al.*, 2020). This suggests that factors like wet or slippery road surfaces, which lighting conditions can influence, have the potential to affect how well AEB systems operate. Consequently, it implies that road lighting conditions, being an integral component of the overall road infrastructure, could potentially play a role in influencing the performance of AEB systems.

2.4 Light Detection and Ranging (LiDAR)

Light Detection and Ranging, or LiDAR, has drawn much interest due to its use in transportation systems and road infrastructure. LiDAR technology is useful for several road-related applications, including inventory mapping, road surface analysis, traffic sign detection, and road detection, since it offers accurate three-dimensional information about the surrounding road environment (Suleymanoglu *et al.*, 2023). Reutebuch et al. (2003) found that LiDAR's accuracy and utility in forestry further bolster its potential for road-related applications (Reutebuch *et al.*, 2003). LiDAR has also been applied to terrain analysis, road design, and management, indicating its recognized value in the planning and building phases of roads (Hatta Antah *et al.*, 2021).

The ability to detect and map roads has been further improved by the combination of LiDAR with other technologies, such as cameras and neural networks. Caltagirone et al. (2019) highlight the potential of LiDAR in this sector and highlight the benefits of multimodal systems for road detection through fusion approaches incorporating LiDAR and cameras, as well as the development of deep learning approaches for road detection utilizing LiDAR data (Caltagirone *et al.*, 2019). LiDAR has also been used in metropolitan settings to extract road lane markers, road centerlines, and road points, demonstrating its adaptability in a variety of road infrastructure applications (Zeybek, 2021).

LiDAR's importance in improving road safety, infrastructure planning, and environmental mapping is highlighted by its function in extracting road information, including vehicle trajectories, drainage design, and environmental perception for actual road applications (Sun *et al.*, 2018). Furthermore, LiDAR technology's capacity to produce high-definition (HD) maps-incredibly comprehensive 3D maps of road environments-further validates its potential for smooth vehicle positioning and smart road applications (Zhang, Khoshelham and Khodabandeh, 2021).

LiDAR technology is a useful instrument for a various road-related applications, such as environmental perception, infrastructure planning, and road detection and mapping. It is a promising asset in road infrastructure and development because of its precision, adaptability, and potential for integration with other technologies.

2.4.1 Impact of LiDAR in Road Lane

LiDAR technology is frequently used in many road-related applications, such as mapping forest road alignments, extracting lane markings from roads, detecting road markings, and detecting roads and road edges (Suleymanoglu *et al.*, 2023). LiDAR is a useful technique for analyzing zebra crossing zones and assessing the effects of work zone design on traffic operations due to its accuracy in providing geometric data and its resilience to varying weather conditions (Esmorís *et al.*, 2023). Moreover, LiDAR-based systems have been applied to ego-lane recognition, in-lane localization, and lane-level map building, indicating its importance in mapping road infrastructure and vehicle navigation (Yu *et al.*, 2021). Various studies have demonstrated the precision and reliability of LiDAR in identifying road boundaries, barriers, and lane markers, highlighting its potential to improve autonomous vehicle performance and safety (Kim, Park and Kim, 2023).

Road widening, measuring the slope of roadside surfaces, and evaluating roadways have all benefited from LiDAR's capacity to produce high-quality digital elevation models from mobile LiDAR data. To further emphasize the importance of LiDAR data in describing road infrastructure, it has also been utilized to extract road features such as road grade, cross-sectional slope, and road prism shape. To achieve full road environment perception, the integration of LiDAR with other sensors, like cameras, for multisensory fusion has been proposed for in-lane localization and ego-lane recognition (Choi et al., 2020). LiDAR's utility in interactive road situation analysis for driver assistance and safety warning systems has also been demonstrated by its involvement in differentiating items, such as moving objects, roadside reflectors, and overhead signs (Cheng et al., 2007).

LiDAR technology offers precise road and lane detection, accurate mapping of road features, and strong environmental awareness for cars, all of which significantly impact on road infrastructure and safety. Its uses cover a wide range of road engineering, transportation, and autonomous driving domains, rendering it an invaluable instrument for augmenting road safety and effectiveness.

2.5 New Car Assessment Programme (NCAP)

The European New Car Assessment Programme (Euro NCAP) was established in 1997 to provide safety performance assessments for the most popular cars in Europe (Van Ratingen *et al.*, 2016). Euro NCAP has been influential in promoting vehicle safety, leading to the adoption of similar programs in other parts of the world, such as the Japanese New Car Assessment Program (JNCAP) and the Chinese New Car Assessment Program (C-NCAP) (Magosi *et al.*, 2022). Euro NCAP's testing procedures and evaluations are independent, uniting European ministries, automobile clubs, and underwriting associations. The program has also been instrumental in encouraging the fitment of advanced safety systems in vehicles, as evidenced by the development of rating schemes to promote the integration of these systems (Edwards *et al.*, 2015).

Euro NCAP's safety ratings have become a benchmark for vehicle safety, with studies indicating that a 5-star rating in Euro NCAP crash tests is a key indicator of a safe vehicle (Rasmana *et al.*, 2021). Furthermore, the program has influenced the development of safety regulations, with multiple new regulations mandating the integration of driver monitoring systems into Advanced Driver Assistance Systems (ADAS) in future production cars (Bickerdt et al., 2021). Additionally, the Euro NCAP safety rating has been used to indicate vehicle safety in European studies, highlighting its significance in assessing vehicle safety.

The impact of Euro NCAP extends beyond Europe, with its influence evident in the ASEAN NCAP, which has successfully high safety standards in the automobile industry (Sukadarin et al., 2020). Euro NCAP's awareness and ratings have increased over time, influencing consumer behavior towards safer car purchasing decisions (Abu Kassim *et al.*, 2016). Moreover, the program has prompted manufacturers to improve seat belt performance, demonstrating its historical role in driving safety improvements in vehicles.

2.5.1 ASEAN New Car Assessment Programme (ASEAN NCAP)

Since its establishment in 2011, ASEAN NCAP has substantially contributed to improving vehicle safety in Southeast Asia. It has significantly improved the safety features of passenger cars through its series of crash tests, raising the bar for safety in the automotive sector (Roslin *et al.*, 2020). According to Kassim et al. (2017), the program's emphasis on increasing consumer awareness and stimulating the market for safer cars has produced significant and encouraging results in the direction of a safer automotive environment for Malaysian drivers (Abu Kassim, Mohd Jawi and Md Isa, 2017). Additionally, the ASEAN NCAP's 2017 implementation of a new upper and lower limit crash pulse curve improved the depiction of the crashworthiness of cars sold in the ASEAN market, highlighting its dedication to enhancing vehicle safety (Hussein et al., 2021).

The impact of ASEAN NCAP extends beyond vehicle safety assessments, as it has influenced consumer behavior towards purchasing decisions. The demand for vehicles equipped with advanced safety technologies has increased in Malaysia due to the improved vehicle regulations imposed on new vehicles and the establishment of the ASEAN NCAP safety-rating initiative (Abu Kassim *et al.*, 2016). Moreover, the program's collaboration with the Malaysian Institute of Road Safety Research (MIROS) and Global NCAP underscores its commitment to fostering cooperation efforts aimed at enhancing vehicle safety in the region (Roslin *et al.*, 2020).

2.5.2 Comparison Between Asean and Euro NCAP

The ASEAN NCAP has significantly contributed to Malaysia’s automotive ecosystem, echancing vehicle safety and providing added value to car ownership (Abu Kassim, Mohd Jawi and Md Isa, 2017). It has also facilitated the implementation of relevant safety technologies in new vehicles and encouraged consumers to choose safer cars, thereby influencing consumer behaviour towards purchasing decisions (Abu Kassim *et al.*, 2016). Additionally, the ASEAN NCAP has conducted comprehensive crash tests on popular passenger cars, ensuring a thorough assessment of their safety performance (Solah *et al.*, 2014). Furthermore, the program aims to elevate motor vehicle safety in the region, aligning with global road safety standards and promoting the market for safer vehicles (Mohd Khairudin *et al.*, 2014).

The Euro NCAP serves as a benchmark for the ASEAN NCAP, providing a reference for assessing safety standards and testing methodologies (Rasmana *et al.*, 2021). This allows for a comprehensive review and development of safety rating schemes, ensuring that the ASEAN NCAP aligns with international safety standards and best practices. Moreover, the comparison of safety levels and occupant injury risk for vehicles in both NCAPs highlights the importance of safety features, as seen in the contrasting performance of vehicles such as the TATA Super Ace and the Daihatsu Hijet Cargo DX (Johari *et al.*, 2021).

Both the Euro NCAP and ASEAN NCAP play vital roles in enhancing road safety in Malaysia. While the ASEAN NCAP has made significant strides in improving the automotive ecosystem and influencing consumer behaviour, the Euro NCAP provides valuable benchmarks and comparisons to ensure that the ASEAN NCAP aligns with international safety standards. Together, these initiatives contribute to promoting safer vehicles and reducing road accidents in Malaysia.

2.6 The Effects of Weather Conditions on Road Light Intensity

The impact of weather conditions on road light intensity is a critical factor in ensuring road safety and traffic flow. Weather elements such as rain, fog, snow, and variations in daylight have been shown to impact road visibility and illumination significantly. As a result, driver reaction time increases, potentially leading to traffic accidents. Additionally, inclement weather affects traffic demand, safety, and flow relationships (Maze et al., 2006). The impact of adverse weather on road mobility has been highlighted, with crash frequencies increasing significantly during such conditions (Dey, Mishra and Chowdhury, 2015). Furthermore, the study by emphasizes the need to consider weather affecting visibility in intelligent streetlamp control systems, indicating the importance of adapting lighting based on weather conditions.

Moreover, the quality and quantity of road lighting have been analysed in varying weather conditions, highlighting the need to understand weather impact on road light intensity (Ekrias, Eloholma and Halonen, 2007). The study by also examined the combined effects of light conditions, posted speed limit, and weather conditions on driving speed, emphasizing the intricate relationship between these factors (Jägerbrand and Sjöbergh, 2016). Furthermore, the influence of weather on road lighting quantity and quality has been acknowledged, signifying the need for comprehensive analysis in varying weather conditions (Ekrias, Eloholma and Halonen, 2007).

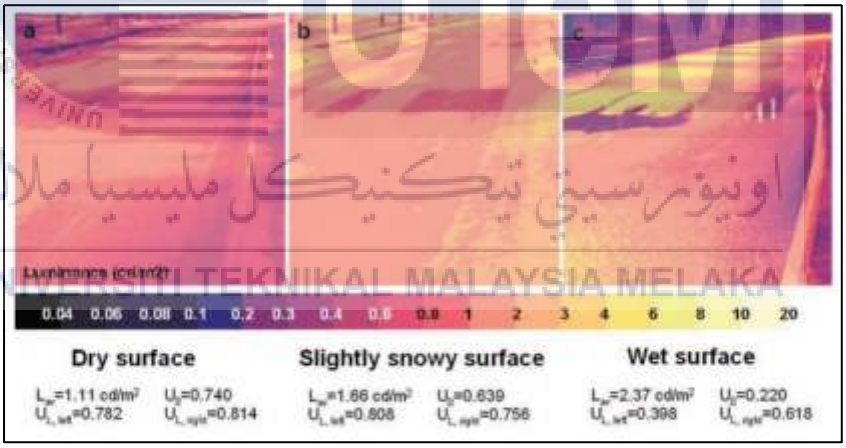


Figure 2.3 Luminance distributions (Ekrias, Eloholma and Halonen, 2007)

The effect of weather conditions on road light intensity is a multifaceted issue that encompasses visibility, traffic flow, and road safety. It is imperative to consider the impact of adverse weather on road lighting and its implications for driver behavior and traffic management. Understanding these dynamics is crucial for developing intelligent streetlamp control systems and the enhancement of road safety measures.

2.6.1 Environmental Considerations in Road Lighting Solutions

Road lighting is essential for ensuring the safety and comfort of road users, particularly in preventing accidents and facilitating visual tasks (Boyce, Fotios and Richards, 2009). The efficiency of road lighting solutions is a significant concern, with a focus on reducing energy consumption and greenhouse gas emissions (Kostic and Djokic, 2009). Transitioning to more efficient luminaires is essential to achieve energy savings and create attractive street lighting (Kostic and Djokic, 2009). Additionally, integrating renewable energy sources for street lighting is highlighted to improve energy efficiency (Yuliatti, Husin and Sutikno, 2022). LED technology has emerged as a promising solution for road lighting, with studies evaluating its compliance with regulations, potential in energy savings, and improvements for energy efficiency (Rofaie, Phoong and Abdul Mutalib, 2022). Furthermore, using smart systems, such as wireless sensor networks, for energy-saving road lighting management is being explored to enhance efficiency (Fecser *et al.*, 2023).

Environmental considerations in road lighting extend beyond energy efficiency to encompass sustainability and life cycle assessments. Life cycle assessments of road pavement surfaces and construction materials are being conducted to evaluate their environmental impact and long-term sustainability (Oreto *et al.*, 2023). The integration of circular economy principles in road pavement design is also being explored to reduce waste and environmental pollution compared to traditional solutions (Russo, Oreto and Veropalumbo, 2021). Moreover, road construction projects’ environmental impact, including road lighting, is being assessed through models that consider factors such as traffic, pavement maintenance, and lighting (Trunzo, Moretti and D’Andrea, 2019).

The environmental considerations in road lighting solutions encompass energy efficiency, sustainability, and life cycle assessments. The transition to more efficient luminaires, integrating renewable energy sources, and the evaluating LED technology for compliance with regulations and energy savings are key focus areas. Additionally, the assessment of environmental impact indicators in road construction projects and the integration of circular economy principles in road pavement design are contributing to the advancement of environmentally conscious road lighting solutions.

2.7 Road Light Intensity and Roadway Maintenance

Roadway maintenance and lighting play a crucial role in ensuring the safety and efficiency of the transportation system. Proper design and timely maintenance of street lighting can improve the safety of the roadway system by enhancing the visibility of pedestrians (Stoker *et al.*, 2015). Additionally, roadway lighting has been used to reduce crashes and improve the safety of all road users (Gibbons *et al.*, 2022). Furthermore, research from Finland suggests that it is feasible to reduce road lighting intensity when car headlights are available, indicating the potential for energy and cost savings (Pihlajaniemi, Juntunen and Luusua, 2022). Moreover, proactive, and reactive maintenance activities are essential to minimize adverse impacts of adverse weather on roadways and to keep them in optimum condition (Dey, Mishra and Chowdhury, 2015).

In terms of roadway maintenance, it is crucial to consider the impact of roadway exposure on various factors. For instance, residential proximity to major roadways has been associated with increased levels of circulating angiogenic cells, highlighting the potential health implications of roadway proximity (DeJarnett *et al.*, 2015). Furthermore, intelligent transportation systems can mitigate adverse weather impacts on road mobility, emphasizing the importance of proactive maintenance activities to minimize adverse impacts (Dey, Mishra and Chowdhury, 2015). Expansive soils, a significant problem in many parts of the United States, are responsible for premature maintenance and rehabilitation activities on many miles of roadway each year, indicating the need for effective maintenance strategies (Ivoke, Khan and Nobahar, 2021).

Roadway lighting and maintenance are critical aspects of transportation infrastructure. Proper lighting design and maintenance enhance safety and have the potential for energy and cost savings. Additionally, proactive maintenance activities are essential to mitigate adverse weather impacts and ensure the longevity and efficiency of roadways. Furthermore, the environmental implications of roadway maintenance underscore the need for sustainable and effective maintenance strategies.

2.7.1 The Psychological Impact of Road Light Intensity on Drivers

The psychological impact of road light intensity on drivers is a multifaceted issue that encompasses various aspects of human behavior and perception. Research has shown that road lighting intensity can significantly influence drivers' behavior and visual performance (Bassani and Mutani, 2012)(Pihlajaniemi et al., 2022)(Haque et al., 2016). For instance, low road lighting intensity can lead to reduced speed and increased concentration among drivers (Bozorg Chenani *et al.*, 2017). Additionally, road lighting has been found to enhance visibility, reduce the effect of glare, and improve drivers' visual adaptation, thereby positively impacting their psychological state (Pihlajaniemi, Juntunen and Luusua, 2022). Conversely, bad weather and decreased road illumination have been associated with decreased visibility, increased driver reaction time, and a higher likelihood of traffic accidents. Furthermore, studies have indicated that drivers feel safer and experience greater clarity in identifying traffic signs and road markings in the presence of road lighting (Setyaningsih *et al.*, 2018). These findings underscore the crucial role of road lighting in shaping drivers' psychological responses and safety perception.

Furthermore, the psychological dynamics that lead to risky and aggressive driving behavior have been explored in the literature, emphasizing the public health implications of road rage and aggressive driving (James, 2016). Additionally, the relationship between physical activity and sedentary time and its impact on health has been investigated, suggesting that light-intensity physical activity may be a practical strategy to reduce the risk of type 2 diabetes and cardiovascular disease (Healy *et al.*, 2007) (Dohrn *et al.*, 2018). This broader perspective underscores the interconnectedness of drivers' psychological well-being, physical activity, and road safety.

2.7.2 The Relationship Between Road Light Intensity and Driver Fatigue

The relationship between road light intensity and driver fatigue is critical to road safety. Several studies have highlighted the impact of road light intensity on driver fatigue (Thiffault and Bergeron, 2003). conducted a simulator study and found that the monotony of the road environment can contribute to driver fatigue (Thiffault and Bergeron, 2003). Additionally, Li et al. (2022) emphasized the importance of the light environment, suggesting that increased brightness and mixed light can potentially improve driver fatigue (Peng *et al.*, 2022). Furthermore, Chenani et al. (2017) demonstrated that low road lighting intensity can reduced the speed and increased driver concentration (Bozorg Chenani *et al.*, 2017).

2.8 Nighttime Visibility and Driver Safety

Seeing well at night is essential for driver safety, especially when spotting oncoming traffic and anticipating incidents. et al. focused on how poor visibility affects nighttime driving skills and other road users' safety, particularly how driver age and visual status are affected (Kimlin, Black and Wood, 2017). Furthermore, their research brought to light the compelling evidence that poor visibility plays a significant role in the high rates of nighttime fatalities, as vehicles frequently fail to see and react to pedestrians at a safe distance at night (Wood *et al.*, 2015). Moreover, emphasized the significance of comprehending the effects of glare and association with mesopic visual function, pointing out that older drivers are at higher risk of fatal nighttime crashes (Kimlin, Black and Wood, 2017).

2.9 Colour Temperature and Visual Comfort in Road Lighting

Road lighting colour temperature significantly impacts perceptions of safety, eyestrain, comfort, and efficacy. According to Wang et al. (2021), a colour temperature of 4500K combined with an illuminance range of 500–750 lux can reduce eyestrain and enhance visual efficacy in mixed lighting settings (Wang *et al.*, 2021). It is crucial to remember, nevertheless, that a study also found that at 500 lux, a low colour temperature (3500K) can aid in reducing eyestrain and a high colour temperature (6000K) can enhance visual efficacy. Setyaningsih et al. (2018) found that, despite findings from other earlier studies to the contrary, yellowish road lighting increases the feeling of visual safety compared to white lighting (Setyaningsih *et al.*, 2018). Additionally, Yang et al. (2023) emphasized the importance of colour temperature concerning glare, sunlight index, colour quality, and visual comfort.

Moreover, the quality of light sources, including colour rendering, has been identified as a significant factor in visual comfort. The colour rendering index (CRI) and colour quality scale have been used to evaluate the differences in colour rendering between LED lightings with identical correlated colour temperature but various spectra (Donners *et al.*, 2019) recommended a minimum vertical illuminance level of 3.6 lux for road lighting in residential areas to enhance visual comfort.

Furthermore, there has been worried about the ecological effects of light pollution in road lighting, regardless of colour temperature. Pawson & Bader (2014) emphasized the significance of taking ecological consequences into account when deciding road lighting by highlighting the increased ecological impact of light pollution related with LED lighting (Pawson and Bader, 2014).

Moreover, the impact of lighting on drivers' well-being and safety has been studied in various contexts, such as long underground roads, tunnels, and urban areas (He *et al.*, 2017). It has been suggested that light sources' characteristics, including color temperature, color rendering, and luminous intensity, play significant roles in driving recognition efficiency (Hu *et al.*, 2019). Additionally, using driving simulators has revealed that excessive luminance of road surfaces, especially at night, may impair drivers' visual performance and impact the visibility of obstacles on the road (Zalesinska, 2015). These findings highlight the importance of considering lighting design and characteristics in promoting drivers' well-being and safety.

The colour temperature of road illumination greatly impacts perceptions of safety, eyestrain, comfort, and effectiveness. In addition, road lighting design and implementation must consider the ecological effects of light pollution as well as the quality of light sources, including colour rendering.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this analysis of road lighting intensity, the methodology aims to thoroughly examine the impact of both height and angle variations on the illumination of a single-lane road. To achieve this, a systematic measurement and analysis of light intensity at different heights from the road surface will be conducted, exploring how varying distances from the source influence brightness levels. Additionally, the effects of altering the angle of the light source will be investigated, examining how orientation changes impact the distribution and overall effectiveness of road lighting. By addressing these objectives, valuable insights into optimizing road lighting systems for enhanced visibility and safety will be provided, contributing tto developing more effective lighting strategies for single-lane road infrastructure.

3.2 Data Collection

The data collecting procedure for assessing light intensity in this project is a systematic effort to methodically capture pertinent information for subsequent analysis. Commencing with the meticulous choice of a representative single-lane road characterized by a side-located lamp pole, the study area is primed by specific starting and concluding points for data collection. The lux meter, a pivotal tool in this undertaking, is conscientiously configured following manufacturer guidelines and project specifications, with particular attention devoted to meticulous calibration to guarantee measurement accuracy.

Selecting key measurement points along the road, at varying distances from the central lamp pole, is essential to cover different situations. Data collection sessions are carefully planned for each condition, considering changes in the lamp pole's height and angle to capture a wide range of light intensities. Measurements are taken at regular intervals to account for changes over time. Using the lux meter's data logging feature ensures a continuous dataset, reducing the risk of missing important variations in light intensity.

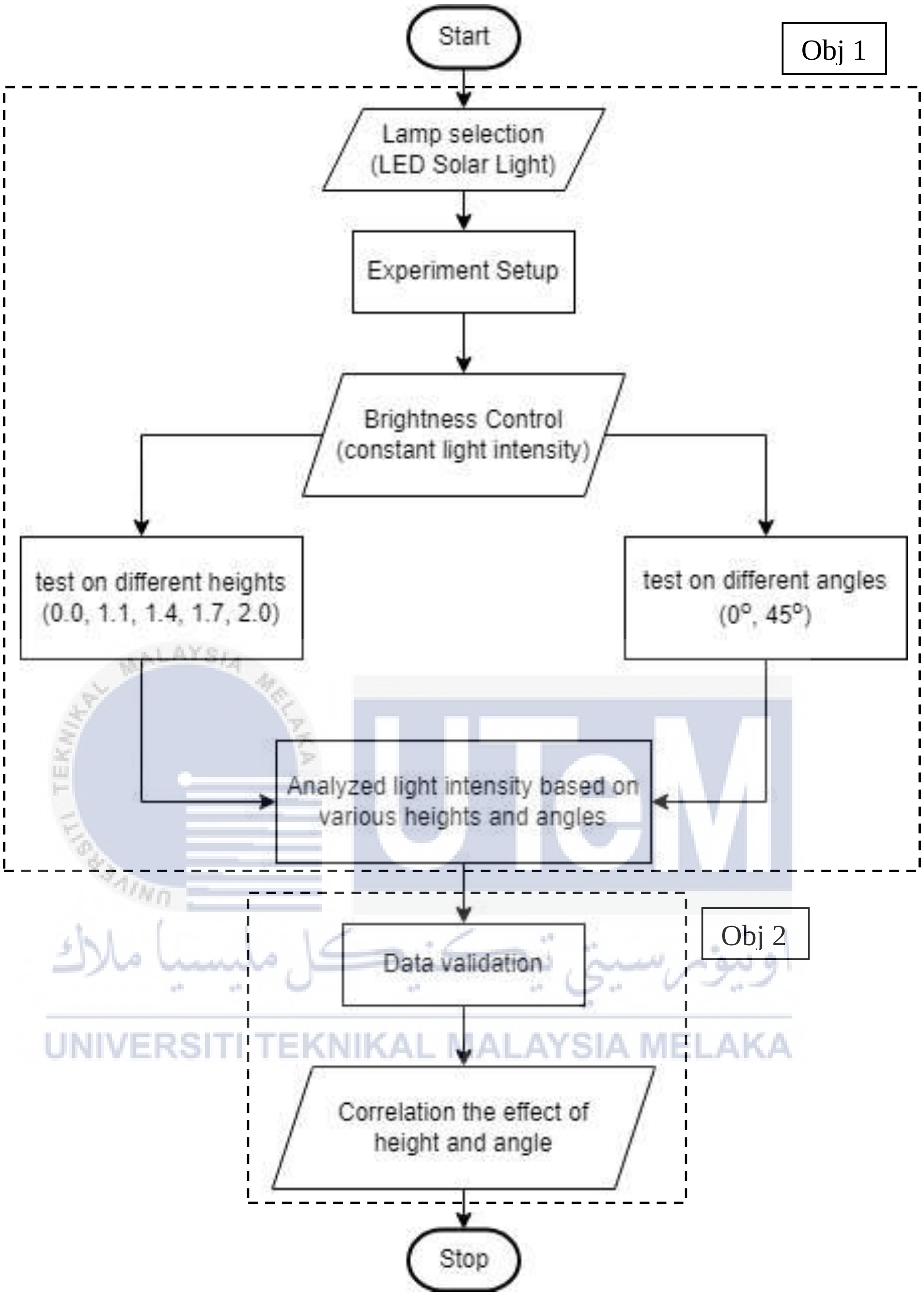


Figure 3.1 Flowchart of the Methodology

This study investigates the impact of road lamp height and angle on street light intensity. Beginning with a thorough literature review, the research proceeds to measure street light intensity and test various road lamps at different heights and angles. The collected data is then analysed, validated, and used to select a suitable light intensity range. An investigation is conducted to understand the effects of light intensity variations on visibility and safety. The findings, methodologies, and recommendations are consolidated in a detailed report, providing valuable insights for optimizing street lighting to create safer and well-illuminated public spaces, with implications for future development.

3.3 General Experimental Setup

This project is dedicated to assessing the illumination levels of individual road lights, considering the road type and the positioning of lamp poles. The key variables under consideration for measuring light intensity on a single lane road with lamps situated alongside the lane include the height and angle of the lamp pole, road width, and the spacing between each lamp pole.

Figure 3.2 Single Lane Road with Lamp Pole on the Side

3.4 Instrument and Equipment

The instrumentation employed for assessing road light intensity in this study involves the utilization of a high-quality lux meter. The selection process is conducted carefully, prioritizing features such as an extensive measurement range, precise illuminance sensors, and compatibility with prevailing environmental conditions. Preceding the commencement of data acquisition, rigorous calibration procedures are meticulously undertaken to ascertain the lux meter's accuracy and dependability. The chosen instrument is endowed with data logging capabilities, facilitating the automated recording of illuminance measurements at predetermined intervals. The imperative of portability necessitates a design that ensures facile mobility along the single-lane road. Moreover, enabling seamless interpretation and visualization of the amassed data. This holistic approach to lux meter selection and application offers meticulous and precise insights into road light intensity on single lane roads featuring centrally positioned lamp poles.

Figure 3.3 Lux Meter

3.4.1 Portable Lamp

The portable luminaire devised for measuring road light intensity is endowed with an advanced system tailored for exacting fieldwork. The luminaire is meticulously crafted with a portable and modifiable telescopic structure, affording versatility in height adjustments. Furthermore, it incorporates an adjustable angle mechanism, allowing users the capability to modify the light source angle, thereby directing illumination precisely to the designated area of interest. Enhancing its adaptability, the luminaire integrates a brightness control mechanism, allowing to accommodate varying environmental conditions and measurement scenarios. The incorporation of a robust power supply system ensures operational efficiency during fieldwork, thereby enabling prolonged monitoring of measurement outcomes.

Figure 3.4 LED Lamp

LED Solar Light with modified intensity controller

- Power: 1500 W
- Lamp size: 735 x 235 x 70 mm
- Panel size: 600 x 230 mm

(a) (b)

Figure 3.5 (a) Lamp Remote (b) Brightness Controller

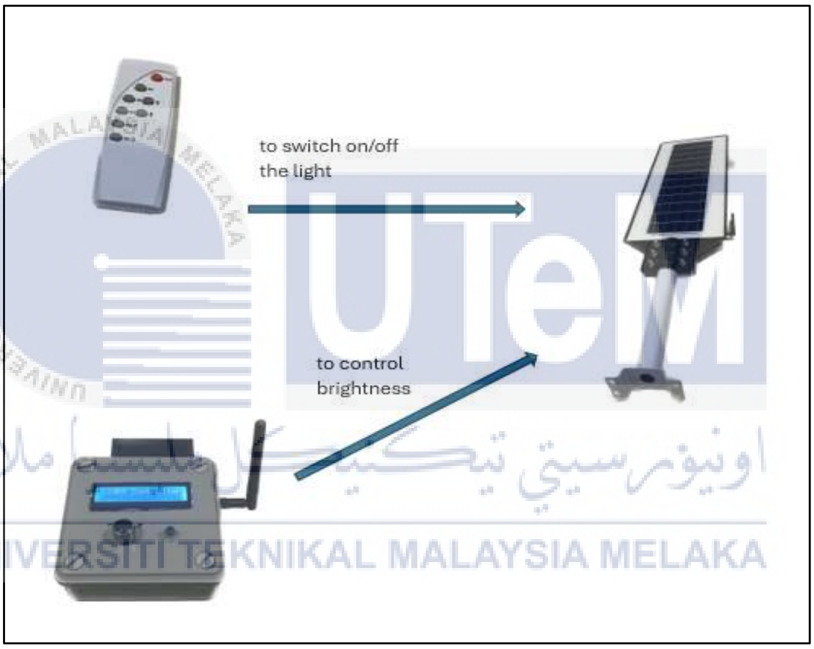


Figure 3.6 Lamp setup

3.4.2 Lamp Brightness Control

Figure 3.7 Lamp brightness inspection

The brightness control of the road lights was carefully calibrated to ensure reliable and consistent results. A brightness controller was employed to accurately regulate the amount of light emitted by the bulbs, maintaining the brightness at a predetermined level. This step was crucial to ensure the lighting in the testing area remained consistent throughout the experiment. By standardizing the brightness, we ensured that any variations in light intensity detected by the lux meter were due to the height and angle of measurement, rather than fluctuations in the lamp's output.

3.5 Research Methodology

Method of test: Measure the actual light intensity through grid points based on a single-lane road with lamp pole on the kerb side edge.

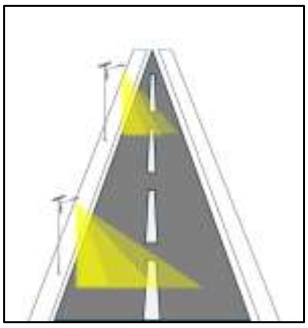


Figure 3.8 Single Lane Road with lamp pole on the kerb side edge.

3.5.1 Measurement Parameters

The lighting arrangement includes lamp poles spaced 15 meters apart and an 8-meter lane width. Each lamp post stands 10 meters tall. During testing, the ambient temperature ranges from 24 to 26 degrees Celsius. Measured data includes light intensity (lux) readings at various heights from the road surface (0, 1.1, 1.4, 1.7, and 2.0 meters) and angles (0 and 45 degrees) to account for car windscreen angles.

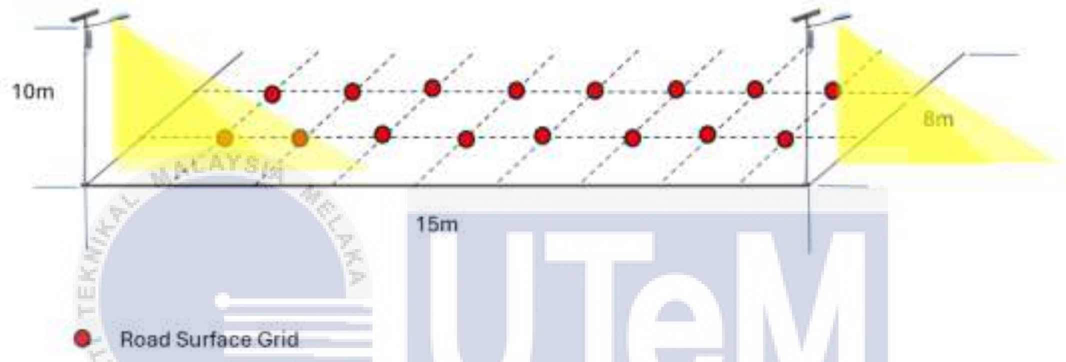


Figure 3.9 Grid Measurement Layout

3.5.2 Gridline Construction

To accurately measure light intensity, a grid was constructed on the road surface. This grid consisted of evenly spaced lines that created measurement points at each intersection. This systematic arrangement allowed for uniform data collection across the entire study area. The gridlines formed a network of squares or rectangles, spaced at regular intervals in length and width. The lux meter was placed at each intersection point to measure the light intensity. This approach minimized potential biases and gaps in the data, ensuring a comprehensive mapping of the light distribution and providing a precise and detailed depiction of the lighting pattern.

Figure 3.10 Gridline construction

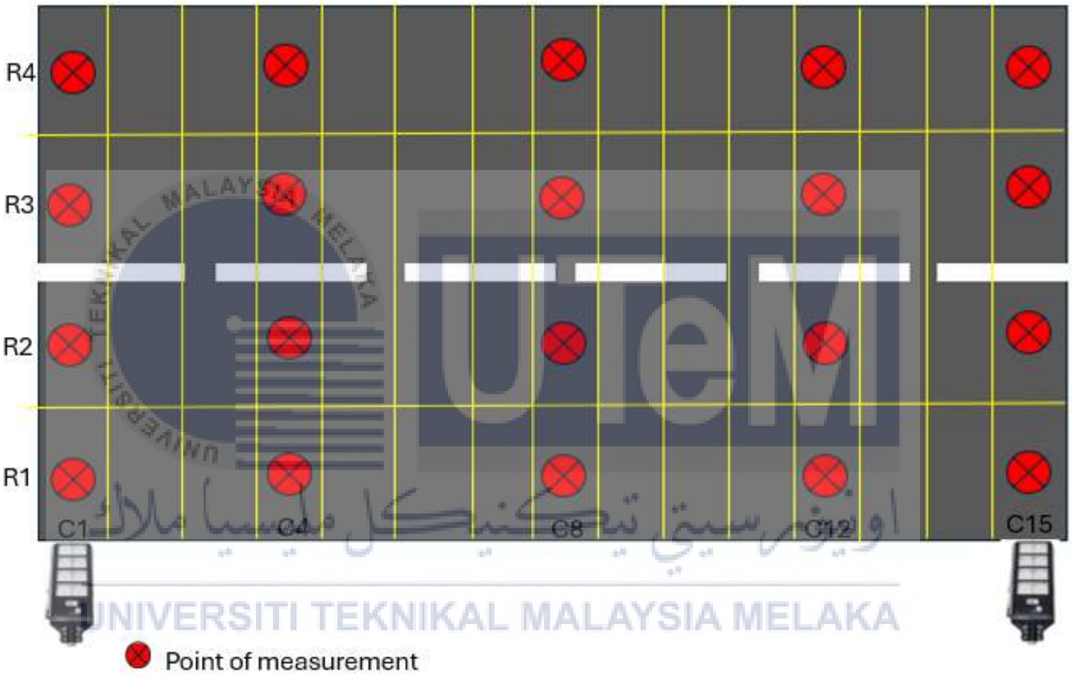


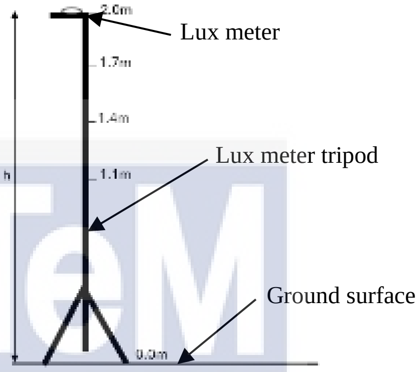
Figure 3.11 Gridline layout

From Figure 3.10, C indicates the distance of the experimental road which where the road lamp was placed at the experimental roadside, C1 and C15. While R indicates the width of the experimental road where R1 is 2 meters from the roadside and continue to R2, 4 meters, R3, 6 meters and R4, 8 meters. The red dot with cross symbol indicates the coordinate of measuring point for lux meter.

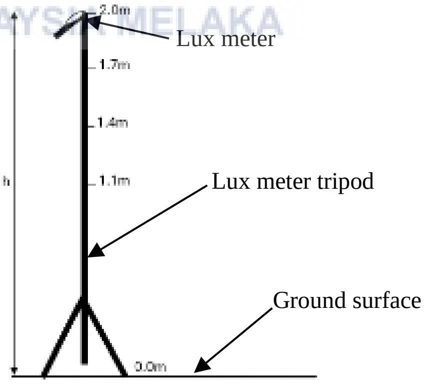
3.5.3 Angle and Height of Lux Meter

A critical step in data collection involved measuring the lux meter's angle, which was recorded at two distinct positions: 0° and 45°. The lux meter was initially positioned at a 0-degree angle relative to the road surface for the first set of measurements. Subsequently, the lux meter was adjusted to a 45-degree angle relative to the road surface for the next set of measurements.

- The angle of the lux meter at 0^o



- The angle of the lux meter at 45^o



To assess how illumination varied with the angle of view, the study recorded lux values at both 0 and 45 degrees. The 45-degree angle provided an indirect perspective, illustrating how light might scatter or be perceived at an angle, while the

0-degree angle offered insights into the direct light intensity experienced at ground level.

The lux meter's height was subsequently adjusted to represent various distances from the road surface. Baseline readings were obtained with the lux meter positioned at 0 meters above the road surface. The height was then incrementally increased to 1.1, 1.4, 1.7, and 2.0 meters. The lux meter was held in place at each height long enough to capture accurate light intensity readings. This variation in height allowed for a comprehensive analysis of the light's dispersion and intensity at different distances from the road surface. Starting at zero meters, the lux meter evaluated the immediate surroundings of the road. As the height increased, measurements were taken at progressively greater distances from the road surface, providing insights into the vertical distribution of light.

3.5.4 Data Collecting

Data collection involved recording information about the brightness of the road lights using a lux meter. Measured the brightness at different heights from the road surface, including 0, 1.1, 1.4, 1.7, and 2.0 meters. At each height, the measurements were recorded with the lux meter positioned at two angles: 0 and 45 degrees.

3.5.5 Background of Illuminance

The backdrop illumination is assessed at the collision point. To evaluate background illumination, switch off all lamps. Figure 3.10 shows a visual representation of the problem. To avoid shortcomings in the idea, the highest permissible background illumination in a test location at night should be less than 1lux (IEB).

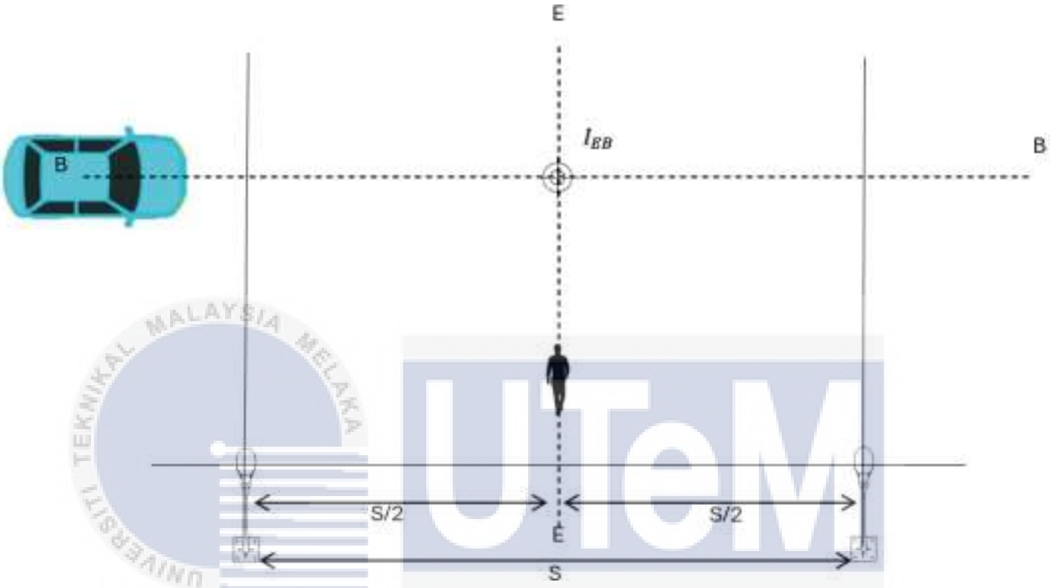


Figure 3.12 Background of Illuminance

EE : Axis of centreline of pedestrian dummy
BB : Axis of centreline of vehicle under Test
S : Distance between streetlamps
⌖ : Measurement point

3.5.6 Illuminance at VUT Path

The average illuminance of the VUT path ($\overline{I\,VUT}$) is calculated by averaging illuminance measurement points along the trajectory BB, as shown in Figure 3.8. The average illuminance must fall within a specified range.

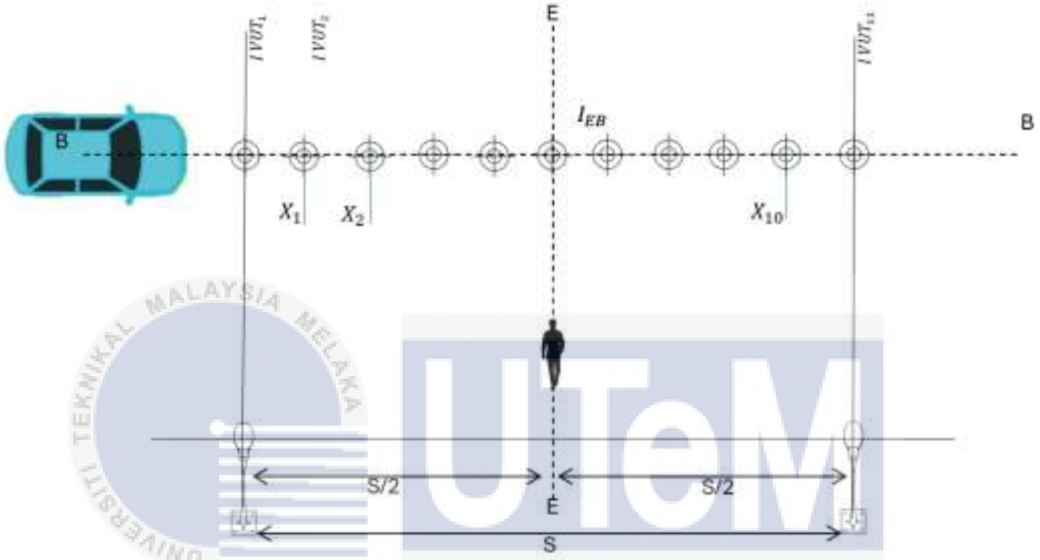


Figure 3.13 Illuminance at VUT Path

EE : Axis of centreline of pedestrian dummy
BB : Axis of centreline of Vehicle under Test
S : Distance between streetlamps
X_i : Distance between measurement points

3.5.7 Illuminance at EPT path

The figure 3.12 below depicts the illuminance along the Euro NCAP Pedestrian Target (EPT) path. The illuminance at EPT path and trajectory EE should be at least I EPT > 4.4 lux.

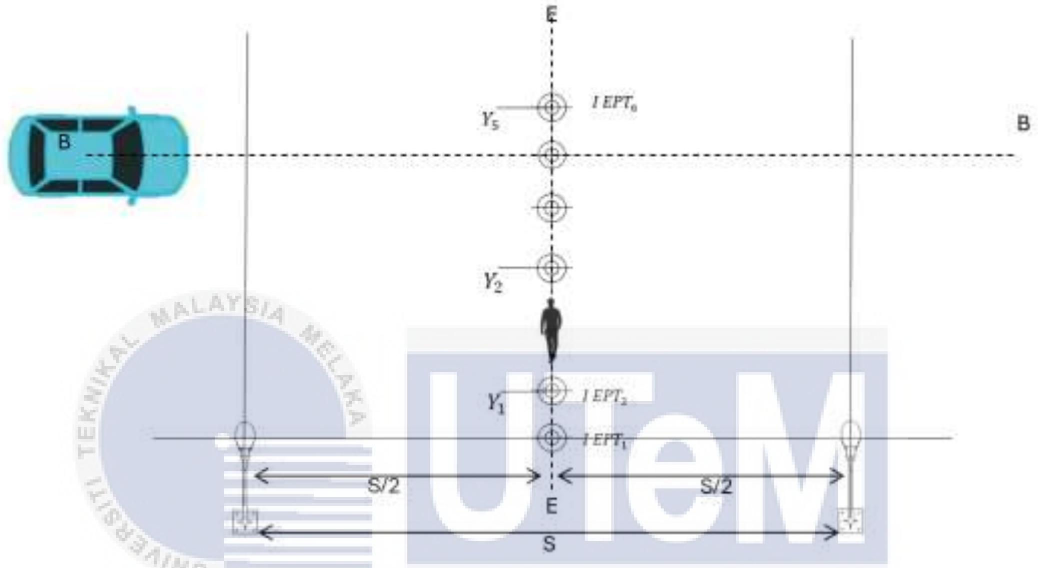


Figure 3.14 Illuminance at EPT path

EE : Axis of centreline of pedestrian dummy
BB : Axis of centreline of Vehicle under Test
S : Distance between streetlamps
Y_i : Distance between measurement points

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter delves into the analysis and discussion of the experimental results obtained from the study on light intensity at varying heights and angles from road surfaces. This chapter provides an in-depth analysis and discussion of the experimental results obtained from the study on light intensity at various heights and angles relative to road surfaces. The primary objective of this experiment is to present a comparative analysis of the recorded data. The findings are illustrated through graphs and contour color maps, capturing a range of variables including the distance between lamp poles, the height at which light intensity readings were taken, the width of the road, and the light distribution angles. These variables significantly impact the measured light intensity. This research offers insights that could enhance the efficiency of the (AEB) system in the future.

4.2 Effect of Light Intensity at 0-Degree Angle

The experiment's findings highlight a clear comparison. It was evident that the light intensity at different heights followed a similar pattern across all road widths (R1 to R4). Moreover, the general trend was consistent, with higher intensities observed at both ends of the road and a notable decline in the middle.

4.2.1 Height of 0 meter

Figure 4.1 shows the light intensity along a road at ground level. The intensity values range from around 0 to 12 lux. At both the starting point (0 meters) and the endpoint (15 meters), the intensity is relatively high, approximately 11.7 lux. In contrast, there is a noticeable dip in the middle section of the road, where the intensity drops to about 2 lux. The pattern is consistent, with higher intensities at the ends and a significant decrease in the centre.

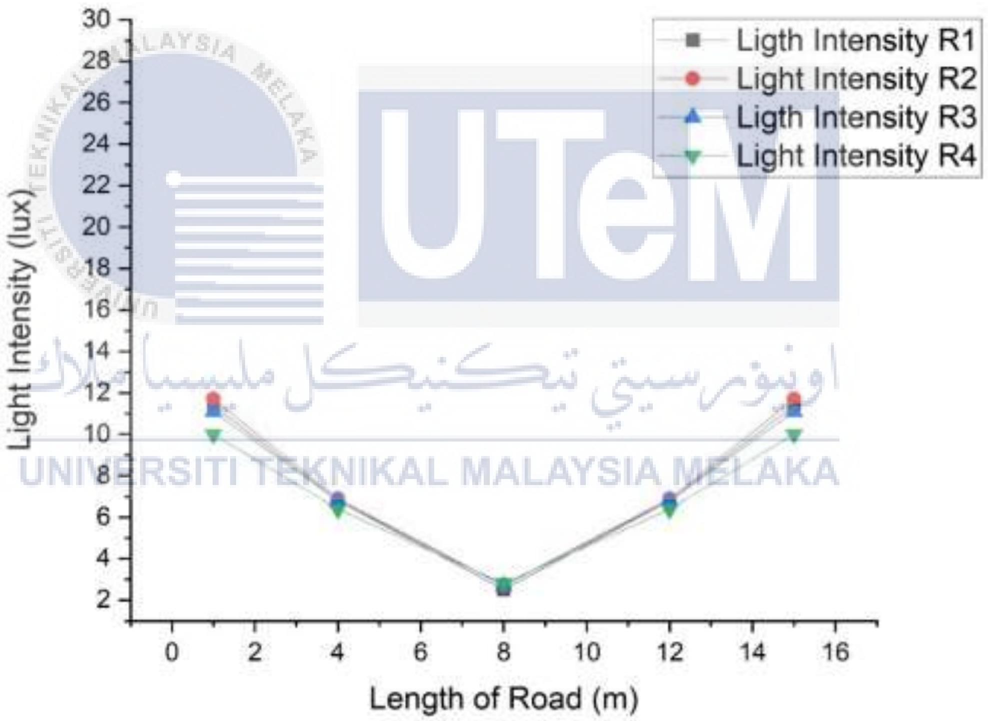


Figure 4.1 Light Intensity at 0 m Height (0°)

4.2.2 Height of 1.1 meter

Figure 4.2 illustrates the light intensity along the road at a height of 1.1 meters above the ground. The trend remains consistent with higher intensities at both ends and a significant mid-level dip. However, Figure 4.2 shows a broader distribution of light intensity across the road's width (R1 to R4), with a peak value of 17 lux, compared to the peak value of 11.7 lux in Figure 4.1.

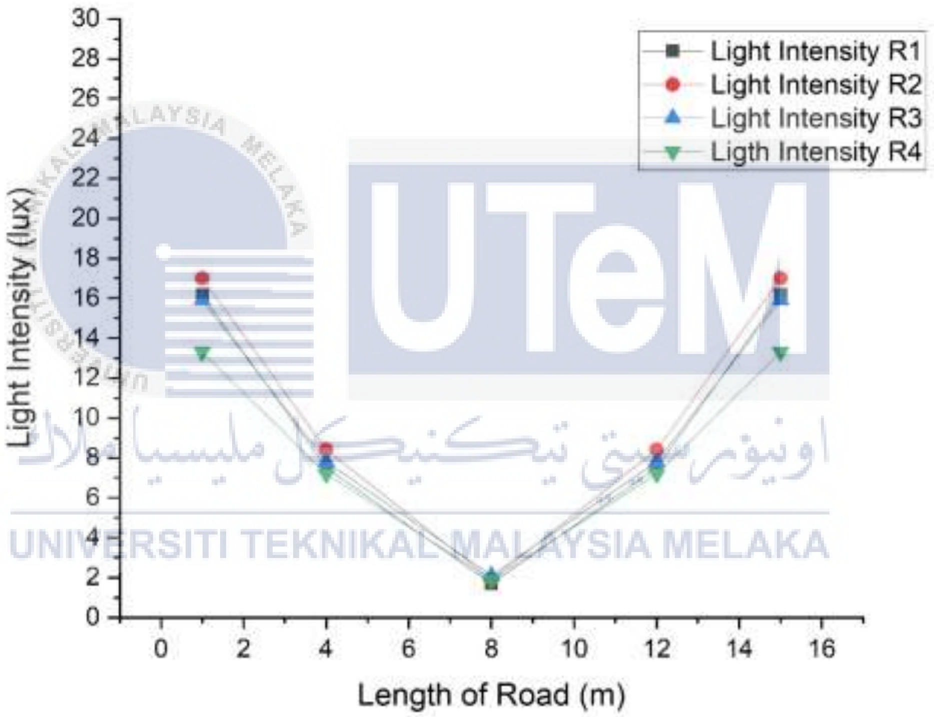


Figure 4.2 Light Intensity at 1.1 m Height (0°)

4.2.3 Height of 1.4 meter

Figure 4.3 shows the light intensity along the road at a height of 1.4 meters above the ground. The intensity is relatively high at the starting point (0 meters) and the endpoint (15 meters), approximately 17.8 lux. In contrast, there is a noticeable dip in the middle section of the road, with values dropping to around 1.8 lux. Despite the change in height, the overall trend remains consistent, with higher intensities at both ends and a significant decrease in the middle.

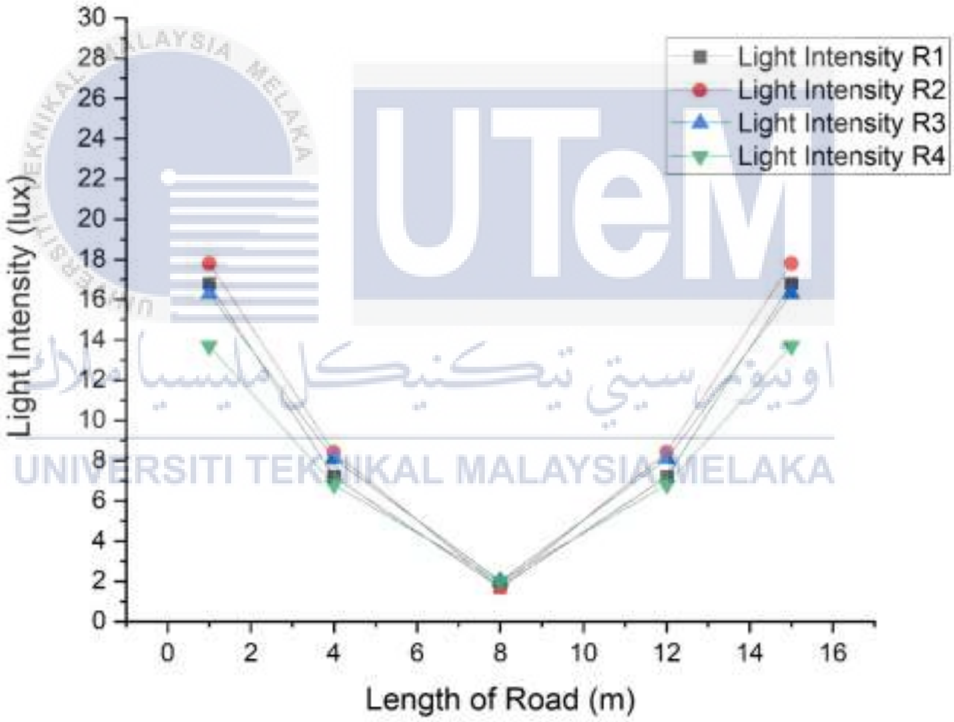


Figure 4.3 Light Intensity at 1.4 m Height (0°)

4.2.4 Height of 1.7 meter

Figure 4.4 illustrates the light intensity along a road at a height of 1.7 meters, spanning four different segments (R1 to R4). The data indicates that the light intensity is highest at both the starting point (0 meters) and the endpoint (15 meters) for all segments, gradually decreasing towards the center, reaching a minimum of approximately 1.0 lux. This consistent pattern across all segments suggests that the lighting setup creates a U-shaped light intensity distribution along the road's length.

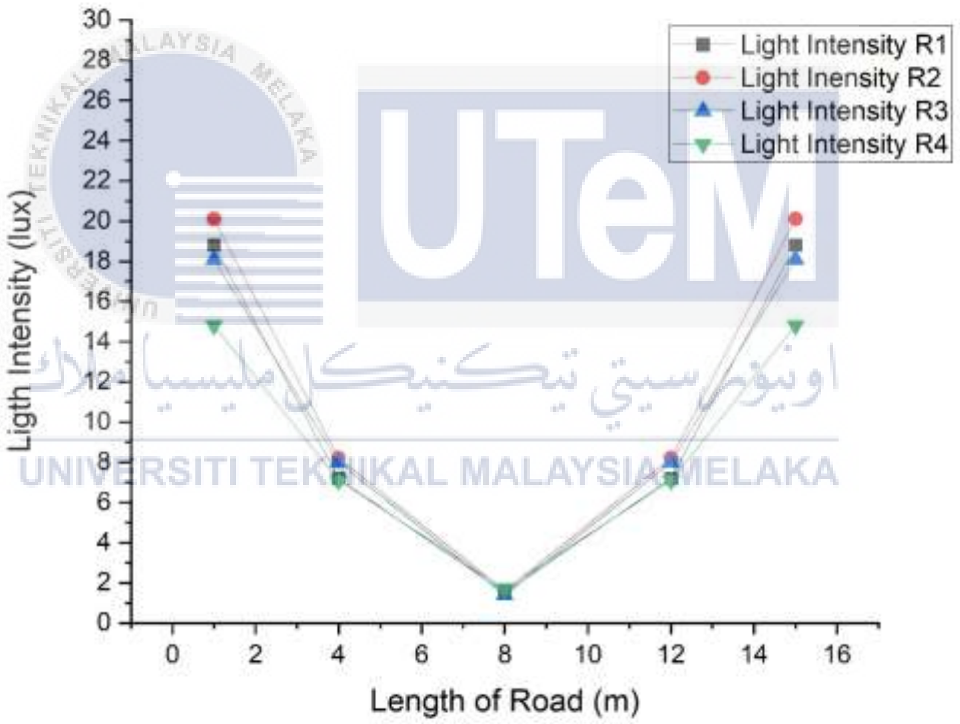


Figure 4.4 Light Intensity at 1.7 m Height (0°)

4.2.5 Height of 2.0 meter

Figure 4.5 shows the light intensity along the road, measured at 2 meters above the ground, for the same four segments (R1 to R4). Similar to Figures 4.2, 4.3, and 4.4, the light intensity is highest at both the starting point (0 meters) and the endpoint (15 meters), decreasing towards the center and reaching a low of about 1 lux. This pattern indicates that even at a slightly higher measurement height, the light intensity distribution along the road maintains a U-shaped profile, with peaks at the edges and a dip in the middle across all segments.

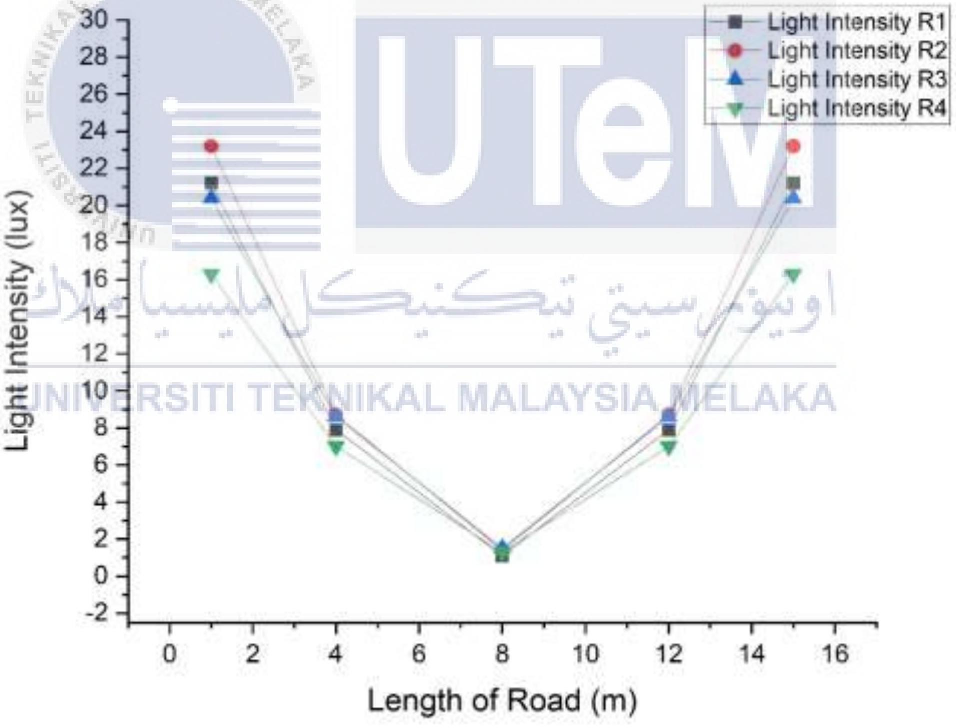


Figure 4.5 Light Intensity at 2 m Height (0°)

From Figures 4.1, 4.2, 4.3, 4.4 and 4.5, the plotted data shows that the light intensity at road width 4 meter (R2) has the highest value among all width. This shows that, at the angle of 0 degrees, the lux meter reading read the highest light intensity any height which has been set from 0 meter up until 2 meters from the road. This is due to the good distance and position at the road width of 4 meter from the light source. As for the road width of 8 meter (R4), the light intensity measured clearly shows a contradictory value compared to R2 which recorded the lowest value among other widths. This clearly indicates that the farther the distance from the light source, the lower the light intensity obtained. For all four data sets (R1, R2, R3 and R4), light intensity is highest at the ends of the experimental road (1 and 15 meters) and lowest in the middle (8 meters). The light intensity decreases from the start (0 meters) to the middle (8 meters) and then increases again towards the end (15 meters). The graphs show a consistent pattern of light intensity along the experimental road, with maximum values at the end near the road lamp and a drop to minimum values at the centre between two road lamps. This pattern is consistent across all four measurement points, indicating uniform lighting conditions along the road width. The light intensity values decrease as the distance increases. This indicates that light intensity diminishes with increased height due to the increased distance from the light source and broader dispersion. The light intensity drops sharply to about 2 lux in the middle, demonstrating a significant reduction in illumination at the road midpoint.

4.3 Effect of Light Intensity at 45-Degree Angle

The lux intensity at a 45° angle varies with height and has been recorded and plotted across the entire width of the road (R1 to R4). In all instances, the intensity distribution pattern remains similar, displaying a noticeable dip in the middle of the road. This indicates that while the angle of the light source affects overall intensity levels, the distribution pattern stays consistent. It is evident that lower heights from the lamp pole result in lower light intensity, while higher heights closer to the lamp pole lead to higher light intensity.

4.3.1 Height of 0 meter

The graph shows light intensity measured along the length of a road at ground level (0 meters) and at a 45° angle. Multiple datasets representing the road width (R1 to R4) are plotted, each with different markers and colors. The light intensity peaks at 8.2 lux at both ends of the road and drops to a minimum of 1 lux in the middle. Despite these variations, the overall trend is consistent, with higher intensities at the ends and a significant decrease in the middle, forming a U-shaped profile.

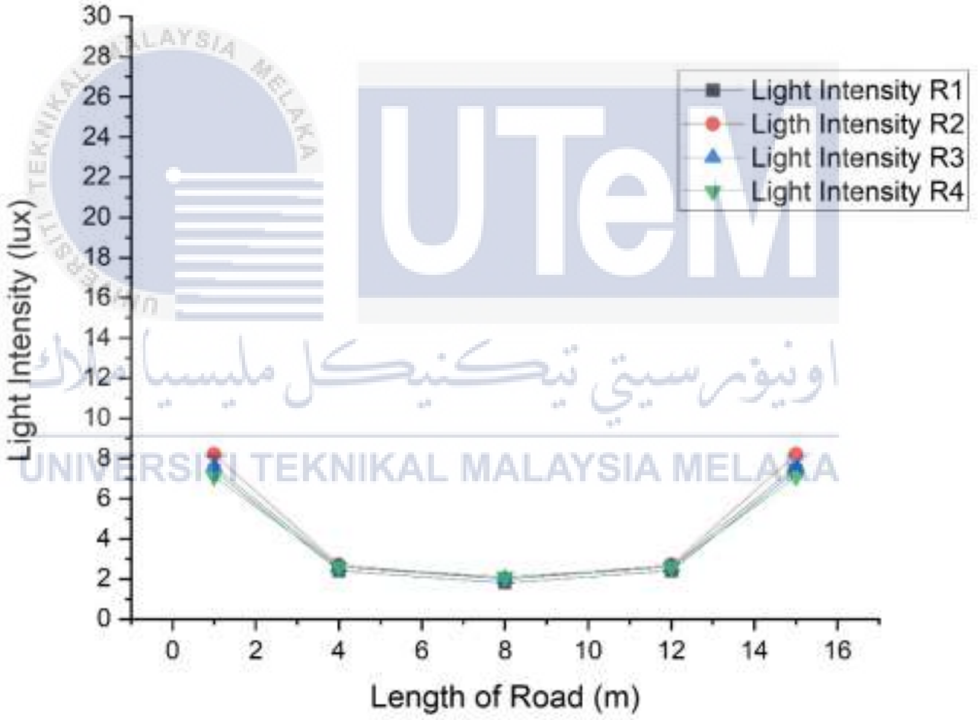


Figure 4.6 Light Intensity at 0 m Height (45°)

4.3.2 Height of 1.1 meter

Figure 4.7 illustrates the light intensity along the road, measured at a height of 1.1 meters above the ground. The graph shows light intensity readings across various road widths (R1 to R4) over a 15-meter length. The data indicates that light intensity peaks at both ends of the road, ranging from 11 to 14 lux, and significantly decreases in the middle to around 2 to 4 lux, forming a symmetrical pattern. This suggests that the lighting is strongest at the ends and weakens towards the center, likely due to the positioning of lights at the road's ends, resulting in uneven illumination distribution along the road's length.

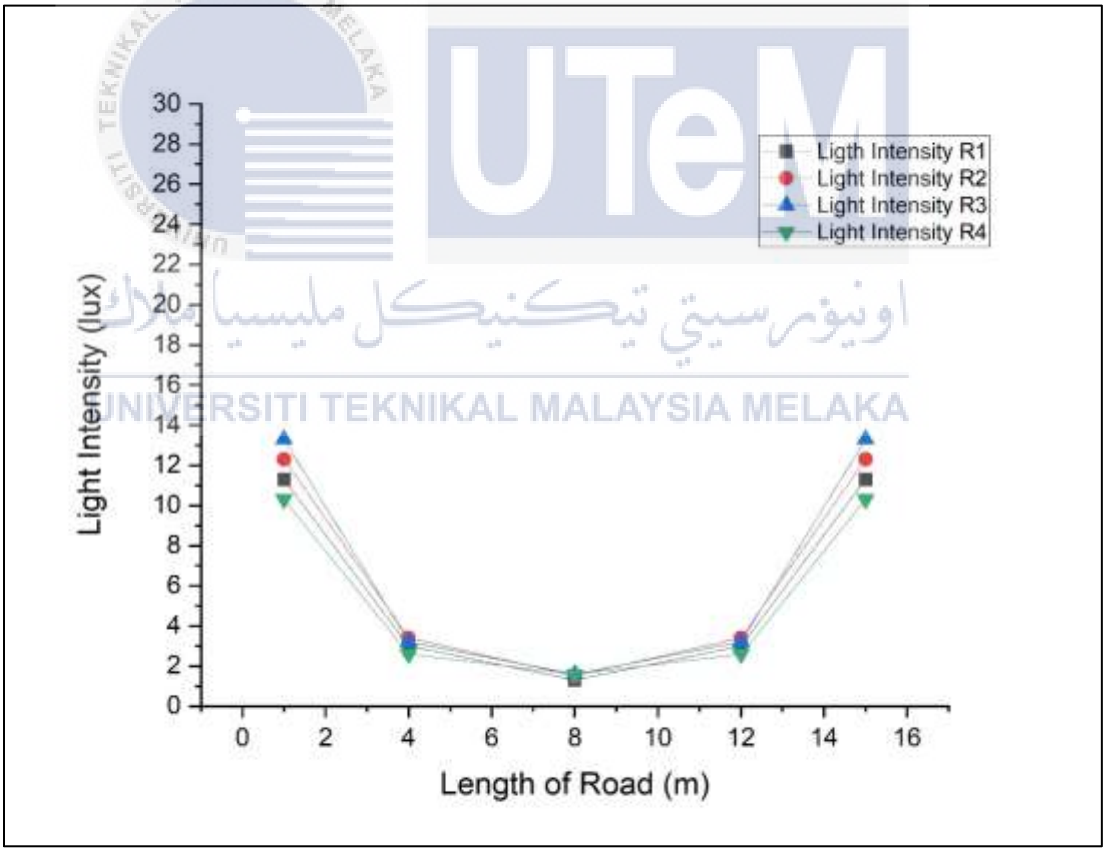


Figure 4.7 Light Intensity at 1.1 m Height (45°)

4.3.3 Height of 1.4 meter

Figure 4.8 shows the light intensity along a road, measured at a height of 1.4 meters and at a 45-degree angle. The graph displays light intensity readings (in lux) across various road widths (R1 to R4) over a 15-meter length. The data reveals that light intensity peaks at both ends of the road, reaching approximately 10 to 14 lux, and significantly decreases in the middle to about 1 to 4 lux, forming a symmetrical pattern. This suggests that lights are positioned at the ends of the road, resulting in stronger illumination at these points and a decrease in intensity toward the middle, leading to an uneven distribution of light along the road's length.

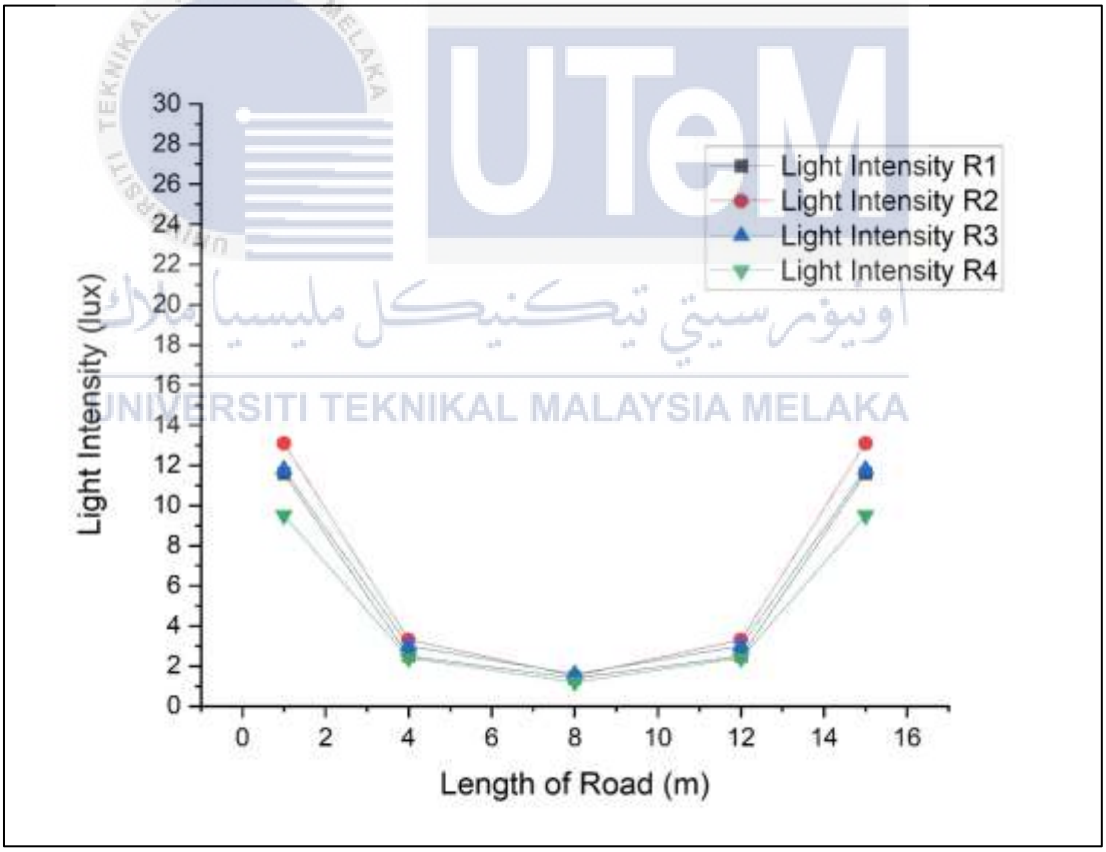


Figure 4.8 Light Intensity at 1.4 m Height (45°)

4.3.4 Height of 1.7 meter

Figure 4.9 shows the distribution of light intensity along a road, measured at a height of 1.7 meters from the ground. The graph displays varying light readings across different road widths (R1 to R4) over a 15-meter distance. The light intensity peaks at approximately 15 lux at both ends of the road and sharply declines towards the center, reaching around 0.9 lux. This symmetrical pattern indicates that the light sources are predominantly positioned at the ends of the road, resulting in higher illumination levels at these points and a noticeable decrease towards the middle. Thus, the data suggests an uneven distribution of light along the road's length.

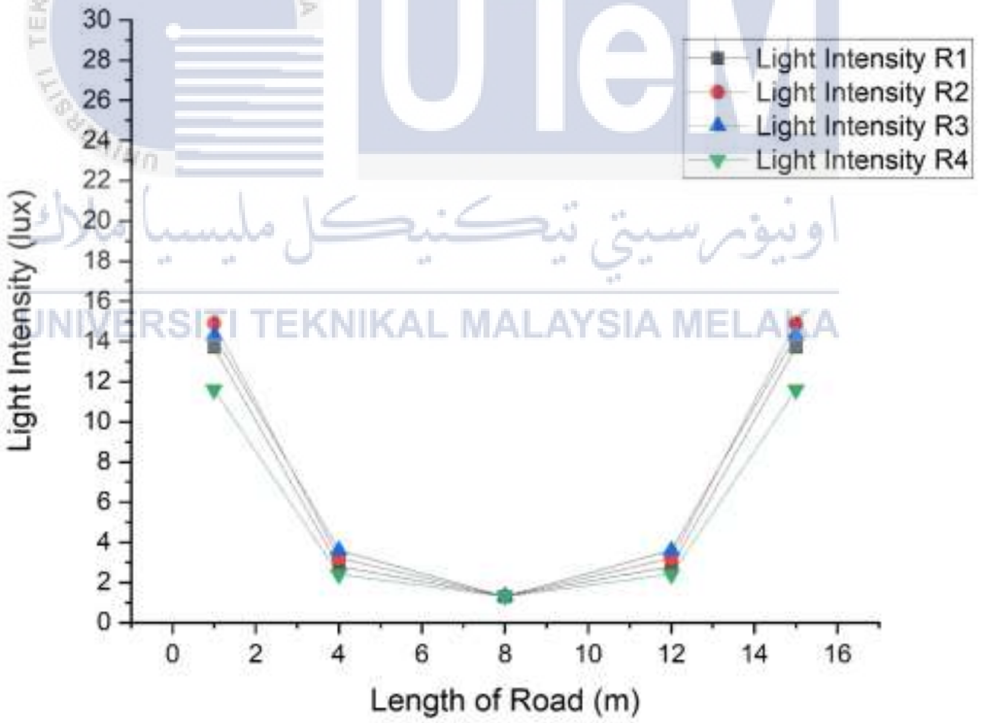


Figure 4.9 Light Intensity at 1.7 m Height (45°)

4.3.5 Height of 2.0 meter

Based on the data depicted in Figure 4.5, the graph illustrates the variation in light intensity along a road, measured at a height of 2 meters above the ground. It encompasses eight segments of the road (R1 to R4). Similar to Figures 4.2, 4.3, and 4.4, the graph consistently shows that the highest light intensity is found at both ends of the road (0 and 15 meters), gradually decreasing towards the center and reaching its lowest point at 8 meters. This pattern indicates that at a slightly raised measurement height, along the road follows a uniform U-shaped profile, characterized by peaks in intensity at the edges and a noticeable decline towards the center across all segments.

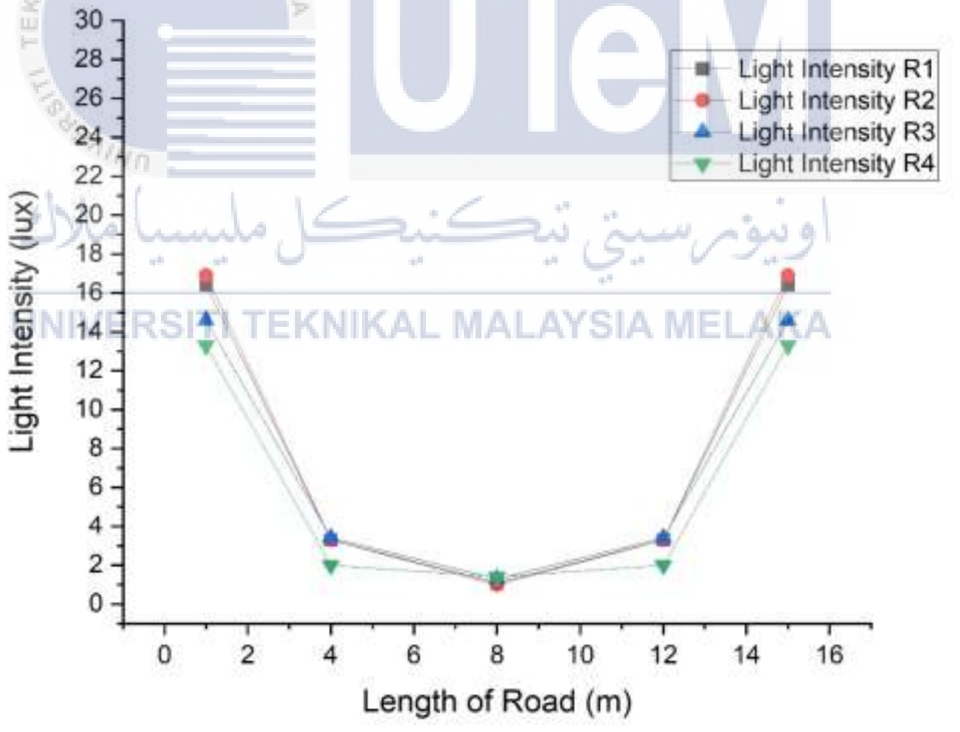


Figure 4.10 Light Intensity at 2 m Height (45°)

From Figure 4.6, 4.7, 4.8, 4.9 and 4.10, the plotted data shows the light intensity at different height at 0, 1.1, 1.4, 1.7, 2m respectively from the road surface at the angle of 45-degree. In figure 4.7, the data shows a distinct reading from the other. At the road width 6 meter (R3) from the light source, the light intensity shows the highest value at the height of 1.1 meter from the road surface. This conclude that the angle of 45-degree affects the reading which also affects to the real situation of drivers on the road. The other data measured almost the same as 0-degree condition. This due to the precise location at the road width 4 meter from the lamp pole. Other than that, the light intensity measured at R4, which is 8 meters from the light source shows the opposite reading, the lowest value among other widths. This indicates that the wider the road, the lower light obtained near to the end of road width. Light intensity is highest at the extremities of the experimental road (1 and 15 meters) and lowest in the middle (8 meters) for all four data sets (R1, R2, R3, and R4). From the beginning (0 meters) to the middle (8 meters), the light intensity drops, and then it rises once more toward the finish (15 meters). The graphs along the experimental road display a consistent pattern of light intensity, with greatest values near the road lamp at the ends and a drop to minimum values in the middle between two road lamps. The uniform illumination conditions along the road width are indicated by this pattern, which is consistent across all four measurement stations. As the distance grows, the light intensity levels drop. This indicates that light intensity diminishes with increased height due to the increased distance from the light source and broader dispersion.

4.4 Average Light Intensity at 0-Degree Angle

Figure 4.11 illustrates the average light intensity measurements for a single-lane road equipped with lamp poles situated at the kerb side edge. This average light intensity is plotted in relation to the road's length, ranging from 1 meter to 15 meters, and the height at which the light intensity is measured from the ground, spanning from 0 meters to 2 meters. The primary variable examined in this graph is the 0° angle of lamp distribution. Notably, the highest recorded average light intensity occurs at a road length of 1 meter and a measurement height of 2 meters, registering a value of 20.275 lux. Conversely, the lowest recorded average light intensity is observed at a road length of 8 meters and a measurement height of 2 meters, with a value of 1.35 lux. This data highlights significant variations in light intensity based on the specified parameters of road length and measurement height.

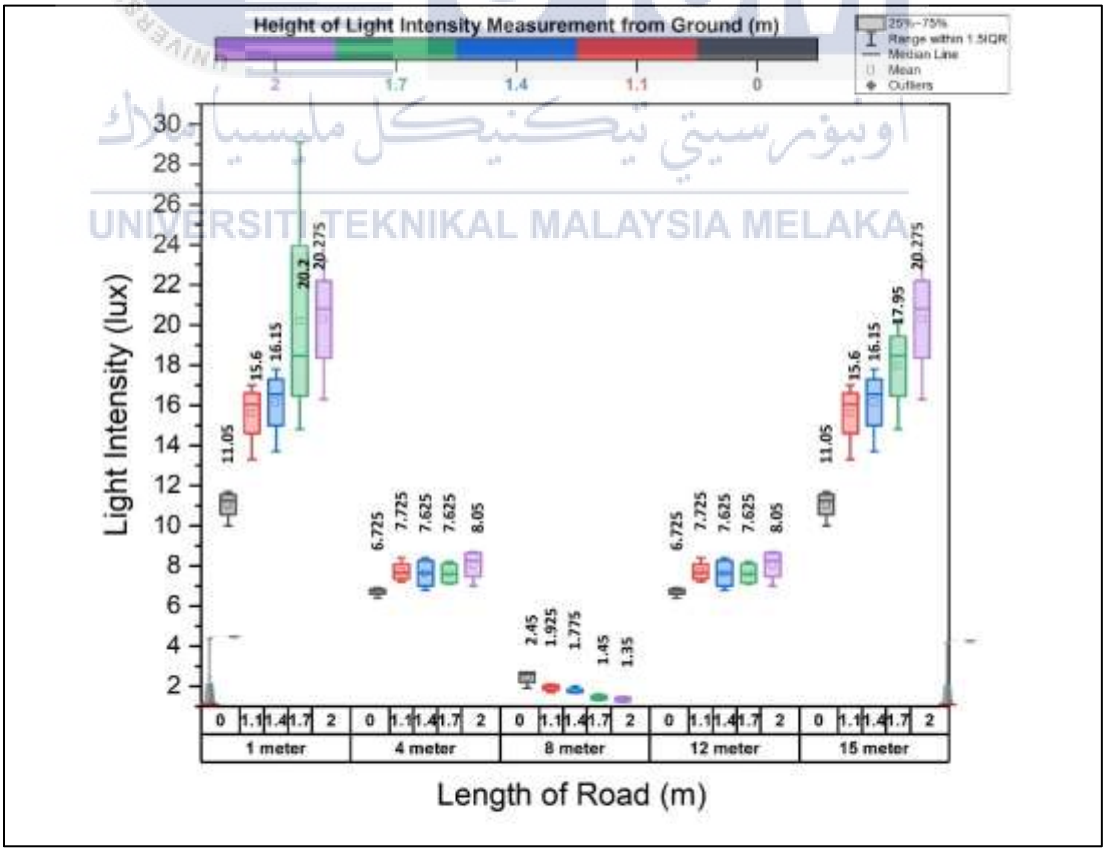


Figure 4.11 Average light intensity of 0° angle

4.5 Average Light Intensity at 45-Degree Angle

Figure 4.12 presents the results of the average light intensity for a single-lane road illuminated by a lamp pole positioned at the kerb side, with the lamp distribution set at a 45° angle. In this figure, the x-axis represents the road's length and height at which the light intensity is measured. The highest average light intensity recorded in this configuration is 16.7 lux, occurring at a road length of 15 meters and a measurement height of 2 meters. On the other hand, the lowest average light intensity observed is 1.2 lux, found at a road length of 8 meters and a measurement height of 2 meters. This figure underscores the variation in light intensity distribution along the length of the road and at different heights, influenced by the 45° angle of lamp distribution.

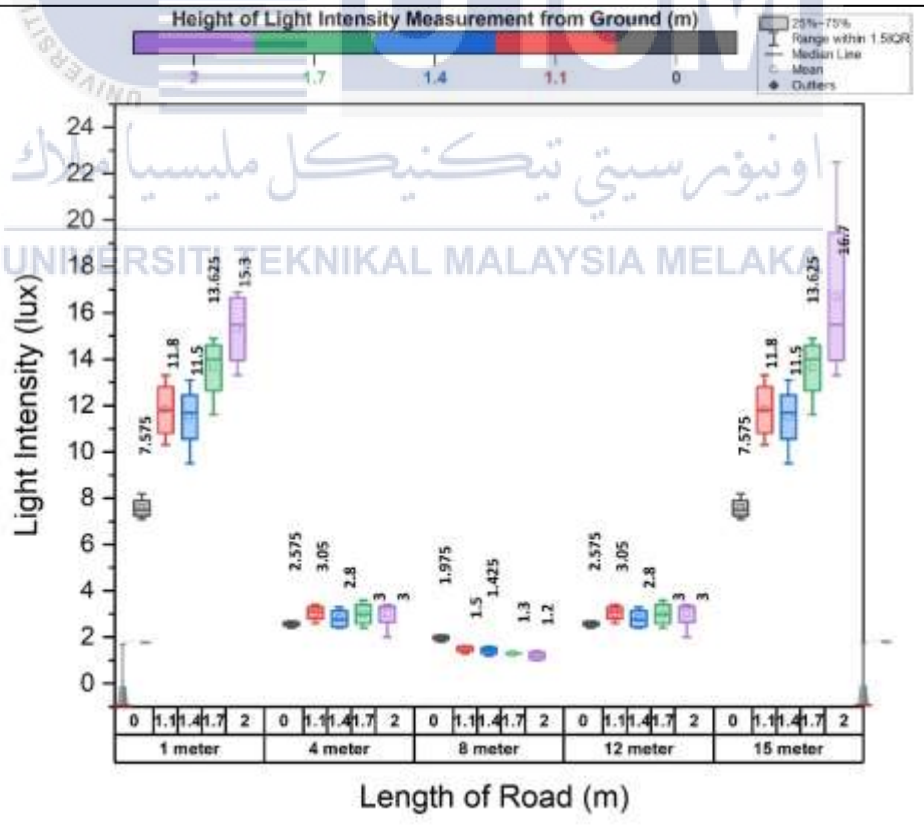


Figure 4.12 Average light intensity of 45° angle

Analysing Figures 4.11 and 4.12, it becomes evident that the recorded average values of both the highest and lowest light intensities occur at the same relative positions along the road. Specifically, the highest average light intensities are recorded near the light source and at the end of the illuminated area, with the measurements taken at road lengths of 1 meter and 15 meters, and at a height of 2 meters. Conversely, the lowest average light intensity is consistently recorded at the midpoint between two light sources, specifically at a road length of 8 meters and a measurement height of 2 meters. This pattern highlights the influence of the lamp's positional arrangement and the angles of distribution on the variations in light intensity along the road.

4.6 Correlation Effect of Height and Angle on Light Intensity

Figure 4.13 presents scatter plots illustrating variations in light intensity across different lengths of road. This figure highlights the similarities that influence light intensity levels where the road length is the primary factor. Findings show road lengths of 1 meter and 15 meters exhibit the highest average light intensity compared to other lengths. This is due to the measurement point that is close to the road lamp, which results in higher intensity readings. The other factor that influences the light intensity is the angle of lamp distribution. The scatter plots indicate that a lamp distribution angle of 0° contributes more to light intensity than a 45° angle. This is because a 0° angle allows for a more effective deployment of light.

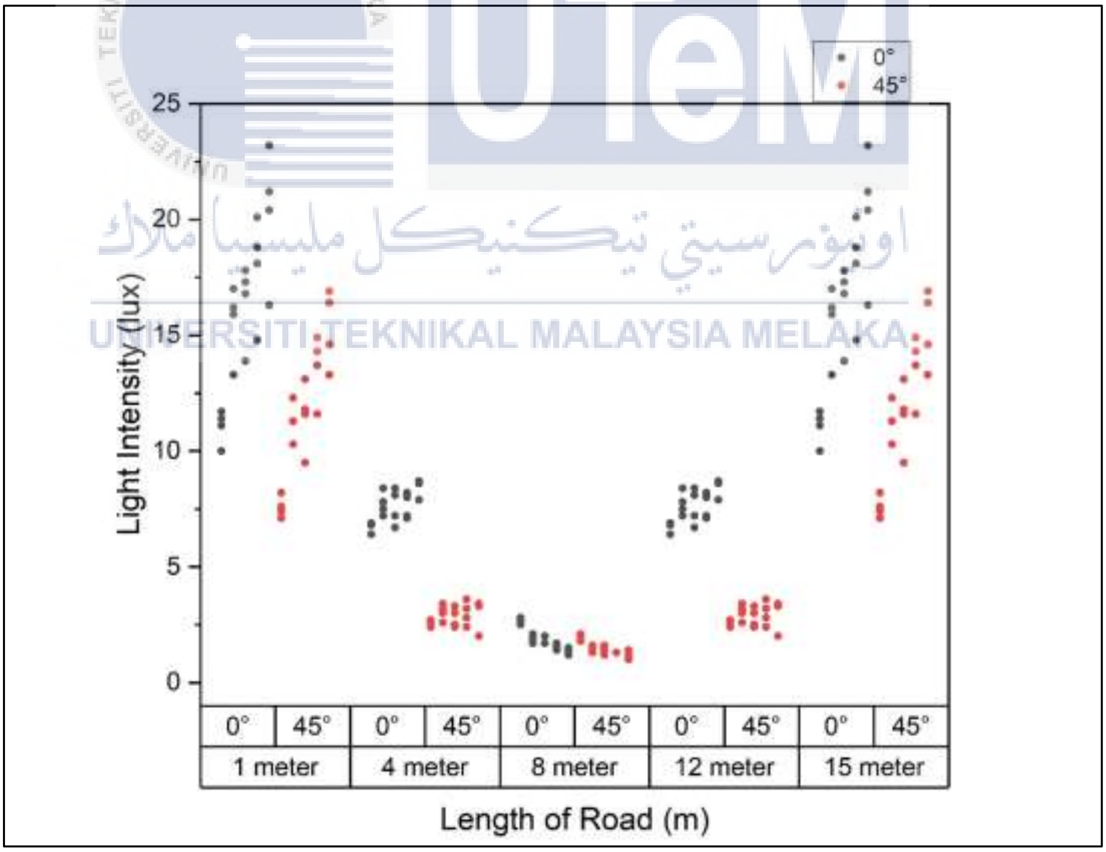


Figure 4.13 Scatter Graph of Validation along Experimental Road

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The final chapter summarizes the overall findings and focuses on two important aspects: the varying height and angle of light intensity from lamp positions on the kerb side edge. Road lighting intensity was measured at various heights and angles for the first and second objectives. The maximum average light intensity was discovered to be 20.275 lux at 2-meter height from the ground. Other than that, the average light intensity also prove that lamp distribution angle of 0-degree contributes more to light intensity than a 45-degree angle. This situation is also influenced by the other variables, such as the width and length of the road. In the meantime, in order to accomplish the second goal, an investigation has been conducted to look at the relationship between different road lighting heights and angles as well as the impact of light intensity on drivers' real-time conditions in nighttime.

5.2 Future Recommendations

For future studies on road light intensity, it is recommended to expand the scope to gain a deeper understanding of its effects on safety and technology. Examine how weather conditions, such as rain and fog, impact road light intensity. This understanding will contribute to designing AEB systems that function effectively under adverse weather. Exploring adaptive lighting systems that adjust light intensity based on real-time conditions could enhance road safety and energy efficiency.

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APPENDIX A

SITE AREA – CAR PARK UTEM LABORATORY

APPENDIX B

UTeM CAMPUS TECHNOLOGY LOCATION