Enhancement of the Lighting and Control System of Aberdeen Tunnel

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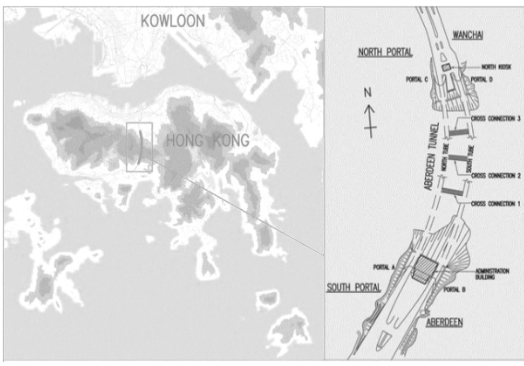
Synopsis

Tunnel Lighting and Control System (TLCS) is one of the most critical systems of a road tunnel to ensure safety and to provide visual comfort for the motorists. Aberdeen Tunnel, a 1.9 km long two-tube road tunnel, linking the north and the south of Hong Kong Island, was commissioned in 1982. The existing TLCS has been put in service for over 30 years. Its failure in any aspects will cause inconvenience to tunnel users and adversely affect the traffic to the Southern District or even the whole Hong Kong Island. To enhance reliability and efficiency, the TLCS will be replaced in order to meet current energy efficiency requirements, to provide better lighting control and to be in compliance with the latest design standards. The project will involve the replacement of about 3,600 sets of tunnel luminaires, a lighting control system, and modification of the power supply with dual supply sources.

This paper presents the background information, design criteria, system enhancement and the anticipated challenges in this replacement project.

1. Background Information

Aberdeen Tunnel marks an important improvement in road communications between the southern side and the commercial areas on the north shore of Hong Kong Island. The two-tube tunnel, with the carriageway measuring 6.75m wide and the clear headroom of 5.1m, runs through Mount Cameron and Mount Nicholson. Each tunnel tube has two traffic lanes and carries traffic from Aberdeen to the northern part of Hong Kong Island and the Cross-Harbour Tunnel, thus relieving congestion on the road at the western Mid Levels. The daily flow was 65,000 vehicles in 2012.



Location of Aberdeen Tunnel

The existing tunnel lighting system has been in use since 1982 following the tunnel commissioning. The TLCS has reached the end of its serviceable life. Any failures in the lighting system will cause inconvenience to tunnel users and adversely affect the traffic between the Southern District and other parts of Hong Kong Island. It will also very likely have a knock-on effect on other major road networks on the Island. To enhance the reliability and efficiency of the tunnel lighting system as well as the safety of tunnel users, replacement of the system is deemed necessary.

2. Tunnel Lighting System

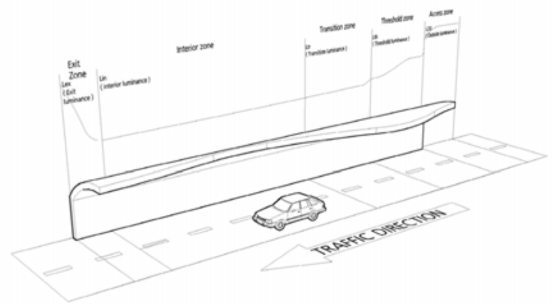
The objective of a tunnel lighting system is to ensure that traffic can enter, pass through and leave the tunnel, day and night, with the same level of safety as on the approaching open roads. To achieve this, it is necessary for the carriageway to be clearly visible throughout the length of the tunnel, and that the carriageway and tunnel walls give a clear view of the road. In further details, the lighting must meet the following requirements[i]:

- The lighting shall give the carriageway an adequate luminance level, and the luminance shall be uniformly distributed over the carriageway, in wet and dry conditions;
- The lower part of the tunnel wall must receive an adequate level of luminance;
- The lighting must not give rise to glare; and
- The lighting must not produce flicker.

The most important function of tunnel lighting is to illuminate the tunnel sufficiently to enable the drivers to see all that needs to be seen during the entire passage of the tunnel. Tunnel lighting is most critical during daytime because the eye, accustomed to daylight, cannot immediately adapt to the relative darkness of the tunnel. As it takes time for the eye to adapt, it is necessary for the light intensity to decline from daylight to the lower level in a tunnel over a certain distance. If the lighting level is not high enough, the driver will be unable to see inside the tunnel, the so-called “black hole effect”.[ii]

3. Design Criteria

A. <u>Lighting Zones</u>



Lighting zones of a Road Tunnel

In designing tunnel lighting systems, it is necessary to take care of good visibility conditions for the motorists, which require lighting levels that match the adaptation of the motorists’ eyes. As the adaptation level gradually changes throughout the tunnel, for lighting purposes, a tunnel can be divided into five lighting zones[iii], namely the access, threshold, transition, interior and exit zones.

B. Luminance Requirements

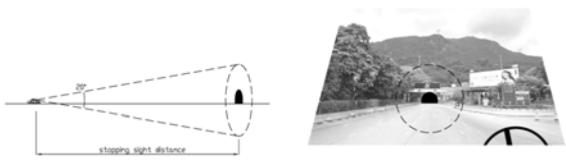
Stopping sight distance

It is the forward distance required by a motorist, driving at a designated speed, to bring a vehicle to a complete standstill safely. It covers the distance for perception, reaction and breaking. The stopping sight distance is a function of design speed as shown below:

Design Speed (km/h)	50	60	70	85	100
Stopping sight distance (m)	50	70	90	120	160

Luminance of the Access Zone: L_{20}

Luminance of the access zone can be determined by direct measuring the average luminance from surroundings, sky, tunnel entrance and road in a visual cone of 20^o, centred on the line of sight of the driver from the beginning of the access zone[iv].



Measurement of Luminance at Access Zone

Alternatively, L_{20} can be estimated during the initial design stage by using typical luminance values of different types of background surrounding the entrance of the tunnel.

Typical luminance ranges from a few thousand to tens of thousand Cd/m^2.

Luminance of the Threshold Zone: L_{th}

The maintained average road surface luminance over the first half of the threshold zone $L_{th(1)} = k\ L_{20}$ where k equals to:

Design Speed (km/h)	**k value**
50	0.04
60	0.04
70	0.05
85	0.05
100	0.07

The lighting level for the other half of the threshold zone ($L_{th(2)}$) may gradually and linearly reduce to 0.4 $L_{th(1)}$ at the end of the threshold zone.

Luminance of the Transition Zone: L_{tr}

The minimum lighting level required is depicted by the formula[v]:

$L_{tr} = L_{th(2)}\ (1.9 + t)^{-1.4}$ where t is the time in second a motorist enters the transition zone. The end of the transition zone is determined by the lighting level that has been dropped to three times the lighting level in the interior zone.

Luminance of the Interior Zone: L_{in}

The lighting level in the interior zone at various design speeds is stipulated as follows:

Design Speed (km/h)	**Daytime Interior Zone maintained Average Luminance (Cd/m^2)**
50	4-5
60	4-5
70	5-6
85	5-6
100	8-10

Luminance of the Exit Zone: L_{ex}

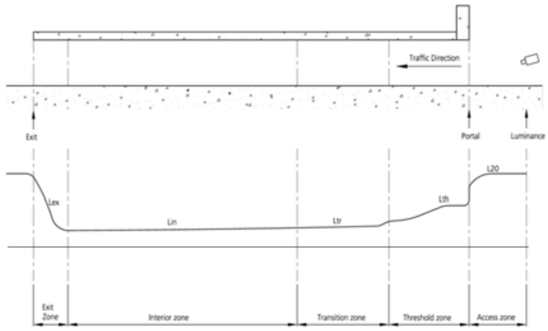
Exit zone lighting shall be provided to assist egress adaptation and enable motorists to view the following traffic by rear view mirrors. The lighting level over the last 60m of the tunnel shall be 5 times the level of the interior zone.

The luminance requirements for the different lighting zones of a road tunnel are summarized as follows:

Zone	Luminance	Remark	Typical (Cd/m^2)
Access	L_{20}	By measure-ment / Estimation	5,000
Threshold	1st half: $L_{th(1)}$: 0.04-0.07 L_{20} 2nd half: $L_{th(2)}$: $L_{th(1)}$ ⇨ 0.4$L_{th(1)}$	Reduction of lighting level between successive steps shall not exceed 3:1	250 ⇨ 100
Transition	$L_{tr} = L_{th(2)} (1.9 + t)^{-1.4}$ ⇨3L_{in}		100 ⇨ 15
Interior	L_{in}	4-10 Cd/m^2	5
Exit	$L_{ex} = L_{in}$ ⇨ 5 L_{in}	-	5 ⇨ 25

The lighting level at the entrance of a tunnel, i.e. threshold zone, is much higher than that at the exit zone because the adaptability of the eye on between entry to a tunnel from daylight and leaving from a tunnel into daylight is not symmetrical. The eye adapts far more quickly to the higher luminance level for the latter case.

Typical Longitudinal Section of a Tunnel



Luminance Profile of a Road Tunnel

4. System Enhancement

A. <u>Lighting Luminaires</u>

All existing T8 luminaires will be replaced by T5 luminaires. Under normal conditions, T5 luminaires have a higher luminance efficacy (lm/W) than that of T8 luminaires and are designed for operating with electronic ballasts with greater efficiency. For instance, a 28W T5 luminaire consumed only 30W circuit power and achieved a saving of 36% as compared with 36W T8 luminaire with conventional ballast[vi].

As the diameter of T5 tubes is much smaller than its T8 counterparts, and is closer to a line source, optical control of luminaires with T5 lamps can be more precise and efficient, and hence result in less glare.

B. <u>Lighting Control System</u>

At present, all the tunnel lighting luminaires are controlled by hard-wired contactors. The lighting control can be determined either manually or automatically by means of photometers, installed at both ends of the tunnel, which detect the lighting level outside the tunnel.

There are altogether 6 lighting stages in accordance with different lighting intensities outside the tunnel. However, such control system lacks the flexibility in meeting the change in programmed scene, re-grouping of luminaires and integration of settings in a daylight-dependent control system.

The new TLCS will be operated with DALI (Digital Addressable Lighting Interface) as the communication interface for the lighting system. A DALI network consists of a controller and one or more lighting devices such as ballasts and dimmers that interfaced with DALI. The controller can monitor and control each light by means of a bi-directional data exchange. The DALI protocol permits devices to be individually addressed and it also incorporates broadcast messages to simultaneously address multiple devices, leading to the flexibility in the control of the lights, without the need for formidable wiring connections.

On the other hand, the TLCS will be equipped with a powerful and versatile 32-bit CPU. The master CPU will switch over to the standby CPU within 50ms when the master CPU fails. Redundancy will also be provided for the power supply and the network communication.

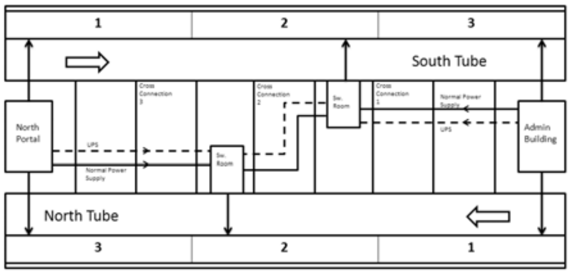
Four modes of operation will be provided:

- Automatic Mode with 6 lighting stages;
- Remote Manual Mode;
- Local Manual Mode;
- Traffic Operation Mode.

The new TLCS will feature distributed intelligence for flexible and reliable control. The control of lighting can be applied to both individual lights and groups of light. In case of changing circumstances, configuration and reconfiguration will be simple by changing the settings of the system without any re-wiring. One added advantage of the system is that the logarithmic dimming behaviour of the system matches the characteristic of human eyes and results in a much smoother transition between different stages of lighting.

C. <u>Main Power Supply System</u>

The power supply system of the tunnel is composed of two separate municipal main power sources and two Uninterruptible Power Supplies (UPS).

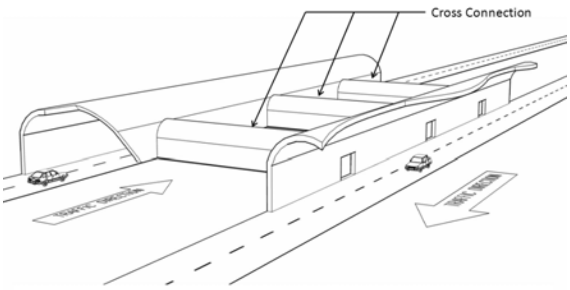


Existing Power Supply Arrangement

For the existing design, tunnel lighting luminaires of the proximal end of approximate two-thirds of the South Tube and one-third of the North Tube are fed from the main power source at the Administration Building (South Portal) and similar arrangement for the rest fed by the main power source at the North Portal.

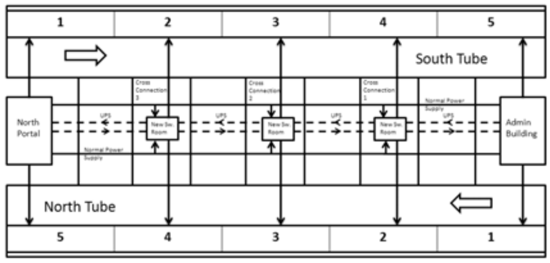
Should either one of the main power sources fail, approximately 60% of the lighting can be maintained; and in case of both of them fail, about 20% can be maintained by means of the UPS.

Nevertheless, the existing arrangement lacks the integrated support by the two separate municipal main power sources, and the two UPS sources. In this project, the reliability of the tunnel lighting system will be further enhanced by rearranging the municipal main power supply sources and the UPS. In re-designing the power supply system, we make use of the three cross connections between the North Tube and the South Tube of the tunnel as shown below:



Cross Connections of Aberdeen Tunnel

New switch boards will be erected inside the three cross connections so that the municipal main power supply from the North Portal and the South Portal can reach the whole length of the tunnel and provide power to any part of the tunnel.



New Power Supply Arrangement

In the new design, about half of the luminaires in the whole length of the South Tube and those of the North Tube will be fed from the municipal main power sources at both the North Portal and the South Portal. In case where either one of the main power sources fails, the tunnel luminaires will be 100% supported by the other healthy main power source by automatic transfer switching. Even when both main power sources fail, 40% of the lighting can be maintained by the UPS.

5. Anticipated Challenges in Project Management

A. Interface between existing and new systems

In order to maintain the normal operation of the tunnel in daytime during the replacement period, the interface between the existing and the new system has to be well planned ahead. As there will be difference in the luminance and zoning between the existing system and the new system, the way to ensure a seamless transition from the existing system to the new system, and to ensure no interruption of tunnel service by maintaining a reliable TLCS during the installation period has to be carefully devised. One of the possible ways may be that the new system is to be installed without disrupting the integrity of the existing system and in case of any hiccups, the TLCS can be reverted to the existing system right away until the problem is solved. However, this is subject to the constraints of space, additional work and prolonged work period.

B. Night Time Work

Nearly all the works have to be carried out at tunnel closure time in order not to affect the normal traffic during daytime. In this regard, most of the site work has to be carried out around the midnight period. Work programme has to be carefully planned ahead in order to tally with the tunnel closure time on one hand, and to ensure that work can be completed in time on the other.

C. Wall Panels

Preliminary design indicates that both power cables and control wires will have to be laid on cable ladders to be installed inside the wall panels. In order to facilitate the erection of cable ladders, the laying of cables and the installation of saddles and cleats, a number of wall panels will have to be taken apart during the working period. Normally, the wall panels can only be taken apart during inspection checks arranged by the tunnel maintenance party. Extensive coordination work will be required to match our installation programme with the inspection check schedules.

D. Luminance Measurement

In order to capture the existing luminance profile of the tunnel, a number of measurements will have to be carried out during the tunnel closure period. However, in case where measurements have to be taken in daytime with tunnel closure such as the measurement of the luminance of the Access Zone (L_{20}), the operator will definitely disapprove of such proposal because of the heavy traffic unless the measurement can be done in a really short period. In this regard, adequate preparation with detailed method statement approved by all stakeholders including the relevant government departments and the tunnel operator is necessary. In order to minimize any possible muffs during actual measurement, prior arrangement with trial runs by the measuring team will have to be planned.

6. Conclusion

Despite the constraints mentioned above, we have confidence that after completion of the work in late 2015, the new TLCS will become more environmentally friendly and flexible in operation, and the new power supply system will be more reliable. All in all, the reliability and efficiency of the TLCS will be significantly enhanced.

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[i] Road Tunnel Lighting, Common Nordic Guidelines, Nordic Road Federation, 1995.

[ii] Lighting of Tunnels, BS5489-2, 2003.

[iii] Public Lighting Design Manual, Highways Department, HKSAR, 2006.

[iv] Tunnel Lighting, Thorn, 2004.

v Guide for the Lighting of Road Tunnels and Underpasses, CIE88:2004.

vi Guidelines on Energy Efficiency Equipment – T5 Fluorescent Lamps, Electrical and Mechanical Services Department, HKSAR.