19950 / **Setyaningsih et al.** / Modeling Night and Daylighting Toll Road Tunnel Using Di

Library

Workflow | Publication

Submission | Review | Copyediting | Production

Submission Files

Search

46771	ModellingDaylighting_Ijaseit.docx	8 March 2024	Article Text

Download All Files

Pre-Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
No Items				

19950 / **Setyaningsih et al.** / Modeling Night and Daylighting Toll Road Tunnel Using Di Library

Workflow | Publication

Submission | Review | Copyediting | Production

Round 1 | Round 2 | Round 3 | Round 4

Round 1 Status

All recommendations are in and a decision is needed.

Notifications

[IJASEIT] Editor Decision	12-03-2024 07:06 AM
[IJASEIT] Editor Decision	17-04-2024 09:23 AM
[IJASEIT] Editor Decision	10-05-2024 10:17 AM
[IJASEIT] Editor Decision	19-05-2024 11:11 PM

Reviewer's Attachments

Search

No Files

Revisions

Search Upload File

46864	Modelling Daylighting_Rev1_Ijaseit.docx	15 March 2024	Article Text

Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
Revision of our manuscript according to the reviewer's comments	endahsetyaningsih25-04-2024 02:53 PM	-	0	

Notifications

×

[IJASEIT] Editor Decision

12-03-2024 07:06 AM

Endah Setyaningsih, Jeanny Pragantha, Henry Candra:We have reached a decision regarding your submission to International Journal on Advanced Science, Engineering and Information Technology, "Modeling Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp". Our decision is to: Revision Required Please update your abstract into 220-250 words and your reference 80% in (2021-2023) from journal indexed by Scopus and all references must include with DOI. Citation and Reference in Paper must using Mendeley with IEEE Style. Please submit your revision in 10 days. More than 10 days of paper will be rejected from the system. Re-upload your revision into journal system NOT via email. Editor ____ International Journal on Advanced Science, Engineering and Information Technologyhttps://ijaseit.insightsociety.org/

Notifications ×

[IJASEIT] Editor Decision

17-04-2024 09:23 AM

Endah Setyaningsih, Jeanny Pragantha, Henry Candra:We have reached a decision regarding your submission to International Journal on Advanced Science, Engineering and Information Technology, "Modeling Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp".Our decision is to: Revision Required Please update your abstract into 220-250 words and your reference 80% in (2021-2023) from journal indexed by Scopus and all references must include with DOI (See examples of right and wrong below). Citation and Reference in Paper must using Mendeley with IEEE Style. doi: 10.1109/iSES47678.2019.00020. (right)doi: https://doi.org/10.1016/j.physa.2019.122537. (wrong) Please submit your revision in 10 days. More than 10 days of paper will be rejected from the system. Re-upload your revision into journal system NOT via email. Editor --Reviewer B:Review Questions: Methodology Evaluation: How appropriate is the methodology employed in this study for evaluating tunnel lighting efficiency? Are there any limitations or potential biases in the simulation approach using DIALux software? Did the authors adequately justify the choice of parameters and lighting technologies used in the simulations? Simulation Results: How do the simulated luminance levels compare between LED and HPS lamps in both single and double-mounted configurations? Are the results consistent with existing standards such as SNI and ANSI/IES Rp-22-11 for tunnel lighting? What are the implications of the observed differences in power consumption between LED and HPS lamps? Discussion and Interpretation: How effectively did the authors discuss the significance of their findings, particularly regarding energy efficiency and safety considerations? Did the discussion adequately address the practical implications for tunnel lighting design and implementation? Are there any additional factors or variables that could influence the effectiveness of the proposed lighting solutions that were not addressed in the discussion? Recommendations and Future Directions: Based on the findings, what recommendations can be made for optimizing tunnel lighting systems, considering both technical and practical aspects? How might future research build upon this study to further enhance energy efficiency and safety in tunnel environments? Are there specific areas where additional empirical validation or field testing would be beneficial? Suggestions for Authors: Clarity and Structure: Ensure the introduction provides a clear and concise overview of the research problem, objectives, and significance. Organize the methodology section in a logical sequence, detailing each step of the simulation process and justification for parameter selection. Data Presentation: Provide clear and informative figures and tables to present simulation results, making it easier for readers to interpret the findings. Consider providing a detailed breakdown of the assumptions and inputs used in the simulations to enhance transparency and reproducibility. Discussion Depth: Expand the discussion section to include a more thorough analysis of the practical implications of the findings for tunnel lighting design and operation. Address potential limitations or challenges associated with implementing the proposed lighting solutions in real-world tunnel environments. Recommendation: Revisions Required--____

International Journal on Advanced Science, Engineering and Information Technologyhttps://ijaseit.insightsociety.org/

Notifications

×

[IJASEIT] Editor Decision

10-05-2024 10:17 AM

Endah Setyaningsih, Jeanny Pragantha, Henry Candra:We have reached a decision regarding your submission to International Journal on Advanced Science, Engineering and Information Technology, "Modeling Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp". Our decision is to: Accepted with Minor Revision Please update your abstract into 220-250 words and your reference 80% in (2021-2023) from journal indexed by Scopus and all references must include with DOI (See examples of right and wrong below). Citation and Reference in Paper must using Mendeley with IEEE Style. doi: 10.1109/iSES47678.2019.00020. (right)doi: https://doi.org/10.1016/j.physa.2019.122537. (wrong) Please submit your manuscript in DOCX file Please submit your revision in 10 days. More than 10 days of paper will be rejected from the system. Re-upload your revision into journal system NOT via email. Editor ____ International Journal on Advanced Science, Engineering and Information Technologyhttps://ijaseit.insightsociety.org/

[IJASEIT] Editor Decision

19-05-2024 11:11 PM

Endah Setyaningsih, Jeanny Pragantha, Henry Candra:We have reached a decision regarding your submission to International Journal on Advanced Science, Engineering and Information Technology, "Modeling Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp".Our decision is to: Accepted Submission As a result of the review and revisions, we are pleased to inform you that your paper has met our requirements. We will proceed to the final editing process.Kind regards Editorial Board -- Reviewer A:This paper already has novelty and good contributions in accordance with existing research objectives. Abstract writing is correct and provides good information about the research objectives, the methods used and the research results. The writing is in accordance with the provisions, namely the maximum number of words is 250 words. The introduction is good with a clear background and has a strong gap in analysis. The introduction has also contained the latest research and good contributions in accordance with the objectives of the research being studied. The research method is clear and systematic, with systematic stages and has a good flow chart. The discussion is good and already has clear and complete arguments with arguments that refer to relevant and current journals. The making of figures and tables is in accordance with the template. The conclusions are good and clear, and are in accordance with the objectives. Reference is relevant and precise and in accordance with the main study of research.-- Reviewer B:Dear Author(s) As a result of the review and revisions, we are pleased to inform you that your paper has met our requirements. We will proceed to the final editing process. Recommendation: Accept Submission -- ____ International Journal on Advanced Science, Engineering and Information Technologyhttps://ijaseit.insightsociety.org/

19950 / **Setyaningsih et al.** / Modeling Night and Daylighting Toll Road Tunnel Using Di

Library

Workflow **Publication**

Submission | Review | Copyediting | Production

Round 1 | Round 2 | Round 3 | Round 4

Round 2 Status

All recommendations are in and a decision is needed.

Notifications

[IJASEIT] Editor Decision	12-03-2024 07:06 AM
[IJASEIT] Editor Decision	17-04-2024 09:23 AM
[IJASEIT] Editor Decision	10-05-2024 10:17 AM
[IJASEIT] Editor Decision	19-05-2024 11:11 PM

Reviewer's Attachments

Search

No Files

Revisions

Search Upload File

47147	Modelling Daylighting_Rev2_Ijaseit.pdf	25 April 2024	Article Text

▸	47148	Correction Table.pdf	25 April 2024	Other
▸	47150	Revision with color block match with the Correction Table.pdf	25 April 2024	Other

Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
▸ Revision of our manuscript according to the reviewer's comments	endahsetyaningsih25-04-2024 02:53 PM	-	0	☐

Table of Corrections According to The Reviewer's Suggestions

No	Reviewed		Correction	Page
1	Abstract:	Please update your abstract into 220-250 words	The abstract has been updated with 237 words	Abstract
2	References	Reference 80% in (2021-2023) from journal indexed by Scopus and all references must include with DOI	88.6% (31 references) of 35 references are from 2021 to 2024 and indexed by Scopus with DOI included. However, 4 references are between 2004 – 2019 which are necessary for the manuscript used as the standards of illumination in the tunnel. From a total of 35 references: 1 reference from 2019 [reference no. 1], 1 reference from 2004 [reference no. 17], 1 reference from 2011 [reference no. 23], 1 reference from 2008 [reference no. 29], which give total 35 – 4 = 31/35x100% = 88,6%.	References
3	Methodology Evaluation:	How appropriate is the methodology employed in this study for evaluating tunnel lighting efficiency?	The additional sentence has been added with 2 additional references: The simulation using DIAlux software has been commonly used and implemented in the study for evaluating lighting efficiency for indoor and outdoor lighting which has become a de facto standard.	Materials and Methods in first paragraph lines 6 - 9.
		Are there any limitations or potential biases in the simulation approach using DIALux software?	Based on our literature review on the research that uses Dialux software to simulate the lighting in many areas including tunnel lighting no significant disadvantages have been reported and associated with the software, highlighting its effectiveness and reliability for such applications. Therefore, no additional explanation was added to the manuscript.	

		Did the authors adequately justify the choice of parameters and lighting technologies used in the simulations?	The authors have adequately justified the choice of parameters and lighting technologies used in the simulations based on ANSI and SNI standards for tunnel lighting. The parameters have been clearly explained in the Introduction, 8th paragraph together with Figure 4. Additional sentence is added in: Material and Methods: The parameters used for the simulation were implemented according to the parameters in Fig. 4 which include the luminance of threshold, transition, and interior zones.	Introduction, 8th paragraph together with Figure 4. Material and Methods: 2nd paragraph lines 1 - 3.
4	Simulation Results:	How do the simulated luminance levels compare between LED and HPS lamps in both single and double mounted configurations?	The question is responded to by editing the following paragraph for the LED lamps: **Result and Discussion: paragraphs 6, 7, and 8 for the LED lamps:** Referring to the SNI for the Interior zone, the recommended luminance is 2.00 cd/m^2 with 0.70 uniformity. Based on the simulated results in Table I, all types of mounts fulfil the recommendations for luminance levels in the interior zone (D.4), for the double mounted, the average luminance in the interior zone is 3.1 cd/m^2 and for the single mounted is 3.5 cd/m^2. Therefore, the average luminance selected is double as it has less average luminance than single mounted which also means less luminaire LED used. For uniformity, the installation of both double-mounted and single-mounted LED lamps slightly does not meet the standard because it has less (0.67) or more (0.76) uniformity compared SNI standard (0.70).	Result and Discussion: paragraphs 6, 7, and 8 for the LED lamps. And paragraph 13 for the HPS lamps.

			For the threshold 1 zone, the luminance level of a double-mounted structure is much greater than that of a single installation. Based on TABLE I and the ANSI/IES RP-22-11 standard, if the access zone is 200 cd/m^2, it is necessary to install double-mounted lamps to produce average luminance in Threshold 1 zone in the amount of 49.9 cd/m^2 (D.1) to compensate for the high luminance value in the access zone and at the start of the threshold zone, especially during the day. **Paragraph 13 for the HPS lamps:** For the HPS lamps, additional sentences are added as follows: Based on TABLE II, the average luminance of double-mounted HPS in the Interior zone and the uniformity meet with SNI standard. For the single-mounted HPS, the average luminance in the Interior zone meets with SNI standard, but the uniformity does not. However, Both double-mounted and single-mounted HPS need Total Power much greater than double and single-mounted LED lamps.	
		Are the results consistent with existing standards such as SNI and ANSI/IES Rp-22-11 for tunnel lighting?	The results are consistent with existing standards such as SNI and ANSI/IES Rp-22-11 for tunnel lighting as explained in the above answers used SNI and ANSI as the standard references.	
		What are the implications of the observed differences in power consumption between LED and HPS lamps?	Based on TABLE I for LED and Tabel II for HPS lamps, the power consumption of HPS both double and single-mounted very much higher	

			than the LED. Therefore, the recommendation refers to the use of LED lamps	
5	Discussion and Interpretation:	How effectively did the authors discuss the significance of their findings, particularly regarding energy efficiency and safety considerations?	For the safety consideration, the 2nd paragraph in the Discussion is added as follows: ANSI/IES Rp-22-11 luminance standard in the access zone is 200 cd/ m2, so double-mounted installation is recommended to compensate for the luminance value at Threshold 1 zone (49.9 cd/m^2) at the entrance of the threshold zone during the day. The purpose of the compensation of average luminance at the Threshold 1 zone is to increase safety by preventing the driver's eyes from losing sight temporarily (or the black hole effect). The discussion about Energy efficiency is explained in the 5th paragraph of the Discussion.	Discussion: 2nd and 5th paragraph
		Did the discussion adequately address the practical implications for tunnel lighting design and implementation?	An additional paragraph is added in the last paragraph of the Discussion as follows: The simulation findings demonstrate that the luminance levels in the interior zone comply with the SNI standard when employing LED or HPS lamps. LED lamps yield greater luminance levels with lower power consumption compared to HPS lamps. This revelation holds promise for enhancing energy efficiency within tunnel environments, thereby fostering sustainable lighting solutions for transportation infrastructure.	Second last paragraph of the Discussion

		Are there any additional factors or variables that could influence the effectiveness of the proposed lighting solutions that were not addressed in the discussion?	In the introduction (2nd paragraph of Introduction), it has been mentioned that organizing the environment by planting trees and plants at the tunnel entrance could influence the effectiveness of the proposed lighting solutions. However, it is beyond the scope of our research focus and this article's writing.	
6	Recommendations and Future Directions:	Based on the findings, what recommendations can be made for optimizing tunnel lighting systems, considering both technical and practical aspects?	1. The question is answered by adding point 7 of Conclusions: Future direction includes: integrating lighting control systems that automatically adjust illumination levels in response to real-time factors like traffic flow, time of day, and weather conditions to ensure optimal visibility while conserving energy during off-peak periods.	Conclusions: point 7
		How might future research build upon this study to further enhance energy efficiency and safety in tunnel environments?	This finding will be used as a basis for further research by researching the future direction mentioned above.	
		Are there specific areas where additional empirical validation or field testing would be beneficial?	The empirical validation for the research results is by conducting measurements in the actual tunnel (Cisumdawu).	
7	Suggestions for Authors: Clarity and Structure:	Ensure the introduction provides a clear and concise overview of the research problem, objectives, and significance.	The following paragraphs are added for the Introduction in the 2 last paragraph: The research problem of this manuscript is how to address the enhancement of energy efficiency and safety in toll road tunnel lighting through an investigation into the comparative effectiveness of HPS lamps and LED lamps across the	2 Last paragraph of the Introduction

			threshold, transition, and interior zones of the tunnel. Therefore, the research aims to utilize DIALux software for simulating and modelling toll road tunnel lighting, comparing HPS and LED lamps. The objective is to identify the most energy-efficient lighting solution for the tunnel's threshold zone, promoting sustainable lighting for transportation infrastructure. It further seeks to evaluate luminance levels, power consumption, and uniformity of both lamp types in this zone. Additionally, the goal is to optimize tunnel lighting systems to enhance traffic safety and minimize energy usage. The significance of the research lies in its potential to contribute to energy efficiency, safety, and sustainability in tunnel lighting for transportation infrastructure. This finding suggests potential improvements in energy efficiency within tunnel environments, contributing to sustainable lighting solutions for transportation infrastructure [27], [10].	
		Organize the methodology section in a logical sequence, detailing each step of the simulation process and justification for parameter selection.	• The following paragraph was added: The simulation process for tunnel lighting using DIALux software and data collected from the Cisumdawu tunnel involves: • Data Collection: Gathering relevant data from the tunnel to serve as input parameters for the simulation.	Materials and Methods in the first paragraph

			• Software Setup: Installing and configuring DIALux software with necessary parameters for accurate simulation. • Model Creation: Creating a 3D model of the tunnel within DIALux, accurately representing its geometry and layout. • Light Source Selection: Choosing HPS lamps and LED lamps as the primary light sources for simulation. • Placement Configuration: Arranging selected lamps in both single and double rows along the tunnel's interior. • Simulation Execution: Initiating the simulation process within DIALux to replicate real-world conditions. • Luminance Analysis: Analyzing simulation results to assess luminance levels across different zones of the tunnel. • Comparison and Evaluation: Comparing the performance of HPS and LED lamps in terms of luminance distribution. Also, the comparison of the two lamps results in the SNI 7391:2008 and ANSI/IES Rp-22-11 standard. • Optimization Strategies: Identifying potential areas for improvement based on simulation outcomes. • 10. Documentation and Reporting: Documenting simulation parameters, results, and findings comprehensively for further analysis.	
8	Data Presentation:	Provide clear and informative figures and tables to present simulation	All the Figures and Tables have been improved and revised as necessary.	All Figures and Tables

		results, making it easier for readers to interpret the findings.		
		Consider providing a detailed breakdown of the assumptions and inputs used in the simulations to enhance transparency and reproducibility.	All the information about the data and assumptions has been explained in detail for transparency and reproducibility so that other researchers can accommodate them for their references.	
9	Discussion Depth:	Expand the discussion section to include a more thorough analysis of the practical implications of the findings for tunnel lighting design and operation.	The discussion has been improved as in no. 5 above to give a more thorough analysis of the practical implications of the findings for tunnel lighting design and operation.	Discussion: 2nd and 4th, and second last paragraph
		Address potential limitations or challenges associated with implementing the proposed lighting solutions in real-world tunnel environments.	The last paragraph is added with the following sentence: Last but not least, implementing proposed lighting solutions in real-world tunnel environments may face challenges such as high initial costs, maintenance requirements, compatibility issues, regulatory compliance, environmental factors, energy efficiency optimization, and emergency preparedness.	Discussion: Last paragraph

Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp

Endah Setyaningsih [a,*], Jeanny Pragantha [b], Henry Candra [c]

[a] Department of Electrical Engineering, Universitas Tarumanagara, Jl. S. Parman,11440, Indonesia

[b] Informatics Engineering, Universitas Tarumanagara, Jl. S. Parman,11440, Indonesia

[c] Department of Electrical Engineering, Universitas Trisakti, Jl. Kyai Tapa, 11440, Indonesia

*endahs@ft.untar.ac.id

Abstract*— In toll road tunnels, the lighting at the threshold zone must balance the brightness of the access zone with natural light. Therefore, artificial lighting is strategically placed in that area to match the brightness to the intensity of natural light. This balance shifts during nighttime to ensure uniform brightness throughout the tunnel equivalent to street lighting. Additionally, to realize this artificial lighting, a significant amount of power is required. There are several lamp technologies used for tunnel lighting; one commonly used is HPS lamps, which have low energy efficiency. Currently, there are LED lamps available that are energy-efficient. The challenge is determining artificial lighting in the threshold zone using energy-efficient lamps. To address this issue, simulations were conducted to compare the two lamp types applied in tunnels to achieve the greatest power savings. This research creates a model of toll road tunnel lighting using DIALux software to better understand the characteristics of toll road tunnel lighting using HPS and LED lamps. The Indonesian National Standard (SNI) and ANSI/IES Rp-22-11 are the standards used. The research utilizes the Cisumdawu tunnel as a case study example. The simulation results show that the luminance in the interior zone using LED or HPS lamps, can meet the SNI standard. Using LED lamps results in higher luminance with less power than using HPS. This discovery can potentially improve energy efficiency in tunnel environments, thereby contributing to sustainable lighting solutions for transportation infrastructure.

***Keywords*— Tunnel lighting, Cisumdawu lighting, Daylighting, Night lighting, Lighting Simulation.**

Manuscript received 15 Oct. 2020; revised 29 Jan. 2021; accepted 2 Feb. 2021. Date of publication 17 Feb. 2021.

I. INTRODUCTION

Based on research in tunnel lighting that the authors conducted (decentralization research that the Higher Education Department funded), it was found that the lighting in the Pasar Rebo tunnel and the Cibubur tunnel did not meet the lighting standards for both nighttime lighting and daylight lighting [1].

The research conducted to enhance energy efficiency in tunnel lighting applies three methodological approaches: implementing smart lighting technology in the tunnel [2], [3], [4], [5], [6], [7]; organizing the environment by planting trees and plants at the tunnel entrance [8], [9]; and by replacing HPS lamps with LED lamps. The average lighting during the day is either very excessive, that is, the illumination and luminance exceeds the SNI standards and international standards, or much less than standard, especially at mid-day [10], [11]. As a result, the face of the tunnel looks very dark compared to sunlight, which causes the driver's eyes to lose sight temporarily (or black hole effect) [12], [13], [14], [15], [16]. By designing a tunnel lighting system that prioritizes both driver safety and minimizes the disruptive effects of light transitions, we can significantly improve overall safety and reduce negative impacts on drivers' vision within the tunnel [17].

The Cileunyi-Sumedang-Dawuan Tunnel (Cisumdawu Tunnel) is used to overcome congestion and shorten vehicle tracks which is implemented massively in developed countries such as China [18]. This tunnel is part of the Cisumdawu toll road in Cilengser Village. It is located in section II of the toll road, which connects Ranca Kalong and Sumedang, Subang, West Java. The Cisumdawu toll road is expected to shorten the distance from Bandung to Sumedang and West Java International Airport in Kertajati via the Cikampek-Palimanan toll road. The Cisumdawu tunnel is a twin tunnel because it consists of two tunnels: the right tunnel with the initials R (Right) and the left tunnel L (Left). Fig. 1 is the Cisumdawu tunnel, the twin tunnel. The inside view of the Cisumdawu tunnel can be seen in Fig. 2. Fig. 3 shows the location of the Cisumdawu toll road in the West Java area. The Cisumdawu Tunnel is the longest in Indonesia, with a length of 472 m and a diameter of 14 m for each tunnel [19].

A tunnel is a road whose surroundings are covered by structures. Generally, this road is below ground level [8].

Tunnel can be divided into "long tunnel" and "short tunnel" based on the clarity of view [20]. In the tunnel road, drivers usually have a short visual blind zone and visual shock when entering and exiting the tunnels [21], [22]. In a short tunnel, the exit is visible from a point directly in front of the tunnel entrance when no vehicles are passing. Usually, the short tunnel length is limited to 75 meters [9]. During the day, the short tunnel generally does not require a lighting system because the inclusion of daylight from both sides of the short tunnel, plus the silhouetted effect of the bright light at the other end of the tunnel, generally guarantees satisfactory visibility. In contrast to long tunnels, the driver cannot see the exit end of the tunnel. Tunnels that are less than 75 m long but whose paths are not straight so drivers cannot see the exit end of the tunnel are defined as long tunnels [9], [23].

Fig. 1 Cisumdawu Tunnel, the Twin Tunnel

The essential purpose of tunnel lighting is to provide sufficient and comfortable visibility for tunnel users to pass through the tunnel safely day and night [24], [17], [5]. Several things must be considered To achieve this goal, which are [16], [12]:

1. Lighting must provide a sufficient and even level of illuminance to the driver throughout the tunnel in dry and wet conditions.
2. The angle of incidence of the lamp light relative to the driver's vision should provide a high level of sight of the road markings in all weather conditions.
3. Lighting should not cause glare.
4. Lighting should not flicker [25].

Fig. 2 Inside Cisumdawu Tunnel

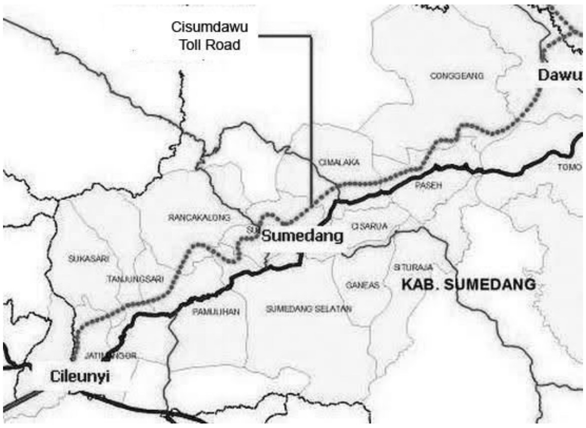

Fig. 3 Map of Cisumdawu Tunnel in Rancakalong Sumedang

In the long tunnel, acknowledging the difference in human visual adaptation speeds for light and dark transitions, five distinct lighting zones are implemented (refer to Fig. 4 below the paper) [17], [23], [26]:

- Access Zone: The driver's approach to the tunnel is illuminated by the same ambient light level as outside, allowing them to see the tunnel entrance.
- Threshold Zone: Upon entering, the tunnel reveals its interior gradually over a distance equal to the stopping distance. The luminance within the first part is maintained constant, matching the outside level and adapting to traffic conditions. As the zone progresses, the luminance is smoothly reduced to 40% of its initial value.

- Transition Zone: A gentle transition bridges the gap between the threshold's dimmed lighting and the interior's deeper darkness. The luminance level is progressively lowered, mimicking the natural light changes of a sunset. The length and stages of this transition are carefully designed to match the human eye's adaptation capabilities, ensuring a comfortable shift.
- Interior Zone: Within the tunnel's depths, sunlight is replaced by a consistent artificial lighting level. This unwavering luminance provides a stable visual environment for drivers, akin to navigating a starlit cavern bathed in a constant glow.
- Exit Zone: As the tunnel's end approaches, a sense of emergence is created by the gradual increase in light level. The luminance smoothly rises, replicating the experience of dawn, until it seamlessly matches the natural environment outside.

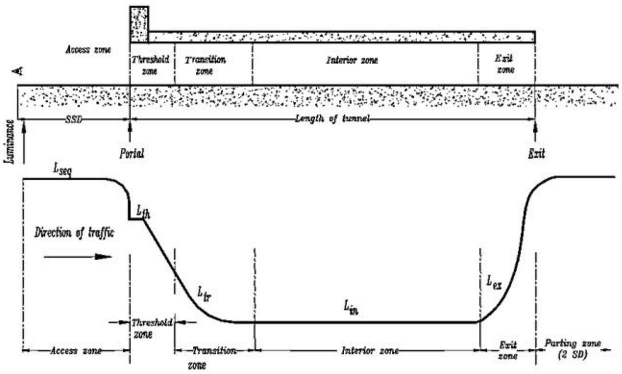

Fig. 4 Five Tunnel Zone [17], [23], [26]

Air characteristics in the tunnel differ from those of ordinary roads. In the tunnel, the concentration of vehicle exhaust gas will be higher than on regular roads because the air exchange is slower than on ordinary roads. Thus, the lighting must also be more resistant to dangerous substances in vehicle exhaust gases such as sulfuric acid, nitric acid, carbon monoxide, and others. Several types of lamps recommended for tunnel lighting are High-Pressure Sodium (HPS) lamps and Light Emitting Diode (LED) lamps [24], [27], [28].

In this paper, to address the challenge of determining energy-efficient artificial lighting in the threshold zone, simulations are conducted to compare lamp types in tunnels, aiming for maximum power savings. This research involves modelling toll road tunnel lighting using Dialux software, examining characteristics with both HPS and LED lamps using the Indonesian National Standard (SNI) and ANSI/IES Rp-22-11 as reference [29], [23]. The Dialux software is commonly used for tunnel lighting planning [30], [31]. Using the Cisumdawu tunnel as a case study, a dynamic lighting system capable of adapting to night and daylighting is demonstrated. The investigation into night and daylighting simulation for the Cisumdawu double tunnel in Indonesia reveals that Simulation results indicate that LED or HPS lamps can meet SNI standards for luminance in the interior zone. Furthermore, the double-mounted LED lamps surpass their HPS counterparts, offering increased luminance while consuming less power [32].

The research problem of this manuscript is how to address the enhancement of energy efficiency and safety in toll road tunnel lighting through an investigation into the comparative effectiveness of HPS lamps and LED lamps across the threshold, transition, and interior zones of the tunnel.

Therefore, the research aims to utilize DIALux software for simulating and modelling toll road tunnel lighting, comparing HPS and LED lamps. The objective is to identify the most energy-efficient lighting solution for the tunnel's threshold zone, promoting sustainable lighting for transportation infrastructure. It further seeks to evaluate luminance levels, power consumption, and uniformity of both lamp types in this zone. Additionally, the goal is to optimize tunnel lighting systems to enhance traffic safety and minimize energy usage.

The significance of the research lies in its potential to contribute to energy efficiency, safety, and sustainability in tunnel lighting for transportation infrastructure. This finding suggests potential improvements in energy efficiency within tunnel environments, contributing to sustainable lighting solutions for transportation infrastructure [27], [10].

II. Materials and Methods

In this study, a simulation was carried out to determine the luminance in the five tunnel zones mentioned above, using data from the Cisumdawu tunnel, such as tunnel length and geometry. Lamp data and others are determined according to lighting requirements. The simulation was carried out using DIALux 4.12 software. The simulation using DIAlux software has been commonly used and implemented in the study for evaluating lighting efficiency for indoor and outdoor lighting which has become a de facto standard [33], [34]. The simulation process for tunnel lighting using DIALux software and data collected from the Cisumdawu tunnel involves:

1. Data Collection: Gathering relevant data from the tunnel to serve as input parameters for the simulation.
2. Software Setup: Installing and configuring DIALux software with necessary parameters for accurate simulation.
3. Model Creation: Creating a 3D model of the tunnel within DIALux, accurately representing its geometry and layout.
4. Light Source Selection: Choosing HPS lamps and LED lamps as the primary light sources for simulation.
5. Placement Configuration: Arranging selected lamps in both single and double rows along the tunnel's interior.
6. Simulation Execution: Initiating the simulation process within DIALux to replicate real-world conditions.
7. Luminance Analysis: Analyzing simulation results to assess luminance levels across different zones of the tunnel.
8. Comparison and Evaluation: Comparing the performance of HPS and LED lamps in terms of luminance distribution. Also, the comparison of the two lamps results in the SNI 7391:2008 and ANSI/IES Rp-22-11 standard.
9. Optimization Strategies: Identifying potential areas for improvement based on simulation outcomes.
10. Documentation and Reporting: Documenting simulation parameters, results, and findings comprehensively for further analysis.

The parameters used for the simulation were implemented according to the parameters in Fig. 4 which include the luminance of threshold, transition, and interior zones. The DIALUX simulations were carried out using two light sources commonly used for tunnel lighting: HPS lamps and LED lamps. In addition, simulations were carried out by placing the lights in one row (single-mounted lamps) and two rows (double-mounted lamps). The results of this simulation can be used to provide input to the Ministry of Public Works and Public Housing (Kementrian PUPR), the agency responsible for constructing the Cisumdawu tunnel.

This research uses data from the Cisumdawu tunnel, a semicircular tunnel with a length of 472 m and a diameter of 14 m. Other data is determined according to tunnel conditions in Indonesia, which includes road surface material in the form of concrete paving, with a reflux value of 30%, and tunnel walls in the form of concrete, with a reflectance value of 24% (Source: data available from the Dialux software). The lamps used in the simulations for the tunnels are High-Pressure Sodium (HPS) and light-emitting diode (LED) lamps of various types from the Philips brand lamp manufacturer [35], [36]. The choice of this brand was based entirely on the ease of obtaining the photometric data of the lamp and the light polar diagram required for the simulation, and there was no sponsorship message in this regard. The types of HPS lamps used are HNF901 C 1xSON-T250W WB_220 and HNF901 C 1xSON-T400W WB_220. This simulation still uses HPS lamps because some roads and tunnels in DKI Jakarta and Indonesia still use HPS lamps, although some have been replaced with LED lamps. The types of LED lamps used are:

- Philips BVP161 LED26 30W
- Philips BVP381 LED60 50W
- Philips BVP382 LED180 150W
- Philips BVP383 LED270 240W

For this study, there are two variations of the simulation were carried out, namely:

- Simulation using HPS and LED lamps
- Simulations with single and double-mounted lamps.

A. *Tunnel Lighting Simulation for Cisumdawu Tunnel with Single and Double Mounted LED Lamps*

The simulation is carried out using the Cisumdawu tunnel dimension equipped with the following data:

- Tunnel: Cisumdawu
- Direction: East-West
- Length of tunnel: 472m
- Simulation time: 21 Juli 2018
- Road reflectance: 30%
- Wall reflectance: 24%
- Threshold zone: 100 m
- Transition zone: 110 m
- Lamp mounted: at the tunnel's ceiling
- Type of Lamp:
  - Threshold zone: Philips BVP382 LED180 150W or Philips BVP383 LED270 240W.
  - transition and interior zones:Philips BVP161 LED26 30W or Philips BVP381 LED60 50W

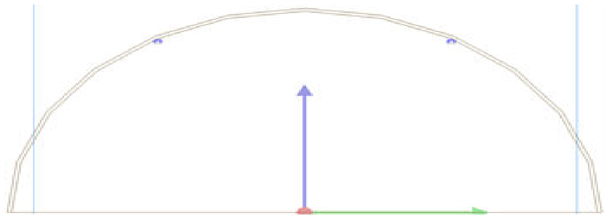

Fig. 5 Dimensions of Cisumdawu tunnel with a diameter of 14 m and a height of 7m

III. Result and Discussion

The simulation results are presented in the following. First, the luminance colour reference for the simulation results is shown in Fig. 6.

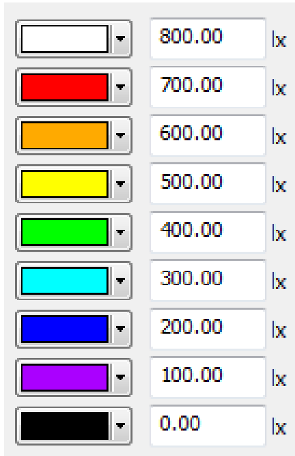

Fig. 6 The luminance colour reference for the simulation results

Second, we present the simulation results for the semicircle tunnel with LED lights with single mounting in Fig. 7, followed by the simulation results for the semicircle tunnel with LED lights using double mounting in Fig. 8.

To achieve a high level of luminance in the access zone and threshold (12 to 30 cd lm/m2), it used:

- 50 Philips BVP382 LED180 150W for double-mounted lamps.
- 25 Philips BVP383 LED270 240W for single-mounted lamps.
- For transition, interior, and exit zones, types and number of lamps are used:
- 94 Philips BVP161 LED26 30W for double-mounted lamps.
- 47 Philips BVP381 LED60 50W for single-mounted lamps.

The simulated luminance level using LED with double-mounted lamps can be seen in Fig. 9. Total power needed = 50 x 150W + 94 x 30W =10320W. The simulated luminance level using LED with single-mounted lamps can be seen in Fig. 10. Total power needed = 25x240W+47x50=8350W.

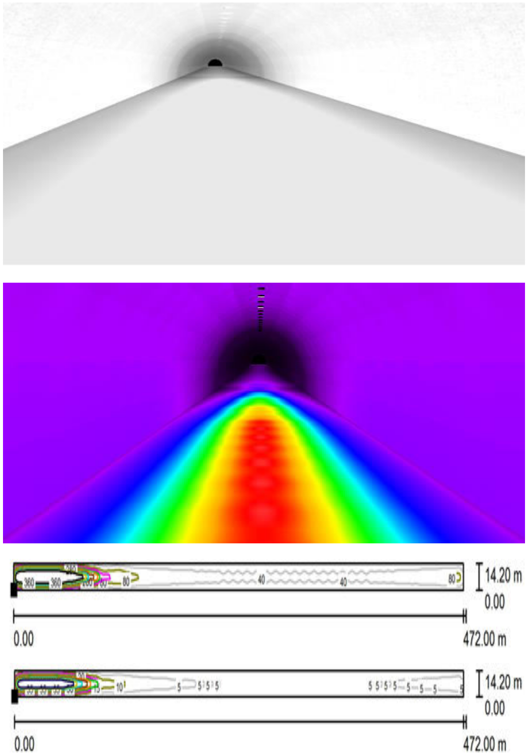

Fig. 7 Simulation results of semicircle tunnel with LED lights with a single mounting

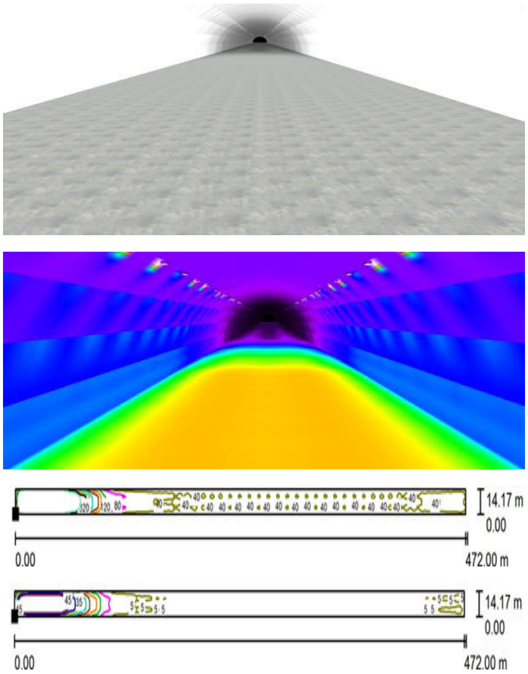

Fig. 8 Simulation results of semicircle tunnel with LED lights with double mounting

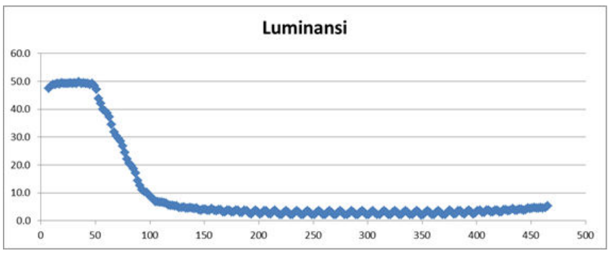

Fig. 9 Simulated luminance level using double-mounted LED lamps

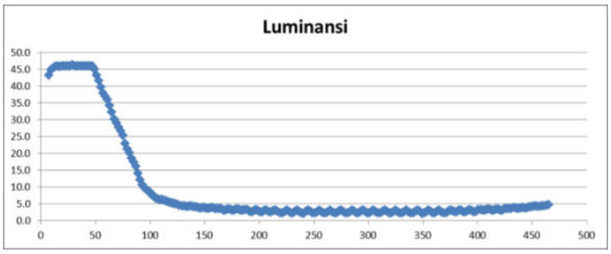

Fig. 10 Simulated luminance level using single-mounted LED lamps

In summary, the luminance level in the tunnel with the installation of single and double-mounted lights can be seen in Table 1 below this paper.

TABLE I

The simulation results of the semicircle tunnel using double and single-mounted LED lamps

A	Mounted	Double mounted	Single mounted
B	Luminaires	50x BVP382 150W 94 x BVP161 30W	25x BVP383 240W 47x BVP381 50W
C	Total power	10320 Watt	8350 Watt
D	Average luminance in the zone:		
	1. Threshold 1	49.9 cd/ m^2	33.6 cd/m^2
	2. Threshold 2	26.4 cd/m^2	18.3 cd/m^2
	3. Transition	4.5 cd/m^2	4.9 cd/m^2
	4. Interior	3.1 cd/m^2	3.5 cd/m^2
E	Uniformity (Uo)	0.67	0.76

Referring to the SNI for the Interior zone, the recommended luminance is 2.00 cd/m^2 with 0.70 uniformity. Based on the simulated results in Table I, all types of mounts fulfil the recommendations for luminance levels in the interior zone (D.4), for the double mounted, the average luminance in the interior zone is 3.1 cd/m^2 and for the single mounted is 3.5 cd/m^2. Therefore, the average luminance selected is double as it has less average luminance than single mounted which also means less luminaire LED used.

For uniformity, the installation of both double-mounted and single-mounted LED lamps slightly does not meet the standard because it has less (0.67) or more (0.76) uniformity compared SNI standard (0.70).

For the threshold 1 zone, the luminance level of a double-mounted structure is much greater than that of a single installation. Based on TABLE I and the ANSI/IES RP-22-11 standard, if the access zone is 200 cd/m^2, it is necessary to install double-mounted lamps to produce average luminance in Threshold 1 zone in the amount of 49.9 cd/m^2 (D.1) to compensate for the high luminance value in the access zone and at the start of the threshold zone, especially during the day.

A. *Tunnel Lighting Simulation with HPS Lights installed in Single and Double Mounted*

To achieve a high level of luminance in the access zone and threshold, we used:

- 50 HNF901 276W lamps for double-mounted installation

- 25 HNF901 433W lamps for single-mounted installation.

For the transition zone, interior, and exit, we used:

- 94 BVP116 35W lamps for double-mounted installation
- 47 BVP117 54W lamps for single-mounted installations

The simulation results for the semicircle tunnel with HPS lights with single mounting are presented in Fig. 11, and the simulation of the double mounting in Fig. 12.

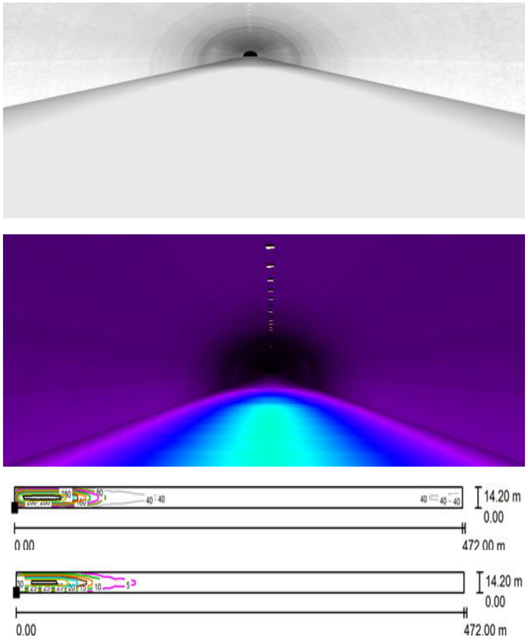

Fig. 11 Simulation results of semicircle tunnel with HPS light using single mounting

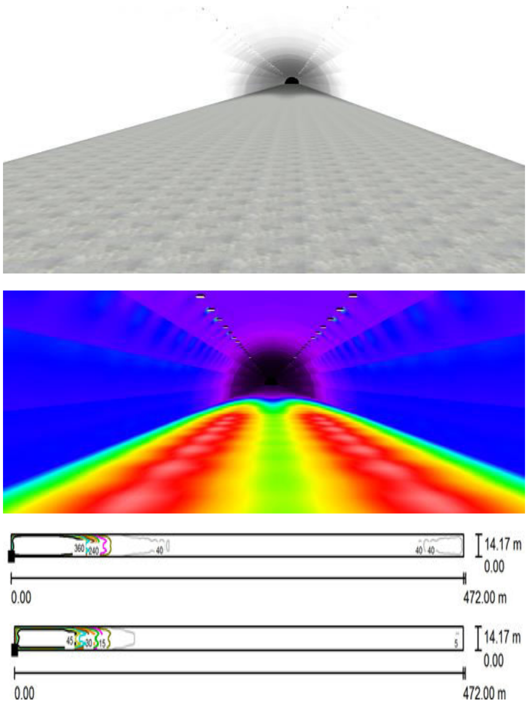

Fig. 12 Simulation results of semicircle tunnel with HPS light using double mounting.

The simulated luminance level for the single-mounted HPS lamps can be seen in Fig. 13. Total power needed = 25 × 240W + 47 × 50 = 13363W. Followed by the simulated luminance level using double-mounted HPS lamps is shown in Fig. 14. The total power needed = 50 × 150W + 94 × 30W = 17090W.

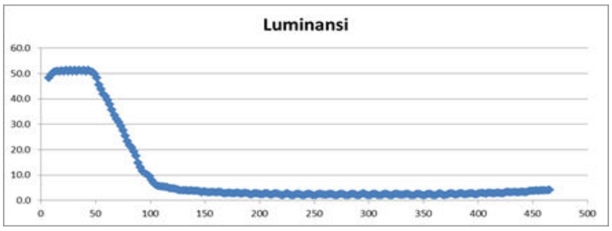

Fig. 13 Simulated luminance curve using single-mounted HPS lamps

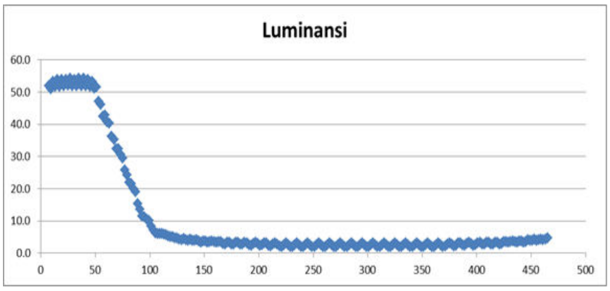

Fig. 14 Simulated luminance curve using double-mounted HPS

In summary, the simulation results of luminance level in the tunnel with the installation of conventional (HPS) lamps in single and double mounted can be seen in TABLE II below.

TABLE II

The simulation result of the semicircle tunnel using double and single-mounted HPS lamps

A	Mounted	Double mounted	Single Mounted
B	Luminaire	50x HNF901 276W 94x BVP116 35W	25x HNF901 433W 47x BVP117 54W
C	Total power	17090 Watt	13363 Watt
D	Average luminance in the zone:		
	1. Threshold 1	52.7 cd/ m^2	23.3 cd/m^2
	2. Threshold 2	28.5 cd/m^2	12.6 cd/m^2
	3. Transition	4.1 cd/m^2	3.0 cd/m^2
	4. Interior	2.8 cd/m^2	2.2 cd/m^2
E	Uniformity (Uo)	0.70	0.79

Based on TABLE II, the average luminance of double-mounted HPS in the Interior zone and the uniformity meet with SNI standard. For the single-mounted HPS, the average luminance in the Interior zone meets with SNI standard, but the uniformity does not. However, Both double-mounted and single-mounted HPS need Total Power much greater than double and single-mounted LED lamps.

B. *Discussion*

For the threshold 1 zone, using either LED or HPS lights, the luminance value of a double-mounted installation is much greater than that of a single-mounted structure. The comparison is shown in Fig. 15 for the LED and Fig. 16 for the HPS lights.

ANSI/IES Rp-22-11 luminance standard in the access zone is 200 cd/ m2, so double-mounted installation is recommended to compensate for the luminance value at Threshold 1 zone (49.9 cd/m^2) at the entrance of the threshold zone during the day. The purpose of the compensation of average luminance at the Threshold 1 zone is to increase safety by preventing the driver's eyes from losing sight temporarily (or the black hole effect).

For the threshold 2 zone and transition zone, the lamp's position has been designed to follow the curve from the CIE standard graph. The distance between the lights can be adjusted, or with the addition of a controller, the output level of the lamps (dim) can be adjusted to obtain a more significant decrease. Referring to the SNI for the Interior zone, the recommended luminance is 2.00 cd /m2 with a uniformity of 0.70.

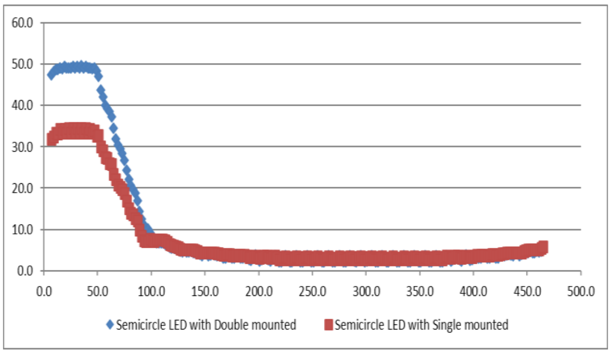

Fig. 15 Luminance Comparison of Double-mounted vs. Single-mounted LED

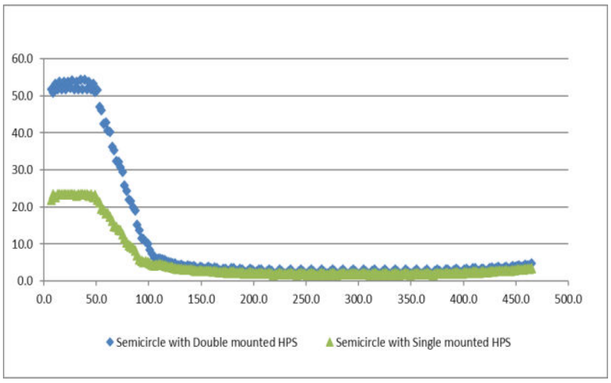

Fig. 16. Luminance Comparison of Double-mounted vs. Single-mounted HPS

All lamps and installations meet the recommended luminance level based on the simulated conditions. For uniformity, the structure of double-mounted LED lamps does not meet the standard. There is no significant difference in luminance level in the interior zone for a single or double-mounted installation.

When comparing the use of LED and HPS lamps in terms of power, LED lamps produce higher luminance with less power. Similar results have been reported in [37]. The comparison of LED and HPS using double and single mounted is presented in Fig. 17. Therefore, it is better to use LED lamps instead of HPS lamps in the future to achieve energy efficiency.

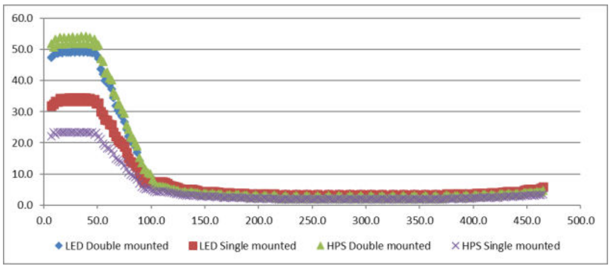

Fig. 17 Comparison of Luminance using LED and HPS with Double-mounted and Single-mounted

The simulation findings demonstrate that the luminance levels in the interior zone comply with the SNI standard when employing LED or HPS lamps. LED lamps yield greater luminance levels with lower power consumption compared to HPS lamps. This revelation holds promise for enhancing energy efficiency within tunnel environments, thereby fostering sustainable lighting solutions for transportation infrastructure.

Last but not least, implementing proposed lighting solutions in real-world tunnel environments may face challenges such as high initial costs, maintenance requirements, compatibility issues, regulatory compliance, environmental factors, energy efficiency optimization, and emergency preparedness.

IV. Conclusion

The conclusion obtained from the simulation results with DIALux 12.4 software for the Cisumdawu tunnel with two types of lamps and two installation methods are:

1. The installation of double-row lights in the Cisumdawu tunnel is more recommended to compensate for the luminance value of the threshold zone during the day rather than the installation of single-row lamps.
2. In the Cisumdawu tunnel for the threshold zone, the luminance value of the double lamp installation is much greater than that of the single lamp installation, using either an LED lamp or an HPS lamp.
3. Based on the ANSI / IES standard Rp-22-11, the luminance in the initial zone is 200 cd/m2. For this reason, the installation of double lights in the Cisumdawu tunnel is recommended to offset the luminance value at the beginning of the threshold zone during the day.
4. The luminance in the interior zone, using either LED lights or HPS lamps, can meet the SNI standard, which is 2 cd / m2.
5. For uniformity of 0.7, installing a dual LED lamp does not meet the standard.
6. The use of LED lamps results in higher luminance with less power than using HPS lamps.
7. Future directions include: integrating lighting control systems that automatically adjust illumination levels in response to real-time factors like traffic flow, time of day, and weather conditions to ensure optimal visibility while conserving energy during off-peak periods.

ACKNOWLEDGMENT

The authors would like to thank the Department of Research and Community Service (Lembaga Penelitian dan Pengabdian Masyarakat - LPPM) Universitas Tarumangara for the research funding granted to us to conduct this research.

REFERENCES

[1] E. Setyaningsih and J. Pragantha, "Lighting Simulation of Flat and Slightly Arched Type Tunnel Based on Pasar Rebo Tunnel Data," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 508, no. 1, p. 12077, Apr. 2019, doi: 10.1088/1757-899X/508/1/012077.

[2] R. Xu *et al.*, "Intelligent dimming control and energy consumption monitoring system of tunnel lighting," *Light. Res. Technol.*, vol. 56, no. 1, pp. 72–86, Mar. 2023, doi: 10.1177/14771535231158078.

[3] W. Wang and J. Ma, "Exploration of Smart Tunnel Solutions," in *2023 35th Chinese Control and Decision Conference (CCDC)*, 2023, pp. 697–702. doi: 10.1109/CCDC58219.2023.10327189.

[4] S. Yu, C. Zhao, L. Song, Y. Li, and Y. Du, "Understanding traffic bottlenecks of long freeway tunnels based on a novel location-dependent lighting-related car-following model," *Tunn. Undergr. Sp. Technol.*, vol. 136, p. 105098, 2023, doi: 10.1016/j.tust.2023.105098.

[5] Y. Song, H. Zhu, Y. Shen, and S. Feng, "Green tunnel lighting environment: A systematic review on energy saving, visual comfort and low carbon," *Tunn. Undergr. Sp. Technol.*, vol. 144, p. 105535, 2024, doi: 10.1016/j.tust.2023.105535.

[6] F. Xu, Z. Du, J. Mei, and L. Han, "Transmittance optimization of tunnel shading shed for maximum energy savings and traffic safety: When replacing tunnel lighting in threshold zone," *Tunn. Undergr. Sp. Technol.*, vol. 143, p. 105493, 2024, doi: 10.1016/j.tust.2023.105493.

[7] P. Chiradeja and S. Yoomak, "Development of public lighting system with smart lighting control systems and internet of thing (IoT) technologies for smart city," *Energy Reports*, vol. 10, pp. 3355–3372, 2023, doi: 10.1016/j.egyr.2023.10.027.

[8] Ming, Liu, Zhiqiang, Liu, and Rongrong, Qiang, "Discussion on Landscape and Greening Technology of Highway Structural Tunnel Entrance," *E3S Web Conf.*, vol. 261, p. 3035, 2021, doi: 10.1051/e3sconf/202126103035.

[9] Y. Que, H. Tang, Z. Zhang, and H. Zhao, "A brief analysis method in plant landscape design of motorway," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 702, no. 1, p. 12048, Mar. 2021, doi: 10.1088/1755-1315/702/1/012048.

[10] P. Chiradeja and S. Yoomak, "Optimal tunnel lighting design in aspect of lighting quality and energy performance," *Tunn. Undergr. Sp. Technol.*, vol. 131, p. 104837, 2023, doi: 10.1016/j.tust.2022.104837.

[11] J. Chen, L. You, M. Yang, and X. Wang, "Traffic safety assessment and prediction under different lighting service states in road tunnels," *Tunn. Undergr. Sp. Technol.*, vol. 134, p. 105001, 2023, doi: 10.1016/j.tust.2023.105001.

[12] J. Niu, B. Liang, S. He, C. Qin, and J. Xiao, "Assessment and optimization of tunnel lighting quality based on drivers' visual comfort: From methodology to application," *Tunn. Undergr. Sp. Technol.*, vol. 143, p. 105487, 2024, doi: 10.1016/j.tust.2023.105487.

[13] X. Wang, R. Wen, K. Cheng, and M. Yang, "Evaluation and analysis of tunnel lighting service status based on driving safety," *Traffic Inj. Prev.*, vol. 24, no. 5, pp. 436–444, 2023, doi: 10.1080/15389588.2023.2204986.

[14] X. Wang, L. You, J. Chen, and S. Han, "The impact of different service states of tunnel lighting on traffic safety," *Accid. Anal. Prev.*, vol. 192, p. 107237, 2023, doi: 10.1016/j.aap.2023.107237.

[15] J. Niu, B. Liang, S. He, J. Xiao, and C. Qin, "Long tunnel lighting environment improvement method based on multiple-parameter intelligent control: Considering dynamic changes in luminance difference," *Tunn. Undergr. Sp. Technol.*, vol. 128, p. 104637, 2022, doi: 10.1016/j.tust.2022.104637.

[16] A. Peña-García, "Sustainable tunnel lighting: One decade of proposals, advances and open points," *Tunn. Undergr. Sp. Technol.*, vol. 119, p. 104227, 2022, doi: 10.1016/j.tust.2021.104227.

[17] C. I. de L'Ecclairage, *CIE Technical Report: Guide for Lighting Road Tunnels and Underpasses CIE 88-2004*, 2nd ed. Vienna: CIE Central Bureau, 2004.

[18] B. Su, J. Hu, J. Zeng, and R. Wang, "Traffic Safety Improvement via Optimizing Light Environment in Highway Tunnels.," *Int. J. Environ. Res. Public Health*, vol. 19, no. 14, Jul. 2022, doi: 10.3390/ijerph19148517.

[19] A. L. W. Wijaya, P. P. Rahardjo, "Investigation of Twin Tunnel Deformation with Umbrella Grouting Protection & NATM Tunneling using 3D Finite Element: Case Study," *U Karst*, vol. 5, no. 2, pp. 252–267, 2021, doi: 10.30737/ukarst.v5i2.1977.

[20] S. Ma, J. Hu, E. Ma, W. Li, and R. Wang, "Cluster Analysis of Freeway Tunnel Length Based on Naturalistic Driving Safety and Comfort," *Sustainability*, vol. 15, p. 11914, 2023, doi: 10.3390/su151511914.

[21] S. Wang, Z. Du, G. Chen, H. Zheng, Z. Tang, and F. Jiao, "Drivers' visual characteristics in small-radius optically long tunnels on rural roads," *Tunn. Undergr. Sp. Technol.*, vol. 113, p. 103969, 2021, doi: 10.1016/j.tust.2021.103969.

[22] Y. Zhou, S. He, X. Li, Y. Li, and G. Du, "Study on Drivers' Visual Load Features in Lighting Environments of Interior Zones of Extra-Long Tunnels over 10 km," *Adv. Civ. Eng.*, vol. 2022, p. 4840334, 2022, doi: 10.1155/2022/4840334.

[23] I. E. S. of N. A. (IES), "RP-22-11 TUNNEL LIGHTING," 2011.

[24] S. G. Li, G. Tu, and Q. Zhou, "An optimal design model for tunnel lighting systems," *Optik (Stuttg).*, vol. 226, p. 165660, 2021, doi: 10.1016/j.ijleo.2020.165660.

[25] S. Chen, Y. Lin, and H. Zhao, “Effects of flicker with various brightness contrasts on visual fatigue in road lighting using fixed low-mounting-height luminaires,” *Tunn. Undergr. Sp. Technol.*, vol. 136, p. 105091, 2023, doi: 10.1016/j.tust.2023.105091.
[26] M. Cengiz, “Simulation and Design Study for Interior Zone Luminance in Tunnel Lighting,” *Light Eng.*, vol. 27, pp. 42–51, 2019, doi: 10.33383/2018-043.
[27] H.-Y. Liao *et al.*, “Design and Prototyping of Efficient LED Counter Beam Light with Free-Formed Surface for Meeting International Tunnel Lighting Standards,” *Energies*, vol. 14, no. 2, 2021, doi: 10.3390/en14020488.
[28] L. Qin, A. Peña-García, A. S. Leon, and J.-C. Yu, “Comparative Study of Energy Savings for Various Control Strategies in the Tunnel Lighting System,” *Appl. Sci.*, vol. 11, no. 14, 2021, doi: 10.3390/app11146372.
[29] BSN, *Standar Nasional Indonesia, SNI 7391:2008, Spesifikasi penerangan jalan di kawasan perkotaan, Badan Standarisasi Nasional. Jakarta.* Jakarta.
[30] Y. Su, H. Chen, Y. Gao, and R. Wei, “Calculation model for tunnel lighting based on DIALux,” in *International Conference on Smart Transportation and City Engineering (STCE 2023)*, 2024, vol. 13018, p. 130185N. doi: 10.1117/12.3024160.
[31] C.-C. Hsieh, C.-L. Tsai, and T.-C. Li, “The research for designing the LED tunnel light for highway tunnels.,” *Heliyon*, vol. 10, no. 4, p. e26305, Feb. 2024, doi: 10.1016/j.heliyon.2024.e26305.
[32] D. Katzin, L. F. M. Marcelis, and S. van Mourik, “Energy savings in greenhouses by transition from high-pressure sodium to LED lighting,” *Appl. Energy*, vol. 281, p. 116019, 2021, doi: 10.1016/j.apenergy.2020.116019.
[33] A. Hangga *et al.*, “Modelling of lighting system utilizing natural and artificial lighting using DIALux,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 969, no. 1, p. 12024, Jan. 2022, doi: 10.1088/1755-1315/969/1/012024.
[34] M. L. Nurrohman, P. Feros, Wahyuning, R. F. Madina, and N. Pratiwi, “Efficient Lighting Design for Multiuse Architecture Studio Classroom using Dialux Evo 9,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 738, no. 1, p. 12034, Apr. 2021, doi: 10.1088/1755-1315/738/1/012034.
[35] E. Setyaningsih, Y. Calvinus, and B. A. Pramudia, “CSL19 design excellence analysis for street lights with previous products,” *AIP Conf. Proc.*, vol. 2680, no. 1, p. 20077, 2023, doi: 10.1063/5.0128005.
[36] J. Fat, E. Setyaningsih, Y. Calvinus, V. Reinard, and A. Hendisutio, “Temperature, humidity, voltage and current data logger for LED street light luminaire,” in *AIP Conference Proceedings*, 2023, p. 20053. doi: 10.1063/5.0127315.
[37] A. Nauta, J. Han, S. H. Tasnim, and W. D. Lubitz, “Performance Evaluation of a Commercial Greenhouse in Canada Using Dehumidification Technologies and LED Lighting: A Modeling Study,” *Energies*, vol. 16, no. 3, 2023, doi: 10.3390/en16031015.

Modeling Night and Daylighting Toll Road Tunnel Using Dialux to Compare the Performance of HPS and LED Lamp

Endah Setyaningsih [a,*], Jeanny Pragantha [b], Henry Candra [c]

[a] Department of Electrical Engineering, Universitas Tarumanagara, Jl. S. Parman,11440, Indonesia

[b] Informatics Engineering, Universitas Tarumanagara, Jl. S. Parman,11440, Indonesia

[c] Department of Electrical Engineering, Universitas Trisakti, Jl. Kyai Tapa, 11440, Indonesia

*endahs@ft.untar.ac.id

***Abstract*— In toll road tunnels, the lighting at the threshold zone must balance the brightness of the access zone with natural light. Therefore, artificial lighting is strategically placed in that area to match the brightness to the intensity of natural light. This balance shifts during nighttime to ensure uniform brightness throughout the tunnel equivalent to street lighting. Additionally, to realize this artificial lighting, a significant amount of power is required. There are several lamp technologies used for tunnel lighting; one commonly used is HPS lamps, which have low energy efficiency. Currently, there are LED lamps available that are energy-efficient. The challenge is determining artificial lighting in the threshold zone using energy-efficient lamps. To address this issue, simulations were conducted to compare the two lamp types applied in tunnels to achieve the greatest power savings. This research creates a model of toll road tunnel lighting using DIALux software to better understand the characteristics of toll road tunnel lighting using HPS and LED lamps. The Indonesian National Standard (SNI) and ANSI/IES Rp-22-11 are the standards used. The research utilizes the Cisumdawu tunnel as a case study example. The simulation results show that the luminance in the interior zone using LED or HPS lamps, can meet the SNI standard. Using LED lamps results in higher luminance with less power than using HPS. This discovery can potentially improve energy efficiency in tunnel environments, thereby contributing to sustainable lighting solutions for transportation infrastructure.**

***Keywords*— Tunnel lighting, Cisumdawu lighting, Daylighting, Night lighting, Lighting Simulation.**

Manuscript received 15 Oct. 2020; revised 29 Jan. 2021; accepted 2 Feb. 2021. Date of publication 17 Feb. 2021.

I. INTRODUCTION

Based on research in tunnel lighting that the authors conducted (decentralization research that the Higher Education Department funded), it was found that the lighting in the Pasar Rebo tunnel and the Cibubur tunnel did not meet the lighting standards for both nighttime lighting and daylight lighting [1].

The research conducted to enhance energy efficiency in tunnel lighting applies three methodological approaches: implementing smart lighting technology in the tunnel [2], [3], [4], [5], [6], [7]; organizing the environment by planting trees and plants at the tunnel entrance [8], [9]; and by replacing HPS lamps with LED lamps. The average lighting during the day is either very excessive, that is, the illumination and luminance exceeds the SNI standards and international standards, or much less than standard, especially at mid-day [10], [11]. As a result, the face of the tunnel looks very dark compared to sunlight, which causes the driver's eyes to lose sight temporarily (or black hole effect) [12], [13], [14], [15], [16]. By designing a tunnel lighting system that prioritizes both driver safety and minimizes the disruptive effects of light transitions, we can significantly improve overall safety and reduce negative impacts on drivers' vision within the tunnel [17].

The Cileunyi-Sumedang-Dawuan Tunnel (Cisumdawu Tunnel) is used to overcome congestion and shorten vehicle tracks which is implemented massively in developed countries such as China [18]. This tunnel is part of the Cisumdawu toll road in Cilengser Village. It is located in section II of the toll road, which connects Ranca Kalong and Sumedang, Subang, West Java. The Cisumdawu toll road is expected to shorten the distance from Bandung to Sumedang and West Java International Airport in Kertajati via the Cikampek-Palimanan toll road. The Cisumdawu tunnel is a twin tunnel because it consists of two tunnels: the right tunnel with the initials R (Right) and the left tunnel L (Left). Fig. 1 is the Cisumdawu tunnel, the twin tunnel. The inside view of the Cisumdawu tunnel can be seen in Fig. 2. Fig. 3 shows the location of the Cisumdawu toll road in the West Java area. The Cisumdawu Tunnel is the longest in Indonesia, with a length of 472 m and a diameter of 14 m for each tunnel [19].

A tunnel is a road whose surroundings are covered by structures. Generally, this road is below ground level [8].

Tunnel can be divided into "long tunnel" and "short tunnel" based on the clarity of view [20]. In the tunnel road, drivers usually have a short visual blind zone and visual shock when entering and exiting the tunnels [21], [22]. In a short tunnel, the exit is visible from a point directly in front of the tunnel entrance when no vehicles are passing. Usually, the short tunnel length is limited to 75 meters [9]. During the day, the short tunnel generally does not require a lighting system because the inclusion of daylight from both sides of the short tunnel, plus the silhouetted effect of the bright light at the other end of the tunnel, generally guarantees satisfactory visibility. In contrast to long tunnels, the driver cannot see the exit end of the tunnel. Tunnels that are less than 75 m long but whose paths are not straight so drivers cannot see the exit end of the tunnel are defined as long tunnels [9], [23].

Fig. 1 Cisumdawu Tunnel, the Twin Tunnel

The essential purpose of tunnel lighting is to provide sufficient and comfortable visibility for tunnel users to pass through the tunnel safely day and night [24], [17], [5]. Several things must be considered To achieve this goal, which are [16], [12]:

1. Lighting must provide a sufficient and even level of illuminance to the driver throughout the tunnel in dry and wet conditions.
2. The angle of incidence of the lamp light relative to the driver's vision should provide a high level of sight of the road markings in all weather conditions.
3. Lighting should not cause glare.
4. Lighting should not flicker [25].

Fig. 2 Inside Cisumdawu Tunnel

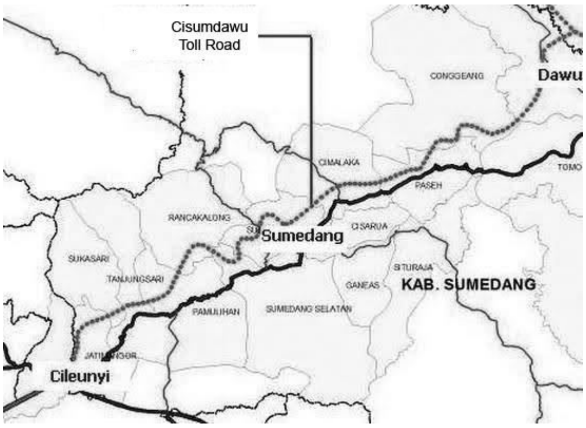

Fig. 3 Map of Cisumdawu Tunnel in Rancakalong Sumedang

In the long tunnel, acknowledging the difference in human visual adaptation speeds for light and dark transitions, five distinct lighting zones are implemented (refer to Fig. 4 below the paper) [17], [23], [26]:

- Access Zone: The driver's approach to the tunnel is illuminated by the same ambient light level as outside, allowing them to see the tunnel entrance.
- Threshold Zone: Upon entering, the tunnel reveals its interior gradually over a distance equal to the stopping distance. The luminance within the first part is maintained constant, matching the outside level and adapting to traffic conditions. As the zone progresses, the luminance is smoothly reduced to 40% of its initial value.

- Transition Zone: A gentle transition bridges the gap between the threshold's dimmed lighting and the interior's deeper darkness. The luminance level is progressively lowered, mimicking the natural light changes of a sunset. The length and stages of this transition are carefully designed to match the human eye's adaptation capabilities, ensuring a comfortable shift.
- Interior Zone: Within the tunnel's depths, sunlight is replaced by a consistent artificial lighting level. This unwavering luminance provides a stable visual environment for drivers, akin to navigating a starlit cavern bathed in a constant glow.
- Exit Zone: As the tunnel's end approaches, a sense of emergence is created by the gradual increase in light level. The luminance smoothly rises, replicating the experience of dawn, until it seamlessly matches the natural environment outside.

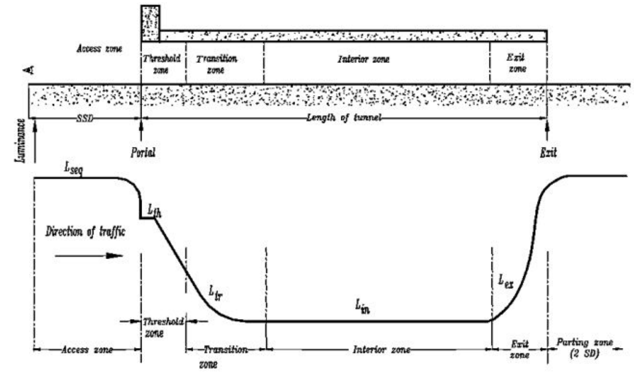

Fig. 4 Five Tunnel Zone [17], [23], [26]

Air characteristics in the tunnel differ from those of ordinary roads. In the tunnel, the concentration of vehicle exhaust gas will be higher than on regular roads because the air exchange is slower than on ordinary roads. Thus, the lighting must also be more resistant to dangerous substances in vehicle exhaust gases such as sulfuric acid, nitric acid, carbon monoxide, and others. Several types of lamps recommended for tunnel lighting are High-Pressure Sodium (HPS) lamps and Light Emitting Diode (LED) lamps [24], [27], [28].

In this paper, to address the challenge of determining energy-efficient artificial lighting in the threshold zone, simulations are conducted to compare lamp types in tunnels, aiming for maximum power savings. This research involves modelling toll road tunnel lighting using Dialux software, examining characteristics with both HPS and LED lamps using the Indonesian National Standard (SNI) and ANSI/IES Rp-22-11 as reference [29], [23]. The Dialux software is commonly used for tunnel lighting planning [30], [31]. Using the Cisumdawu tunnel as a case study, a dynamic lighting system capable of adapting to night and daylighting is demonstrated. The investigation into night and daylighting simulation for the Cisumdawu double tunnel in Indonesia reveals that Simulation results indicate that LED or HPS lamps can meet SNI standards for luminance in the interior zone. Furthermore, the double-mounted LED lamps surpass their HPS counterparts, offering increased luminance while consuming less power [32].

The research problem of this manuscript is how to address the enhancement of energy efficiency and safety in toll road tunnel lighting through an investigation into the comparative effectiveness of HPS lamps and LED lamps across the threshold, transition, and interior zones of the tunnel.

Therefore, the research aims to utilize DIALux software for simulating and modelling toll road tunnel lighting, comparing HPS and LED lamps. The objective is to identify the most energy-efficient lighting solution for the tunnel's threshold zone, promoting sustainable lighting for transportation infrastructure. It further seeks to evaluate luminance levels, power consumption, and uniformity of both lamp types in this zone. Additionally, the goal is to optimize tunnel lighting systems to enhance traffic safety and minimize energy usage.

The significance of the research lies in its potential to contribute to energy efficiency, safety, and sustainability in tunnel lighting for transportation infrastructure. This finding suggests potential improvements in energy efficiency within tunnel environments, contributing to sustainable lighting solutions for transportation infrastructure [27], [10].

II. Materials and Methods

In this study, a simulation was carried out to determine the luminance in the five tunnel zones mentioned above, using data from the Cisumdawu tunnel, such as tunnel length and geometry. Lamp data and others are determined according to lighting requirements. The simulation was carried out using DIALux 4.12 software. The simulation using DIAlux software has been commonly used and implemented in the study for evaluating lighting efficiency for indoor and outdoor lighting which has become a de facto standard [33], [34]. The simulation process for tunnel lighting using DIALux software and data collected from the Cisumdawu tunnel involves:

- Data Collection: Gathering relevant data from the tunnel to serve as input parameters for the simulation.
- Software Setup: Installing and configuring DIALux software with necessary parameters for accurate simulation.
- Model Creation: Creating a 3D model of the tunnel within DIALux, accurately representing its geometry and layout.
- Light Source Selection: Choosing HPS lamps and LED lamps as the primary light sources for simulation.
- Placement Configuration: Arranging selected lamps in both single and double rows along the tunnel's interior.
- Simulation Execution: Initiating the simulation process within DIALux to replicate real-world conditions.
- Luminance Analysis: Analyzing simulation results to assess luminance levels across different zones of the tunnel.
- Comparison and Evaluation: Comparing the performance of HPS and LED lamps in terms of luminance distribution. Also, the comparison of the two lamps results in the SNI 7391:2008 and ANSI/IES Rp-22-11 standard.
- Optimization Strategies: Identifying potential areas for improvement based on simulation outcomes.

- Documentation and Reporting: Documenting simulation parameters, results, and findings comprehensively for further analysis.

The parameters used for the simulation were implemented according to the parameters in Fig. 4 which include the luminance of threshold, transition, and interior zones. The DIALUX simulations were carried out using two light sources commonly used for tunnel lighting: HPS lamps and LED lamps. In addition, simulations were carried out by placing the lights in one row (single-mounted lamps) and two rows (double-mounted lamps). The results of this simulation can be used to provide input to the Ministry of Public Works and Public Housing (Kementrian PUPR), the agency responsible for constructing the Cisumdawu tunnel.

This research uses data from the Cisumdawu tunnel, a semicircular tunnel with a length of 472 m and a diameter of 14 m. Other data is determined according to tunnel conditions in Indonesia, which includes road surface material in the form of concrete paving, with a reflux value of 30%, and tunnel walls in the form of concrete, with a reflectance value of 24% (Source: data available from the Dialux software). The lamps used in the simulations for the tunnels are High-Pressure Sodium (HPS) and light-emitting diode (LED) lamps of various types from the Philips brand lamp manufacturer [35], [36]. The choice of this brand was based entirely on the ease of obtaining the photometric data of the lamp and the light polar diagram required for the simulation, and there was no sponsorship message in this regard. The types of HPS lamps used are HNF901 C 1xSON-T250W WB_220 and HNF901 C 1xSON-T400W WB_220. This simulation still uses HPS lamps because some roads and tunnels in DKI Jakarta and Indonesia still use HPS lamps, although some have been replaced with LED lamps. The types of LED lamps used are:

- Philips BVP161 LED26 30W
- Philips BVP381 LED60 50W
- Philips BVP382 LED180 150W
- Philips BVP383 LED270 240W

For this study, there are two variations of the simulation were carried out, namely:

- Simulation using HPS and LED lamps
- Simulations with single and double-mounted lamps.

A. *Tunnel Lighting Simulation for Cisumdawu Tunnel with Single and Double Mounted LED Lamps*

The simulation is carried out using the Cisumdawu tunnel dimension equipped with the following data:

- Tunnel: Cisumdawu
- Direction: East-West
- Length of tunnel: 472m
- Simulation time: 21 Juli 2018
- Road reflectance: 30%
- Wall reflectance: 24%
- Threshold zone: 100 m
- Transition zone: 110 m
- Lamp mounted: at the tunnel's ceiling
- Type of Lamp:
  - Threshold zone: Philips BVP382 LED180 150W or Philips BVP383 LED270 240W.
  - transition and interior zones:Philips BVP161 LED26 30W or Philips BVP381 LED60 50W

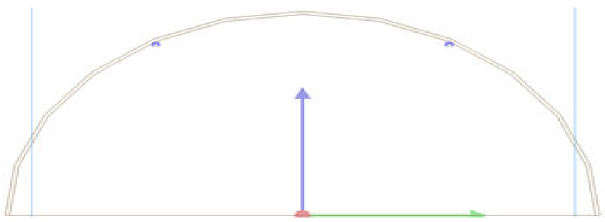

Fig. 5 Dimensions of Cisumdawu tunnel with a diameter of 14 m and a height of 7m

III. Result and Discussion

The simulation results are presented in the following. First, the luminance colour reference for the simulation results is shown in Fig. 6.

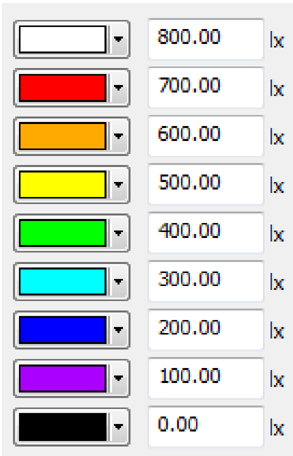

Fig. 6 The luminance colour reference for the simulation results

Second, we present the simulation results for the semicircle tunnel with LED lights with single mounting in Fig. 7, followed by the simulation results for the semicircle tunnel with LED lights using double mounting in Fig. 8.

To achieve a high level of luminance in the access zone and threshold (12 to 30 cd lm/m2), it used:

- 50 Philips BVP382 LED180 150W for double-mounted lamps.
- 25 Philips BVP383 LED270 240W for single-mounted lamps.
- For transition, interior, and exit zones, types and number of lamps are used:
- 94 Philips BVP161 LED26 30W for double-mounted lamps.
- 47 Philips BVP381 LED60 50W for single-mounted lamps.

The simulated luminance level using LED with double-mounted lamps can be seen in Fig. 9. Total power needed = 50 x 150W + 94 x 30W =10320W. The simulated luminance level using LED with single-mounted lamps can be seen in Fig. 10. Total power needed = 25x240W+47x50=8350W.

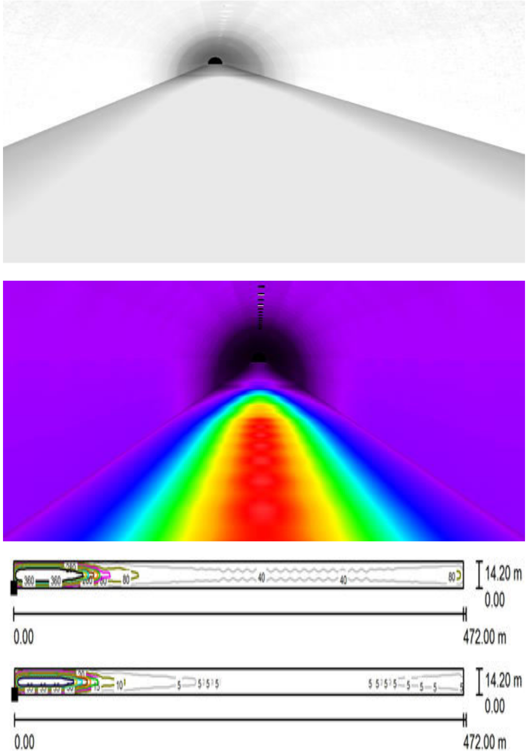

Fig. 7 Simulation results of semicircle tunnel with LED lights with a single mounting

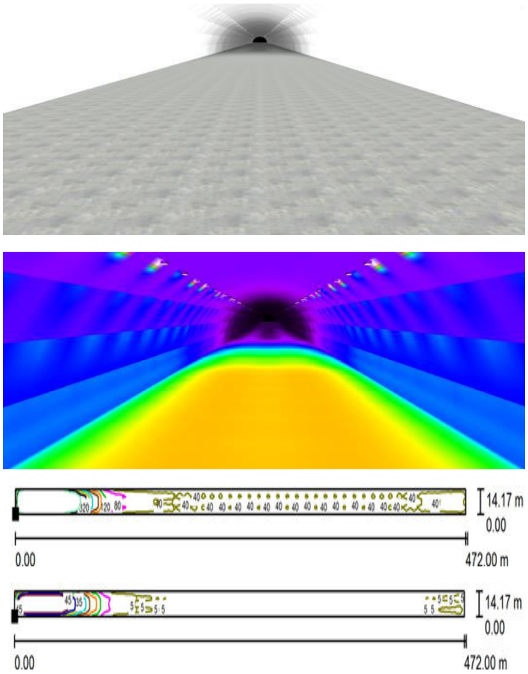

Fig. 8 Simulation results of semicircle tunnel with LED lights with double mounting

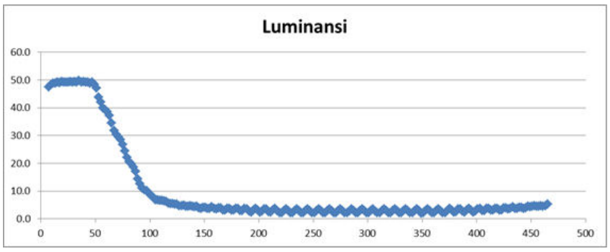

Fig. 9 Simulated luminance level using double-mounted LED lamps

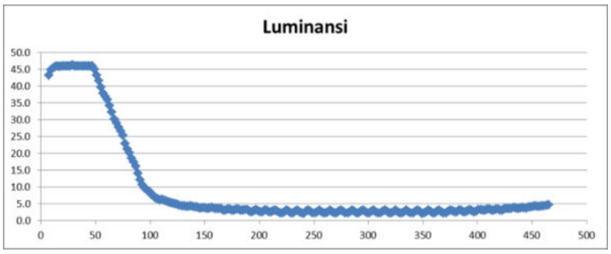

Fig. 10 Simulated luminance level using single-mounted LED lamps

In summary, the luminance level in the tunnel with the installation of single and double-mounted lights can be seen in Table 1 below this paper.

TABLE I

The simulation results of the semicircle tunnel using double and single-mounted LED lamps

A	Mounted	Double mounted	Single mounted
B	Luminaires	50x BVP382 150W 94 x BVP161 30W	25x BVP383 240W 47x BVP381 50W
C	Total power	10320 Watt	8350 Watt
D	Average luminance in the zone:		
	1. Threshold 1	49.9 cd/ m²	33.6 cd/m²
	2. Threshold 2	26.4 cd/m²	18.3 cd/m²
	3. Transition	4.5 cd/m²	4.9 cd/m²
	4. Interior	3.1 cd/m²	3.5 cd/m²
E	Uniformity (Uo)	0.67	0.76

Referring to the SNI for the Interior zone, the recommended luminance is 2.00 cd/m^2 with 0.70 uniformity. Based on the simulated results in Table I, all types of mounts fulfil the recommendations for luminance levels in the interior zone (D.4), for the double mounted, the average luminance in the interior zone is 3.1 cd/m^2 and for the single mounted is 3.5 cd/m^2. Therefore, the average luminance selected is double as it has less average luminance than single mounted which also means less luminaire LED used.

For uniformity, the installation of both double-mounted and single-mounted LED lamps slightly does not meet the standard because it has less (0.67) or more (0.76) uniformity compared SNI standard (0.70).

For the threshold 1 zone, the luminance level of a double-mounted structure is much greater than that of a single installation. Based on TABLE I and the ANSI/IES RP-22-11 standard, if the access zone is 200 cd/m^2, it is necessary to install double-mounted lamps to produce average luminance in Threshold 1 zone in the amount of 49.9 cd/m^2 (D.1) to compensate for the high luminance value in the access zone and at the start of the threshold zone, especially during the day.

A. *Tunnel Lighting Simulation with HPS Lights installed in Single and Double Mounted*

To achieve a high level of luminance in the access zone and threshold, we used:

- 50 HNF901 276W lamps for double-mounted installation

- 25 HNF901 433W lamps for single-mounted installation.

For the transition zone, interior, and exit, we used:

- 94 BVP116 35W lamps for double-mounted installation
- 47 BVP117 54W lamps for single-mounted installations

The simulation results for the semicircle tunnel with HPS lights with single mounting are presented in Fig. 11, and the simulation of the double mounting in Fig. 12.

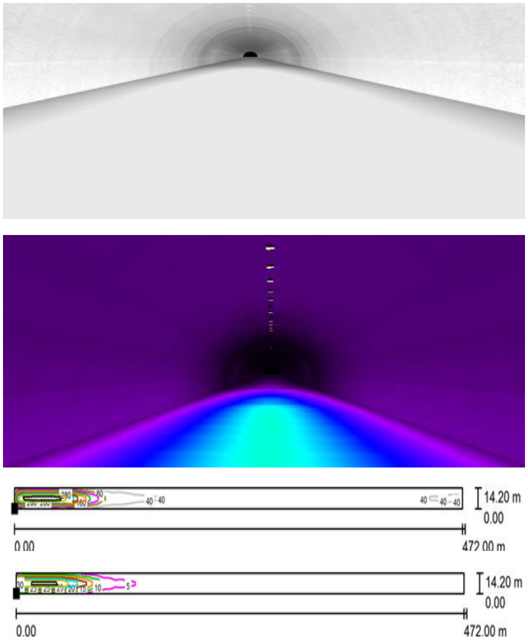

Fig. 11 Simulation results of semicircle tunnel with HPS light using single mounting

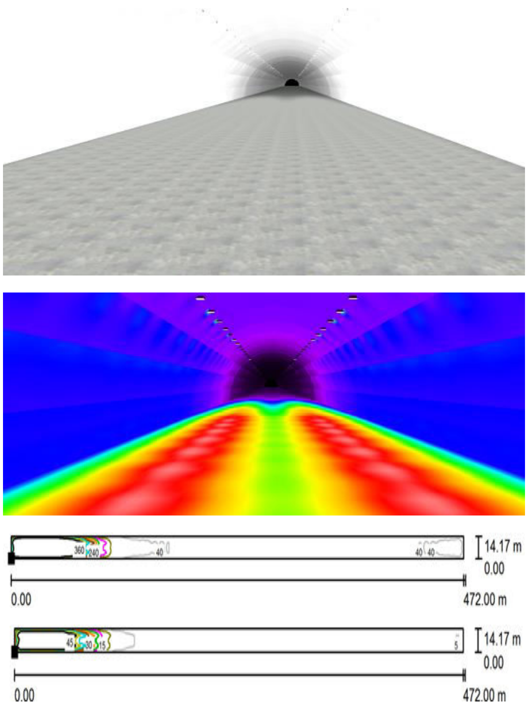

Fig. 12 Simulation results of semicircle tunnel with HPS light using double mounting.

The simulated luminance level for the single-mounted HPS lamps can be seen in Fig. 13. Total power needed = 25 × 240W + 47 × 50 = 13363W. Followed by the simulated luminance level using double-mounted HPS lamps is shown in Fig. 14. The total power needed = 50 × 150W + 94 × 30W = 17090W.

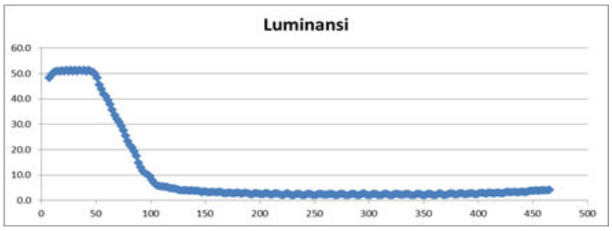

Fig. 13 Simulated luminance curve using single-mounted HPS lamps

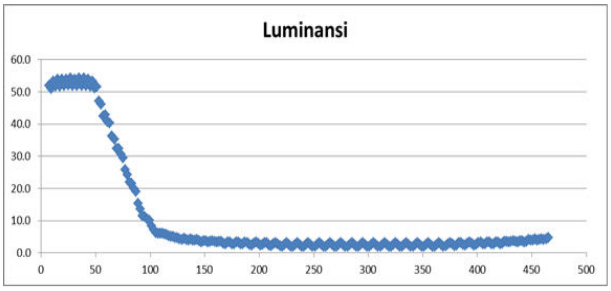

Fig. 14 Simulated luminance curve using double-mounted HPS

In summary, the simulation results of luminance level in the tunnel with the installation of conventional (HPS) lamps in single and double mounted can be seen in TABLE II below.

TABLE II

The simulation result of the semicircle tunnel using double and single-mounted HPS lamps

A	Mounted	Double mounted	Single Mounted
B	Luminaire	50x HNF901 276W 94x BVP116 35W	25x HNF901 433W 47x BVP117 54W
C	Total power	17090 Watt	13363 Watt
D	Average luminance in the zone:		
	1. Threshold 1	52.7 cd/ m^2	23.3 cd/m^2
	2. Threshold 2	28.5 cd/m^2	12.6 cd/m^2
	3. Transition	4.1 cd/m^2	3.0 cd/m^2
	4. Interior	2.8 cd/m^2	2.2 cd/m^2
E	Uniformity (Uo)	0.70	0.79

Based on TABLE II, the average luminance of double-mounted HPS in the Interior zone and the uniformity meet with SNI standard. For the single-mounted HPS, the average luminance in the Interior zone meets with SNI standard, but the uniformity does not. However, Both double-mounted and single-mounted HPS need Total Power much greater than double and single-mounted LED lamps.

B. *Discussion*

For the threshold 1 zone, using either LED or HPS lights, the luminance value of a double-mounted installation is much greater than that of a single-mounted structure. The comparison is shown in Fig. 15 for the LED and Fig. 16 for the HPS lights.

ANSI/IES Rp-22-11 luminance standard in the access zone is 200 cd/ m2, so double-mounted installation is recommended to compensate for the luminance value at Threshold 1 zone (49.9 cd/m^2) at the entrance of the threshold zone during the day. The purpose of the compensation of average luminance at the Threshold 1 zone is to increase safety by preventing the driver's eyes from losing sight temporarily (or the black hole effect).

For the threshold 2 zone and transition zone, the lamp's position has been designed to follow the curve from the CIE standard graph. The distance between the lights can be adjusted, or with the addition of a controller, the output level of the lamps (dim) can be adjusted to obtain a more significant decrease. Referring to the SNI for the Interior zone, the recommended luminance is 2.00 cd /m2 with a uniformity of 0.70.

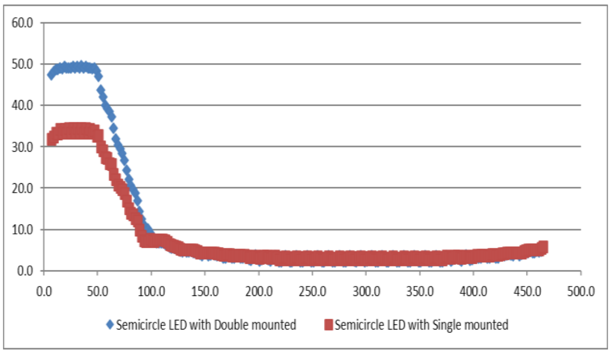

Fig. 15 Luminance Comparison of Double-mounted vs. Single-mounted LED

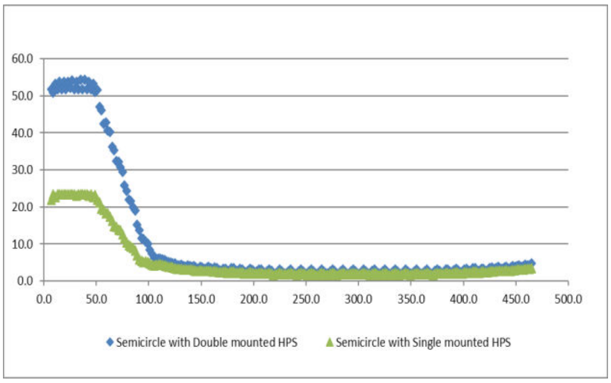

Fig. 16. Luminance Comparison of Double-mounted vs. Single-mounted HPS

All lamps and installations meet the recommended luminance level based on the simulated conditions. For uniformity, the structure of double-mounted LED lamps does not meet the standard. There is no significant difference in luminance level in the interior zone for a single or double-mounted installation.

When comparing the use of LED and HPS lamps in terms of power, LED lamps produce higher luminance with less power. Similar results have been reported in [37]. The comparison of LED and HPS using double and single mounted is presented in Fig. 17. Therefore, it is better to use LED lamps instead of HPS lamps in the future to achieve energy efficiency.

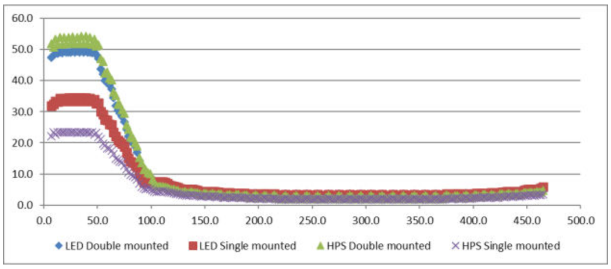

Fig. 17 Comparison of Luminance using LED and HPS with Double-mounted and Single-mounted

The simulation findings demonstrate that the luminance levels in the interior zone comply with the SNI standard when employing LED or HPS lamps. LED lamps yield greater luminance levels with lower power consumption compared to HPS lamps. This revelation holds promise for enhancing energy efficiency within tunnel environments, thereby fostering sustainable lighting solutions for transportation infrastructure.

Last but not least, implementing proposed lighting solutions in real-world tunnel environments may face challenges such as high initial costs, maintenance requirements, compatibility issues, regulatory compliance, environmental factors, energy efficiency optimization, and emergency preparedness.

IV. Conclusion

The conclusion obtained from the simulation results with DIALux 12.4 software for the Cisumdawu tunnel with two types of lamps and two installation methods are:

1. The installation of double-row lights in the Cisumdawu tunnel is more recommended to compensate for the luminance value of the threshold zone during the day rather than the installation of single-row lamps.
2. In the Cisumdawu tunnel for the threshold zone, the luminance value of the double lamp installation is much greater than that of the single lamp installation, using either an LED lamp or an HPS lamp.
3. Based on the ANSI / IES standard Rp-22-11, the luminance in the initial zone is 200 cd/m2. For this reason, the installation of double lights in the Cisumdawu tunnel is recommended to offset the luminance value at the beginning of the threshold zone during the day.
4. The luminance in the interior zone, using either LED lights or HPS lamps, can meet the SNI standard, which is 2 cd / m2.
5. For uniformity of 0.7, installing a dual LED lamp does not meet the standard.
6. The use of LED lamps results in higher luminance with less power than using HPS lamps.
7. Future directions include: integrating lighting control systems that automatically adjust illumination levels in response to real-time factors like traffic flow, time of day, and weather conditions to ensure optimal visibility while conserving energy during off-peak periods.

Acknowledgment

The authors would like to thank the Department of Research and Community Service (Lembaga Penelitian dan Pengabdian Masyarakat - LPPM) Universitas Tarumangara for the research funding granted to us to conduct this research.

References

[1] E. Setyaningsih and J. Pragantha, "Lighting Simulation of Flat and Slightly Arched Type Tunnel Based on Pasar Rebo Tunnel Data," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 508, no. 1, p. 12077, Apr. 2019, doi: 10.1088/1757-899X/508/1/012077.

[2] R. Xu *et al.*, "Intelligent dimming control and energy consumption monitoring system of tunnel lighting," *Light. Res. Technol.*, vol. 56, no. 1, pp. 72–86, Mar. 2023, doi: 10.1177/14771535231158078.

[3] W. Wang and J. Ma, "Exploration of Smart Tunnel Solutions," in *2023 35th Chinese Control and Decision Conference (CCDC)*, 2023, pp. 697–702. doi: 10.1109/CCDC58219.2023.10327189.

[4] S. Yu, C. Zhao, L. Song, Y. Li, and Y. Du, "Understanding traffic bottlenecks of long freeway tunnels based on a novel location-dependent lighting-related car-following model," *Tunn. Undergr. Sp. Technol.*, vol. 136, p. 105098, 2023, doi: 10.1016/j.tust.2023.105098.

[5] Y. Song, H. Zhu, Y. Shen, and S. Feng, "Green tunnel lighting environment: A systematic review on energy saving, visual comfort and low carbon," *Tunn. Undergr. Sp. Technol.*, vol. 144, p. 105535, 2024, doi: 10.1016/j.tust.2023.105535.

[6] F. Xu, Z. Du, J. Mei, and L. Han, "Transmittance optimization of tunnel shading shed for maximum energy savings and traffic safety: When replacing tunnel lighting in threshold zone," *Tunn. Undergr. Sp. Technol.*, vol. 143, p. 105493, 2024, doi: 10.1016/j.tust.2023.105493.

[7] P. Chiradeja and S. Yoomak, "Development of public lighting system with smart lighting control systems and internet of thing (IoT) technologies for smart city," *Energy Reports*, vol. 10, pp. 3355–3372, 2023, doi: 10.1016/j.egyr.2023.10.027.

[8] Ming, Liu, Zhiqiang, Liu, and Rongrong, Qiang, "Discussion on Landscape and Greening Technology of Highway Structural Tunnel Entrance," *E3S Web Conf.*, vol. 261, p. 3035, 2021, doi: 10.1051/e3sconf/202126103035.

[9] Y. Que, H. Tang, Z. Zhang, and H. Zhao, "A brief analysis method in plant landscape design of motorway," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 702, no. 1, p. 12048, Mar. 2021, doi: 10.1088/1755-1315/702/1/012048.

[10] P. Chiradeja and S. Yoomak, "Optimal tunnel lighting design in aspect of lighting quality and energy performance," *Tunn. Undergr. Sp. Technol.*, vol. 131, p. 104837, 2023, doi: 10.1016/j.tust.2022.104837.

[11] J. Chen, L. You, M. Yang, and X. Wang, "Traffic safety assessment and prediction under different lighting service states in road tunnels," *Tunn. Undergr. Sp. Technol.*, vol. 134, p. 105001, 2023, doi: 10.1016/j.tust.2023.105001.

[12] J. Niu, B. Liang, S. He, C. Qin, and J. Xiao, "Assessment and optimization of tunnel lighting quality based on drivers' visual comfort: From methodology to application," *Tunn. Undergr. Sp. Technol.*, vol. 143, p. 105487, 2024, doi: 10.1016/j.tust.2023.105487.

[13] X. Wang, R. Wen, K. Cheng, and M. Yang, "Evaluation and analysis of tunnel lighting service status based on driving safety," *Traffic Inj. Prev.*, vol. 24, no. 5, pp. 436–444, 2023, doi: 10.1080/15389588.2023.2204986.

[14] X. Wang, L. You, J. Chen, and S. Han, "The impact of different service states of tunnel lighting on traffic safety," *Accid. Anal. Prev.*, vol. 192, p. 107237, 2023, doi: 10.1016/j.aap.2023.107237.

[15] J. Niu, B. Liang, S. He, J. Xiao, and C. Qin, "Long tunnel lighting environment improvement method based on multiple-parameter intelligent control: Considering dynamic changes in luminance difference," *Tunn. Undergr. Sp. Technol.*, vol. 128, p. 104637, 2022, doi: 10.1016/j.tust.2022.104637.

[16] A. Peña-García, "Sustainable tunnel lighting: One decade of proposals, advances and open points," *Tunn. Undergr. Sp. Technol.*, vol. 119, p. 104227, 2022, doi: 10.1016/j.tust.2021.104227.

[17] C. I. de L'Ecclairage, *CIE Technical Report: Guide for Lighting Road Tunnels and Underpasses CIE 88-2004*, 2nd ed. Vienna: CIE Central Bureau, 2004.

[18] B. Su, J. Hu, J. Zeng, and R. Wang, "Traffic Safety Improvement via Optimizing Light Environment in Highway Tunnels.," *Int. J. Environ. Res. Public Health*, vol. 19, no. 14, Jul. 2022, doi: 10.3390/ijerph19148517.

[19] A. L. W. Wijaya, P. P. Rahardjo, "Investigation of Twin Tunnel Deformation with Umbrella Grouting Protection & NATM Tunneling using 3D Finite Element: Case Study," *U Karst*, vol. 5, no. 2, pp. 252–267, 2021, doi: 10.30737/ukarst.v5i2.1977.

[20] S. Ma, J. Hu, E. Ma, W. Li, and R. Wang, "Cluster Analysis of Freeway Tunnel Length Based on Naturalistic Driving Safety and Comfort," *Sustainability*, vol. 15, p. 11914, 2023, doi: 10.3390/su151511914.

[21] S. Wang, Z. Du, G. Chen, H. Zheng, Z. Tang, and F. Jiao, "Drivers' visual characteristics in small-radius optically long tunnels on rural roads," *Tunn. Undergr. Sp. Technol.*, vol. 113, p. 103969, 2021, doi: 10.1016/j.tust.2021.103969.

[22] Y. Zhou, S. He, X. Li, Y. Li, and G. Du, "Study on Drivers' Visual Load Features in Lighting Environments of Interior Zones of Extra-Long Tunnels over 10 km," *Adv. Civ. Eng.*, vol. 2022, p. 4840334, 2022, doi: 10.1155/2022/4840334.

[23] I. E. S. of N. A. (IES), "RP-22-11 TUNNEL LIGHTING," 2011.

[24] S. G. Li, G. Tu, and Q. Zhou, "An optimal design model for tunnel lighting systems," *Optik (Stuttg).*, vol. 226, p. 165660, 2021, doi: 10.1016/j.ijleo.2020.165660.

[25] S. Chen, Y. Lin, and H. Zhao, “Effects of flicker with various brightness contrasts on visual fatigue in road lighting using fixed low-mounting-height luminaires,” *Tunn. Undergr. Sp. Technol.*, vol. 136, p. 105091, 2023, doi: 10.1016/j.tust.2023.105091.
[26] M. Cengiz, “Simulation and Design Study for Interior Zone Luminance in Tunnel Lighting,” *Light Eng.*, vol. 27, pp. 42–51, 2019, doi: 10.33383/2018-043.
[27] H.-Y. Liao *et al.*, “Design and Prototyping of Efficient LED Counter Beam Light with Free-Formed Surface for Meeting International Tunnel Lighting Standards,” *Energies*, vol. 14, no. 2, 2021, doi: 10.3390/en14020488.
[28] L. Qin, A. Peña-García, A. S. Leon, and J.-C. Yu, “Comparative Study of Energy Savings for Various Control Strategies in the Tunnel Lighting System,” *Appl. Sci.*, vol. 11, no. 14, 2021, doi: 10.3390/app11146372.
[29] BSN, *Standar Nasional Indonesia, SNI 7391:2008, Spesifikasi penerangan jalan di kawasan perkotaan, Badan Standarisasi Nasional. Jakarta.* Jakarta.
[30] Y. Su, H. Chen, Y. Gao, and R. Wei, “Calculation model for tunnel lighting based on DIALux,” in *International Conference on Smart Transportation and City Engineering (STCE 2023)*, 2024, vol. 13018, p. 130185N. doi: 10.1117/12.3024160.
[31] C.-C. Hsieh, C.-L. Tsai, and T.-C. Li, “The research for designing the LED tunnel light for highway tunnels.,” *Heliyon*, vol. 10, no. 4, p. e26305, Feb. 2024, doi: 10.1016/j.heliyon.2024.e26305.
[32] D. Katzin, L. F. M. Marcelis, and S. van Mourik, “Energy savings in greenhouses by transition from high-pressure sodium to LED lighting,” *Appl. Energy*, vol. 281, p. 116019, 2021, doi: 10.1016/j.apenergy.2020.116019.
[33] A. Hangga *et al.*, “Modelling of lighting system utilizing natural and artificial lighting using DIALux,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 969, no. 1, p. 12024, Jan. 2022, doi: 10.1088/1755-1315/969/1/012024.
[34] M. L. Nurrohman, P. Feros, Wahyuning, R. F. Madina, and N. Pratiwi, “Efficient Lighting Design for Multiuse Architecture Studio Classroom using Dialux Evo 9,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 738, no. 1, p. 12034, Apr. 2021, doi: 10.1088/1755-1315/738/1/012034.
[35] E. Setyaningsih, Y. Calvinus, and B. A. Pramudia, “CSL19 design excellence analysis for street lights with previous products,” *AIP Conf. Proc.*, vol. 2680, no. 1, p. 20077, 2023, doi: 10.1063/5.0128005.
[36] J. Fat, E. Setyaningsih, Y. Calvinus, V. Reinard, and A. Hendisutio, “Temperature, humidity, voltage and current data logger for LED street light luminaire,” in *AIP Conference Proceedings*, 2023, p. 20053. doi: 10.1063/5.0127315.
[37] A. Nauta, J. Han, S. H. Tasnim, and W. D. Lubitz, “Performance Evaluation of a Commercial Greenhouse in Canada Using Dehumidification Technologies and LED Lighting: A Modeling Study,” *Energies*, vol. 16, no. 3, 2023, doi: 10.3390/en16031015.

Review Discussions-Round 2

Revision of our manuscript according to the reviewer's comments

×

Participants Edit

Rahmat Hidayat (rahmat)

Endah Setyaningsih (endahsetyaningsih)

Messages

Note	From
To Journal Editor, Attached is the revision of our paper based on the input and corrections from the reviewer. We also include the correction table and the revised paper with color blocks to mark the changes we have made according to the reviewer's comments. Thank you and best regards Endah Setryaningsih	endahsetyaningsih25-04-2024 02:53 PM

Add Message

19950 / **Setyaningsih et al.** / Modeling Night and Daylighting Toll Road Tunnel Using Di Library

Workflow | Publication

Submission | Review | Copyediting | Production

Round 1 | Round 2 | Round 3 | Round 4

Round 3 Status
All recommendations are in and a decision is needed.

Notifications

[IJASEIT] Editor Decision	12-03-2024 07:06 AM
[IJASEIT] Editor Decision	17-04-2024 09:23 AM
[IJASEIT] Editor Decision	10-05-2024 10:17 AM
[IJASEIT] Editor Decision	19-05-2024 11:11 PM

Reviewer's Attachments

Search

No Files

Revisions

Search Upload File

47301	Modelling Daylighting_Rev3_Ijaseit.docx	14 May 2024	Article Text

Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
Revision of our manuscript according to the reviewer's comments	endahsetyaningsih25-04-2024 02:53 PM	-	0	

Review Discussions-Round 3

Revision of our manuscript according to the reviewer's comments

×

Participants Edit

Rahmat Hidayat (rahmat)

Endah Setyaningsih (endahsetyaningsih)

Messages

Note	From
To Journal Editor, Attached is the revision of our paper based on the input and corrections from the reviewer. We also include the correction table and the revised paper with color blocks to mark the changes we have made according to the reviewer's comments. Thank you and best regards Endah Setryaningsih	endahsetyaningsih25-04-2024 02:53 PM

Add Message

19950 / **Setyaningsih et al.** / Modeling Night and Daylighting Toll Road Tunnel Using Di

Library

Workflow | Publication

Submission | Review | Copyediting | Production

Round 1 | Round 2 | Round 3 | Round 4

Round 4 Status
Submission accepted.

Notifications

[IJASEIT] Editor Decision	12-03-2024 07:06 AM
[IJASEIT] Editor Decision	17-04-2024 09:23 AM
[IJASEIT] Editor Decision	10-05-2024 10:17 AM
[IJASEIT] Editor Decision	19-05-2024 11:11 PM

Reviewer's Attachments

Search

No Files

Revisions

Search Upload File

No Files

Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
Revision of our manuscript according to the reviewer's comments	endahsetyaningsih25-04-2024 02:53 PM	-	0	

Review Discussions-Round 4

Revision of our manuscript according to the reviewer's comments ×

Participants Edit

Rahmat Hidayat (rahmat)

Endah Setyaningsih (endahsetyaningsih)

Messages

Note	From
To Journal Editor, Attached is the revision of our paper based on the input and corrections from the reviewer. We also include the correction table and the revised paper with color blocks to mark the changes we have made according to the reviewer's comments. Thank you and best regards Endah Setryaningsih	endahsetyaningsih25-04-2024 02:53 PM

Add Message