A STUDY ON THE LIFE CYCLE COST ANALYSIS IN LIGHT RAIL TRANSIT BRIDGES: FOCUSED ON SUPERSTRUCTURE

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Abstract

The demand for light-rail construction projects has recently been increasing, and they are mostly supervised by private construction companies. Therefore, a private construction company that aim to raise gains from the operation of the facilities during the contract period greater than what they invested should b able to accurately calculate the costs from the aspect of Life Cycle Cost (LCC). In particular, a light-rail transit bridge that has a heavier portion from the aspect of the cost of light-rail transit construction requires a more accurate calculation method than the conventional LCC calculation method. For this, an LCC analysis model was developed and a cost breakdown structure was suggested based on literature review. The construction costs by shape of the upper part of a light-rail transit were calculated based on the cost breakdown system presented in this paper, and the cost generation cycle and cost unit price were collected and analyzed based on records on maintenance costs, rehabilitation and replacement. In addition, after forming some hypotheses in order to perform the LCC analysis, economic evaluation was conducted from the aspect of the LCC by using performance data by item.

Keywords: LCC(Life Cycle Cost), Economic Evaluation, CBS (Cost Breakdown Structure)

1. Introduction

In Korea, light-rail transit construction projects have recently been adjusted in accordance with public opinion, and projects to construct diverse lines will be implemented within the coming five years. Thus, the light-rail transit market is expected to gradually grow. Such light-rail transit projects are driven mainly under the leadership of private companies (BTL business: Build Transfer Lease). As a result, profitability is a critical factor for a company undertaking such a project. A construction company invests private capital in a light-rail transit construction project and collects the amount invested from the operating profits during the contract period, so a company will only undertake a project when the estimated operating profits during the contract period are greater than what it is going to invest in the facilities. Therefore, it is a prerequisite for a successful project to accurately estimate the initial cost from the design stage to the construction stage, the operating costs required during operation, and the maintenance stage and profits during the operation period.

However, for an accurate estimation, a company should have diverse construction experience, cumulative data and know-how, and it is a reality that accurate estimation by individual breakdown has been limited so far. There was a case wherein in order to estimate the construction cost of a light-rail transit structure, KRW 30 billion per kilometer for a high-rise structure and KRW 60 billion per kilometer for an underground structure were applied en bloc. However, such estimations do not have sufficient basis and they have a very low confidence level. In estimating the costs for long-term operation, maintenance companies use a certain ratio of the construction cost annually. On the other hand, bridges comprise a large portion of the diverse facilities in a light-rail transit construction in terms of size and resources needed for operation and maintenance. In addition, bridges show different rates, cycles and costs depending on their upper structure, setting the construction cost aside. Therefore, there is a greater need to analyze the LCC of a bridge using diverse alternatives.

This study aims to support decision-making on whether a private construction company should participate in a light-rail transit construction project or not by analyzing the LCC of the light-rail transit bridge. Through the review of existing literature, we formulated an LCC analysis procedure and a model and designed a cost breakdown structure appropriate for a light-rail transit construction project. Based on the cost breakdown structure drawn up in this manner, we analyzed the real costs of investment for the construction of a rail or a road on the subject of a light-rail transit bridge. The main hypotheses passed sensitivity analysis to raise the confidence level of the analytical result. In this manner, the breakdown was reviewed from the aspect of the LCC by applying each cost to a real structure in order to support the decision-making on whether a private construction company should participate in a light-rail transit construction or not.

2. LCC Analysis of Light Rail Transit Bridges

2.1 LCC Analysis Procedure

The study employed the LCC analysis procedure for a light-rail transit bridge construction, as shown in Fig. 1. The different upper structures of bridges suitable to the construction field in which a light-rail transit is applied were selected as research subjects and the cost breakdown items for the analysis subjects and cost data were collected and analyzed. After setting the hypotheses, such as the discount rate and the analysis period, we performed the LCC analysis for the subjects using the method for present value. With the view of considering the uncertainty of the future value, we conducted a sensitivity analysis on the hypotheses and breakdown items and also analyzed the changes in the LCC analysis result depending on the uncertainty of the data analyzed.

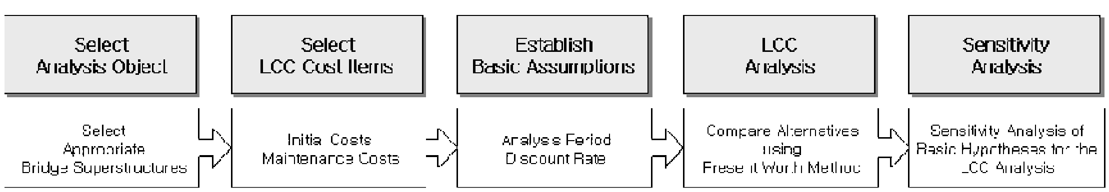


Fig. 1 LCC analysis procedure

2.2 LCC Analysis Model

For the LCC Analysis Model, the Analysis Model and Breakdown Structure of Ehlen & Marshall (1996) were adopted in this study.

$$PVLCC = IC+PVOMR+PVD \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad \text{Eqn. (1)}$$

Here, PVLCC: Present Value Life Cycle Cost
IC: Initial Costs,   PVOMR: Present Value of Operation, Maintenance and Repair Costs
PVD: Present Value of Disposal Costs

The initial costs (IC), the present value of operation, maintenance, and repair costs (PVLCC), and the present value of disposal costs (PVD) presented in the equation (1) above can be ramified, as shown in Table 1. Only the items, which should be considered more carefully by a private company, were selected using the cost analysis factors because they affect the company's investment and collection costs. This is because this paper aims to support the decision-making of private construction companies.

Table 1. LCC cost breakdown structure for light rail transit bridge

Major Group	Sub-major	Minor	Note	Remarks
Initial Costs	Design Costs / Supervision Costs	Design cost	C	On the factors needed for private construction companies to consider are selected factors for analysis
		Implementation design cost		
		Construction consulting cost & Supervision cost		
	Construction Costs	Direct construction cost	C	
		Indirect construction cost		
		General administration cost & profit		
	Compensation Cost for Site and Existing Structure	Compensation cost	N/C	
Maintenance Costs	Inspection / Diagnosis Cost	Regular inspection cost	C	
		Precise inspection cost		
		Precise examination cost		
	Maintenance & Repair	Repair	C	
		Rehabilitation		
		Replacement Cost		
	User Cost	Vehicle operating cost	N/C	
		Time delay cost		
Waste Deposit Costs	Waste Deposit Cost	Disassembling cost	N/C	
		Waste disposal cost		
	Residual value	Waste recycling & Reuse cost(profit) and etc	N/C	

Note: C = Considered and N/C = Not Considered

2.3 Cost Breakdown Structure (CBS)

To understand the costs spent in building a bridge, a systemic cost breakdown structure is required. Rail bridges, including light-rail transit bridges, have different purposes, and the materials and cost breakdown items required for each bridge are also shown to be more or less different. These differences result from the different characteristics between a rail bridge on which ballast and a rail are installed and a road bridge on which thee bridge deck pavement is done after floor plate construction of a bridge. Because of these reasons, different materials are used for the bridge bearings and expansion joints. Taking the abovementioned points into account, we collected the cost data after listing the cost breakdown structure, as shown in Fig. 2.

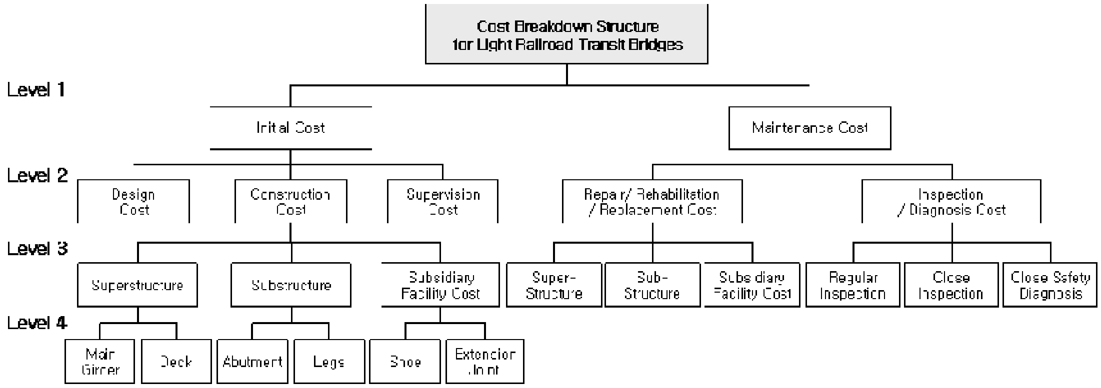


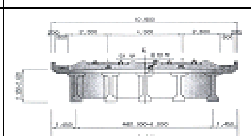
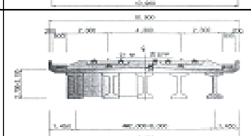
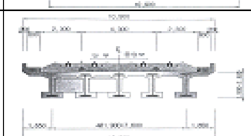
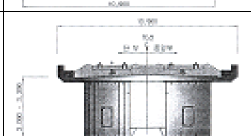
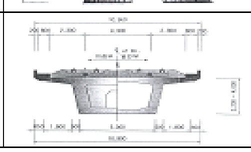
Fig. 2 Cost breakdown structure

2.4 Breakdown Items for LCC Analysis

2.4.1 Initial Costs

The construction cost, which accounts for the largest portion of the initial investment cost (initial costs), is estimated in Table 2, showing each upper structure of a bridge based on conventional performance data. Table 2 was made based on the performance data on a lot of bridge structures adopted as a rail-transit bridge in Korea. The upper structure of a bridge should be selected accordingly depending on the situation of a construction site.

Table 2. Estimated construction costs by each upper structure of a bridge

Structure	Drawing	Length(m)	Construction Cost	Application
PSC BEAM		20.0m-25.0m	Upper: KRW 629.2 Million /m Lower: KRW 569.8 Million /m Total construction cost : KRW 1,199 Million/m	·Standard Section
IPC GIRDER		30.0m-35.0m	Upper: KRW 1,003 Million /m Lower: KRW 758 Million /m Total construction cost: KRW 1,761.Million/m	·Standard Section ·Section required under-bridge height and double span
PF BEAM		30.0m-35.0m	Upper: KRW 2,180 Million /m Lower: KRW 758 Million /m Total construction cost: KRW 2,938 Million/m	·Section required under-bridge height and double span
STEEL BOX GIRDER		40.0m-50.0m	Upper: KRW 1,903 Million /m Lower: KRW 811 Million/m Total construction cost: KRW 2,714 Million/m	·Crosscut Section over a river and road
PSC BOX GIRDER		40.0m-50.0m	Upper: KRW 1,641 Million /m Lower: KRW 946 Million /m Total construction cost: KRW 2,587 Million /m	·Crosscut Section over a river and road

In addition, the design cost and consulting cost were calculated based on the Engineering Business Cost Standard (issued by the Ministry of Science and Technology) and the Construction Consulting Cost Standard (Korea Construction Consulting Engineers Association), as shown Table 3.

Table 3. Standard for calculating basic/implementation design & consulting costs

Rate Construction Cost	Rate by task (%)			
	Basic design	Implementation design	Construction consulting	Total
Under KRW 10 Million	3.87	7.75	4.30	15.92
Under KRW 20 Million	3.29	6.57	3.65	13.51
Under KRW 30 Million	3.03	6.06	3.36	12.45
Under KRW 50 Million	2.73	5.46	3.02	11.21
Under KRW 100 Million	2.56	5.11	2.85	10.52
Under KRW 200 Million	2.04	4.08	2.26	8.38
Under KRW 300 Million	1.87	3.73	2.06	7.66
Under KRW 500 Million	1.69	3.39	1.89	6.97
Under KRW 1 Billion	1.49	2.99	1.66	6.14
Under KRW 2 Billion	1.37	2.75	1.53	5.65
Under KRW 3 Billion	1.32	2.65	1.48	5.45
Under KRW 5 Billion	1.30	2.60	1.45	5.35
Under KRW 10 Billion	1.27	2.53	1.41	5.21
Under KRW 20 Billion	1.23	2.45	1.37	5.05
Under KRW 30 Billion	1.22	2.44	1.35	5.01
Under KRW 50 Billion	1.19	2.39	1.33	4.91
Under KRW 100 Billion	1.18	2.35	1.30	4.83
Under KRW 200 Billion	1.16	2.32	1.28	4.76
Under KRW 300 Billion	1.15	2.29	1.25	4.69
Under KRW 500 Billion	1.13	2.27	1.23	4.63

2.4.2 Maintenance and Repair Costs

(1) Agency Costs
The agency costs were divided into regular inspection cost, regular precise inspection cost and regular precise examination. Each cost was estimated under the standard of regular inspection and regular precise examination cost (cost estimation) in No. 2003-195 (issued by the Ministry of Construction and Transportation on August 3, 2003).

(2) Maintenance and Repair Costs
The maintenance and repair costs were divided into maintenance cost, rehabilitation cost and replacement cost, which are continuously spent even after the light-rail transit bridge construction has been completed. The costs are a very significant part of the LCC costs. A certain rate of the total construction cost has been used annually in the conventional method of estimating the maintenance and repair costs due to the difficulty in obtaining or collecting the data. However, for a more accurate estimation cycle, the repair or rehabilitation rate and cost should be estimated based on the past data of maintenance and repair or an estimation standard.
In Korea, data on the maintenance and repair of road bridges have been accumulated relatively better than those of railroad bridges, including light-rail transit bridges. Even though some data have been accumulated, the data have not been ramified into detailed parts. Therefore, in this study, the data on maintenance and repair was provided by the Korea Highway Corporation (see Table 4).

Table 4. Maintenance and repair data by upper structure of a bridge

Element	Type	Cycle					Repair rate	Rehabilitation rate	Replacement rate	Repair cost Unit (KRW 1000)	Rehabilitation cost Unit (KRW 1000)	Replacement cost Unit (KRW 1000)
		Repair	Additional repair	Rehabilitation	Additional rehabilitation	Replacement						
Cast	PSC Beam Bridge	10	8	19	11		18.4%	21.6%	-	124.248	346.000	
	PSC Box Girder Bridge	10	8	20	12		18.4%	21.6%	-	124.248	346.000	
	Steel Box Girder Bridge	10	7	20	12		19.1%	19.8%	-	151.889	321.453	392.180/m^2
	IPC Girder Bridge	8	7	20	11		18.4%	21.6%	-	124.248	346.000	

	PF Beam Bridge	9	8	20	13		18.4%	21.6%	-	124.248	346.000	
Floor Plate	PSC Beam Bridge	18	15	25	23		21.0%	22.3%	-	150.220	249.366	
	PSC Box Girder Bridge	17	14	23	20		21.0%	22.3%	-	150.220	249.366	
	Steel Box Girder Bridge	18	13	22	21		21.0%	22.3%	-	150.220	249.366	
	IPC Girder Bridge	15	12	22	20		21.0%	22.3%	-	150.220	249.366	
	PF Beam Bridge	15	12	23	20		21.0%	22.3%	-	150.220	249.366	
Bridge bearings		8	8	-	-	22	18.3%	-	100.0%	219.560	-	1,199.781
Expansion joints		4	4	-	-	9	20.2%	-	100.0%	398.290	-	1,971.733
Paint	Inner					15	-	-	-			
							-	-	-			
	Outer					13	-	-	-			
							-	-	-			
Lower structure	Legs	12	8	23	20		28.6%	20.6%	-	180.180	180.180	
	Abutment	17	8	23	20		24.4%	20.6%	-	174.870	174.870	

Source: Made by reference to Korea Highway Corporation, 2003

The data was collected by ramifying the components of the data on the maintenance and repair costs of a bridge into casts, floor plates, bridge bearings, expansion joints, paint and lower structure, as shown in Table 4. However, the replacement cycle and replacement unit cost of bridge bearings and expansion joints were not assorted by structure and a cycle of each structure and the arithmetic average of the costs were used, respectively, because bridge bearings and expansion joints applied to road bridges and railroad transit bridges are different and it is realistically hard to collect the data appropriate for railroad transit bridges. However, in the conventional LCC analysis of road bridges, certain values are assigned to the rate of repair and rehabilitation for bridges bearings or expansion joints and unit cost en bloc, regardless of the type of bridge bearing and expansion joint, so it was believed that applying the arithmetic value of the replacement cost and replacement cycle in this study would not significantly affect the analysis result.

2.5 Basic Hypotheses for LCC Analysis

2.5.1 Analysis Period

At present, data for light-rail transit bridges for a durable period has not been prepared in Korea. An analysis period was set by referencing to data on the service life of conventional road bridges (see Table 5).

Table 5. Service life by bridge type

Type	Service life	Reference
General Bridge	75	AASHTO LRFD Spce.
RC Bridge	70	Piringer(1993)
	50	Nishikawa(1997)
PC Bridge	70	Piringer(1993)
Steel Bridge	80	Piringer(1993)
High performance steel bridge (no paint, PC Deck used)	Over 200 yrs	Nishikawa(1997)
Steel Composite Bridge	70	Piringer(1993)

Source: Development of A LCC Analysis Model for Bridges and Study on DB Building," 2002.12., p47, The Ministry of Construction and Transportation

However, when one performs an LCC analysis and compares the alternatives with different service lives, one should set an identical analysis period in order to obtain more accurate results. The reason why people should set an identical analysis period is because the effect of choosing one should be identical to the effect of choosing another. The two methods below are generally used to set the identical analysis period.

- Setting the least common multiple of the different life cycles to be the analysis period.
- Setting the shortest life cycle of the different life cycles to be the analysis period and setting the cost generated after the analysis period in the longer life cycles to be residual value.

In this study, we mentioned two kinds of method above and we performed LCC analysis using the second method of two. When we set up the analysis period by the first method, there is a good possibility that the analysis period exceeds life cycle. That's why we used second method. For example, if the alternatives of LCC analysis are PC bridge and Steel bridge the lowest common multiple of service life of two bridges' facilities is 560 years and when we fix this period as LCC analysis, meaningless results can be come out.

2.5.2 Real Discount Rate

The real discount rate is used to convert the value of money to the value at a specific time to objectively compare the values of money with different maturities. It contains composite factors such as government bond yield, interest rate and inflation rate. The nominal discount rate needed in calculating the real discount rate refers to the market discount rate. It is a principle to use a long-term government bond rate as the nominal discount rate. However, the market scale of long-term government bonds is too small to take the lead of rates in Korea. In this LCC analysis, the interest rate was used as the nominal discount rate (Korea Research Institute for Human Settlement, Korea Institute of Construction Safety Technology, 2006, 6). This paper used the 'lending rate for companies', which private construction companies most frequently face, and the 'Consumer Price Index', which are generally applied as the normal discount rate and inflation rate, respectively. With these values, the real discount rate can be calculated as shown in Eq. (2). In this paper, the real discounts for the past ten years were calculated and their arithmetic average of 4.83 percent was applied to the LCC analysis (see Table 6).

$$i_r = \frac{(1+i_n)}{(1+f)} - 1 \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad \text{Eqn. (2)}$$

At this time, ir: Real Discount Rate, in: Nominal Discount Rate, f: Inflation Rate

Table 6. Setting real discount rate (Unit: %)

Year	Nominal Discount rate(in)	Inflation rate(f)	Real discount rate(ir)
1996	10.98	4.90	5.80
1997	11.75	4.40	7.04
1998	15.20	7.50	7.16
1999	8.91	0.80	8.05
2000	8.18	2.30	5.75
2001	7.49	4.10	3.26
2002	6.50	2.70	3.70
2003	6.17	3.60	2.48
2004	5.92	3.60	2.24
2005	5.65	2.70	2.87
Average	**8.68**	**3.66**	**4.83**

Source: Bank of Korea(http://www.bok.or.kr)

As shown in Table 6, the nominal discount rates and inflation rates in both 1998 and 1999 showed big differences in comparison to those of other years. The differences resulted from the financial crisis in the Asian region during those years. For this reason, the real discount rates for those years were excluded in many conventional studies on LCC analysis. However, those values were not excluded in this study because it is considered that a discount rate, by itself, is uncertain. In addition, sensitivity analysis of discount rates was performed after the LCC analysis and changes in the LCC were examined. However, it is dominant perspective of many economic professionals that the nominal discount rate and inflation rate will keep dropping at the level of developed countries (2~3%) in 10 years (Korea National Housing Corporation, 2000) and a method to more accurately calculate the real discount rate should be developed.

3. LCC Analysis for Case Bridge

3.1 Outline of the Bridge for LCC Analysis

In this study, the "A-B Section" of a bridge crossing over two roads in an existing light-rail transit construction project was selected as the object for LCC analysis. The ground plan and the profile of the bridge are shown in Fig. 3.

In Fig. 3, the upper structure of the "A-B Section" was all formed as a rigid box girder regardless of the situation of the construction site. In other words, the rigid box girder bridge structure is applied even to "Ga" and "Na" where there is no crossing section and a long span suspension is not needed, as well as the section crossing over two existing roads. Therefore, this paper suggested an alternative to apply another upper structure to "Ga" and "Na" and analyzed both the LCC of the original and the LCC of the alternative. The specifications of the original and the alternative are shown in Table 7.

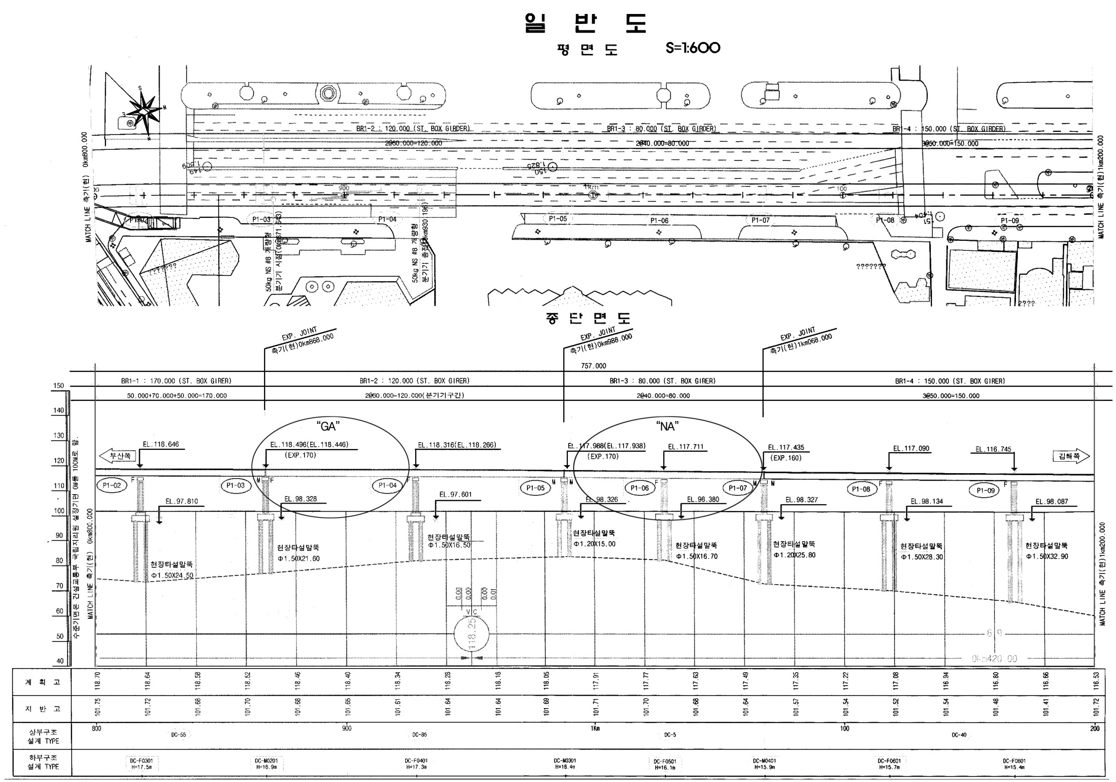


Fig. 3 General diagram of the case bridge for LCC analysis

Table 7. Specifications of the Original and the Alternative

Division	Original	Alternative
Span length applied	2@60+2@40+3@50 = 350m	3@20+1@60+4@20+3@50 = 350m
Overall width	8.9m	8.9m
Upper structure	Steel Box Girder	PSC Beam, Steel Box Girder
Lower structure	T type	T type

3.2 LCC Analysis Result

Before LCC analysis, basic hypotheses such as the analysis period and the discount rate were set. The analysis period was set as the least common multiple because they had different service lives – 70 years for a PC Bridge and 80 years for a Steel Bridge, as shown in Table 5 – and the cost generated after the analysis period was also set as the residual value. In addition, the real discount rate was set as 4.83%, as suggested in Table 6.
Based on these basic hypotheses and the cost data presented in the previous chapter, the LCC analysis results converted into the present value as of 2006 are shown in Table. 8.

Table 8. LCC analysis result (Unit: KRW 1000)

Division			**Original (A)**	**Alternative (B)**	**Remarks (A-B)**
Initial investment Costs	Construction cost		9,499,000	7,378,000	2,121,000
	Basic & Implementation design, consulting cost		495,847	385,131	110,716
Maintenance, Rehabilitation & Repair Costs	Repair	Floor plate	52,037	58,826	-6,789
		Cast	0	122,439	-122,439
		Cross beam	0	0	0
		Steel bridge paint	264,834	156,788	108,046
		Bridge bearings	2,651	3,307	-656
		Expansion joints	93,932	147,607	-53,675
		Lower structure	21,688	43,375	-21,688
		Sub-total	**435,142**	**532,344**	**-97,202**
	Rehabilitation	Floor plate	125,387	117,120	8,267
		Cast	762,733	643,087	119,646
		Cross beam	0	0	0
		Steel bridge paint	0	0	0
		Bridge bearings	0	0	0
		Expansion joints	0	0	0
		Lower structure	5,549	11,099	-5,549
		Sub-total	**893,669**	**771,306**	**122,363**
	Replacement	Floor plate	0	0	0
		Cast	0	0	0
		Cross beam	0	0	0
		Steel bridge paint	638,646	380,084	258,562
		Bridge bearings	285,807	59,686	226,121
		Expansion joints	482,776	1,390,218	-907,442
		Lower structure	0	0	0
		Sub-total	**1,407,229**	**1,829,988**	**-422,759**
	Safety Audit Cost		979,419	1,580,203	-600,784
Residual value	Residual value		81,758	0	81,758
Total LCC			**13,792,064**	**12,476,972**	**1,315,092**

As shown in Table 8, the alternative bridge composed of the PSC Beam and the rigid box girder gains an advantage over the original bridge composed only of the rigid box girder bridge from the aspect of LCC. However, the advantage resulted from the lower initial cost invested in the early stage. Therefore, if the cost is set aside, the original bridge, the rigid box girder bridge, is more economical than the alternative bridge only when compared from the aspect of maintenance and repair costs because the PSC Beam Bridge made of concrete requires more frequent repair, rehabilitation and replacement than the ridge box girder bridge. Therefore, if the costs not considered in this paper such as user cost or disassembly and waste disposal costs are taken into account, the alternative cannot always be said to be more advantageous than the original. In addition, uncertain factors such as the analysis period and the discount rate can affect the final LCC results. In other words, the results can be changed due to the factors, so that a final decision-maker should compositely consider such factors when selecting a design.

3.2 Sensitivity Analysis

To understand the changes in the analysis result in accordance with the uncertainty of the analysis period and discount rate among the hypotheses for the LCC analysis, a sensitivity analysis was performed and the results are shown in Table 9. and Table 10.. As shown in Table 9, the LCC analysis results were changed in accordance with the changes in the analysis period. The LCC result differences between the original and the alternative are drastically narrowed at 40th year of the analysis period and then gradually became stable.

Table 9. LCC analysis results in accordance with the changes in the analysis period(Unit: KRW Million)

Division	10 years	20 years	30 years	40 years	50 years	60 years	70 years	80 years	90 years	100 years
Original(A)	10,570	11,974	12,582	12,974	13,387	13,585	13,792	13,792	13,835	13,860
Alternative(B)	8,819	10,255	11,114	11,738	12,114	12,340	12,477	12,583	12,629	12,663
Difference(A-B)	1,751	1,719	1,468	1,237	1,273	1,246	1,315	1,209	1,206	1,197

In addition, as shown in Table 10., even though the discount rate changes within a certain range, there was no change in the superiority of cost between the original and the alternative. However, as the discount rate goes down, the LCC analysis results of the original and the alternative become narrower. Similarly, uncertain factors can affect the analysis results so that the range and distribution of the uncertain factors should be suggested based on further analyses in the future to derive more significant results.

Table 10. LCC analysis results in accordance with the changes in the discount rate(Unit: KRW Million)

Division	2.00 %	2.50 %	3.00 %	3.50 %	4.00 %	4.50 %	4.83 %	5.00 %	5.50 %	6.00 %
Original	18,463	17,217	16,204	15,374	14,688	14,117	13,792	13,639	13,235	12,891
Alternative	17,995	16,531	15,337	14,356	13,543	12,864	12,477	12,294	11,810	11,395

4. Conclusion

LCC analyses have been performed for bridge facilities that require regular and continuous maintenance and have a large weight in light-rail construction projects, which have been on the rise recently. For this, an LCC analysis model was prepared and then the cost breakdown structure appropriate for a light-rail transit construction project was suggested. Based on the cost breakdown structure suggested in this paper and in conjunction with the recorded construction costs for the upper structure of a light-rail transit bridge, the repair costs, rehabilitation costs and replacement costs, cost generation cycles and cost units were collected and analyzed. From the analysis results, when the bridge structure is changed, there is an alternative to save costs from the aspect of LCC. However, this alternative seems to save costs in the construction stage, but its maintenance costs rather increase. Therefore, it is believed that more composite analyses should be conducted before making a decision. In addition, the sensitivity analyses showed changes resulting in accordance with changes in the analysis period and the discount rate, so that such factors need to be taken into account.

Studies on LCC analysis have not been sufficiently conducted so far, so it is expected that the cost breakdown structure and the data related to maintenance and repair presented in this paper will be used the basis for systemic maintenance and repair activities. When additional data on the uncertain hypotheses for LCC analysis and parameter distribution are accumulated in the future, it is expected that the LCC analysis results with higher confidence levels can be obtained.

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