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A Simple Method for Energy Saving in Tunnel Lighting

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ABSTRACT **Number of highway tunnels continues to increase reducing transport times and costs around the world. As the length of the tunnel increases, the consumed electricity increases also. The biggest chunk of energy is used for tunnel interior luminance. While the tunnels are generally illuminated by sodium vapor lamps, light emitting diodes (LED) based are being increasingly practiced in recently constructed tunnels. In this study, innovations for illumination and lamp control methods for tunnels are examined and the amount of energy savings was theoretically calculated by a simple control method.**

Keywords: Illumination, Tunnels, Energy Saving, Lighting Control, Lighting Control Interface

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1. INTRODUCTION

Electricity consumed for lighting reaches 40% of total electricity consumption in some cities [1]. Electricity consumption in Turkey was reported to be 278.3 TWh approximately in 2016 [2]. Street and tunnel lighting corresponds to 2 to 4.6 % of all electricity consumption in Turkey [3]. High-pressure sodium vapor (HPS) lamps, low pressure sodium vapor lamps (LPS), and light emitting diode (LED) lamps are used for illumination purposes. The use of mercury vapor lamps for lighting has reduced due to their heavy metal content. The use of LED lamps has been increasing around the globe in recent years. The most important reason for this change is the high illumination efficiency of LED lamps. The number of lamps used in the lighting in the tunnels, and the level of the road luminance vary with the lighting level at tunnel exit and the speed of the vehicle. On the other hand, braking distance depends on the speed of the vehicle, the wetness of the road surface, and the highest road slope value of the tunnel [4]. The changes of the brake distance according to the vehicle speeds are shown in Table 1 [5].

The tunnel is divided into zones, and each zone has a different luminance level. These regions are called as the outer (access) zone, the entrance (threshold) zone, the transition zone, the interior zone, and the exit zone, as shown in Figure 1 [6].

Table 1. Brake distance according to road condition and vehicle speed

Road Condition	Vehicle Speed (km/hour)		
	90	110	130
	Break Distance (meter)		
Wet	90	120	160
Dry	120	160	220

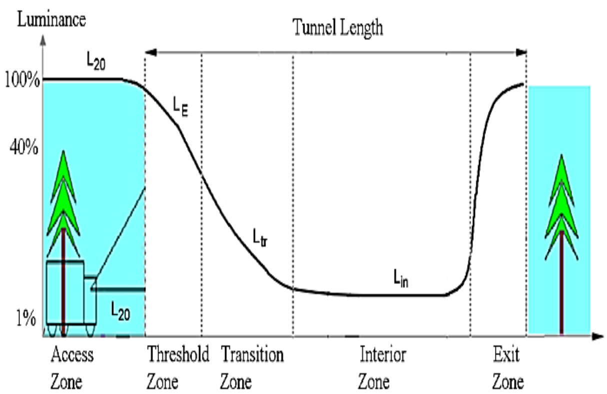

Fig.1. Zones of tunnel based on luminance level

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The interior zone of the tunnel has the least luminance compared to the other zone. The luminance in this zone is same and the distance between the lamps is fixed. The average road surface luminance level of the interior zone varies from 1.5 cd/m^2 to 10 cd/m^2 according to the vehicle speed and the number of vehicles as shown in Table 2 [7].

Table 2. Luminance level of interior zone of tunnel

Break Distance	The number of cars (NoC) passing in an hour		
	NoC <100	100< NoC <1000	1000< NoC
160 m	5 cd/m^2	10 cd/m^2	10 cd/m^2
100 m	2 cd/m^2	4 cd/m^2	6 cd/m^2
60 m	1,5 cd/m^2	2 cd/m^2	3 cd/m^2

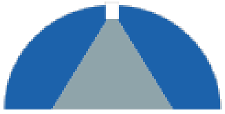
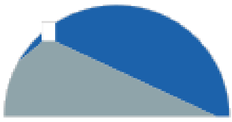
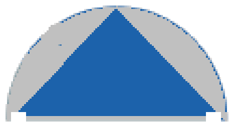
Adjusting luminance of roads depending on the braking distance saves electricity [8]. Braking distance is highly affected by weather conditions (dry vs. wet road surface). For this reason, the luminance level should be selected carefully in rainy weather conditions.

2. TUNNEL LIGHTING TYPES

Most of the traffic accidents happening in tunnels occur at either entrances or at exits of the tunnels. One of the reasons of the accident is that the human eye cannot quickly adapt to the darkness. This event is called the "*black hole*" effect. The human eyes cannot adapt to light instantaneously when the light level falls below 1/3 of previous level. On the other hand, the human eyes are easy to adapt to bright light. The luminance of the access and exit zone is important for better vision. Luminance of the exit zone should be at least 1/5 of luminance of the outside of tunnel. The luminance level in the tunnels is defined in the CIE (International Commission on Illumination)-88 standard. The selection and installation of the lighting lamps vary based on the length of the tunnel. Common lamp installations are shown in Table 3 [9].

The luminance level of outer zone is measured by photometer. In addition, the number of vehicles is determined by the instant light change obtained data from the photometer. Generally, high-pressure sodium lamps are used in the tunnels. These lamps have ballasts and power setting ranges are not flexible. Contrarily control of LED lamps is very flexible. These two types of lamps compete with each other and the market share of HPS lamps continues to decline. [10]. Besides, induction lamps (IND) which have very little maintenance cost, can be considered as an alternative as these lamps have advantages including light efficiency (LE), long life, simplicity and operating costs. Nevertheless, they contain ballast and mercury in small quantity. The production costs of LED lamps are decreasing and the light efficiency is increasing day by day. High pressure sodium lamps are widely used in rural area lighting because of their low cost. Metal halide lamps are used indoors and outdoors such as sports fields, museum due to the high color rendering index and high light efficiency factor.

Table 3. Advantage and disadvantage of lamp installations

Installation Type & Location	Advantages	Disadvantages
	Best lighting, glare limited	Heavy installation, workmanship
	Low-cost installation, and maintenance	Two ways must be closed in fault
	Easy access, and one way closed in fault	Low use factor, high glare factor
	Low-cost for installation, and maintenance	Blocking of ceiling light by high cars
	Easy installation and maintenance and ways open	Insufficient lighting, temporary

Technical specification of these lamps is shown in Table 4.

Table 4. Technical specification of lamps used in tunnels

Feature	IND Lamps	LED Lamp	Sodium HPS	Metal Halide
Illumination	Sudden	Sudden	5 min	5 min
Lifespan (hr)	100K	50K	24K	10K
Mercury (mg)	5	0	50	1000
LE (lm/W)	80	150	120	110
CRI	80	75	21	64
Consumption	Low	Low	High	High
Oscillation	None	None	Yes	Yes
Maintenance	Low	Low	High	High
Light Level Control	%50	%100	%50	%75

3. LIGHTING CONTROL INTERFACE

The tunnels are usually controlled by supervisory control and data acquisition (SCADA) software. Lamps, ventilation and values of luminance of access zone are controlled and detected by this system. Luminance of all regions except the interior zone of tunnel is different at daylight and night time. The luminance level of the access, transition and exit zones are adjusted from control center based on the information obtained from the photometer [11]. The efficiency factor of the light sources and the saving potential in tunnel are shown in Figure 2 and 3 [12, 13].

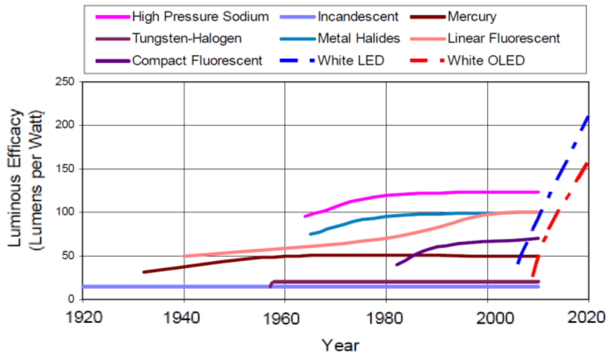


Fig. 2. Efficiency factor of the light sources by years

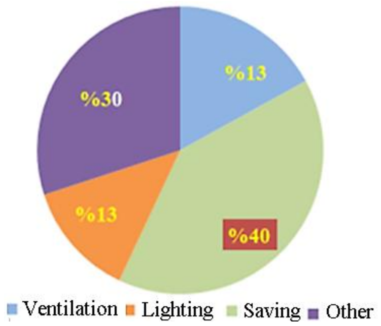


Fig. 3. Tunnel electricity consumption components and saving potential

Besides, data communication for lamp controlling is carried out via cable or wireless communication. Advantages and disadvantages of control interfaces are discussed below and compared in Table 5.

Table 5. The control interfaces of tunnel lamps

Feature	DSI	DALI	Wi-Fi
Setup difficulty	Low	Medium	High
Change difficulty	High	High	Low
Control distance	≤300	≤100	≤90
Number of controlled device	1	≤64	≤255
Independent control	None	Yes	Yes
Transmission media	Cable	Cable	Air

Digital Serial Interface (DSI): It was developed in 1992. Control information is transmitted by cable. The controller uses an 8-bit "*Manchester*" code for communication. The DSI units control the lamps with a DC supply of between 1 and 10V. For example; 1V means 10% of maximum light. Maximum length of control cable is average 100 meters and communication is single way. One DSI unit can control all the lamps of the interior zone [14].

Digital Addressable Lighting Interface (DALI): It is an advanced form of DSI. The difference from DSI is that many different companies' light sources can be controlled together from a single control system. 64 lamps can be controlled separately with the DALI interface. Maximum length of control cable is 300 meters (average). Other units, such as, ventilator, auxiliary lighting, air conditioning (HVAC), alarm signal etc. are controlled by adding other modules (KNX, LON) to DALI control system [15].

Control with Wireless Network: Wireless communication technologies, such as Wi-Fi, are also used in lighting applications [16]. A sample schematic of the LED lamps that can be controlled with Wi-Fi is given in Figure 4.

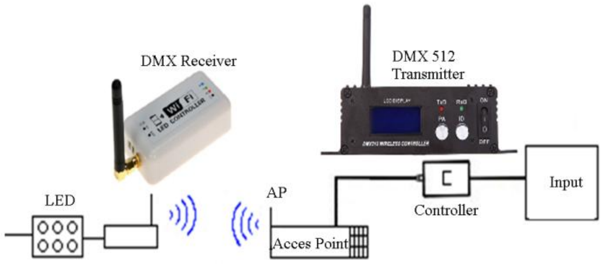


Fig. 4. Wi-Fi control equipment for lamps

4. PROPOSED METHOD FOR LIGHTING SAVING

The number of vehicles that pass through tunnels at night is usually less than the daytime. But lamps in interior zone are on all the times. This situation is not sustainable for energy saving. It is possible to save energy by pulling luminance to lowest level of CIE-88 standard when the vehicles are not in the tunnel zones at nights. The proposed control flow diagram for saving is shown in Figure 5. This method also helps to lower the joint temperature of the LED lamps. As a result, lifetime of LED lamps will increase.

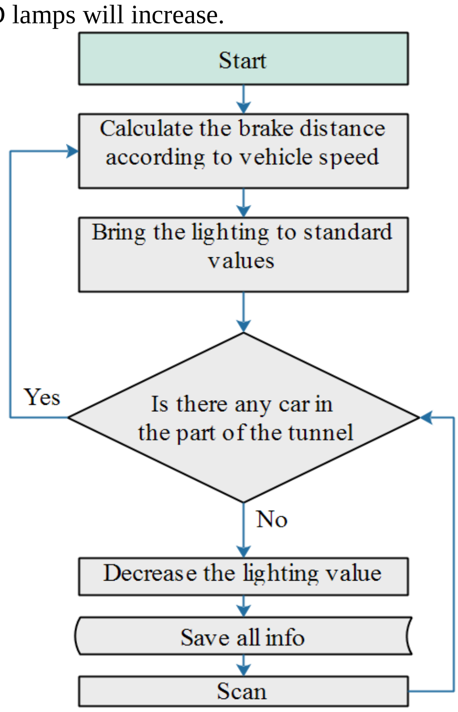


Fig. 5. Suggested flowchart for power saving

As a case study, Araklı Tunnel in Trabzon, Turkey was studied. The speed limit of the Araklı tunnel which is shown in Figure 6 is 80 km/h, and the total length is 1900 meters. The length of the interior zone which is shown Figure 7 is about 1600 meters, 160 lamps are positioned symmetrically totally. There are two 150 watt E-40 lamps in single armature. The luminance value of interior zone of the tunnel is 4.84 cd/m^2. This luminance level is kept throughout the tunnel. The amount of electricity consumed is 100 kW per hour and 825 MW per year. Total electricity consumption in 2015 is 289.960 TL (≈ 100.000 $) as shown in Figure 8 [17].

Fig. 6. Access zone of tunnel

Fig. 7. Interior zone of tunnel

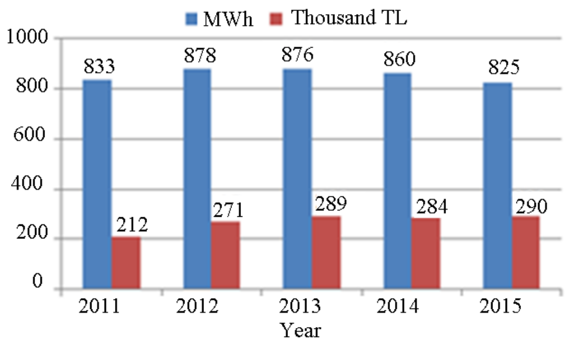


Fig. 8. Electricity consumption by tunnel lighting by years

The number of vehicles passing through the tunnel on years is shown in Figure 9. Number of vehicles passing through the tunnel between 4:00 a.m. and 5:00 a.m. is about 30, and shown in Figure 10 graphically in order to two different days in March 2016.

Braking distance of the vehicles is chosen 160 meter in current study. Interior zone of the tunnel is divided into 10 groups. The representation of these lighting groups is shown in Figure 11.

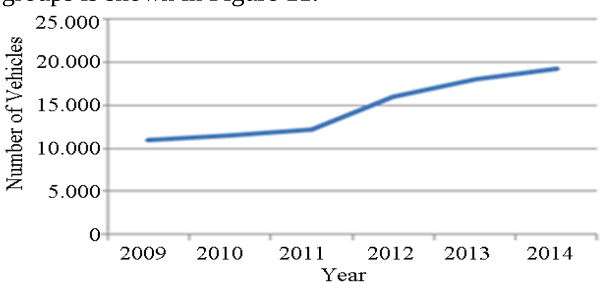


Fig. 9. Total number of vehicles pass through the Araklı tunnel by years

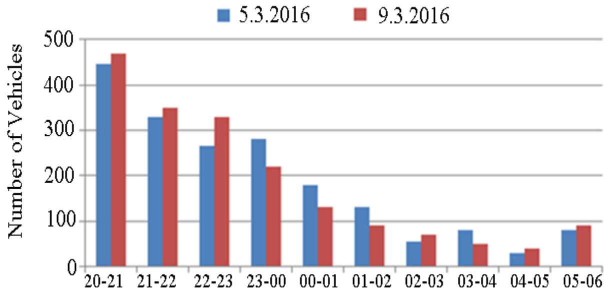


Fig. 10. Number of vehicles passes through tunnel during night time at two different dates

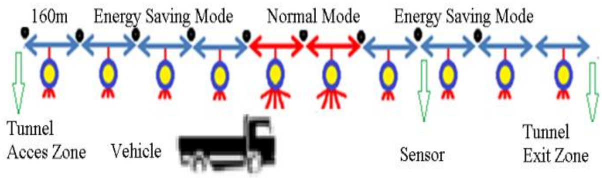


Fig 11. Representation of ten groups of the inner part of the tunnel

It was assumed that the car speed is 82 km/h and has passed all 10 lighting groups in 70 seconds. The lamps are controlled by sensors at the beginning of groups. The luminance of the two groups in front of the car is increased when the car enters into the next lighting group zone. The normal illuminated road length varies between 160 and 320 meters. A 75 Watt LED lamp was used instead of a 150 watt HPS lamp for efficiency. The use of LEDs allows the use of low power and cheaper in selecting power supply and generator.

A car can only affect two groups of lights while in tunnel-saving mode. Therefore, the other interior lamps of the tunnel are in saving mode. The control scheme of luminance of interior zone is shown in Figure 12.

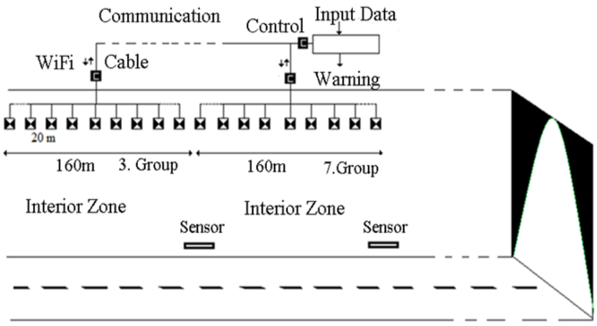


Fig. 12. The lamp control scheme of interior zone of tunnel

Saving rates and electricity consumption of interior zone are shown in Table 6. As it can be seen, the saving can be as high as 70 % when LEDs are used with half and full control.

Table 6. Savings rate between 4:00 am and 5:00 am

Operation Mode	Without Control (Full Power)		With Control (Full and Half)
Lamp type	Sodium	LED	LED
Energy (kWh)	24	12	7,2
Working time	70 sec	70 sec	14 or 56 sec
Saving rate	None	%50	%70

In addition, there are different ways to increase energy savings in long tunnels [18]. For example, lamps can be controlled individually with different control algorithms [19]. In addition, the road brightness value of the interior zone can be adjusted according to the vehicle speed of the road [20]. On the other hand, the problem that may arise in the detectors will adversely affect the luminance. When a problem is encountered, the level of luminance should remain constant at nominal level.

5. RESULTS

In this study, a simple control method is proposed to reduce energy consumption in tunnel illumination. The amount of annual savings is calculated theoretically for a number of vehicles that pass through Araklı Tunnel between 4-5 A.M. hours. Saving rate can further be increased by other control methods. The use of different types of lamps together for efficiency and economy is another solution that can be implemented. On the other hand, high power LED lamps are still expensive nowadays and their efficiencies are still under development. In addition, maintenance costs of tunnels other important factor. Also security should never be compromised while energy saving is achieved in consumption especially at speeds over 80 km/h of cars. Therefore, road lighting on accidents that may occur in tunnels should not be an element that creates an accident.

References

[1] Smart Cities Council, Smart Street Lighting 101: How advanced street lighting systems can transform cities in remarkable ways, (2015).

[2] Information Center, Republic of Turkey Ministry of Energy and Natural Resources, http://www.enerji.gov.tr/tr-TR/Sayfalar/Elektrik, (Last access date: 02/05/2018).

[3] S. Kılavuz, LED road lighting and energy efficiency, 9th National Lighting Congress in Izmir, Turkey, (2013).

[4] K. İzbek, Brake Distance in Tunnel Lighting Design and Some Misplaced Applications in Turkey,www.emo.org.tr/ekler/b5cfc2cb39ac654_ek.pdf (Last access date: 02/05/2018).

[5] G. Parise, L. Martirano, and L. Parise, The energetic impact of the lighting system in the road tunnels. In Industrial & Commercial Power Systems Technical Conference (I&CPS) IEEE IEEE/IAS 51st, 1-7, (2015).

[6] International Commission on Illumination, Technical Report CIE 088:2004, Guide for the Lighting of Road Tunnels and Underpasses, 3-5, (2004).

[7] K. İzbek, Tunnel Lighting Technique (In Turkish Language) Ege University Printing Office, ISBN-ISSN: 9944595802, 118-144, (2006).

[8] International Commission on Illumination, Technical Report CIE 088:1990, Guide for the Lighting of Road Tunnels and Underpasses, 30-36, (1990).

[9] Thorn Lighting Holdings Ltd, Tunnel Lightning http://ww.thornlighting.com/download/TunnelINT.pdf, (Last access date: 02/05/2018).

[10] F. J. Nogueira, and L. A. Vitoi, Street lighting LED luminaries replacing high pressure sodium lamps: Study of case, In Industry Applications IEEE (INDUSCON), 1-8, (2014).

[11] S. Cattini, and L. Rovati, Low-cost imaging photometer and calibration method for road tunnel lighting. IEEE Transactions on Instrumentation and Measurement, 61(5), 1181-1192, (2012).

[12] Lighting Unit's, Lighting Technologies, http://www.lightinglab.fi/IEAAnnex45/guidebook/5_lighting%20technologies.pdf, 93-134, (Last access date: 02/05/2018).

[13] R. Dzhusupova, J.F.G. Cobben, and W.L. Kling, Zero energy tunnel: Renewable energy generation and reduction of energy consumption. In Universities Power Engineering Conference (UPEC), 47th IEEE International, 1-6, (2012).

[14] Tridonic, Lighting Control System, http://www.tridonic.com/ae/download/data_sheets/DS_smartDIM_SM_lp_en.pdf, (Last access date: 02/05/2018).

[15] SGS Lighting Solution, http://sgslight.com/led-panel-work-with-dali, (Last access date: 02/05/2018).

[16] M. Magno, T. Polonelli, L. Benini, and E. Popovici, A low cost, highly scalable wireless sensor network solution to achieve smart LED light control for green buildings, IEEE Sensors Journal, 15(5), 2963-2973, (2015).

[17] Trabzon Tenth District Directorate of Highways, Technical Documents, (2016).

[18] H. Zeng, J. Qiu, X. Shen, G. Dai, P. Liu, and S. Le, Fuzzy control of LED tunnel lighting and energy conservation, Tsinghua Science & Technology, 16(6), 576-582, (2011).

[19] D. Wang, H. Jiang, J. Ma, and X. Zheng, Dynamic Dimming Control Method Research on Tunnel LED Lighting Based on LED Controllability, In Remote Sensing, Environment and Transportation Engineering (RSETE), IEEE. 2nd International Conference, 1-4, (2012).

[20] H. Yi, L. Changbin, W. Aiguo, and F. Shouzhong, LED lighting control system in tunnel based on intelligent illumination curve, In Intelligent Computation Technology and Automation (ICICTA), IEEE. Fifth International Conference, 698-701, (2012).

Biography

Alkan AKSOY was born in, 1980 in Trabzon, Turkey. He received his B.Sc. and M.Sc. degree in Electrical & Electronics Engineering from Karadeniz Technical University (KTU) in Trabzon, Turkey, in 2003 and 2016 respectively. He is currently a Lecturer in Electricity and Energy Department of KTU Sürmene Abdullah Kanca Vocational School. He is also Ph.D. candidate at Atatürk University.

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