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Economic Evaluation of LED Luminaires for Tunnel Interior Zones

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Abstract

There has been a need for the systematic evaluation of the economic efficiency between conventional fluorescent lamp lighting systems that have been used in tunnels and LED lighting systems. This study has evaluated basic tunnel lighting between the conventional fluorescent lighting systems and the LED lighting system using the evaluation tool of tunnel lighting by Life Cycle Cost (LCC) and using the economic efficiency evaluation method. In addition, the unit discount rate of the LED lighting system and the estimated increase in the price of electricity have made the estimated cost of LCC the same if two luminaires were used in the basic part of the tunnel.

Key Words : Economics Evaluation, Life Cycle Cost(LCC), Interior Zone of Road Tunnels

1. Introduction

For saving energy and applying low-CO_2-emission LED luminaires to basic tunnel lighting, it is necessary to assess the economic efficiency of the tunnel lighting environment and lighting conditions. LED luminaires differ from conventional basic tunnel lighting - fluorescent lamps - in terms of unit price, installation cost and luminous flux. After analyzing and estimating these input factors, this study has assessed economic efficiency. To apply the same LCC based on the evaluation of the economic efficiency between the two luminaires, appropriate values have been estimated by applying the unit discount rate and estimated growth rate in the price of electricity to the LED luminaire. The payback period for early-stage facility investment costs in the two luminaires has been estimated by luminaire.

2. Evaluation of Economic Efficiency of Tunnel Lighting

To assess the economic efficiency of tunnel lighting, tools that have adopted cost-benefit analysis, precision lighting economic analysis, present value comparison and annual payment equivalence comparison among the LCC economic

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efficiency evaluation methods have been used. In terms of data for the evaluation, actual design data on tunnel lighting have been used. In tunnel lighting, because lighting design differs depending on tunnel conditions, the location of the luminaires, the type of light source and the size of the facility, it is difficult to compare it to a general evaluation of the economic efficiency of lighting facilities at the entrance, body and exit of the tunnel. In this study, therefore, only the lighting for the basic part of the tunnel has been examined for the evaluation of economic efficiency [1].

2.1 Input data for evaluation of economic efficiency of tunnel lighting

Based on the actual lighting design of Tunnel'A', the economic efficiency has been evaluated. Table 1 revealed the current conditions of Tunnel'A', including tunnel length, interior material, and the type of luminaires in the basic section, number of luminaires and the Coefficient of Utilization (CU). Tunnel'A' has an average traffic flow of a 2-lane freeway. For basic lighting, a fluorescent lighting system (FL 32W/3) has been used. In terms of design luminance, 21lx (daytime) and 126lx (night time) were provided in the entrance and body of the tunnel. In the basic section and exit, 20lx (night time) and 125lx (daytime) were provided.

Table 1. Current lighting design in the interior zone of 'A' Tunnel

Category	Description
Speed	100km/h
Traffic Volume	6,656 cars/day
Length	617m
Type of Road	2-lane Freeway (One-way)
Interior Material	Ceiling: Concrete, Wall: White Tile (2m), Floor: Concrete
reflectance	Concrete-25%, White Tile-60%
Lighting in the interior zone	FL 32W/3 (109 lamps - One side in the bilateral wall array)
CU	0.33 (Inner lane) + 0.47 (Passing lane) = 0.8
Maintainability	Threshold (0.7), Interior and Exit (0.63)
Lumen of Lamp, Rated Power	9300lm, 115W
No. of Luminaires	31 (Threshold), 39 (Transition), 9 (Interior), 30 (Exit) = 109 (One Side), 109 X 2 = 218
Design Luminance (Luminance by FL 32W/3 except for high-pressure sodium)	Threshold and transition: 21lx (night time), 126lx (daytime) Interior and exit (20lx (nighttime), 125lx (daytime)

Table 2 explains the estimated input data for the evaluation of economic efficiency (ex: Useful life, unit wage for internal line, estimated unit manpower and materials, electric bill, etc.) of the conventional fluorescent lighting system (FL 32W/3) and the LED lighting system (LED, 80W) in Tunnel 'A'. An LED luminaire, which is the same as the fluorescent luminaire (8,000lm) in terms of luminous flux, was selected for comparison. Because the unit price of the LED luminaires greatly varies, the median was used for the evaluation of economic efficiency. In terms of useful life, 12 years (80% of the useful life of the discharge luminaire) was established in consideration of the thermal degradation and dirt pollution. In terms of the daily power consumption ratio, about 66% of the 24-hour lighting conditions of the fluorescent lamp (FL 32W/3) was established considering 12 hours of lighting at night (FL 32W/1) and 12 hours of lighting during the day (FL 32W/3).

Table 2. Selection of Input Data for Evaluation of Economic Efficiency of Tunnel Lighting (Tunnel 'A')

Category	FL 32W/3	LED (80W)	Remark
No. of Luminaires	218	218	FL 32W/3: No. of luminaires based on actual design LED (80W): No. of luminaires based on replacement only
Rated Power (W)	115	80	Rated power under the same lumen
Lame Life (h)	8,000	50,000	Set by the manufacturer
Unit Price of Luminaire (KRW)	354,081	1050,000	FL 32W/3: Unit price based on actual design LED (80W): Median on the unit price of luminaire (Public Procurement Service, July, 2012)
Unit Wage (KRW) and Standard of estimate	122,891 *0.3231	122,891 *0.3231	Actual design estimated unit manpower and materials applied (unit wage for internal line: KRW 122,891)
Useful Life	12	12	15 years (life of discharge luminaire on the road) x 0.8 (thermal deterioration and dirt considered)
Electric Bill (KRW)	Basic rate: 5420, 74.0 (KRW/kW), VAT (10%), Electric Power Industry Basis Fund (3.7%) * Public electric bill (KRW/kW) applied		
Annual Lighting Hours	8,760		24 hours x 365 days = 8,760 hours
Daily Power Consumption Ratio	0.66		About 66% estimated based on 12 night hours (1 fluorescent lamp) and 12 daylight hours (3 fluorescent lamps)

2.2 Results and analysis of the evaluation for the economic efficiency of tunnel lighting

Table 3 reveals an output of the evaluation for the economic efficiency of lighting in the basic part of Tunnel 'A'. In terms of early-stage facility investment costs, the LED lighting system is higher than the conventional fluorescent lighting system by about 176%. However, the former is lower than the latter in both repair & maintenance costs as well as electricity cost and CO_2 emission cost by 83.5%, 30.5% and 30.5%, respectively. Among the LCCs, however, the LED luminaires are now about 3 times greater than the current fluorescent luminaires in terms of unit price in the 'estimation of total cost in present values.' Therefore, the LED lighting system is about 11.5%

Table 3. Evaluation of Economic Efficiency by Luminaire in Tunnel 'A' (Unit: KRW)

Category	FL 32W/3	LED 80W	Increase (Decrease)	Increase (Decrease) Percentage (%)
Early-stage Facility Investment Costs	85,845,584	237,555,926	151,710,342	△176.7
Repair & Maintenance Cost	32,911,518	5,426,439	-27,485,079	▽83.5
Electricity Cost	12,217,818	8,491,384	-3,726,434	▽30.5
CO_2 EmissionCost	2,075,904	1,442,753	-633,151	▽30.5
LCC				
Estimation of Total Cost in Present Value	592,004,613	660,225,179	68,220,566	△11.5

Table 4. Evaluation for the Economic Efficiency when the Unit Price of LED Luminaire was discounted by 10.3% (Unit: KRW)

Category	FL 32W/3	LED 80W (Unit Price of Luminaire: 13% of Discount Applied)	Increase (Decrease)	Increase (Decrease) Percentage (%)
Early-stage Facility Investment Costs	85,845,584	207,409,796	121,564,212	△141.6
Repair & Maintenance Cost	32,911,518	5,426,439	-27,485,079	▽83.5
Electricity Cost	12,217,818	8,491,384	-3,726,434	▽30.5
CO_2EmissionCost	2,075,904	1,442,753	-633,151	▽30.5
LCC				
Estimation of Total Cost in Present Value	592,004,613	592,008,074	3,461	△0

higher than the fluorescent lighting system in terms of unit price. However, the unit price of the LED luminaires has gradually declined, and it is most likely that the price of electricity would increase due to increases in oil prices. Considering these two factors, this study has evaluated the economic efficiency with the discount rate of the LED luminaires and the estimated growth rate in the price of electricity as a means to make the LCC the same.

Table 4 shows the results of the evaluation of the economic efficiency after estimating the discount rate of the LED luminaires and the estimated growth rate in the price of electricity that makes the LCC between the two luminaires the same. If the unit price of the LED luminaires decreases by 13%, the early-stage facility investment costs could be reduced by 35% (176% to 141%), and the LCC would be the same.

Table 5 shows the results of the evaluation of the economic efficiency after estimating the unit price discount rate of the LED luminaires and the growth rate in the price of the lighting system and the LED lighting system when the unit price of LED luminaires was discounted by 10.3% with a 1.5 times increase in electricity rates, which makes the LCC between the two luminaires the same by adjusting the unit price discount rate of the LED luminaires and the growth rate in the price of electricity. As a result, the same LCC was observed

Table 5. Evaluation of the Economic Efficiency when the Unit Price of the LED luminaires was discounted by 10.3% with a 1.5 Times Increase in Electricity Rates (Unit: KRW)

Category	FL 32W/3	LED 80W	Increase (Decrease)	Increase (Decrease) Percentage (%)
Early-stage Facility Investment Costs	85,845,584	214,002,116	128,156,532	△149.3
Repair & Maintenance Cost	32,911,518	5,426,439	-27,485,079	▽83.5
Electricity Cost	17,762,668	12,345,054	-5,417,614	▽30.5
CO_2EmissionCost	2,075,904	1,442,753	-633,151	▽30.5
LCC				
Estimation of Total Cost in Present Value	640,874,005	640,889,937	15,932	△0

in both the fluorescent The figures below show the comparison of the evaluation of the economic efficiency when the unit price of the LED luminaires was discounted by 13%, or when it was discounted by 10.3% with a 1.5 times increase in electricity rates.

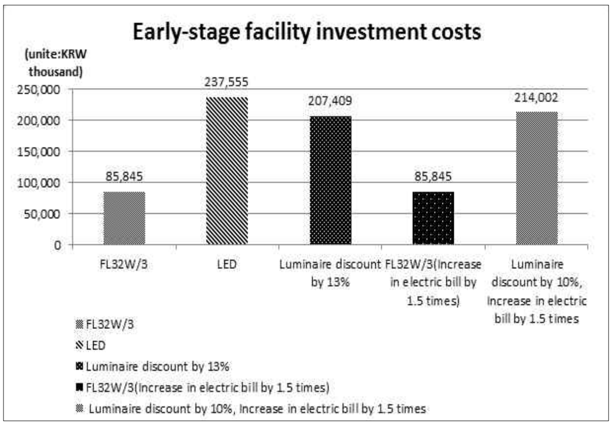

Fig. 1. Comparison of early-stage facility investments between the fluorescent lighting system and the LED lighting system

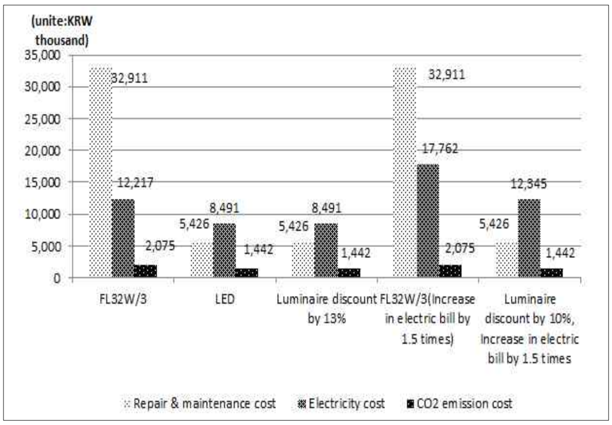

Fig. 2. Comparison of the operating cost between the fluorescent lighting system and the LED lighting system

Fig. 1 reveals a comparison of the early-stage facility investment costs while Fig. 2 shows a comparison of the repair & maintenance costs, electricity cost and CO_2 emission cost. In terms of the early-stage facility investment costs, the LED lighting system was higher than the conventional fluorescent lighting system. However, the former was lower than the latter in terms of repair & maintenance costs, electricity cost and CO_2 emission cost.

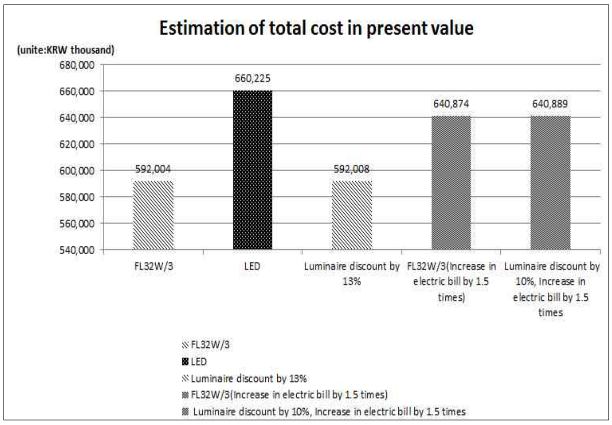

Fig. 3. LCC of fluorescent lighting system and LED lighting system

Fig. 3 is a comparison of the LCCs. When the LED luminaires were discounted by 13%, the LCC was fairly similar to the lower early-stage facility investment costs. When the LED luminaires were discounted by 10.3% with a 1.5 times increase in electricity rates, the LCC became the same between the two luminaires because of the increase in the number of fluorescent luminaires.

According to the analysis of the results, the LED lighting system is about 3 times higher than the fluorescent lighting system in terms of early-stage facility investment costs. However, the LCC was the same when the unit price of the LED luminaires was lowered by about 13%, or when it was discounted by 10.3% with a 1.5 times increase in electricity rates. Using this method, economic efficiency can be assessed when LED luminaires are applied to the lighting in the basic sections of the tunnel and LCCs can be compared.

2.3 Estimation of the payback period on the discrepancy of early-stage facility investment costs after the application of LED

The LED lighting system is higher than the fluorescent lighting system in terms of early-stage facility investment costs. In terms of repair & maintenance costs and electricity cost, on the contrary, the former is lower than the latter. Therefore, this study has estimated the payback period based on the discrepancy of early-stage facility investment costs when the LED lighting was applied to tunnel lighting. The payback period was calculated based on the following formula: (early-stage facility investment costs (LED) - early-stage facility investment costs (fluorescent) / (operating cost (fluorescent) - operating cost (LED) without considering interest rates. The annual operating cost was estimated by summing up the repair & maintenance costs and electricity cost. The figures below show the accumulated costs for early-stage facility investment costs and annual operating costs by the luminaire under different conditions.

Fig. 4 shows the accumulated cost of the early-stage facility investment costs and the annual operating costs between the fluorescent lighting system and the LED lighting system. In the beginning, the payback period on the discrepancy of early-stage facility investment cost between fluorescent lighting systems and LED lighting systems was 4.86 years. As shown in Fig. 5, this figure dropped to 3.89 years when the unit price of the LED luminaires was discounted by 13%. In Fig. 6, it decreased to 3.9 years when the unit price of the LED luminaires was discounted by 10.3% with a 1.5 times increase in electricity rates. Therefore, the payback period was shortened when the unit price of the LED luminaires was discounted and when electricity rates were raised.

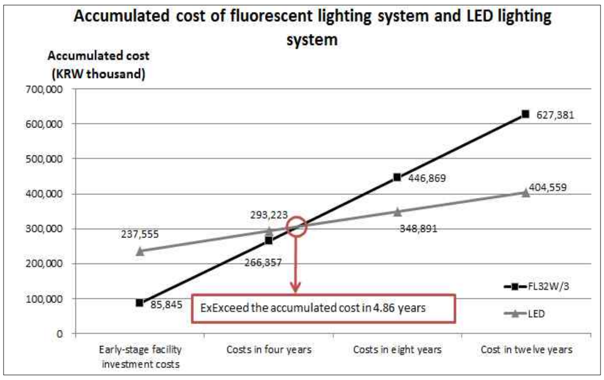

Fig. 4. LCC of fluorescent lighting system and LED lighting system

Fig. 5. Comparison of early-stage facility investments between fluorescent lighting system and LED lighting system

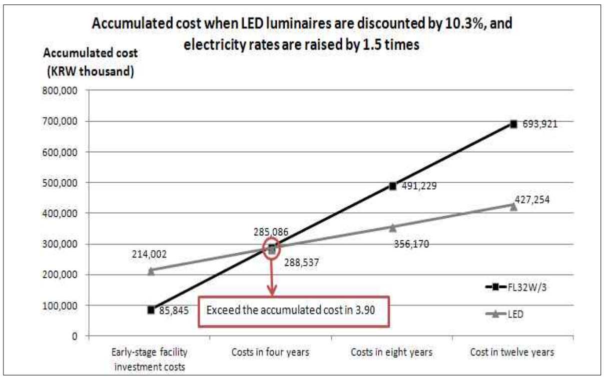

Fig. 6. Comparison of operating cost between fluorescent lighting system and LED lighting system

3. Conclusions

This study has evaluated the economic efficiency of the fluorescent lighting system (FL 32W/3) that is used in the basic section of Tunnel 'A' with the LED lighting system (80W) and performed a comparative analysis of their efficiency. Compared to the fluorescent lighting system (FL 32W/3), the LED lighting system (80W) is more energy-efficient (saving energy by 30%) and more environmentally-friendly, with lower electricity and CO_2 emission costs. However, the fluorescent luminaires (just about one-third of the unit price of LED) are lower than the LED luminaires in terms of unit price. Therefore, the LCC is lower than the fluorescent lighting system due to lower early-stage facility investment costs. Hence, appropriate value was estimated after applying the discount rate and the increased rate in the price of electricity to make the LCC the same. In fact, the LCCs became almost the same between the two luminaires when the unit price of the LED luminaires was discounted by about 13%, or when the unit price was discounted by 10.3% with a 1.5 times increase in electricity rates.

In this study, the payback period on the difference cost of early-stage facility investment costs between fluorescent and LED luminaires was estimated. According to this estimation, the LED lighting system was higher than the fluorescent lighting system in terms of early-stage facility investment costs. In terms of repair & maintenance costs and electricity cost, however, the former was lower than the latter. Therefore, the payback period is set to 4-5 years. Since tunnel luminaires and lamps vary, and because each tunnel has a different lighting environment, it is necessary to consider the lighting design after the exact evaluation of economic efficiency. This would make it possible to install the most efficient and economic lighting system.

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Biography

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