Light & Engineering
Vol. 28, No. 4, pp. 47–56, 2020

https://doi.org/10.33383/2019-037
Svetotekhnika #2, 2020, pp. 47–55

EFFECTS OF LUMINAIRE ANGLE AND ILLUMINATION TOPOLOGY ON ILLUMINATION PARAMETERS IN ROAD LIGHTING

Mehmet Sait Cengiz

Department of Technical Vocational School, Bitlis Eren University, Turkey
E-mail: msaitcengiz@gmail.com

ABSTRACTS

In this study, refers to two errors in road lighting. It explains the advantages of the staggered layout of luminaires and the problems associated with the use of luminaires located at an angle to the horizontal line of the road. The errors made by the simulation program were proved quantitatively and suggestions for their solution were presented. The loss of luminance of the road surface when illuminated by luminaires located at an angle to the horizontal has been quantitatively proved. In addition, it was found that with the appropriate choice of the layout of luminaires with road lighting, the step between the poles could be reduced by 9.3 %.

Keywords: road lighting, luminaire angle, luminance

1. INTRODUCTION

Primary purpose of road lighting is to ensure safe flow of vehicles or traffic during day and night conditions. Performance of road lighting is evaluated depending on such parameters as illuminance of road surface and walls, overall and longitudinal lighting uniformity, glare control, formation of the contrast required to perceive the objects and flicker frequency [1, 2].

Road lighting improves visibility of pedestrians and other objects. The lighting allows the driver and springs to move safely. Accurately designed road lighting prevents traffic jams and gives people a sense of security.

The driver using any vehicle on highways should have detailed visual information about the way he is driving. Especially at high speeds, the driver should be able to see the route easily, the driver should be able to perceive the position and movements of the vehicle he is driving, be able to monitor the movements of other vehicles, and easily be able to see the obstacles on the road.

CIE reports the results of 30 different studies covering road lighting studies that improve vision conditions. According to this report, fulfillment of road lighting standards: pedestrian accidents decreased from 57 % to 45 %, fatal accidents decreased from 65 % to 48 %, severe injuries decreased from 30 % to 24 %, and the total number of accidents decreased from 53 % to 14 % [3].

Even if there is little traffic at night, the number of accidents that occur on roads or in tunnels without lighting is about three times higher than in daylight hours. The reason for this is the lack of road lighting in accordance with the standards. Ensuring appropriate road lighting to the CIE reduces the rate of crime committed on city roads. According to the studies in the literature, the number of forensic cases on urban roads has decreased by 20 % due to the proper lighting. In terms of the severity of crimes committed, there was a decrease of 40 % [4, 5].

2. ROAD LUMINANCE

The most important objective in design of lighting systems is to obtain sufficient light without supplying excessive lighting and increasing energy cost [6]. Luminance is the most important parameter for

Table 1. Road Lighting Class Selection Parameters

Parameter	Options	Weight factor
Speed	Very high	1
	High	0.5
	Middle	0
Traffic jam	Very high	1
	High	0.5
	Middle	0
	Low	–0.5
	Very low	–1
Traffic layout	Mixed with a high proportion of non-motorized traffic	1
	Mixed	0.5
	Only motor vehicles	0
Middle median strip on the road	Yes	1
	No	0
Intensity of intersection	High	1
	Middle	0
Parked vehicle	Yes	0.5
	No	0
Environmental lighting	High	1
	Middle	0
	Low	–1
Traffic control	Weak	0.5
	Medium or good	0
Total of weight factors		4

road lighting, and *L* indicates luminance using the cd/m^2 unit. To ensure good visibility of objects and visual comfort of the driver, it is necessary to ensure the uniform distribution of luminance on the road surface. Today, road lighting is based on *ASI* luminance method *Alan*, which is based on road surface luminance. The horizontal illuminance of a point *P* on an illuminated road is the sum of the horizontal illuminance levels that all the light sources acting at point *P* have at this point.

2.1. Average Luminance of the Road Surface

In the road lighting, the fund of objects is the road surface that forms the driver's field of view. At the same time, increasing the average luminance of the road surface $L_{average}$ leads to improved visibility, providing more background luminance. Increasing $L_{average}$ increases the sensitivity of the driver's eye by increasing the luminance of the objects located on the road. Therefore, the most important parameter for detection is $L_{average}$. The average luminance is calculated using the glitter values on the selected *mxn* pieces on the road. For $L_{average}$, the luminance values of all the light sources affecting the account area are calculated and collected as vector. In this way, the glare value at each point is calculated. The average luminance of the road surface is calculated separately for each observer [7–9].

2.2. Luminance Uniformity

Although lighting systems provide a good average luminance of the road surface, there may be areas with low luminance where contrast is weak and small obstacles cannot be detected. It is expected that the difference between the minimum and average luminance of the road surface in the field of view will be below a certain value in order to get sufficient lighting at all points of the road. This re-

Table 2. Road Lighting Quality Parameters [18]

Lighting class	$L_{average}$, cd/m²	U_O	U_I	*TI*, %
M1	>2.0	>0.4	>0.7	<10
M2	>1.5	>0.4	>0.7	<10
M3	>1.0	>0.4	>0.5	<10
M4	>0.75	>0.4	>0.5	<15
M5	>0.50	>0.35	>0.4	<15
M6	>0.30	>0.35	>0.4	<15

quirement leads to the formation of overall and longitudinal uniformity of road surface luminance, which are important secondary characteristics of road lighting.

On the road (on the road surface), there should be an equal distribution of luminance to ensure a clear view for the driver. Two types of uniformity are considered important in road lighting [7–10]. These are overall (resultant) uniformity (U_o) and longitudinal uniformity (U_l).

2.3. Light Sources

High-pressure sodium lamps (HPSL) are preferred in conditions where high levels of brightness are required, including in underwater tunnels, since HPSL have higher luminous flux and are smaller than low-pressure lamps. In previous studies, the photometric properties of luminaires used in road lighting with HPSLs and luminaires with LEDs were compared. In the study, it was shown that lighting of roads of classes *M*3, *M*4, and *M*5 could be ensured by luminaires with LED power of 100 W and 150 W. However, for roads of classes *M*1 and *M*2, these luminaires did not provide the required level of illumination. Since the object of this study is a road of class *M*2 in terms of lighting, the luminaires based on LED are not considered here, but the luminaires with HPSL, which are widely used for road lighting, are considered. As a result, this study simulation was performed with HPSLs accordingly [12–16].

3. ROAD LIGHTING DESIGN

Road types are defined in international technical reports, and the optimal range of solution is technically presented for these road types. Design estimates should be made for luminaires with known photometric characteristics, as a result of which the number and types of luminaires are determined [17–19].

The lighting class of the road that corresponds to a particular road is determined using the table in the *CIE115–2010* [18]. According to Table 1, the *M*2 road lighting class was found, and the corresponding parameter values are also shown in it.

Road lighting class was found with Eq. 1, Eq. 2, and Eq. 3:

$$MX = 6 - total\, of\ weight\ factors, \qquad (1)$$

$$MX = 6 - 4 = 2, \qquad (2)$$

$$MX = M2. \qquad (3)$$

The road lighting quality parameters are shown in Table 2.

3.1. Features of Road Lighting

The road surface is asphalt, class *R*4. Additionally, Q_o = 0.08, and the height of the luminaire is 11 m. The maintenance factor of the luminaire is 0.91, and all calculated luminance values are corrected. The ratio of the minimal luminance value to average luminance value is greater than 0.4 in the calculations for road lighting, ensuring that the rate of the minimal luminance value to the maximum at the latitude coordinate of the observer is greater than 0.7 ($U_I \geq 0.7$).

The levels of luminance and uniformity of road surface luminance conform to the relevant standards. All luminaires were installed in (cross (staggered layout of the luminaires) or mutual (opposite layout of the luminaires)) two lines from the walking ways to the axis of the road and at a height of 11 m. Table 3 illustrates the road and lighting parameters [20–22].

Table 3. Road and Lighting Parameters

Common lighting parameters			
Lighting pole type	Galvanized	Lighting class	*M*2
Number of road lanes	2	Console length (m)	1
Strip Width (m)	3.5	Console Angle	0°/5°/10°/15°
Road Width (m)	7	Luminaire Angle	0°/5°/10°/15°
Road Class	*R*4	Lamp type	HPS
Q_o	0.08	Lamp power (W)	150
Distance to illumination	0	Lamp luminous flux (lm)	17000
Illumination height from ground (m)	11	Maintenance factor (once a year)	0.91

3.2. Simulation Study

The main purpose of the new study is to achieve the most cost-effective results that provide adequate conditions. In the new study on road lighting, classifications are taken into account in various scenarios. The most accurate reference to road lighting are international standards. For this reason, the simulation is adapted to *CIE* standards. According to *CIE140*, the luminance values, average luminance level, overall and longitudinal uniformity of road surface luminance values of all points were calculated for observers.

Luminaires for use in road lighting should be selected taking into account the level of glare, luminance level of the road, uniformity of road surface luminance and efficiency, as well as determined by computer calculations using the luminance method [24–31].

Various options for the road parameters are available in the simulation program. For the road parameters, the lighting system (opposite layout of the luminaires, staggered layout of the luminaires, divided road, road with single luminaire, road with two luminaires, etc.), road class (*R*1, *R*2, *R*3, *R*4, *N*1, *N*2, *N*3, *N*4, etc.), number of lanes, lane width, refuge width, and road lighting class (*M*1, *M*2, *M*3, *M*4, *M*5, *M*6, etc.) can be chosen. For the lighting parameters, select characteristics such as distance between the luminaires, height of the luminaire, distance of the luminaire from the road, console angle, IP protection class, pollution rate, cleaning period, and maintenance factor for post or hanger system lighting. As for the parameters of the luminaire, the name, angle of the luminaire (angle relative to the road), power of the lamp used, lifetime, luminance flux, the power of the ballast and new luminaires can be added into this simulation under the database process at any time [1, 2, 20–23]. A simple and accurate calculation is achieved because of modeling for the lighting system that the data is entered into.

4. APPLICATIONS OF ROAD LIGHTING

In this study, two problems encountered in road lighting were investigated. These problems related to angled lighting and layout of lumanaries under road lighting. For this purpose, it has been proven using a simulation program that the angled lighting, encountered almost everywhere in the road lighting,

Fig. 1. Examples of road lighting console angles

Table 4. Lighting Results for Opposite and Staggered Layout of the Luminaires at 0°, 5°, 10°, and 15° Angles

Angle of illumination	**0°**		**5°**		**10°**		**15°**	
Observer No	1	2	1	2	1	2	1	2
Location, m	1.75	5.25	1.75	5.25	1.75	5.25	1.75	5.25
Staggered layout of the luminaires								
$L_{average}$, cd/m^2	1.50	1.50	~~1.28~~	~~1.28~~	~~1.11~~	~~1.11~~	~~0.98~~	~~0.98~~
U_o	0.75	0.77	0.80	0.81	0.85	0.81	0.82	0.78
U_1	0.72	0.72	0.80	0,80	0.84	0.84	0.86	0.86
TI,%	5.7	5.8	5.9	5.9	5.7	5.7	5.4	5.4
Opposite layout of the luminaires								
$L_{average}$, cd/m^2	1.64	1.64	~~1.40~~	~~1.40~~	~~1.21~~	~~1.21~~	~~1.07~~	~~1.07~~
U_o	0.67	0.67	0.73	0.73	0.77	0.77	0.77	0.77
U_1	0.70	0.70	0.79	0.79	0.86	0.86	0.86	0.86
TI,%	8.0	8.0	8.0	8.0	7.9	7.9	7.6	7.6

is inaccurate. It is proved instead of angled lighting, it is necessary to perform lighting parallel (by the angle of 0°) to the road surface. The second important problem with road lighting is that it is possible to increase the distance between the lighting poles due to the layout of the luminaires. For this purpose, two-lane road with the opposite layout of the luminaires with HPSLs of 150 W is examined. For the opposite layout of the luminaires, the distance between the poles is 43 m. However, with the help of simulation, when the poles are examined in staggered layout of the luminaires, the distance between the lighting poles is calculated as 47 m. For this road lighting, a 9.3 % longer road with two lanes can be illumitated using staggered layout of the luminaires instead of the opposite one. This example showed that using simulation environment for roads, you could find new solutions for different type of luminaires and lamps of different power.

4.1. Angle Effect in Lighting

Various design tools or physical measurements are used to determine the illumination level of certain points selected in lighting scenes. These are physical measurements carried out by models, numerical equations, and computer programs or illuminance meter under real conditions. In this study, dual luminaires with HPSLs of 150 W installed at a height of 11 m are used on the road. Determination of console angle (0°, 5°, 10° and 15°) for a luminaire with protection class IP65 with HPSL of 150 W is performed simulatively. Fig. 1 illustrates examples of road lighting console and luminaire angles.

As it can be seen in Fig. 1, the luminaires in road lighting are used at an angle due to the console or adjustable fixture mounting. It causes loss efficiency of angled lighting. Efficiency loss was calculat-

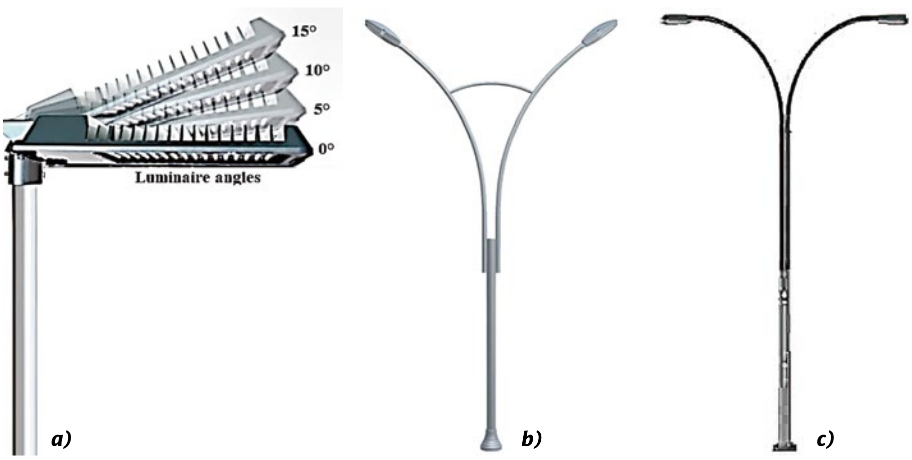

Fig. 2. Luminaire angles (a), inefficient lighting angle (b), and efficient lighting (c)

Table 5. Calculation Results of Road Lighting with Opposite and Staggered Layout of the Luminaires

Parameters of road lighting	Opposite layout of the luminaires		Staggered layout of the luminaires	
Observer location (m)	1.75	5.25	1.75	5.25
$L_{average}$ (cd/m^2)	1.64	1.64	1.5	1.5
U_o	0.67	0.67	0.75	0.77
U_l	0.70	0.70	0.72	0.72
TI (%)	8.00	8.00	5.70	5.80
$E_{average}$ (lx)	25.55		23.4	
E_{min} (lx)	13.31		16.81	
E_{max} (lx)	49.20		34.39	
U_{oa}	0.53		0.73	
U_{la}	0.27		0.49	
Lamp power (W)	150		150	
Luminous flux (lm)	17000		17000	
Distance between illuminations (m)	43		47	

ed based on simulation. As the angle increased, the luminance efficiency in the road decreased. Fig. 2 shows luminaire angles, inefficient (angle) and efficient lighting.

This study investigated a 2-lane road, which is suitable for *CIE140–2000* and *2019* (2nd edition) road lighting calculations in simulated environment. Calculations were made at angles of 0°, 5°, 10°, and 15° for luminaires with HPSL of 150 W. With the exception of 0°, 5°, 10°, and 15° angles, illumination has been found to cause loss of efficiency. For example, if the opposite layout of the luminaires is used, the distance between the poles is 43 m, and luminaire angle 0°, than $L_{average}$ =1.50 cd/m^2. This corresponds to *CIE140–2000* and *2019* (2nd edition) road lighting calculations for *M*2 [10, 11]. By opposite layout of the luminaires, if the luminaire angle is 5°, 10°, and 15°, $L_{average}$ is less than 1.50 cd/m^2 (the distance between the poles is 43 m). If $L_{average}$ =1.50 cd/m^2 less than the lighting is not suitable for *CIE140–2000* and *2019* (2nd edition).

If the staggered layout of the luminaires is used, the distance between the poles is 47 m, and luminaire angle 0°, than $L_{average}$=1.64 cd/m^2. This corresponds to *CIE140–2000* and *2019* (2nd edition) road lighting calculations for *M*2 [10, 11]. By opposite layout of the luminaires, if the luminaire angle is 5°, 10°, and 15°, $L_{average}$ is less than 1.50 cd/m^2 (the distance between the poles is 47 m). If $L_{average}$ =1.50 cd/m^2 less than the lighting is not suitable for *CIE140–2000* and *2019* (2nd edition). Table 4 shows lighting results for opposite and staggered layout of the luminaires at angles of 0°, 5°, 10°, and 15°.

If the he $L_{average}$ for 0° is assumed to be 100 % for each of the opposite and staggered layout of the luminaires in Table 4, than:

– The loss rate for luminaire angle 5° is approximate 15 %;

– The loss rate for the luminaire angle 10° is approximate 26 %;

– The loss rate for the luminaire angle 15° is approximate 35 %.

4.2. Effect of Opposite and Staggered Layout of the Luminaires on Lighting

Another subject examined in this study is the effect of layout of the luminaires in lighting. Despite the fact that all parameters are equal, the layout of lighting poles provides benefits in road lighting. To confirm this, the lighting of a two-lane road was modeled with luminaires with an HPSL of 150 W, arranged in the opposite layout of the luminaires. According to Table 5, all values correspond to *CIE140:2019* road lighting calculations. The distance between the poles is 43 m in the road lighting by the opposite layout of the luminaires. However, the maximum distance between the poles is 47 m. By opposite and staggered layout of the luminaires, all parameters are equal. However, in staggered layout of the luminaires the distance between the poles

Table 6. Luminance Values in Direction of Observer 1 for Opposite Layout of the Luminaires

Observer 1 $L_{average}$=1.64 cd/m^2, U_o=0.67, U_l=0.70, TI=8 % Opposite layout of the luminaires with HPSL of 150 W															
	1.43	**4.30**	**7.17**	**10.03**	**12.90**	**15.77**	**18.63**	**21.50**	**24.37**	**27.23**	**30.10**	**32.97**	**35.83**	**38.70**	**41.57**
0.58	1.58	1.51	1.40	1.27	1.35	1.52	1.70	1.79	1.79	1.70	1.56	1.57	1.69	1.67	1.65
1.75	1.74	1.61	1.49	1.42	1.52	1.73	1.91	2.01	1.97	1.84	1.66	1.66	1.82	1.75	1.77
2.92	1.69	1.56	1.42	1.41	1.55	1.82	2.05	2.13	2.00	1.85	1.68	1.66	1.70	1.71	1.72
4.08	1.68	1.55	1.42	1.41	1.55	1.79	1.99	2.06	1.97	1.83	1.66	1.66	1.69	1.70	1.71
5.25	1.65	1.51	1.37	1.28	1.38	1.58	1.79	1.88	1.84	1.76	1.60	1.62	1.77	1.72	1.74
6.42	1.46	1.37	1.23	1.10	1.16	1.32	1.50	1.61	1.61	1.59	1.47	1.50	1.62	1.62	1.58

Table 7. Luminance Values in Direction of Observer 2 for Opposite Layout of the Luminaires

Observer 2 $L_{average}$=1.64 cd/m^2, U_o=0.67, U_l=0.70, TI=8 % Opposite layout of the luminaires with HPSL of 150 W															
	1.43	**4.30**	**7.17**	**10.03**	**12.90**	**15.77**	**18.63**	**21.50**	**24.37**	**27.23**	**30.10**	**32.97**	**35.83**	**38.70**	**41.57**
0.58	1.46	1.37	1.23	1.10	1.16	1.32	1.50	1.61	1.61	1.59	1.47	1.50	1.62	1.62	1.58
1.75	1.65	1.51	1.37	1.28	1.38	1.58	1.79	1.88	1.84	1.76	1.60	1.62	1.77	1.72	1.74
2.92	1.68	1.55	1.42	1.41	1.55	1.79	1.99	2.06	1.97	1.83	1.66	1.66	1.69	1.70	1.71
4.08	1.69	1.56	1.42	1.41	1.55	1.82	2.05	2.13	2.00	1.85	1.68	1.66	1.70	1.71	1.72
5.25	1.74	1.61	1.49	1.42	1.52	1.73	1.91	2.01	1.97	1.84	1.66	1.66	1.82	1.75	1.77
6.42	1.58	1.51	1.40	1.27	1.35	1.52	1.70	1.79	1.79	1.70	1.56	1.57	1.69	1.67	1.65

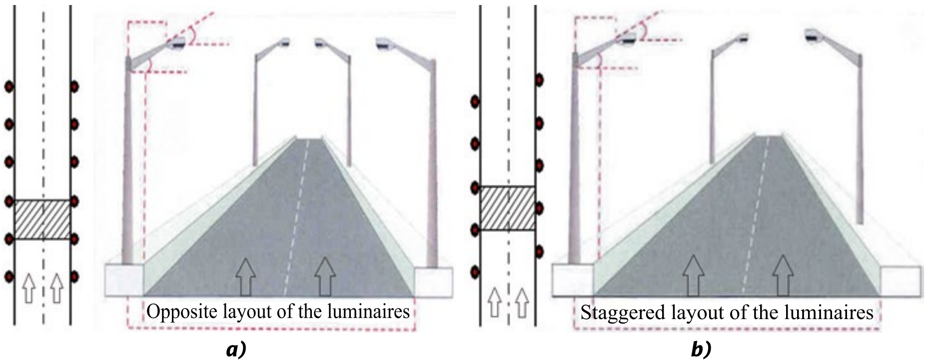

Fig. 3. Opposite and staggered layout of the luminaires

is 4 m higher (suitable for *CIE140:2000* and *2019* (2nd edition)). Therefore, the staggered layout of the luminaires a road that is 9.3 % longer.

For this reason, special solutions, such as in this example should be analyzed in simulated environments with road lighting. This reduces unnecessary costs during initial installation. Energy consumption can be reduced in lighting. Fig. 3 shows the opposite and the staggered layout of the luminaires. Table 5 shows results of calculating road lighting with the opposite and the staggered layout of the luminaires.

Tables 6–9 show the luminance values in the direction of observers 1 and 2, respectively, with opposite and staggered layout of the luminaires. In this case, the requirements *CIE140–2000* and *2019* (2nd edition) are fulfilled at all points [10, 11]. The maximum distance between the poles is 43 m for the opposite layout of the luminaires, and the maximum distance between the poles is 47 m for staggered layout of the luminaires.

Staggered layout of the luminaires increased the maximum distance between the poles by 4 m. Table 6 and Table 7 show luminance values in the di-

Table 8. Luminance Values in Direction of Observer 1 for Staggered Layout of the Luminaires

Observer 1 $L_{average}$**=1.50 cd/m²,** U_o**=0.75,** U_l**=0.72,** TI**=5.7 %** **Staggered layout of the luminaires with HPSL of 150 W**																
	1.47	4.41	7.34	10.28	13.22	16.16	19.09	22.03	24.97	27.91	30.84	33.78	36.72	39.66	42.59	45.53
0.58	1.58	1.58	1.49	1.35	1.40	1.59	1.59	1.57	1.53	1.48	1.37	1.23	1.21	1.29	1.41	1.55
1.75	1.70	1.68	1.58	1.44	1.51	1.76	1.75	1.82	1.79	1.62	1.47	1.33	1.32	1.40	1.51	1.62
2.92	1.80	1.67	1.51	1.40	1.42	1.58	1.68	1.77	1.78	1.64	1.48	1.38	1.38	1.46	1.60	1.74
4.08	1.87	1.68	1.49	1.35	1.32	1.37	1.47	1.59	1.64	1.59	1.49	1.41	1.49	1.67	1.77	1.85
5.25	1.76	1.58	1.41	1.24	1.21	1.26	1.36	1.49	1.56	1.54	1.49	1.38	1.47	1.72	1.73	1.81
6.42	1.40	1.36	1.26	1.14	1.12	1.20	1.29	1.40	1.46	1.42	1.37	1.24	1.30	1.48	1.50	1.49

Table 9. Luminance Values in Direction of Observer 2 for Staggered Layout of the Luminaires

Observer 2 $L_{average}$**=1.50 cd/m²,** U_o**=0.77,** U_l**=0.72,** TI**=5.8 %** **Staggered layout of the luminaires with HPSL of 150 W**																
	1.47	**4.41**	**7.34**	**10.28**	**13.22**	**16.16**	**19.09**	**22.03**	**24.97**	**27.91**	**30.84**	**33.78**	**36.72**	**39.66**	**42.59**	**45.53**
0.58	1.58	1.58	1.49	1.35	1.40	1.59	1.59	1.57	1.53	1.48	1.37	1.23	1.21	1.29	1.41	1.55
1.75	1.70	1.68	1.58	1.44	1.51	1.76	1.75	1.82	1.79	1.62	1.47	1.33	1.32	1.40	1.51	1.62
2.92	1.80	1.67	1.51	1.40	1.42	1.58	1.68	1.77	1.78	1.64	1.48	1.38	1.38	1.46	1.60	1.74
4.08	1.87	1.68	1.49	1.35	1.32	1.37	1.47	1.59	1.64	1.59	1.49	1.41	1.49	1.67	1.77	1.85
5.25	1.76	1.58	1.41	1.24	1.21	1.26	1.36	1.49	1.56	1.54	1.49	1.38	1.47	1.72	1.73	1.81
6.42	1.40	1.36	1.26	1.14	1.12	1.20	1.29	1.40	1.46	1.42	1.37	1.24	1.30	1.48	1.50	1.49

rections of observer 1 and observer 2 for the opposite layout of the luminaires. Table 8 and Table 9 show luminance values in the directions of observer 1 and observer 2 for the staggered layout of the luminaires.

5. CONCLUSION

Road lighting installations are important for both driving comfort and safety. The main purpose of the new study is to reach the most cost-effective results that provide adequate conditions. For this reason, when developing new suggestions in the field of road lighting, both the classification of roads by lighting and the corresponding lighting requirements are taken into account.

The most accurate reference to road lighting and the choice of luminaires to be used are international standards. For this reason, simulated road lighting is adapted to *CIE* standards. According to *CIE140–2000*, the luminance values, averaged luminance level, overall and longitudinal uniformity values of road surface luminance in all points were calculated for observers. The data of the used lamp was processed in the simulation database and the results were analyzed.

The HPSL of 150 W conforms the standards specified in *CIE140–2000* and *2019* (2nd edition) road lighting calculations with luminaire angle of 0° in the optimum lighting pole range for the opposite and staggered layout of the luminaires. The angle of the luminaire is 5°, 10°, and 15°, while $L_{average}$ is less than 1.50 cd/m². This is not *CIE* compliant. It was shown that compliance with the regulatory requirements was ensured by inefficient and inaccurate lighting installations.

The layout of lighting poles affects the lighting efficiency. Despite the fact that all parameters are equal, the layout of lighting poles provides benefits in road lighting. The optimum distance between the poles for the opposite layout of the luminaires is 43 m. Moreover, the optimum distance between the poles for staggered layout of the luminaires is 47 m. Staggered layout of the luminaires provides an advantage of 4 m (9.3 %).

Lighting simulations can enhance such special solutions. Therefore, as in this example, special solutions should be analyzed in simulated environments when designing road lighting.

The correct layout of the luminaires and lighting poles reduces unnecessary costs in initial setup of road lighting and increases energy efficiency of road lighting.

REFERENCES:

1. Cengiz M.S. A Simulation and Design Study for Interior Zone Luminance in Tunnel Lighting, Light & Engineering, 2019. V27, #2, pp. 42–51.

2. Cengiz M.S. The Relationship Between Maintenance Factor and Lighting Level in Tunnel Lighting, Light & Engineering, 2019. V27, #3, pp. 75–84.

3. International Commission on Illumination, Road lightings as an Accıdent Countermeasure, CIE93, Vienna-Austria, 1992. p. 92.

4. Painter K.A., Farrington D.P. Evaluating Situational Crime Prevention A Young People's Survey, The British Journal of Criminology, London, 2001. V41, #2, pp. 266–284.

5. Gan F., Grabosky P. Improved street Lighting and Crime Reduction, The Promise of Crime Prevention, 2nd edition ISBN0642241724, Canberra: Australian Institute of Criminology, Canberra, 2000. pp. 1326–6004.

6. Cengiz M.S., Cengiz Ç. Numerical Analysis of Tunnel LED Lighting Maintenance Factor, IIUM Engineering Journal, 2018. V19, #2, pp. 154–163.

7. Ongun, A., The Analysis of Optımum Solution Criteria for The Designing of Road Lighting Installations, M. Sc. Thesis, Gazi University Institute of Science and Technology, Ankara, 2007. p. 174.

8. Bommel W.V. Road Lighting: Fundamentals, Technology and Application, Springer Int. Pub. Switzerland, 2015. p. 333, ISBN: 978–3–319–11465–1.

9. Özkaya M., Aydınlatma Tekniği, Birsen Yayınevi, İstanbul-1994. p. 91.

10. CIE140:2000 – Road Lighting Calculations. CIE140, International Commission on Illumination, Road Lighting Calculations, Vienna-Austria, 2000. p. 33.

11. CIE140:2019 Road Lighting Calculations. CIE140, International Commission on Illumination, 2nd Edition ISBN:978–3–902842–56–5.

12. Onaygil S., Güler Ö., Erkin E. Yol Aydınlatmalarında LED Kullanımı, V. Ulusal Aydınlatma Sempozyumu ve Sergisi, 2009.

13. Cengiz Ç., Kaynaklı M., Gencer G., Eren M. Yapici İ., Yildirim S., Cengiz M.S., Selection Criteria and Economic Analysis of LEDs, Book of Abstracts, Imeset Int. Conf. Mult. Sci. Eng. Tech., Bitlis, Turkey, October 27–29, 2017.

14. UN Economic and Social Council, Economic Commission for Europe, Committee on Sustainable Energy, Steering Committee of the Energy Efficiency 21 Project, Final Report of Energy Efficiency Investment Project Development for Climate Change Mitigation, ECE/ENERGY/WP.4/ 2006/2, (21 March 2006).

15. Gencer G., Eren M., Yildirim S., Kaynaklı M., Palta O., Cengiz M.S., Cengiz Ç. Numerical Approach to City Road Lighting Standards, Book of Abstracts, Imeset Int. Conf. Mult. Sci. Eng. Tech., Bitlis, Turkey, October 27–29, 2017.

16. Yıldırım S., Yapıcı İ., Atiç S., Eren M., Palta O., Cengiz Ç., Cengiz M.S., Yurci Y., Numerical Analysis of Productivity and Redemption Periods in LED Illimunation. Imeset Book of Abstracts, Int. Conf. Mult. Sci. Eng. Tech., Baku, 12–14 July 2017.

17. CIE194–2011 On site measurement of the photometric properties of road and tunnel lighting, 2011.

18. CIE115–2010 (CIE2010) CIE115, International Commission on Illumination, Recommendations far the Lighting of Roads for Motor and Pedestrian Traffic, Vienna-Austria, 1995. p. 25.

19. CIE136–2000, Guide to the lighting of urban areas, 3 August 2000.

20. Onaygil S., TEDAŞ Genel Müdürlüğü Meslek İçi Eğitim Semineri, TEDAŞ Basımevi, Ankara, 2005. pp. 1–70.

21. Onaygil S., 2007. TEDAŞ Genel Müdürlüğü Meslek İçi Eğitim Semineri-Gölbaşı Eğitim Tesisleri, Yol aydnlatma Semineri 23–24 Ocak 2007.

22. Onaygil S., Yol aydınlatma projelerinde yol sınıfının belirlemesinin önemi, Kaynak Elektrik Dergisi, 1998. #12, pp. 125–132.

23. Güler Ö., Onaygil S., The effect of luminance uniformity on visibility level in road lighting, Lighting Research Technology, 2002. V35, pp. 199–215.

24. Tetri, E., Chenani, S.B., Rasanen R.S. Advancement in Road Lighting, Light & Engineering, 2018. V26, #1, pp. 99–109.

25. Tetri E., Bozorg Chenani S., Rasanen R-S., Baumgartner H., Vaaja M., Sierla S., Tahkamo L., Virtanen J-P., Kurkela M., Ikonen E., Halonen L., Hyyppa H., and Kosonen I. Tutorial: Road Lighting for Efficient and Safe Traffic Environments., LEUKOS Journal of the Illuminating Engineering Society of North America, 2017. V13, #4, pp. 223–241.

26. Liping G., Marjukka E., and Halonen L. Luminance monitoring and optimization of luminance meter-

ing in intelligent road lighting control systems, Ingineria Iluminatuluin, 2007. V9, pp 24–40.

27. Barua P., Mazumdar S., Chakraborty S., Bhattacharjee S. Road Classification Based Energy Efficient Design and its Validation for Indian Roads, Light & Engineering, 2018. V26, #2, pp. 110–121.

28. Bozorg Chenani S., Vaaja T M., Kurkela M., Kosonen I., Luttinen T. Target detection distances under different road lighting intensities, European Transport Research Review, 2017. #9, pp. 1–17.

29. Iacomussi Rossi G., Soardo P. Energy Saving and Environmental Compatibility in Road Lighting, Light & Engineering, 2012. V20, #4, pp. 55–63.

30. Tahkamo L. Halonen L. Life cycle assessment of road lighting luminaires -Comparison of light emitting diode and high-pressure sodium technologies, Journal of Cleaner Production, 2015. V93. pp. 234–242.

31. Van Bommel W., Van Den Beld G.,. Van Ooyen M. Industrial Light and Productivity, Lighting & Engineering, 2003. V11, #1, pp. 14–21.

Mehmet Sait Cengiz
Turkey Electricity Distribution Company was made director of research and development in the years 2000-2010. He completed his masters degree in 2011 and his doctorate in 2016 in the field of Electrical and Electronics Engineering. He still works in the field of applied lighting