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THE RELATIONSHIP BETWEEN MAINTENANCE FACTOR AND LIGHTING LEVEL IN TUNEL LIGHTING

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ABSTRACT

Performance decreases in lighting equipment with a high level of contamination have been analysed in this study. Effect of decreases in luminous flux arising from abrasions and usage on tunnel illumination levels has been analysed and results of measurements in real environment and simulation environment have been compared. Calculations, which are complicated and difficult by traditional methods, have been visualized by a simulation program prepared in the computer environment. Results recorded at 60 points by measuring by a luxmeter, which was placed in the middle of 2.266 m^2 fields on the road surface into the tunnel, have been compared with simulation results. Thanks to the simulation program used, tunnel lighting measurements would not be necessary, which they take a long time in the physical environment by measurement devices and are carried out by stopping vehicle traffic. Tunnel lighting maintenances, which are complicated and take a long time, will be carried out in a short time and more accurately, and waste of resources could be prevented. It has been determined in the study that more accurate results could be obtained in ergonomic, economic, and using aspects.

Keywords: tunnel lighting, maintenance factor, illumination levels

1. INTRODUCTION

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

Efficient use of energy without any decrease in producing energy conservation, comfort and labour force is not to waste. People have been motived to find new methods to save energy due to rapid and unconscious consumption of the energy resources used [2–4]. For that reason, it is critical to use luminaires of high productivity and efficiency in tunnel lighting systems, which are active continuously. Stopping distance is considered in calculations while tunnel lighting is designed. This distance is related to the time when driver sees the obstacle in front of him/her and reacts to. Stopping distance demonstrates that tunnel lighting is required as well as it constitutes the main foundation of lighting design. It is critical in terms of traffic safety that drivers could enter the tunnel safely and without disturbance throughout the tunnel, go ahead throughout the tunnel, and continue to drive at the tunnel exit. It is required to calculate illumination levels accurately so that drivers could realize an object into the tunnel [3–5].

It is difficult to determine the average life for tunnel lighting systems and determine the rate of losses of light intensity in lighting equipment. It is also complicated to evaluate the working performance of the system and determine maintenance time. Illuminance measurements have been carried out to determine maintenance time for tunnel lighting in this study. In other words, measurements were carried out with a measuring instrument at many points into the tunnel in order to determine, if there is any loss of lighting equipment. However, it is difficult and time-consuming to do so for each tunnel lighting. A study that would take a long time was necessary in order to determine maintenance of lighting system, lifecycle of the system, and losses of lighting equipment in a luxury aspect even though the study was carried out for only one tunnel.

2. PERFORMANCE LOSSES OF LIGHTING SYSTEMS

Lighting, in the simplest term, is to supply the required illuminance for an operation. The most important objective to design lighting systems is to obtain sufficient light without supplying excessive lighting and increasing energy cost [6]. For that reason, it is important to know about factors, which have a direct effect on proper illumination level in an environment. Attenuation of the luminous flux values of the lighting equipment used in tunnels might occur over time. Performance loss of the luminaires, which occurs depending on operating time, affects directly the performance of the system. The most important reason why luminaires loss their performance is that light transmittance decreases since the luminaires are contaminated by environmental reasons. Another reason for performance loss is that light source loss efficiency depending on operating time and the light source expires earlier. Since luminaires loss performance depending on the time, the performance of the lighting system will be identified for the time period specified. The time period may include maintenance works, which would recover performances of the luminaires such as cleaning the glass of luminaires or replacing lamps of the luminaires as well as replacing all the luminaires at the expiration date. A lighting system can supply minimum required lighting even at the end of the period when it has the lowest performance, if the estimated decrease in performance is included in the system performance at design phase [7–9]. Deficiencies in lighting because of the decrease in illumination levels of the lamps and lacks of maintenance would affect visual conditions adversely. Lighting simulation programs to be used at this phase will provide great convenience at the first installation. However, it is still a complicated problem: how to assess the sufficiency of an existing lighting system with a lighting technique. It is required to measure illumination levels in tunnel lighting, at first, in order to evaluate the conformity of illumination levels in the environment. Lighting equipment is maintained at periodic intervals in order to prevent performance loss happened to the lighting equipment.

Fig. 1. Tunnel lighting with double suspensions

3. MAINTENANCE FACTOR IN TUNNEL LIGHTING

A lighting instrument should supply the minimum illumination level during the operating time. Contamination on lighting instrument causes loss of luminous flux in the luminaire and structural defects on the surface of the optical equipment. Loss of lighting performance makes the maintenance of lighting instruments necessary. This effect, which is formed by the mutual effect of several parameters and applied at periodic intervals, is Maintenance Factor (*MF*). *MF* varies by type of lighting system, environmental conditions, and features of luminaires. *MF* should be calculated accurately so that tunnel lighting systems can be implemented in accordance with the objectives and they can sustain the performance to meet the expectations even at the end of maintenance period or lifecycle of the system. *MF* has an important place in the total cost of a lighting system, since it affects directly energy consumption. For luminaires, *MF* is defined as the proportion of total light coming from a luminaire at the end of the maintenance period to total light of the luminaire during the primary use. In accordance with standards associated with the use of *MF* in lighting, lighting system is specified by the chosen lighting equipment, environmental conditions, and the maintenance factor calculated for a specified period of maintenance CIE154:2003. According to CIE154:2003, lighting performance should not drop below minimum levels specified in the standards [10–12]. *MF* consists of Lamp Lumen Maintenance Factor (*LLMF*), which is the proportion of performance loss in the lamp, the luminous flux at the end of the specified period, to the initial luminous flux. *LLMF* value is reached by the catalogue of the manufacturer. Lamp Survival Factor (*LSF*) is the percentage of lamp survival ratio for maintenance factor. *LSF* value is reached by the catalogue of the lamp.

Luminaire Maintenance Factor (*LMF*) is the proportion of luminous flux, which decreases at the end of the described/specified period as a result of a structural feature of the luminaire and also environmental factors, to the initial luminous flux. *LMF* depends on protection class of luminaire against contamination (IP) and environmental pollution. It is specified by the designer according to the contamination condition of the environment during the maintenance period or the relevant specification is consulted. *MF* is calculated according to Equation 1:

$$MF = LLMF \cdot LSF \cdot LMF\,. \tag{1}$$

In the standard concerning the calculation of lighting performances, *MF* is formed by the product of luminous flux *MF* and luminaire *MF*. Equation 2 demonstrates the relationship between *MF* and Lighting Level [1, 13].

$$E = \frac{I \cdot \cos^3 \varepsilon \cdot \Phi \cdot MF}{h^2}, \tag{2}$$

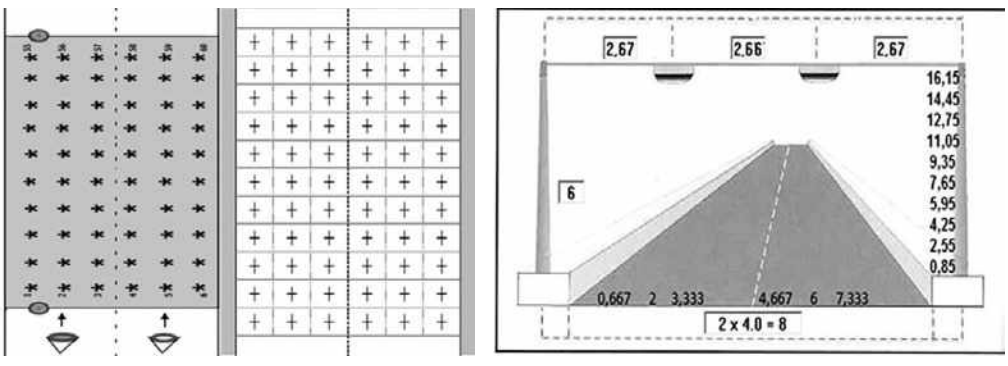
where I is the given luminous intensity value (cd/lm), Φ is the luminous flux (lm), *MF* is the maintenance factor, h is the height of the luminaire from the ground (m), ε is the angle between the light coming from the luminaire to the surface and the normal of the surface.

4. APPLICATION IN TUNNEL LIGHTING

Various design tools or physical measurements are used in order to determine the illumination levels of certain points selected in lighting systems. These are physical measurements carried out by models, numerical equations, and computer programs or by luxmeter in the real environment. In this study, HPS100 W luminaires inserted dually 6 m high are used in the tunnel. Maintenance factor for high-pressure sodium vapour (HPS) luminaires is specified by the product of three main factors described above (Equation 1). Determination of maintenance factor for a 100 W HPS luminaire with protection class IP65 is calculated during simulation. Fig. 1 illustrates a sample of tunnel lighting with double suspensions [11, 12, 14].

4.1. Physical Measurements

Measurements of illuminance levels have been carried out in an active tunnel used in daily life. Measurements have been carried out at night and in the interior zone of the tunnel in order to avoid sunlight. High-pressure sodium vapour lamps (HPS) 100 W were used in the interior lighting of the tunnel. The road in the tunnel was divided into 60 areas of (1.70×1.333) = 2.266 m^2, and measurements were carried out separately in each of these areas (Fig. 2).



a) b)

Fig. 2. *a* – chart of the fields measured in a two-lane tunnel; *b* – section of the road measured

Table 1. The Tunnel Road and Lighting Parameters

Tunnel Road Parameters		Tunnel Lighting Parameters	
Double luminaire, transverse arrangement			
Road class	R3	Luminaire height	6 m
Number of lanes	2	Boom angle	0
Strip width	4 m	IP protection	IP65
Road width	8 m	Pollution category	High
Q_o	0.07	Annual clear period (year)	2
Road lighting class	M2	Distance between luminaires	17 m

4.2. Simulation Design and Planning Process

Various choices are available for the road parameters in the simulation program. For the road parameters, the lighting system (bilateral, displaced, divided road, tunnel road with single luminaire, tunnel road with two luminaires, etc.), road class (R1, R2, R3, R4, N1, N2, N3, N4, etc.), number of lanes, lane width, refuge width, and road lighting class (M1, M2, M3, M4, M5, M6, etc.) can be chosen. For the lighting parameters, features such as distance between the luminaires, the height of the luminaire, distance of the luminaire from the road, boom angle, IP protection class, pollution rate, cleaning period, and maintenance factor are chosen for post or hanger lighting installations. For the luminaire parameters, the name, angle of the luminaire (angle relative to the road), power of the lamp used, lifetime, luminous flux, ballast power, and new lamps can be added into this simulation under the Database process at any time. As a result, it is possible to add any kind of lamp into the simulation [15–18]. An easy and accurate calculation is achieved in the simulation results for the lighting system in which data is entered. Fig. 3 shows the algorithm of the simulation program and the data entered [17].

Table 1 illustrates the road and lighting parameters belonging to the tunnel measured.

Table 2 illustrates type styles luminaire maintenance factor by protection class of luminaire and category of environmental pollution [10–12].

The display of the luminaire parameters in the simulation program are illustrated in Fig. 4.

In this study, the lighting system of a tunnel, which still operates actively and has parameters illustrated in Table 1, has been analysed at first. Parameters in Table 1 has been transmitted to the

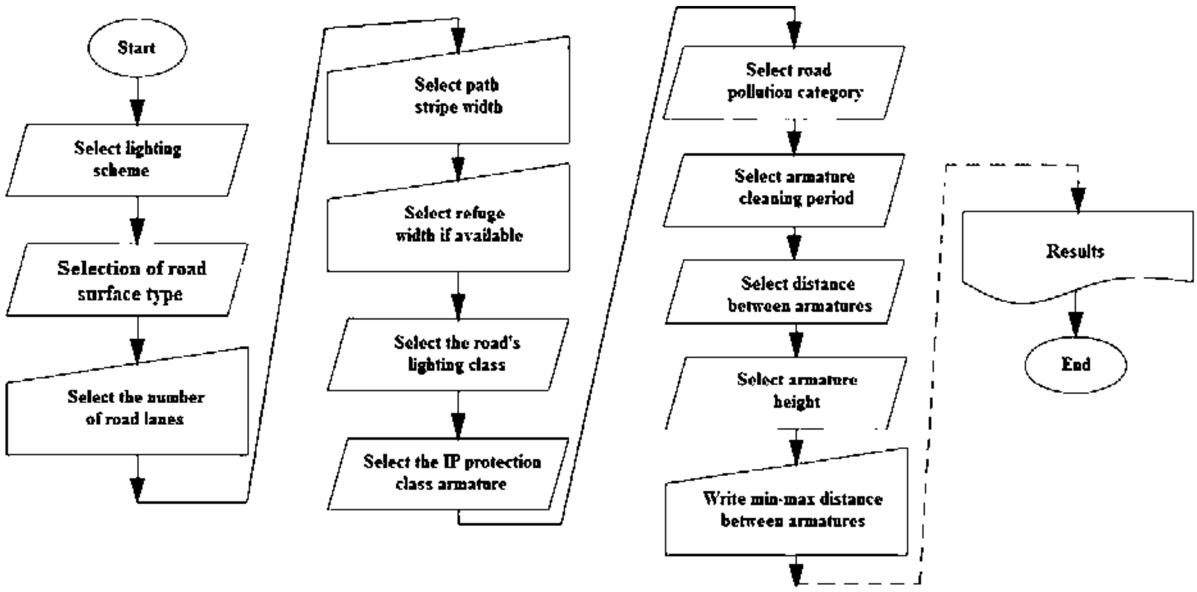


Fig. 3. The algorithm of the simulation program and data entered [17]

Table 2. Type Styles Luminaire Maintenance Factor by Protection Class of Luminaire and Category of Environmental Pollution [11]

Optical Compartment IP Rating	Pollution Category	Exposure time (Years)				
		1	1.5	2	2.5	3
IP2X	High	0.53	0.48	0.45	0.43	0.42
	Medium	0.62	0.58	0.56	0.54	0.53
	Low	0.82	0.80	0.79	0.78	0.78
IP5X	High	0.89	0.87	0.84	0.80	0.76
	Medium	0.90	0.88	0.86	0.84	0.82
	Low	0.92	0.91	0.90	0.89	0.88
IP6X	High	0.91	0.90	0.88	0.85	0.83
	Medium	0.92	0.92	0.89	0.88	0.87
	Low	0.93	0.93	0.91	0.90	0.90

Table 3. Results of Simulation (*E* Values)
MF=0.88; E_{min}=37.54 lx; E_{max}=83.65 lx; $E_{average}$=60.53 lx

1 time in 2 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	68.73	58.92	47.32	38.69	37.54	37.55	38.72	47.36	58.99	68.83
20	83.54	77.59	62.83	52.8	52.12	52.13	52.83	62.87	77.66	83.64
3.3	68.57	69.32	63.25	59.75	66.55	66.56	59.78	63.3	69.39	68.67
4.7	68.57	69.32	63.25	59.75	66.55	66.56	59.78	63.3	69.39	68.67
6.0	83.54	77.59	62.83	52.8	52.12	52.13	52.83	62.87	77.66	83.64
7.3	68.73	58.92	47.32	38.69	37.54	37.55	38.72	47.36	58.99	68.83

simulation designed in Visual Basic Program. The surface of luminaires is cleaned by carrying out maintenance for the luminaires in this tunnel once a year. In addition, lamps, which break down for whatever reason, are replaced. However, they are replaced regardless of the tunnel, road conditions, weather conditions, traffic density or *MF*. 60 measurements have been performed at the points chosen previously by a luxmeter into the tunnel at night when traffic was not busy.

As for the simulation used for this tunnel, numerical results are generated and recorded for *MF*, E_{min}, E_{max}, E_{avr} belonging to tunnel and *E* values belonging to 60 points. Then the results of the measurement and results produced by the simulation were compared and percentage deviations were calculated for 60 points chosen. Road and lighting parameters used in the simulation were obtained from Table 1 and *MF* value was obtained from Table 2. Table 3 has been obtained as a result of these parameters entered into the simulation. *E* values belonging to 60 points chosen in the simulation could be seen provided that maintenance would be carried out once a year.

Table 4 illustrates *E* values formed as a result of measurement performed at 60 points chosen in a tunnel for which maintenance is carried out once a year.

Table 5 illustrates the percentage difference *E* between the physical measurements performed in the tunnel and simulation.

Depending on Table 5, possible performance loss in this tunnel in case of maintenance several times in a year and once every three years will be estimated roughly. Table 6 illustrates simulation results belonging to this tunnel if maintenance is performed once a year. Table 7 is created using Table 5 by determining the amount of the deviation for the

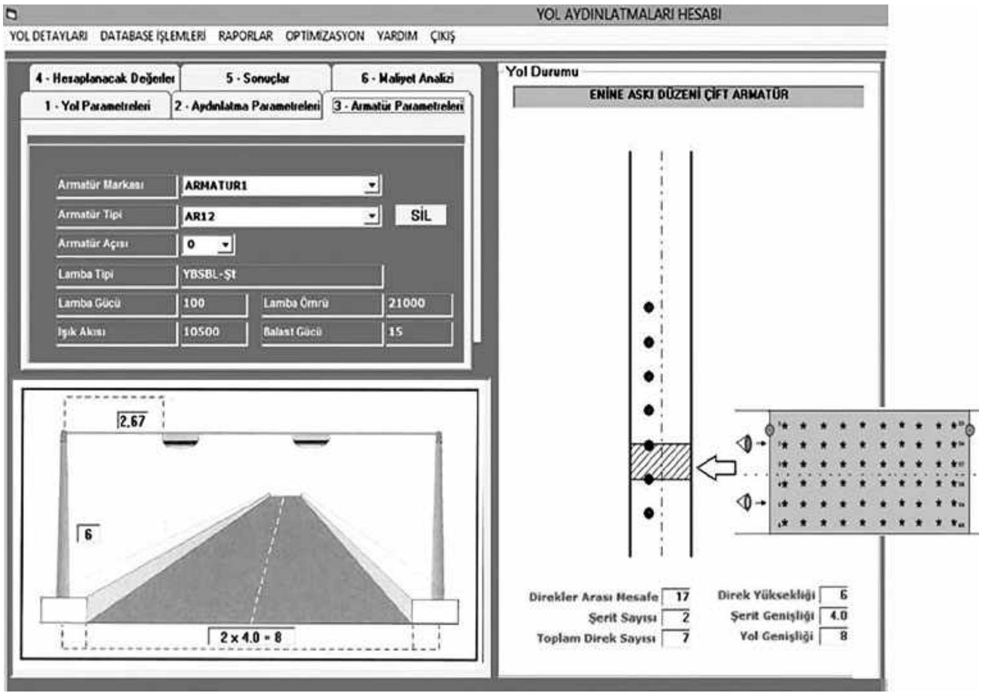


Fig. 4. Luminaire parameters in the simulation program

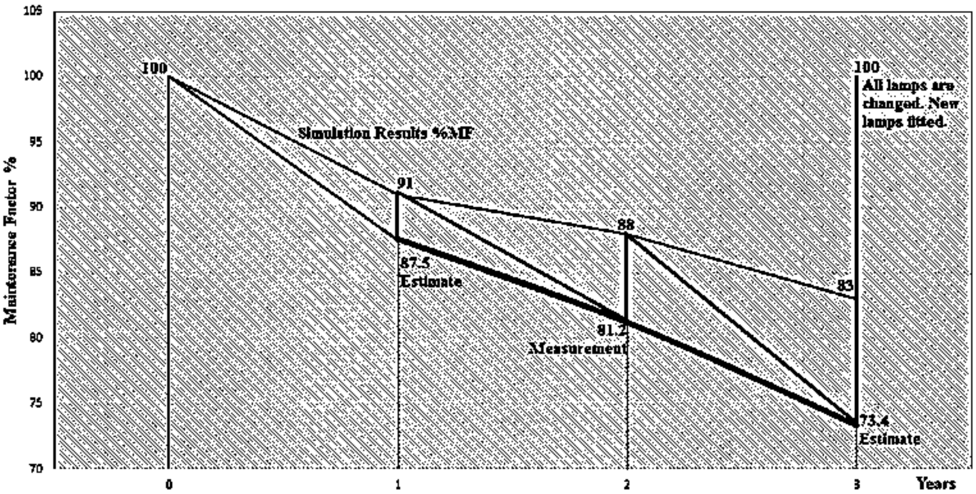


Fig. 5. Optical performance variation with HPS luminaires 100 W

1-year period. If amounts of deviation in Table 7 are applied to Table 6, one can obtain *E* values and *MF* value in Table 8. Table 9 illustrates simulation results belonging to this tunnel if maintenance is performed once every three years. Table 10 is created using Table 5 by determining the amount of the deviation for the 3-year period. If amounts of deviation in Table 10 are applied to Table 9, one can obtain *E* values and *MF* value in Table 11.

Optical performance variation with HPS luminaires 100 W is illustrated in Fig. 5.

When Fig. 5 is examined:

- While *MF* decreases to 84.68 % at the end of the 1st year, *MF* increases to 91 % by cleaning glasses of the luminaires;
- While *MF* decreases to 80.26 % at the end of the 2nd year, *MF* increases to 88 % by cleaning glasses of the luminaires;
- While *MF* reduces to 73.4 % after three years, it increases up to 83 % as a result of the cleaning glasses of the luminaires.

However, all lamps should be replaced since cleaning the glass of luminaires fails to satisfy. Decrease in illuminance levels would not be tolerated because of the decrease in luminous flux of the lamps after 3 years. All lamps used for 3 years should be replaced even though they operate instead of replacing the broken or dead lamps. When examining catalogue of the manufacturer, it is seen that HPS lamps 100 W cannot be used after approx-

Table 4. Results of Measurements (*E* Values)
Measurements: *MF*=0.812; E_{min}=32.11 lx; E_{max}=79.92 lx; $E_{average}$=55.87 lx

1 time in 2 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	65.73	53.05	40.99	35.33	32.92	33.17	35.81	45.21	53.87	65.32
2.0	77.56	69.98	57.68	48.65	46.86	48.59	46.09	57.94	72.04	79.55
3.3	63.51	59.96	58.13	56.32	60.98	59.93	56.66	58.94	65.52	65.97
4.7	64.09	60.95	56.47	56.01	60.96	60.99	56.08	58.72	65.55	66.09
6.0	77.01	73.12	57.27	48.84	47.93	47.91	47.54	56.86	74.73	79.92
7.3	64.11	53.43	42.07	36.31	32.11	33.72	35.95	42.33	56.42	66.61

Table 5. Percentage Difference *E* between the Measurements and Simulation

Deflection	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	4.37 %	9.97 %	13.38 %	8.70 %	12.31 %	11.67 %	7.53 %	4.55 %	8.68 %	5.10 %
2.0	7.17 %	9.81 %	8.20 %	7.87 %	10.11 %	6.80 %	12.76 %	7.85 %	7.24 %	4.90 %
3.3	7.39 %	13.51 %	8.10 %	5.75 %	8.38 %	9.97 %	5.23 %	6.89 %	5.59 %	3.94 %
4.7	6.54 %	12.08 %	10.72 %	6.27 %	8.41 %	8.38 %	6.20 %	7.24 %	5.55 %	3.77 %
6.0	7.83 %	5.76 %	8.85 %	7.51 %	8.05 %	8.11 %	10.02 %	9.57 %	3.77 %	4.46 %
7.3	6.73 %	9.33 %	11.10 %	6.17 %	14.47 %	10.20 %	7.16 %	10.63 %	4.36 %	3.23 %

Table 6. Results of Simulation (*E* Values) Provided that Maintenance Would Be Carried out Once a Year
***MF*=0.91; E_{min}=38.82 lx; E_{max}=86.50 lx; $E_{average}$=62.59 lx**

1 time in 1 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.6	71.07	60.93	48.93	40.01	38.82	38.83	40.04	48.98	61.00	71.17
2.0	86.39	80.23	64.97	54.60	53.90	53.91	54.63	65.02	80.30	86.49
3.3	70.91	71.69	65.40	61.79	68.82	68.83	61.82	65.45	71.76	71.01
4.7	70.91	71.69	65.40	61.79	68.82	68.83	61.82	65.45	71.76	71.01
6.0	86.39	80.23	64.97	54.60	53.90	53.91	54.63	65.02	80.30	86.49
7.3	71.07	60.93	48.93	40.01	38.82	38.83	40.04	48.98	61.00	71.17

imately 26000 hours (it corresponds to 3-year study for tunnel lighting) because of the decrease in luminous flux. For that reason, all lamps should be replaced.

As seen in Fig 5, while *MF* difference is 6.3 % for 1–2 years (for 365 days), *MF* difference increases up to 7.8 % for 2 or 3 years (for 365 days). As it is understood in this aspect, E_{avr} reduces rapidly since the lamps and other equipment used wear off. Results from simulation and prediction promote this thought.

5. RESULTS

As a result of these estimates, it will be easier to make improvements by responding on time after determining, if lighting elements expire and if they have sufficient luminous flux, and thus to prevent waste of electrical energy, which does not turn into light. Since simulation study makes easier to determine contamination time of lighting equipment, it increases the chance to find a solution by estimating workforce gain and losses of energy oc-

Table 7. Percentage Difference *E* between the Estimate Performed in the Tunnel and Simulation

Deflection	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	2.19 %	4.99 %	6.69 %	4.35 %	6.16 %	5.83 %	3.76 %	2.28 %	4.34 %	2.55 %
2.0	3.58 %	4.90 %	4.10 %	3.93 %	5.05 %	3.40 %	6.38 %	3.93 %	3.62 %	2.45 %
3.3	3.69 %	6.76 %	4.05 %	2.88 %	4.19 %	4.99 %	2.62 %	3.44 %	2.79 %	1.97 %
4.7	3.27 %	6.04 %	5.36 %	3.14 %	4.21 %	4.19 %	3.10 %	3.62 %	2.77 %	1.88 %
6.0	3.91 %	2.88 %	4.42 %	3.75 %	4.03 %	4.05 %	5.01 %	4.79 %	1.89 %	2.23 %
7.3	3.37 %	4.66 %	5.55 %	3.08 %	7.23 %	5.10 %	3.58 %	5.32 %	2.18 %	1.61 %

Table 8. Results of Estimation (*E* Values) Provided that Maintenance Would Be Carried out Once a Year

1 time in 1 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	69.51	57.89	45.66	38.27	36.43	36.57	38.53	47.86	58.35	69.36
2.0	83.30	76.30	62.31	52.45	51.18	52.08	51.14	62.46	77.39	84.37
3.3	68.29	66.84	62.75	60.01	65.94	65.40	60.20	63.20	69.76	69.61
4.7	68.59	67.36	61.89	59.85	65.92	65.95	59.90	63.08	69.77	69.68
6.0	83.01	77.92	62.10	52.55	51.73	51.73	51.89	61.91	78.78	84.56
7.3	68.67	58.09	46.21	38.78	36.01	36.85	38.61	46.37	59.67	70.02

Table 9. Results of Simulation (*E* Values) Provided that Maintenance Would Be Carried out Once Every Three Years
MF=0.83; E_{min}=35.41 lx; E_{max}=78.89 lx; $E_{average}$=57.09 lx

1 time in 3 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	64.83	55.57	44.63	36.49	35.40	35.41	36.52	44.67	55.64	64.91
2.0	78.80	73.18	59.26	49.80	49.16	49.17	49.83	59.30	73.24	78.89
3.3	64.67	65.38	59.65	56.36	62.77	62.78	56.39	59.70	65.45	64.77
4.7	64.67	65.38	59.65	56.36	62.77	62.78	56.39	59.70	65.45	64.77
6.0	78.80	73.18	59.26	49.80	49.16	49.17	49.83	59.30	73.24	78.89
7.3	64.83	55.57	44.63	36.49	35.40	35.41	36.52	44.67	55.64	64.91

Table 10. Percentage Difference *E* between the Estimate Performed in the Tunnel and Simulation

Deflection	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	6.56 %	14.96 %	20.07 %	13.05 %	18.47 %	17.50 %	11.29 %	6.83 %	13.02 %	7.65 %
2.0	10.75 %	14.71 %	12.30 %	11.80 %	15.16 %	10.20 %	19.14 %	11.78 %	10.86 %	7.35 %
3.3	11.08 %	20.27 %	12.15 %	8.63 %	12.57 %	14.96 %	7.85 %	10.33 %	8.38 %	5.91 %
4.7	9.81 %	18.12 %	16.08 %	9.41 %	12.62 %	12.57 %	9.30 %	10.85 %	8.32 %	5.65 %
6.0	11.74 %	8.64 %	13.27 %	11.26 %	12.08 %	12.16 %	15.03 %	14.36 %	5.66 %	6.69 %
7.3	10.10 %	13.99 %	16.64 %	9.25 %	21.70 %	15.30 %	10.75 %	15.95 %	6.54 %	4.84 %

Table 11. Results of Estimation (*E* Values) Provided that Maintenance Would Be Carried out Once Every Three Years
MF=0.734; E_{min}=27.72 lx; E_{max}=73.62 lx; $E_{average}$=50.50 lx

1 time in 3 year	0.8	2.5	4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1
0.7	60.57	47.26	35.67	31.73	28.86	29.21	32.40	41.62	48.39	59.95
2.0	70.32	62.41	51.97	43.92	41.71	44.15	40.29	52.31	65.29	73.09
3.3	57.51	52.13	52.41	51.49	54.88	53.39	51.96	53.53	59.96	60.94
4.7	58.33	53.53	50.06	51.06	54.85	54.89	51.14	53.22	60.01	61.11
6.0	69.54	66.85	51.39	44.19	43.22	43.19	42.34	50.79	69.10	73.62
7.3	58.28	47.80	37.20	33.12	27.72	29.99	32.59	37.54	52.00	61.77

curring over time. Energy consumption that does not turn into light because of performance losses with the lighting equipment can be thus prevented.

This study analyzes the importance of designs for lighting systems, which are an essential part of indoor areas such as tunnels, and effects of time-dependent losses of lighting equipment in these environments on lighting systems. Effect of *MF* on tunnel lighting has been analysed by comparing the simulation results with the real measurement results. Predictions on the tunnels, maintenance of which is carried out at 1-year and 3-year intervals, have been made according to the results from measurements, which were performed at 60 points into a tunnel, maintenance period of which is once a year. It is thus found that more accurate results may be obtained by the tunnels having 1-year and 3-year *MF,* physical measurements of which are not performed. Losses formed by the scenarios that tunnel lighting maintenance is performed once a year and once every three years may be determined based on the difference of% between simulation environment and physical measurement.

6. CONCLUSION

It is concluded that it is a successful method in estimating *MF* of the tunnels to use simulation results and real measurements together in tunnel lighting systems, which have similar environmental conditions (contamination, climate, temperature, moisture, wind, vehicle density, etc.). Estimates based on scientific data in simulation environment will offer easier and quicker solutions since it is a difficult and time-consuming process to stop traffic and make physical measurement in the tunnels where traffic is busy.

It is critical to calculate properly *MF* in order to install lighting systems of road pursuant to the purposes and maintain the performance to meet the expectations even at the end of maintenance period or operating time of the system.

MF takes an important part in the total cost of a lighting system since it affects directly energy consumption. It is required to determine which one of these options are more economical depending on energy consumption, cost of lamps and changing lamps.

Start-up costs and maintenance costs of the systems should be considered to compare energy efficiency.

Increasing the maintenance factor used as a multiplier in performance calculations increases the energy efficiency by decreasing the energy consumed.

REFERENCES

1. Özkaya M. Aydınlatma Tekniği // Birsen Yayınevi, İstanbul, 1994, 384 p.

2. Tetri, E., Chenani, S.B., Rasanen R.S. Advancement in Road Lighting // Light & Engineering, 2018, Vol. 26, #1, pp. 99–109.

3. Barua P., Mazumdar S., Chakraborty S., Bhattacharjee S. Road Classification Based Energy Efficient Design and its Validation for Indian Roads // Light & Engineering, 2018, Vol. 26, #2, pp. 110–121.

4. Iacomussi P., Rossi G., Soardo P. Energy Saving and Environmental Compatibility in Road Lighting // Light & Engineering, 2012, Vol. 20, #4, pp. 55–63.

5. Van Bommel W., Van Den Beld, G., Van Ooyen M. Industrial Light and Productivity // Light & Engineering, 2003, Vol. 11, #1, pp. 14–21.

6. Güler Ö., Onaygil S. The effect of luminance uniformity on visibility level in road lighting // Lighting Research Technology, 2002, Vol. 35, pp. 199–215.

7. Jantzen R. Flimmerwirkung der Verkehrsbeleuchtung // Lichttechnik, 1960, Vol. 12.

8. Schreuder D.A. The lighting of vehicular traffic tunnels. Thesis, University of Technology Eindhoven, 1964.

9. Walthert R. Tunnel lighting systems // International Light Review, 1977, Vol. 4, P. 112.

10. CIE Technical Report, CIE-88–2004. Guide for the Lighting of Road Tunnels and Underpasses, 2004.

11. CIE Technical Report, CIE-154–2003. The Maintenance of Outdoor Lighting Systems, 2003.

12. CIE Technical Report, CIE-194–2011. On Site Measurement of the Photometric Properties of Road and Tunnel Lighting, 2011

13. TSE standard: TS EN13201–2, Road lighting – Part 2: Performance requirements, 2016.

14. Master Son-T Apia PlusXtra, HPS-100, 2018. URL: https://www.assets.lighting.philips.com/is /content/PhilipsLighting/fp928483300095-pss-tr_tr

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

16. Onaygil S. TEDAŞ Genel Müdürlüğü Meslek İçi Eğitim Semineri, TEDAŞ Basımevi, Ankara.

17. Cengiz M.S. A Simulation and Design Study for Interior Zone Luminance In Tunnel Lighting // Light & Engineering, 2019, Vol. 27, #2.

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

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