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Analysis of obstacle perception distance by road lighting condition depending on obstacle reflectivity

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Abstract: *For the sake of the driver's safety, appropriate road luminance andluminance contrast shall be provided through road lighting so as to be able to identify the alighment change and obstacle at a certain distance.The brigher the road surface the betetr the visibility to recognize the alighment change by the driver. But whether to identify the risk such as the obstacles ahead is determined by the difference in brightness between the road surface abd obstacle (luminance contrast) Luminance contrast caries deoending on bilateral symmetry, light distribution method such as probea and counter beam and the height of light source such as pole lighting and low-mounted road ligthig. This studyis intended to identify the obstacle sighting distance through the road test with probeam, low-mounted road lighting, pole lighting with symmetric light distribution and headlight (low & high beam) and furthermore, evaluate the visibility by comparing the performance of luminance contrast by type of lighting. As a result, when it comes to pole lighting, the higher the obstacle reflectivity the shorter the obstacle sighting distance but the longer the obstacle sighting distacne in case of the low-mounted road lighting. When driving with high beam lighting and low beam ligting on road without lighting facilities, the higher the obstacle reflectivity the longer the obstacle sighting distance in proportion.* .

Keywords: *Nighttime, Visibility, Pole lighting, low-mounted lighting, headlight*

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I. Introduction

Road lighting is ultimately intended to provide the drivers with appropriate visibility to ensure the drivers secure sufficient time and distance to avoid the risk when finding 'alignment change' or 'obstacles' ahead.

The visibility is defined as the characteristics that the existence of visual target or shape is easily distinguishable even at a great distance and the higher the luminance contrast the greater the visibility. Luminance contrast is defined as the difference in luminance between the visual target and neighboring object in ratio or others.

When the road surface is getting brighter, the driver could see the alignment change better, but the recognition of the obstacles ahead is dependent on the difference in brightness between the road surface and obstacle (luminance contrast) Current road lighting standard wrongly assumes that when the road luminance is higher, it's easier to identify the obstacle without mentioning about the luminance contrast. The pole lighting designed in compliance with the current road lighting standard is costly because of high lighting fixture and pole and requires a huge energy consumption to increase the road luminance and lighting angle is limited due to symmetric light distribution system which makes difficult to enhance the luminance contract between the road and obstacle.

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II. Theoretic Review

II-I. Comparison of road lighting standards

CIE 115 (Commission Internationale de l'Elairage, 2010) is based on luminance concept that evaluates the road lighting quality (grade) based on luminance distribution on road (mean luminance or uniformity ratio of luminance) which has been adopted in most of countries in the world. Schreuder (2008) asserted that "the level of adaptation" is the only factor which the engineer can control to enhance the probability to find the obstacle and since the obstacle on road is mostly the negative contrast (dark object), the brighter the road surface which is the background of the obstacle the higher the luminance contrast and the greater the visibility. Thus according to this logic, improving the road lighting level, that is, improving the luminance is the most clear way to enhance the visibility.

Table:1 Grade of road lighting based on luminance, CIE 1152010

Lighting class	Road surface				Threshold increment	Surround ratio
	Dry			Wet *		
	L_{av} in $cd \cdot m^{-2}$	U_o	U_l	U_o	f_{TI} in %	R_s
M1	2,0	0,40	0,70	0,15	10	0,5
M2	1,5	0,40	0,70	0,15	10	0,5
M3	1,0	0,40	0,60	0,15	15	0,5
M4	0,75	0,40	0,60	0,15	15	0,5
M5	0,50	0,35	0,40	0,15	15	0,5
M6	0,30	0,35	0,40	0,15	20	0,5

*Applicable in addition to dry condition, where road surfaces are wet for a substantial part of the hours of darkness and appropriate road surface reflectance data are available.

On the contrary, RP-8 (American National Standards Institute, 2005) adopts the visibility concept that evaluates the road lighting quality (grade) based on luminance contrast between the road surface and luminance along with the luminance concept. Visibility concept is based on STV (Small target Visibility) method, which was developed from the Revealing Power and Visibility Level (VL) approach. It's the method to weighted average the visibility level calculated for many small obstacles (reflectivity 50%) depending on risk level which is then used as the standard to measure the visibility (quality of road lighting) (Schreuder, 1998, 2008)

Table 2 Small target visibility, RP-8, 2005

Road and Pedestrian Conflict Area		STV Criteria	Luminance Criteria		
Road	**Pedestrian Conflict Area**	**Weighting Average** VL	L_{avg} cd/m^2 Median <7.3 m	L_{avg} * cd/m^2 Median ≥7.3 m	**Uniformity Ratio** L_{max}/L_{min} (Maximum Allowed)
Freeway "A"		3.2	0.5	0.4	6.0
Freeway "B"		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

Table based on a 60 year old driver with normal vision, an 18 cm x 18 cm (7.1 in. x 7.1 in.) 50 percent reflective target, and a 0.2 second fixation time.

For perception of the obstacle ahead by the driver at night, obstacle and the road surface which serves the background shall be greater than the critical luminance contrast which is the boundary for perception. Critical luminance contrast is dependent on adaptation luminance, critical obstacle size, contrast polarity of critical obstacle, observation time by the driver and driver age. Adrian (1989) based on such concept developed the VL (Visibility Level) to quantitatively evaluate the driver's perception capability considering the luminance contrast. VL is the method to evaluate the visibility based on difference in luminance between the obstacle and road surface and evaluates based on difference in luminance between required luminance ( ) and actual road luminance ( ) Adrian (1989) developed VL method in consideration of the lab test result of Blackwell (1946) and the study on drivers' visual capability Blackwell (1946), Aulborn (1964), Adrian (1969), Berek (1943), Schmidt-Chussen (1969) and Blackwell (1989) Theoretically, it possible to find the obstacle when VL is 1 but for the drivers driving the road at night, many other driving tasks are required and for such reason, VL threshold for obstacle perception shall be greater than the value from the test (E Dumont et al, 2008) A field factor which is represented by VL ratio required by lab condition and actual road condition at night is usually 1 ~ 20 range (Dunipace et al, 1974), Ising et al, 2003, Adrian et al, 2005)

Equation to estimate VL is as Equation (1)

$$VL = \frac{\Delta L_{\text{actual}}}{\Delta L_{\text{threshold}}}$$

$$\Delta L_{\text{actual}} = L_t - L_b \quad \Delta L_{\text{threshold}} = k \cdot \left(\frac{\Phi^{1/2}}{\alpha} + l^{1/2}\right)^2 \cdot F_{CP} \cdot \frac{a(\alpha;\, L_b) + t}{t} \cdot AF \qquad (1)$$

VL	visibility level	F_{CP}	contrast polarity factor
L_t	target luminance (cd/m²)	$a(\alpha;\, L_b)$	parameter depends on size of target and background luminance (−)
L_b	background luminance (cd/m²)	t	observation time (s)
Φ	luminous flux function (lm)	AF	age factor
l	luminance function (cd/m²)	k	factor for the probability of perception
α	angle of substance of the target at observer's eye (′)		

Fig.1 Concept of Visibility level

II-IIComparison of road lighting methods

A symmetric light distribution has the limit in identifying the obstacle from a far distance because of low luminance contrast between the road and obstacle. Existing pole lighting according to CIE 115 (2010) is designed to radiate the light symmetrically at 9 to 15m high for economic and technical reasons and a low-mounted lighting system also adopts same bilateral symmetric light distribution system as pole lighting system. While existing pole lighting radiates the light downward, low-mounted lighting radiates the light from the side, which is the only difference between two systems.

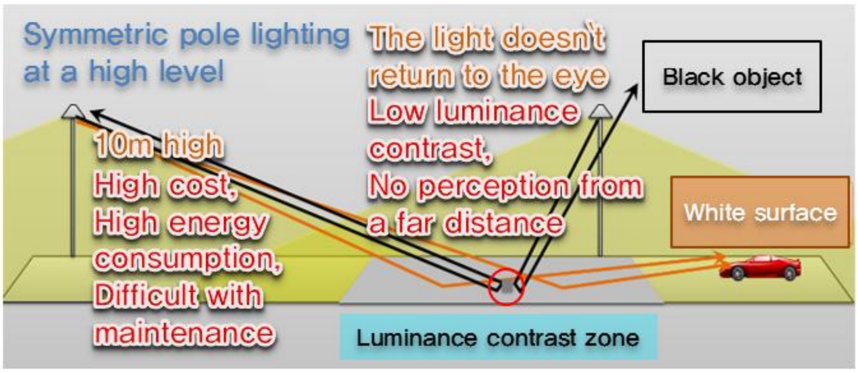

Fig.2 Principle of luminance contrast of pole lighting

A low-mounted lighting using probeam light distribution (Low-mounted lighting) addressed in this study is developed to cope with the technical limit of existing pole lighting and low-mounted lighting with symmetric light distribution. A low-mounted lighting has the advantage in cost, energy consumption, light pollution and maintenance when comparing with the pole lighting system and probeam radiates the light forward as the headlight of the vehicle so as to create positive contrast that makes the obstacle brighter than road surface and is effective in maximizing the luminance contrast, mitigating the dazzling and increasing the distinguishing capability.

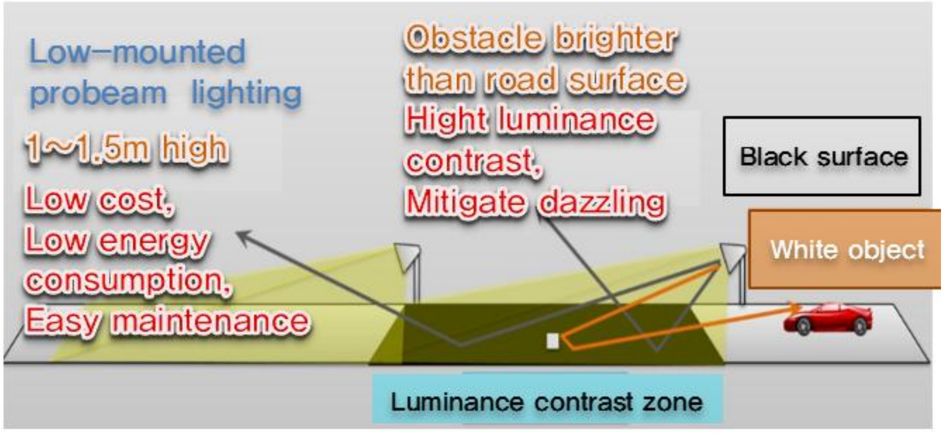

Fig.3 Principle of luminance contrast of low-mounted probeam

III Development of low-mounted probeam road lighting system and performance evaluation

III-I. Development of low-mounted probeam road lighting

A low-mounted lighting using probeam light distribution (Low-mounted lighting) addressed in this study is developed to cope with the technical limit of existing pole lighting and low-mounted lighting with symmetric light distribution. A low-mounted probeam light distribution system radiates the light forward as the headlight of the vehicle so as to create positive contrast that makes the obstacle brighter than road surface and is effective in maximizing the luminance contrast, mitigating the dazzling and increasing the distinguishing capability. In this study, Optical system combining the reflector and lens applicable to a 4-lane road was designed to apply to low-mounted lighting.

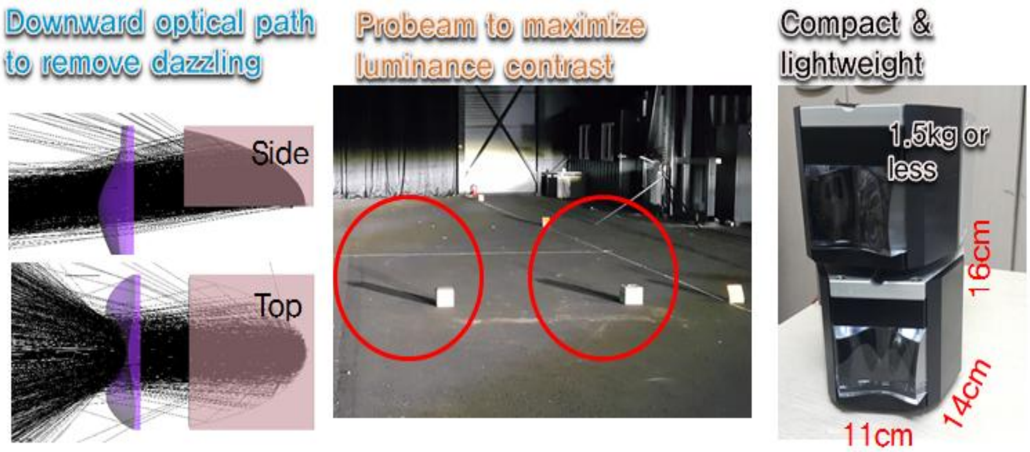

Fig.4 Feature of lighting system developed

III-II Evaluation of luminance contrast performance of low-mounted probeam road lighting

III-II-I Test method and procedure

In this study, vehicle running test was conducted on track in similar environment as real road to identify the sighting distance of probeam lighting (developed system), pole lighting and vehicle headlight, that is, luminance contrast performance. 15* 15* 15cm3 paper boxes with reflectivity 5, 10 and 20% were used as the obstacle and was set at low-mounted lighting zone, pole lighting zone and no lighting zone, respectively. At low-mounted lighting and pole lighting, the car ran at low beam lighting. No lighting zone was divided into two zones and the car ran at high beam and low beam lighting separately.

Perception distance was calculated using GPS and software. Software calculates the distance between the driver and obstacle based on GPS coordinates of current location and obstacle location when the driver who finds the obstacle pushes the button. Total 8 subjects participated in the experiment and the cars were RV and sedan.

The subject ran the track 4 times by reflector and 2 times by RV and 2 times by sedan. Total 12 times were made by each subject (3 types of reflector * 4 times) and perception distance was measured 48 times by each subject (3 types of reflector * run 4 times * 4 segments)

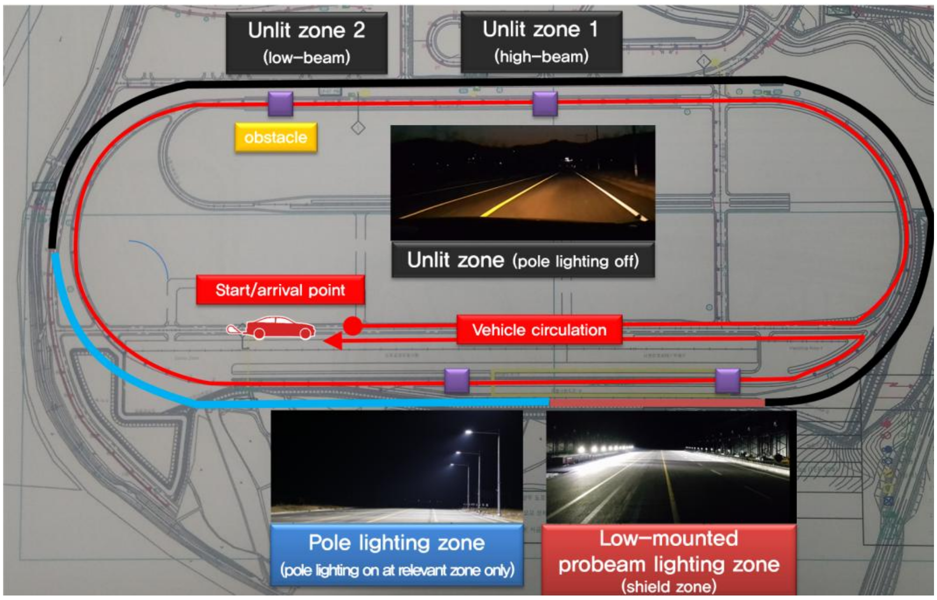

Fig: 5 Experiment summary

Fig:6 Obstacles (pole lighting zone, reflectivity 10%)

III-II-II Experiment result

The data collected was analyzed depending on lighting conditions (developed lighting system, pole lighting and no-road lighting (high bean and low beam) and obstacle reflectivity (5, 10 and 20%) and perception distance in % by combined condition was obtained. Sighting distance in % was estimated according to ascending order. For instance, 25% obstacle sighting(perception) distance means that at the relevant lighting and obstacle reflectivity condition, 25% of the subject could identify the obstacle at the farther distance while 75% could find the obstacle at the nearer distance.

As a result of analysis, obstacle sighting (perception) distance was dependent on flexibility of the obstacle. Low-mounted probeam lighting had the longer perception distance than low beam lighting at no-lighting condition based on 8% flexibility and based on 8 to 12%, perception distance was longer than the pole lighting. When the obstacle flexibility is 15% or higher, perception distance of low-mounted lighting was longer than the high beam lighting at no road lighting condition. More specifically, as a result of analyzing the 25% obstacle perception distance, perception distance of the pole lighting was 77m, the longest, at the flexibility 5% condition, which was followed by high beam lighting at no- road lighting condition (51m), low beam lighting at no road lighting condition (31m) and low-mounted probeam lighting (28m) At obstacle flexibility 10% condition, obstacle perception distance of high beam at no road lighting was 64m, pole lighting was 62m, low-mounted probeam lighting was 44m and low beam lighting at no road lighting was 35m. At obstacle flexibility 20% condition, low0mounted probeam lighting was 118m, high beam at no road lighting was 91mm and low beam at no road lighting was 56m and pole lighting was 31m.

Generally, when it comes to pole lighting, the higher the obstacle flexibility the shorter the perception distance, but in case of low-mounted probeam, the longer the obstacle perception distance significantly. When the car was running with low beam and high beam lighting at no road lighting condition, the higher the obstacle flexibility the longer the obstacle perception distance. When the flexibility was relatively lower (5 to 10%), pole lighting had the longest perception distance and when it was 15% or higher, low-mounted probeam lighting developed in this study had the longest obstacle perception distance.

Table 3 Obstacle perception distance by lighting and obstacle condition

reflectivity	Classification	Obstacle perception distance (m)			
		unlit (high beam)	unlit (low beam)	pole lighting	low-mounted lighting
5%	average	57	34	104	28
	standard deviation	9.7	7.4	32.4	20.2
	25perentile	51	31	77	15
	50perentile	59	33	98	27
10%	average	70	43	87	57
	standard deviation	15.6	10.4	34.8	19.1
	25perentile	64	35	62	44
	50perentile	72	45	84	53
20%	average	104	65	37	141
	standard deviation	14.9	15.1	11.4	34.5
	25perentile	91	56	31	118
	50perentile	103	62	35	146

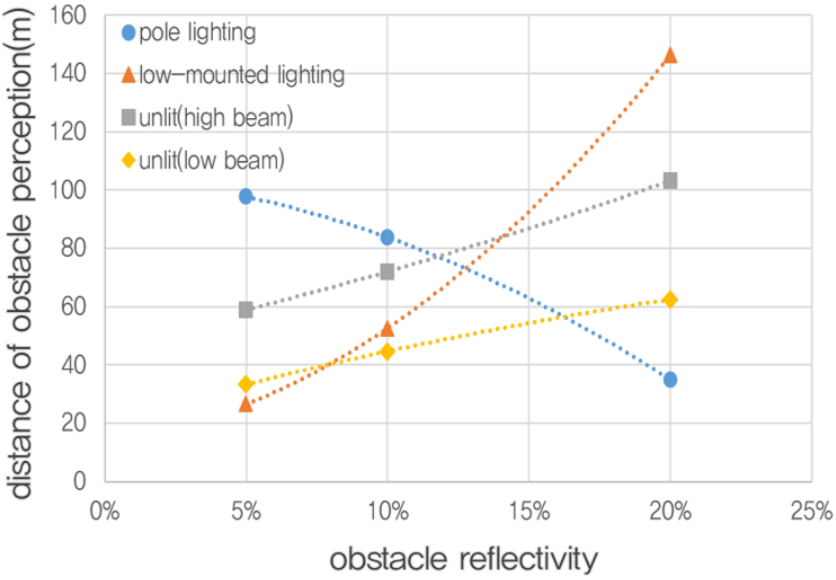

Fig: 7 Analysis of 50% obstacle perception distance
(Distance when 50% of drivers identified the obstacle)

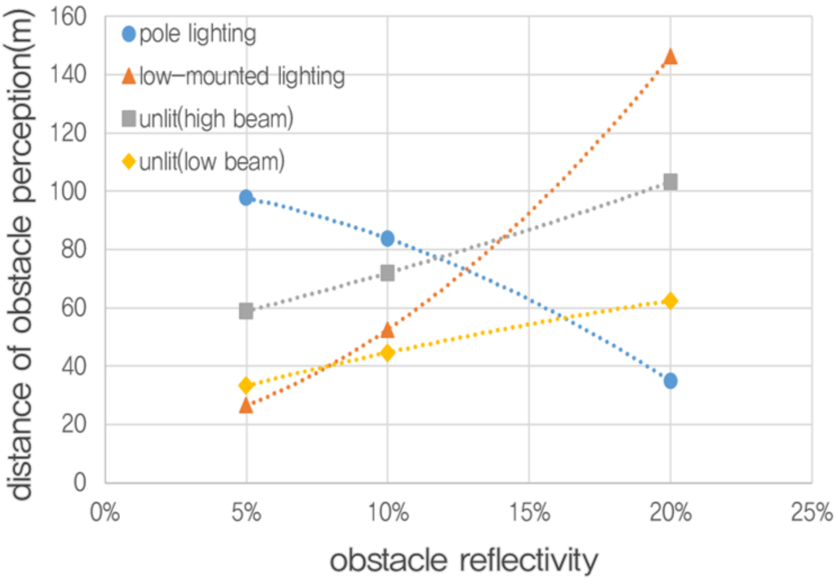

Fig 8 Analysis of 25% obstacle perception distance
(Distance when 75% of drivers identified the obstacle)

III. Conclusion

Whether to be able to identify the risk such as obstacle ahead on road at night is dependent on brightness of the road surface and obstacle (luminance contrast) Each lighting system has different height of light source and radiation angle, making luminance relation between the road surface and obstacle different (degree of luminance contrast) That is, obstacle perception distance is different.

The pole lighting which is the most common road lighting system radiates the light downward symmetrically, which allows the strong light on road surface but has the limit with the obstacle. Thus, at low reflectivity condition, road surface becomes brighter while the obstacle becomes darker, making it possible to secure the certain level of luminance contrast. On the contrary, at high reflectivityy condition, brightness on road surface and obstacle becomes similar and thus the luminance contrast is low. Vehicle headlight radiates the light forward but the lighting distance is limited and thus at the farther distance, both obstacle and road surface are darker, causing low luminance contrast while within the certain distance, obstacle becomes brighter than the road surface and thus the luminance contrast is higher. Low-mounted lighting system developed in this study has the similar principle as the vehicle headlight in securing the luminance contrast and as installed along the road continuously, driver could keep identifying the obstacle at the great distance. In this study, variation of perception distance depending on road lighting, vehicle headlight and obstacle reflectivity condition, that is, variation of visibility, was analyzed. Consequently, visibility varies significantly depending on lighting condition. Particularly, because of the principle of luminance contrast depending on lighting condition, the higher the obstacle reflectivity the longer the obstacle perception distance, comparing to the pole lighting, when running the road at high beam or low beam lighting on road without the lighting system. Such result indicates that visibility is not enhanced by simply increasing the luminance on road surface or obstacle but luminance contrast or luminance relations between the road surface and obstacle is the important factor that determines the visibility.

It's necessary to identify the principle of luminance contrast depending on lighting system as well as develop the various lighting systems based on such principle, thereby creating the environment for the drivers to drive the road safely at night.

Acknowledgements

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