OPTIMIZATION OF PHOTOMETRIC QUANTITIES FOR ROAD LIGHTING FREEWAYS IN INDONESIA

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ABSTRACT

Road lighting is one factor affecting driving safety on the road. Inadequate lighting has the potential to cause a traffic accident based on our previous research. Moreover, many traffic accidents occur between 18.00 - 24.00 and 00.00 - 06.00, even though the traffic volume has decreased at night. In order to investigate further the case mentioned above, this paper discussed the research for the lighting system on Cikampek and Cipularang toll roads as a sample uses case. The results revealed that the lighting system in Cikampek and Cipularang toll roads does not comply with the Indonesian national standard for lighting. In addition, a Dialux software simulation was conducted to determine the most optimum photometric illuminance, including average luminance and uniformity for the road lighting in Cikampek and Cipularang toll roads. The simulation implemented seven variables of the road-lighting design, resulting in 324 scenarios giving average illuminance between 23.88 lux to 24.40 lux with minimum uniformity of 0.53 and average luminance is 1.51 cd/m2 with a uniformity of 0.70. The simulation results show that if the Cikampek and Cipularang toll roads are redesigned according to the simulation results, they will be following SNI 7391: 2008 and able to reduce the risk of accidents.

Keywords: *Illuminance, Luminance, Road Lighting, Photometric, Uniformity*

1. INTRODUCTION

The number of traffic accidents in Indonesia is still very high. The data from the National Traffic Police Corps of Indonesia (Korlantas Polri) shows that there were 100,106 cases of accidents, with 26,416 deaths in 2013. On average, there were 11 cases, with three people dying every hour [1]. Jusuf [2] mentions that road accidents are a severe problem in Indonesia. In 2014, the police reported approximately 28,000 fatalities due to accidents on the streets and roadways of Indonesia. The fatality rate from traffic accidents per 100,000 population was about 12. This fatality rate is very high compared to neighbouring countries like Singapore (4.8) and Australia (5.2).

Traffic accidents should be given more attention in the transportation area. Some of the factors that become the cause of traffic accidents are motorcycles (Suthanaya in Jusuf et al. [2]), and underlying traffic violation behaviours and types of traffic violations committed by young motorcyclists on urban roads in Indonesia (Joewono et al. in Jusuf et al. [2].

Santosa et al. [3] show that the traffic accidents in Indonesia between 2010 and 2014 were dominated by motorcycles, contributing to more than 70% of road traffic accidents. Road traffic accidents involving passenger cars and trucks contributed approximately 12% and 10%, respectively. Road traffic accidents involving buses and special vehicles such as three-wheelers accounted for 5% and 1%, respectively.

According to the data from PT. Jasa Marga Tbk. Purbaleunyi branch about the traffic accident on Cipularang freeways from 2013 to 2015, the type of vehicle that caused the most accidents are 'minibus,' and the four factors causing traffic accident is human factors, vehicle factors, road factors, and environmental factors. The most cause of traffic accidents is human factors [4]. Santosa et al. [3] state that most traffic accidents in Indonesia are caused by human factors (88%), and vehicle factors in traffic accidents amounted to 3%. Road and environmental factors that caused traffic accidents amounted to 8% and were mainly due to road damage and potholes, slippery roads, sharp turns, and inadequate lighting. However, this paper does not include the data to support their statement

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about inadequate lighting. Furthermore, according to the driver's perception, visibility to see traffic signs, the colour of traffic signs, potholes, road medians, sign symbols, and texts is inadequate due to insufficient lighting. [5].

So inadequate road lighting causes traffic accidents. According to Santosa et al. [3], most traffic accidents occur during the daytime/working hours; 30% of accidents occur between 06.00 and 12.00, and 32% occur between 12.00 and 18.00. Most accidents occurred during rush hours when most people were on their way to work in the morning and home in the afternoon. High traffic density and congestion during these hours add to the traffic accident potential. Interestingly, the traffic accident frequency remained significantly high (23,000-24,000) from 18.00 to 24.00. This high frequency of traffic accidents coincided with a high traffic volume of people who elected to avoid the afternoon rush hour.

However, traffic accident also occurs between 00.00 to 06.00 [3]. Therefore, during the nighttime, about 38.5% of traffic accident happens. In that period, the traffic volume decreased compared to other periods. The situation also takes place on the Cipularang freeways [4]. It can be deduced that traffic accidents that occur from human factors are caused by poor visibility, which is affected by inadequate road lighting that creates eye fatigue and drowsiness. The data that support this matter cannot be obtained in Indonesia. Therefore, further study is required to investigate the effect of road lighting on traffic accidents in Indonesia.

Especially for road lighting, according to (Tetri et al. [6]), road lighting is undeniably crucial for users to observe obstacles, anticipate ahead, and avoid accidents. Road lighting reduces the number of an accident on overage by 30%. While according to (Li [7]) good lighting is needed to estimate the car's speed, monitor dangerous conditions from the side, and keep a distance from other vehicles. Several studies have been conducted in Jakarta and Bandung, and the results indicate the presence of uneven illuminance on the road surface and less or excessive illumination according to the road lighting standards National Standard of Indonesia SNI 7391:2008 [8,9,10].

Inadequate road lighting is caused by low average illuminance and average luminance. Therefore, this research focuses on finding the appropriate lighting component settings to obtain sufficient average illuminance and average luminance required on toll roads to reduce the risk of accidents. The research was realized by conducting a simulation using Dialux by taking a case study on the Cikampek and Cipularang toll roads.

2. CIPULARANG FREEWAYS AND NATIONAL STANDARD OF INDONESIA

The research was conducted on Cikampek and Cipularang freeways. The Cikampek freeway Connects the Jakarta freeway to Cikampek, from the Cawang to the Cikampek interchange. At the same time, the Cipularang freeway connects Cikampek to Padalarang freeway from the interchanges of Dawuan to Padalarang. Some of these freeways are part of the Purbaleunyi freeway (Purwakarta-Bandung Cileunyi). The freeways have geometric road elements, including uphill, downhill, straight, and curved ones. A road with such complex geometric elements must consider the visibility of the road users that meet the safety standards [11].

In addition, the Cikampek and Cipularang freeways should have street lightings that meet the law of the Republic of Indonesia [12]. The toll roads have many 'areas with limited visibility. Therefore, the roads should also have street lightings that follow the regulation of the Ministry of Public Works and Housing of the Republic of Indonesia [13]. The National Standard of Indonesia for road lighting is still in effect because the SNI 7391: 2008 regulates urban lighting specifications. This standard is used as a reference in Indonesia's planning and application of street lighting.

Three groups of photometric quantities for international standard consists of (1) the luminance of the road surface of the carriageway for the dry surface condition, the overall uniformity of the luminance (Uo), and the longitudinal uniformity of the luminance (Ul), (2) Disability glare: the threshold increment (TI) and (3) Lighting of surroundings: surround ratio (SR) according to [14,15]. The visual comfort of car/motorcycle drivers is influenced by the parameters above, so by modifying these seven variables, visual comfort can be achieved. Those parameters are regulated in The National Standards of Indonesia (SNI) for toll road lighting, SNI 7391: 2008, which includes the photometric quantities such as average illuminance, average luminance, and glare, shown in Table 1 and is a standard that still applies.

Based on the above analysis, a simulation was carried out using Dialux software to obtain optimization of photometric quantities for road lighting freeways in Indonesia. The simulation using the Dialux software gives the following results, which are discussed in more detail below. The

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existing lighting condition on Cikampek and Cipularang freeways has an average illuminance value (E_{avg}) between 6 - 10 Lux [16]. The average illuminance value varied, caused by using different lamps and Correlated Color Temperature (CCT). Those are High-Pressure Sodium (HPS) with CCT reddish white and LED lamps with CCT bluish white and different wattage lights, different mounting heights, and different installations. Figure 1 shows one example of many other installation methods for inclining or tilting the luminaire on the Cikampek and Cipularang freeways. The average illuminance, which does not follow the recommendation of the Indonesian National Standard (SNI), will make uniformity and visual performance impossible. According to SNI [10], which regulates the street lighting specification in urban areas that is still valid, the average illuminance value E_{av} for freeways is 15 - 20 Lux". Therefore, the road lighting quality in Cikampek and Cipularang toll needs to be improved, including the lighting level (to achieve average road-surface luminance), overall and longitudinal uniformity, surround ratio, and threshold increment [14]. Therefore, this research tries to suggest the most efficient installation method for road lighting freeways through optimization methods of Photometric Quantities using the SNI 7391:2008.

Figure 1: Different tilting of the luminaire on Cikampek and Cipularang toll road

3. RESEARCH DESIGN

The simulations were conducted in Dialux Evo 7.1 software. The simulation objective was to satisfy Indonesia National Standard (SNI) 7391:2008 regarding freeway, as mentioned in subchapter 2, paragraph 2. There are five parameters in SNI: average illumination (E_{avg}), uniformity calculated by dividing minimum illuminance with maximum illuminance (g1), average luminance (L_{avg}), uniformity calculated by dividing minimum luminance with maximum luminance (VD), uniformity calculated by dividing minimum luminance with average luminance (VI), and glare threshold (TJ). In the international standard, VD is a U1 (longitudinal uniformity), and VI is an Uo (overall uniformity), which is shown in Table 1 [15].

The Cikampek and Cipularang toll road was simulated as three traffic lanes, each with a 3.5 m width, 1 m of inner shoulder inside, and 2 m of outer shoulder outside, so the total road width was 13.5 m, as shown in Figure 2.

The toll road consists of 2 directions from Jakarta to Bandung and the opposite. Both directions are separated by road medians. The reflectance value for the simulation based on CIE 2001 in [15, 17], road-surface class limits of the R classification system with the standard Qo value for each class for asphalt is R3 class was 0.07. The surface of the hardened paved with dark aggregate and light reflection models that tend to be specular. Most major streets in Cikampek and Cipularang toll roads have a road surface made of asphalt.

Road-lighting design principally involves planning to illuminate the road surface area ahead so it can be surveyed as efficiently as possible [15]. Eight variables are used for the simulation road-lighting design: lighting arrangements, type of lamp, pole distance or spacing, mounting height, inclining or tilting the luminaire, overhang, boom length, and maintenance factor (Figure 3 and Table 2). There are five basic lighting arrangements: single-sided, staggered, opposite, central, and twin central [15]. The lighting arrangements on the Cikampek and Cipularang toll road is single-sided, but it is not recommended [15, 17]. Therefore, in the simulation, three lighting arrangements were used: the central, the staggered, and the opposite, as shown in Figure 4. The type of lamp used in the simulation was limited to two luminaires of LED BRP372 LED159NW DM MP1 and BRP372 LED159NW DM MP1. The specification and polar luminous intensity diagram of both LED luminaires are given in Figure 5.

Table 1: Part of the SNI 7391:2008 Regarding Toll Road Lighting

Type of Road	Illuminance		Luminance			Glare
	E_{avg}(lux)	Uniformity g1	L_{avg}(cd/m^2)	Uniformity VD	Uniformity VI	TJ (%)
Toll road	15-20	0.14-0.20	1.5	0.40	0.50-0.70	10-20

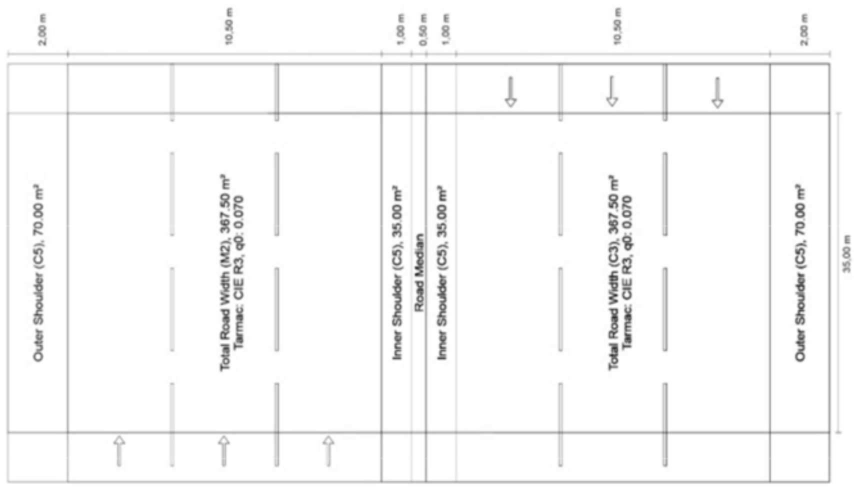


Figure 2: Preview of the Cikampek and Cipularang toll road

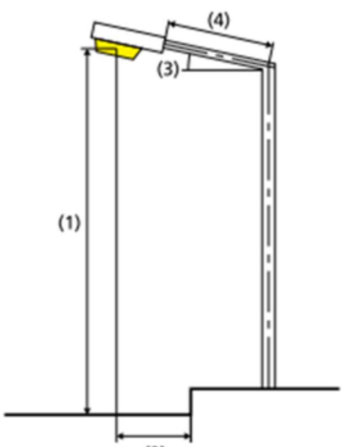
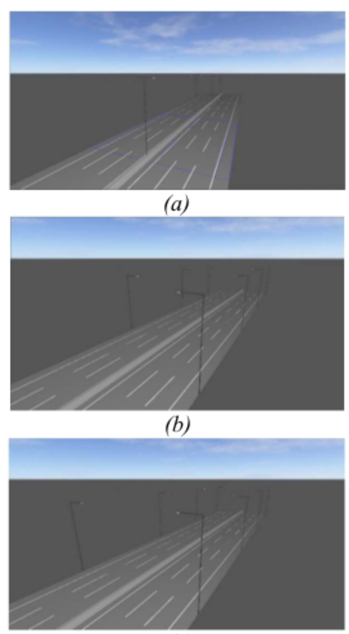


Figure 3: Lighting installation for the (1) Mounting height, (2) Overhang, (3) Inclining or tilting the luminaire, and (4) Boom Length



(a)

(b)

(c)

Figure 4: The Lighting Arrangements (a) Central (b) Staggered (c) Opposite

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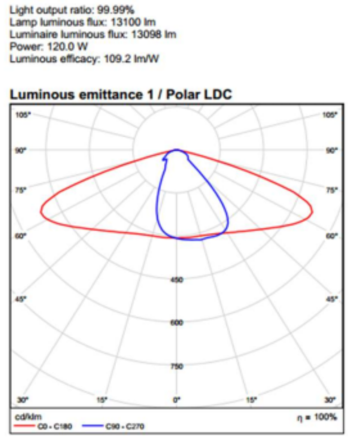
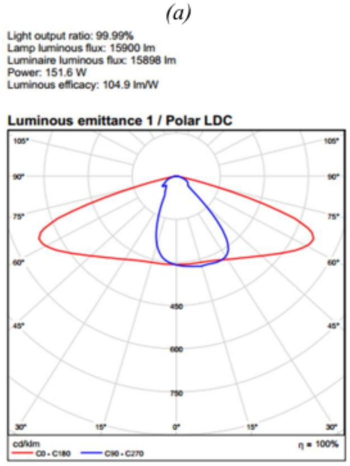


(a)



(b)

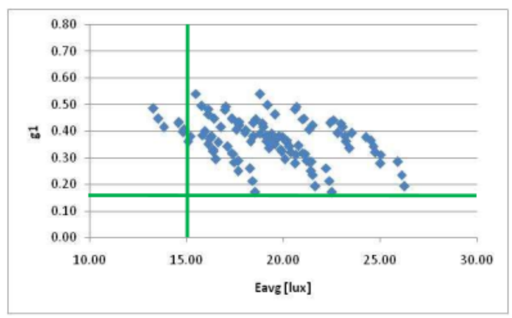
(a) BRP372 LED131NW DM MP1 and
(b) (b) BRP372 LED159NW DM MP1
Figure 5: Specification and Polar Diagram of the LED Luminaires

Table 2: Seven variables of the road-lighting design for the simulation

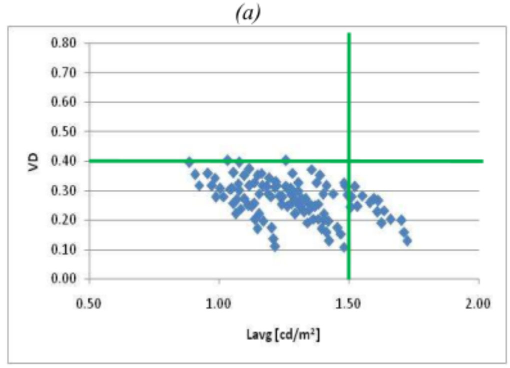
Seven Variable	
Lighting arrangements	The central, the staggered, and the opposite
Mounting height (m)	11 m; 13 m; and 15 m
Light overhang (m)	0.5 m; 1 m; and 1.5 m
Inclining or tilting the luminaire (degree)	0°, 5°, and 10°
Spacing (m)	30 m and 35 m
Type of LED luminaire	BRP372 LED131NW DM MP1 and BRP372 LED159NW DM MP1
Boom length	2.5 m; 3 m; 3.5 m
Maintenance Factor	0.7 [18]

4. SIMULATION RESULTS

Based on the combination of 7 variables used for the road-lighting design in the simulation, 324 scenarios were obtained. The simulation of the data is visualized using a scattered graph. The graph consists of lighting arrangements, the central, the staggered, and the opposite. Therefore, every graph consists of 108 scenarios. Figure 6 shows the central lighting arrangements; Figure 7 visualizes the staggered lighting arrangements, and Figure 8 shows the opposite. The chosen parameter to plot the graph was E_{avg} with g1 and L_{avg} with VD. These parameters were chosen because E_{avg} was the most satisfying data and L_{avg} was the minor satisfying data, while g1 and VD were the uniformity for E_{avg} and L_{avg}, respectively. The blue dots showed all the probabilities, and the red dots represented the combination that satisfied the Indonesia National Standard (SNI). The green line indicates the minimum value from the SNI 7391:2008.

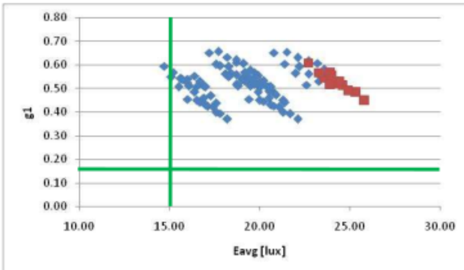


(a)

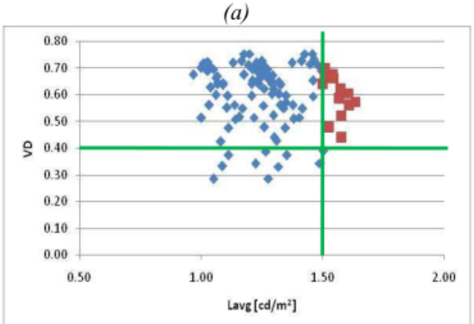


(b)

(a) E_{avg} vs g1; (b) L_{avg} vs VD
Figure 6: Result of Simulation for the Central Lighting Arrangements



(a)

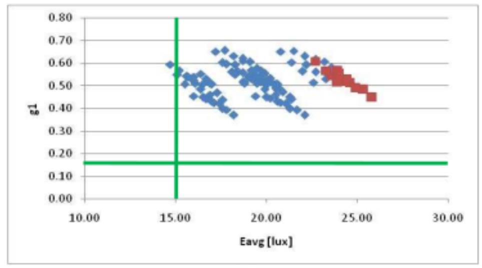


(b)

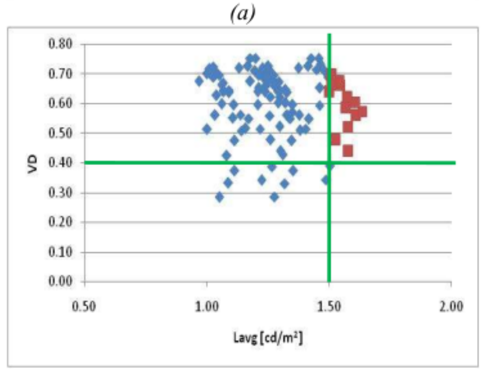
(a) E_{avg} vs g1; (b) L_{avg} vs VD
Figure 7: Result of Simulation for the Staggered Lighting Arrangements

The graphs above show that the most critical metrics were L_{avg} and VD because if these metrics could be satisfied, the other metrics would also be satisfied. Also, it could be seen that the central lighting arrangements method did not give a single combination that could fulfil the national standard. The staggered and opposite lighting arrangements give 14 and 15 out of 108 combinations that fulfilled the national standard. The summary of the satisfying combinations is shown in Tables 3 and 4.

From the result above, the luminaire type that could meet the national standard was only BRP372 LED159NW DM MP1 which had 150W and spacing was 30 meters, while other variables varied. It also could be seen that 11 meters of height resulted in the most satisfying combinations, with 15 out of 29 combinations.



(a)



(b)

(a) E_{avg} vs g1; (b) L_{avg} vs VD
Figure 8: Result of Simulation for the Opposite Lighting Arrangements

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Table 3: Combination Satisfied the SNI 7391:2008 with the staggered lighting arrangements

LED Luminaire	Spac. (m)	M.Height (m)	Incl (°)	Overhang (m)	E_{avg} [lux]	g1	L_{avg} [cd/m2]	VD	VI	TJ [%]
BRP372 LED159NW DM MP1	30	11	0	1.5	24.00	0.52	1.58	0.44	0.64	8
BRP372 LED159NW DM MP1	30	11	5	1.5	24.90	0.49	1.61	0.56	0.77	8
BRP372 LED159NW DM MP1	30	11	5	1.0	24.30	0.52	1.58	0.52	0.73	8
BRP372 LED159NW DM MP1	30	11	5	0.5	23.60	0.54	1.53	0.48	0.69	8
BRP372 LED159NW DM MP1	30	11	10	1.5	25.80	0.45	1.64	0.57	0.75	9
BRP372 LED159NW DM MP1	30	11	10	1.0	25.30	0.49	1.61	0.60	0.80	9
BRP372 LED159NW DM MP1	30	11	10	0.5	24.60	0.51	1.57	0.59	0.79	9
BRP372 LED159NW DM MP1	30	13	0	1.5	22.70	0.61	1.50	0.64	0.82	7
BRP372 LED159NW DM MP1	30	13	5	1.5	23.90	0.52	1.55	0.66	0.81	7
BRP372 LED159NW DM MP1	30	13	5	1.0	23.30	0.57	1.51	0.67	0.85	7
BRP372 LED159NW DM MP1	30	13	10	1.5	24.90	0.49	1.57	0.62	0.75	8
BRP372 LED159NW DM MP1	30	13	10	1.0	24.40	0.53	1.54	0.68	0.82	8
BRP372 LED159NW DM MP1	30	13	10	0.5	23.90	0.57	1.51	0.70	0.86	7
BRP372 LED159NW DM MP1	30	15	10	1.5	24.00	0.55	1.51	0.66	0.75	7

Table 4: Combination Satisfied the SNI 7391:2008 with the Opposite Lighting Arrangements

LED Luminaire	Spac. (m)	M.Height (m)	Incl (°)	Overhang (m)	E_{avg}[lux]	g1	L_{avg} [cd/m2]	VD	VI	TJ [%]
BRP372 LED159NW DM MP1	30	15	10	1.5	24.02	0.57	1.51	0.65	0.74	6
BRP372 LED159NW DM MP1	30	13	0	1.5	22.71	0.61	1.50	0.65	0.82	6
BRP372 LED159NW DM MP1	30	13	5	1.5	23.94	0.54	1.55	0.66	0.80	6
BRP372 LED159NW DM MP1	30	13	5	1.0	23.35	0.58	1.51	0.68	0.84	6
BRP372 LED159NW DM MP1	30	13	10	1.5	24.94	0.50	1.57	0.61	0.73	6
BRP372 LED159NW DM MP1	30	13	10	1.0	24.44	0.55	1.54	0.67	0.80	6
BRP372 LED159NW DM MP1	30	13	10	0.5	23.88	0.58	1.51	0.70	0.85	7
BRP372 LED159NW DM MP1	30	11	0	1.5	24.00	0.53	1.58	0.48	0.69	8
BRP372 LED159NW DM MP1	30	11	0	1.0	23.36	0.55	1.54	0.42	0.63	8
BRP372 LED159NW DM MP1	30	11	5	1.5	24.90	0.51	1.62	0.59	0.79	8
BRP372 LED159NW DM MP1	30	11	5	1.0	24.27	0.54	1.58	0.56	0.77	8
BRP372 LED159NW DM MP1	30	11	5	0.5	23.59	0.56	1.53	0.51	0.73	8
BRP372 LED159NW DM MP1	30	11	10	1.5	25.82	0.46	1.64	0.57	0.73	8
BRP372 LED159NW DM MP1	30	11	10	1.0	25.26	0.50	1.61	0.62	0.81	8
BRP372 LED159NW DM MP1	30	11	10	0.5	24.62	0.54	1.57	0.61	0.81	8

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Table 5: Top ten most optimum results

Arr	Dist (m)	Height (m)	Incl (°)	Overhang (m)	Lavg [cd/m2]	VD	F
OPP	30	13	10	0.5	1.51	0.70	1.71
STG	30	13	10	1.0	1.54	0.68	1.71
TS	30	13	10	0.5	1.51	0.70	1.71
OPP	30	13	10	1.0	1.54	0.67	1.70
STG	30	13	5	1.5	1.55	0.66	1.69
OPP	30	13	5	1.5	1.55	0.66	1.69
OPP	30	11	10	1.0	1.61	0.62	1.69
OPP	30	13	5	1.0	1.51	0.68	1.69
STG	30	13	5	1.0	1.51	0.67	1.68
STG	30	11	10	1.0	1.61	0.60	1.67

OPP=the opposite, and STG = the staggered

Table 6: The Most Optimum Result of Simulation

Luminaire	L.Arr	Spac. (m)	M.Heigt (m)	Incl (°)	Overhang (m)	E_{avg} [lux]	g1	L_{avg} [cd/m2]	VD	VI	TJ [%]
BRP372 LED159NW	OPP	30	13	10	0.5	23.88	0.58	1.51	0.70	0.85	7
BRP372 LED159NW	STG	30	13	10	1.0	24.40	0.53	1.54	0.68	0.82	8
BRP372 LED159NW	STG	30	13	10	0.5	23.90	0.57	1.51	0.70	0.86	7

An objective function was introduced to choose the most optimum combination; since L_{avg} and VD are the most crucial metrics, the objective function should consist of these two metrics with the assumption that these two metrics were weighted the same. VD is unitless metrics, then L_{avg} should be converted to unitless metrics. This metric was divided by 1.5 cd/m^2 to attain the unitless L_{avg}, as 1.5 cd/m^2 was the minimum average luminance value in SNI 7391:2008. The objective function could be written as:

$$F = \frac{L_{avg}}{1.5\, ^{cd}/_{m^2}} + VD \qquad (1)$$

From the top ten (Table 5), 80% of the most optimum solution was 13 meters mounting height though the 11 meters height was dominant in satisfying the SNI 7391:2008. The inclination should be 5° or 10°; the overhang could be all inputs. The optimum result is produced in three combinations with an F value of 1.71. The summary of the result is shown in Table 6.

5. CONCLUSIONS

Based on the simulation results using Dialux, the Cikampek and Cipularang toll roads must be reconfigured with the following lighting components: staggered and opposite lighting arrangements with 30 meters spacing to match the SNI 7391:2008. The mounting height should be 13 meters with an inclining or tilt angle of 10 degrees and an overhang of 0.5 meters or 1.5 meters. By using the configuration above, these combinations will result in average illuminance between 23.88 lux and 24.40 lux, with minimum uniformity of 0.53. The minimum value for average luminance is 1.51 cd/m2 with a uniformity of 0.70.

The result also shows that the average illuminance (E_{avg}) can be fulfilled by almost all combinations possible. On the contrary, only a few fulfil the average luminance (L_{avg}). By increasing the average illuminance and average luminance, it is hoped that the risk of accidents for motorists on the toll road can be minimized. Furthermore, other results show that condition yields an insight that to meet the Indonesia National Standard, the metrics that need attention are L_{avg} and its uniformity, VD (dividing minimum luminance with maximum luminance).

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