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Prediction and Backtracking Models of Life Cycle Cost Based on School Facility Conditions in South Korea

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Abstract: After the introduction of BTL (Build-Transfer-Lease) projects in 2005, most construction projects of school facilities have been implemented in BTL system. However, concern about whether the school facilities can be managed appropriately during the 20 year as operation and management period is increasing. Therefore, the necessity of reference for evaluation standard on operating costs and the establishment of LCC (life cycle costing) prediction models is coming to the fore. In this respect, the goal of this study was to extract the variables for LCC-related models and conduct analyses of the correlations of the variables using statistical analysis tool, in order to establish LCC prediction and backtracking model based on BTL project cases of school facilities. The prediction and backtracking model of LCC will be a key for budget equalization or optimum range as one way of estimating method using LCC by year and school type. In the future, it would provide the accurate reference for analyzing and managing the actual input costs against the plan and evaluating the practical cost for long-term facility management plan as the predictive management.

Key words: Life cycle costing, prediction and backtracking model, school facility.

1. Introduction

Although newly-built projects of school facility, such as elementary, middle and high schools in Korea, were promoted as privately funded BTL (Build-Transfer-Lease) projects, one of the public private partnership, from 2005 to 2011, orders have been reduced due to the fulfilled demand in the end of 2011. Educational Offices are currently interested in knowing the efficiency of facility operation management related to BTL projects realized in last seven years during the remaining project periods, since this efficiency directly affects facility management costs, which are a part of the annually allocated budget. For BTL projects, although the total calculated LCC (life cycle cost) is reflected in the operation and facility management plan due to project characteristics, future publicly financed projects also require operation and facility management costs to be predicted and a cost plan to be established.

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Moreover, the necessity of repair and replacement costs management and prediction for service life is currently emerging for school facility projects. To address this need, LCC analyses are conducted during the planning and design of school facilities, with medium and long-term maintenance plans determined by predicting future costs and establishing a budget. However, it is difficult to analyze realistic LCC because of the fact that repair information such as repair and replacement is not disclosed.

Therefore, in this study, we determine the time, cost, and other key variables affecting LCC analysis as a part of LCC prediction, both for BTL and publically financed school facility projects, analyzing correlations between variables to establish an LCC prediction and backtracking model. It is thought that a more robust LCC prediction model can be established by using the correlation between relevant variables as the main variable and securing reliability by utilizing a standardized school facility LCC prediction model. In other words, we intend to present LCC prediction models based on school facility conditions for establishing a timely maintenance budget based on cases of school facility LCC analysis and to develop an LCC backtracking method relying on the construction work type and number of years elapsed.

We analyzed school facilities of BTL projects announced in 2009~2011 to secure the results of the corresponding LCC analyses at the working design stage, using expert advice and correlation analysis based variable extraction to determine key variables of the school facility LCC prediction model and relying on SPSS (Statistical Package for Social Science) as a statistical analysis program.

2. Theoretical Review

2.1 Elucidation of LCC Variables Based on a Literature Review and Experts

Initially, variables affecting life cycle costs and construction costs were analyzed by reviewing existing literature [1]. The results of this analysis showed that LCC variables can be divided into important factor, cost and base points in time, with the cost-related items being independent variables and LCC values being dependent variables.

On the other hand, the independent variables of construction cost comprised project size, spatial plan, and nominal scale, with the nominal scale categorized according to school class and form, and initial construction cost being a dependent variable.

2.2 Influential Variables According to LCC Analysis

The results of randomly extracting factors affecting LCC analysis and calculation of construction costs currently applied in Korea are in Table 1.

Based on the guidelines for LCC analysis and evaluation announced by the Ministry of Land, Infrastructure and Transport in December, 2008.

As a result of investigating literature published in Korea, LCC variables were divided into key groups, i.e., cost and reference points in time, with the corresponding variables affecting total construction cost shown in Table 2.

As a result of gathering primary and secondary opinions of an expert group to elucidate variables affecting LCC analysis of school facility BTL projects, 26 independent and 4 dependent variables were determined (Table 3). At this point, these variables (taking into account their accuracy) were organized around items mentioned in the RFP (request for proposal) [2]. In the case of Type 2, as the names were somewhat different depending on the RFP of each district, variables were re-classified into five groups.

Table 1 Primary variables by projects.

Classification		Detailed variable items		
Independent variables	Facility size	Total floor area	Lot area	Building area
		Groung/underground area	Number of floors	Floor height
	Schoole size	Number of classes	Number of students	School grade
		Type of rooms	Total consurction cost	-
	Spatial plan	General class	Practical exercise classroom	Study support room
		Administrative room	Public room	Other supporing room
		Indoor sports facility	Outdoor sports stadium	Parking lot
		School type	Elevation plan	Roof type
	Other	Number of elevators	Ratio of public space area to exclusive space area	
		Total project cost	Structural type	Construction period
		Construction method	Core type	District
		Main materials	Heating method	Equipment system
Dependent variables	Total construction cost	LCC 20 year	LCC 20 year per unit area	LCC by cost item
		LCC 65 year	LCC 65 year per unit area	-

Table 2 LCC and construction cost variables determined by literature analysis.

Classification		Detailed items		
LCC variables [3]	Key groups	Facility type	Service life	Total floor area
		Total construction cost	Interest rate	-
	Cost	Construction cost	Repair cost	Replaceement cost
		Inflation rate	Actual discount rate	Interest
	Time	Analysis data	Analysis period	Construction period
Construction cost variables [2]	Project size	Number of classes	Lot area	Total floor area
		Number of students to be accommodated		-
	Apatial plan	Ordinary class	Special class	Special activity room
		Administrative room	Sanitation room	Gymnasium
		Other facility	Public area	-
	Nominal scale	School grade	-	-

Table 3 Independent and dependent variables determined by gathering expert opinions.

Classification		Detailed items			
Independent variables	Type 1	Year	District	City size	Grade
	Type 2	Genernal classroom		Subject/special classroom	
		Study supporing room		Indoor gymnasium	
		Administratation support room		-	
		LCC value of 65 years per number of rooms, area(percentage), and unit area			
	Type 3	Total construction cost		Total floor area	
Dependent variables		LCC value (20 years)		LCC value (20 years) per unit area	
		LCC value (65 years)		LCC value (65 years) per unit area	

Table 4 Number of school facility built BTL projects announced in 2009~2011.

School	2009	2010	2011	2012
Elementary	13	8	3	24
Middle	10	11	-	21
High	7	5	2	14
Total	30	24	5	59

3. Establishment and Verification of Regression Based LCC Prediction Model

3.1 Analysis of School Facility BTL Project Cases

In 2009~2011, a total of 25 school facility BTL projects (85 facilities) were announced across the country, among which 59 cases (Table 4) with a facility project master plan were analyzed.

Of the 59 school facilities located nationwide, 11 are located in major cities, and 48 are located in small and medium cities. Elementary schools, middle schools, and high schools have the highest number of elementary schools. The average total floor area of the school is 8,595 m^2, and 35 facilities exceed the average floor area. The total construction cost is about 9 billion won, ranging from a minimum of 6,700 million won to a maximum of 11,900 million won.

3.2 Elucidation of Variables Based on Expert Advice

Advice from LCC analysis experts was sought on variables determined during the literature review mentioned in Section 2. Ten experts with LCC analysis experience of ten or more school facility projects were selected. As shown in Table 5, independent variables can be divided into facility size and spatial planning, and dependent variables as total cost [3, 4].

3.3 Correlation Analysis

The following variables (Fig. 1) were strongly

Table 5 Key LCC variables based on expert advice.

Classification		Content
Independent variables	Facility size	Total construction cost, total floor area, city size, School grade
	Spatial plan	Number, area, area percentage, area per person General classroom, subject/special classroom, Study supporing room, Indoor gymnasium, Administratation support room
Dependent variables	Total constuction cost	LCC 20 year, LCC 65 year

NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	-0.135	0.009	0.719	0.720	0.662	0.762	0.515	0.618	0.310	0.488	0.328	0.547	-0.069	0.579	-0.197	0.498	-0.764	0.498	0.496	0.642	0.048	-0.087	0.956
2	-0.135	1	-0.103	-0.013	0.005	0.019	-0.261	-0.256	-0.375	-0.339	-0.188	-0.470	-0.470	-0.242	-0.088	0.063	-0.229	0.20	-0.229	0.236	-0.090	0.109	-0.137	-0.251
3	0.009	-0.103	1	-0.31	-0.326	-0.310	-0.063	0.503	0.441	0.355	-0.318	0.084	0.219	0.173	0.210	0.028	0.112	-0.078	0.112	0.150	0.153	0.112	0.219	0.076
4	0.719	-0.013	-0.310	1	0.998	0.950	0.797	-0.147	-0.016	-0.238	0.566	0.337	0.201	-0.204	0.160	-0.173	0.301	-0.622	0.301	0.615	0.587	0.135	-0.183	0.736
5	0.720	0.005	-0.326	0.998	1	0.958	0.802	-0.15	-0.022	-0.244	0.567	0.327	0.193	-0.208	0.159	-0.173	0.300	-0.620	0.300	0.614	0.585	0.137	-0.183	0.729
6	0.662	0.019	-0.310	0.950	0.958	1	0.843	-0.17	-0.046	-0.227	0.576	0.285	0.159	-0.209	0.171	-0.181	0.286	-0.627	0.286	0.549	0.543	0.148	-0.185	0.652
7	0.762	-0.261	-0.063	0.797	0.802	0.843	1	0.147	0.293	0.070	0.533	0.362	0.384	-0.086	0.369	-0.194	0.360	-0.677	0.360	0.497	0.712	0.211	-0.033	0.745
8	0.515	-0.256	0.503	-0.147	-0.150	-0.170	0.147	1	0.942	0.765	-0.058	0.252	0.673	0.249	0.641	-0.112	0.383	-0.354	0.383	0.019	0.180	-0.128	0.054	0.518
9	0.618	-0.375	0.441	-0.016	-0.022	-0.046	0.293	0.942	1	0.803	0.163	0.315	0.715	0.207	0.636	-0.145	0.464	-0.451	0.464	0.099	0.400	-0.029	0.100	0.641
10	0.310	-0.339	0.355	-0.238	-0.244	-0.227	0.070	0.765	0.803	1	0.309	0.142	0.465	0.163	0.422	-0.189	0.409	-0.169	0.409	-0.080	0.113	-0.160	-0.021	0.310
11	0.488	-0.188	-0.318	0.566	0.567	0.576	0.533	-0.058	0.163	0.309	1	0.206	0.125	-0.153	0.087	-0.277	0.434	-0.385	0.434	0.322	0.436	0.017	-0.183	0.512
12	0.328	-0.470	0.084	0.337	0.327	0.285	0.362	0.252	0.315	0.142	0.206	1	0.761	0.369	0.070	-0.064	0.190	-0.370	0.190	0.063	0.250	-0.052	-0.021	0.473
13	0.547	-0.470	0.219	0.201	0.193	0.159	0.384	0.673	0.715	0.465	0.125	0.761	1	0.577	0.630	-0.153	0.353	-0.433	0.353	-0.001	0.280	-0.125	0.071	0.612
14	-0.069	-0.242	0.173	-0.204	-0.208	-0.209	-0.086	0.249	0.207	0.163	-0.153	0.369	0.577	1	0.526	-0.171	0.095	0.120	0.095	-0.277	-0.190	-0.338	-0.046	-0.033
15	0.579	-0.088	0.210	0.160	0.159	0.171	0.369	0.641	0.636	0.422	0.087	0.070	0.630	0.526	1	-0.222	0.353	-0.365	0.353	0.085	0.260	-0.135	0.018	0.510
16	-0.197	0.063	0.028	-0.173	-0.173	-0.181	-0.194	-0.112	-0.145	-0.189	-0.277	-0.064	-0.153	-0.171	-0.222	1	-0.544	-0.124	-0.544	-0.113	-0.175	-0.185	-0.082	-0.198
17	0.498	-0.229	0.112	0.301	0.300	0.286	0.360	0.383	0.464	0.409	0.434	0.190	0.353	0.095	0.353	-0.544	1	-0.094	1	0.234	0.381	0.279	0.226	0.527
18	-0.764	0.200	-0.078	-0.622	-0.620	-0.627	-0.677	-0.354	-0.451	-0.169	-0.385	-0.370	-0.433	0.120	-0.365	-0.124	-0.094	1	-0.094	-0.418	-0.499	0.040	0.173	-0.785
19	0.498	-0.229	0.112	0.301	0.300	0.286	0.36	0.383	0.464	0.409	0.434	0.190	0.353	0.095	0.353	-0.544	1	-0.094	1	0.234	0.381	0.279	0.226	0.527
20	0.496	0.236	0.150	0.615	0.614	0.549	0.497	0.019	0.099	-0.080	0.322	0.063	-0.001	-0.277	0.085	-0.113	0.234	-0.418	0.234	1	0.640	0.264	-0.194	0.550
21	0.642	-0.09	0.153	0.587	0.585	0.543	0.712	0.180	0.400	0.113	0.436	0.250	0.280	-0.190	0.260	-0.175	0.381	-0.499	0.381	0.640	1	0.580	0.244	0.686
22	0.048	0.109	0.112	0.135	0.137	0.148	0.211	-0.128	-0.029	-0.160	0.017	-0.052	-0.125	-0.338	-0.135	-0.185	0.279	0.040	0.279	0.264	0.580	1	0.646	0.073
23	-0.087	-0.137	0.219	-0.183	-0.183	-0.185	-0.033	0.054	0.100	-0.021	-0.183	-0.021	0.071	-0.046	0.018	-0.082	0.226	0.173	0.226	-0.194	0.244	0.646	1	-0.076
24	0.956	-0.251	0.076	0.736	0.729	0.652	0.745	0.518	0.641	0.310	0.512	0.473	0.612	-0.033	0.510	-0.198	0.527	-0.785	0.527	0.550	0.686	0.073	-0.076	1

Fig. 1 Correlation analysis of variables.

correlated: general classroom—number and total floor area, area ratio of general classroom—number and area, area of subject/special classrooms—number and total floor area, total construction cost. In particular, total floor area, total construction cost, and general classroom area were predicted to significantly impact LCC changes in proportion to area.

3.4 Regression Model Establishment

Variables determined with the help of expert advice and correlation analysis are shown in Fig. 2, comprising a total of 26 independent and 4 dependent variables. A regression model was established for variables exhibiting the largest effects on LCC, such as city size, school grade, general classroom area, area of subject/special classrooms, total construction cost and total floor area [3, 4].

The results of the regression analysis using the five variables shown Fig. 2 are shown in Eq. (1):

$$Edu\text{-}LCC \times yr. = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5 \quad (1)$$

where,

a = constant;

b, c, d, e, f = coefficients;

x_1 = city size;

x_2 = school grade;

x_3 = total construction cost;

x_4 = general classroom area(m^2);

x_5 = total floor area.

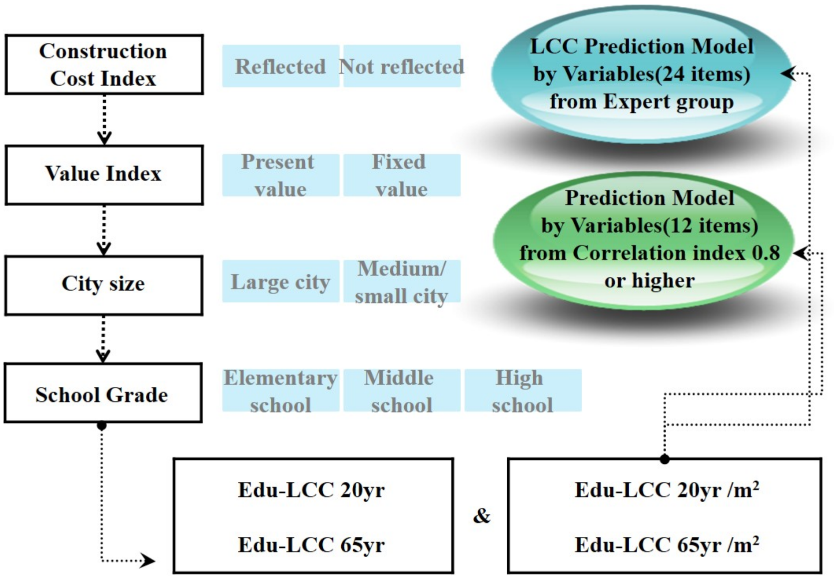

Fig. 2 Process of LCC prediction model.

Table 6 Error analysis results for the regression models.

Classification	(2)	(3)	(4)	(5)	average
Alt 1	3.71	7.37	3.76	7.81	5.66
Alt 2	8.10	34.61	7.58	25.24	18.88
Alt 3	3.70	7.39	3.76	7.82	5.67
Alt 4	5.34	6.96	4.82	6.31	5.86

Based on this, the LCC returns to the construction cost index, invariant, large city, and elementary school are shown in Eqs. (2) to (5). In this case, city size and school grade were substituted by dummy variables. The units of LCC20 and LCC65 years are in KRW (Korea won) million and the units of LCC20 and LCC65 values per unit area are KRW 1,000.

Edu-LCC 20 yr.

$$= -247.435 + 1.649x_3 + 0.903x_4 - 0.052x_5 \quad (2)$$

Edu-LCC 65 yr.

$$= -648.331 + 3.31x_3 - 3.718x_4 - 0.07x_5 \quad (3)$$

Edu-LCC 20 yr./m^2

$$= 1216.147 + 0.174x_3 + 1.773x_4 - 0.15x_5 \quad (4)$$

Edu-LCC 65 yr. /m^2

$$= 2061.488 + 0.355x_3 + 4.452x_4 - 0.28x_5 \quad (5)$$

3.5 Verification Results

Error percentages obtained by comparing the original values for 59 school facility cases with regression model predictions are shown in Table 6. For changes cost value with time difference, correction was carried out using the construction cost index and the value index, with the lowest errors achieved when using fixed values to characterize school facility BTL projects:

- Alt 1: construction cost index not included, fixed value;
- Alt 2: construction cost index not included, present value;
- Alt 3: construction cost index included, fixed value;
- Alt 4: construction cost index included, present value.

4. LCC Backtracking of School Facility in BTL Projects

4.1 Comparison of LCC Results by Analysis Condition and Work Type

For 20 year LCC result of school facility, the initial cost is estimated to be about 2.59 times higher than the maintenance cost, and the initial construction cost ratio is the highest at 79% when the current value and construction cost indexes are revised. The contribution of each work type comprised the effects of construction 9.9%, machinery 8.9%, electricity/communication 5.8%, and outdoor subsidiary facilities 3.3%. According to the service life standard of the Public Procurement Service, the replacement period in the field of equipment and telecommunications does not come until 20 years, and maintenance costs are considerably less than the initial construction cost.

Conversely, in the case of 65-year school facility LCC, the maintenance cost in the case of fixed and present values was higher than the initial construction cost by factors of 1.77 and 0.66, respectively. Considering the contributions of each work type, we find the ordering as for the 20-year case (construction 21.35%, electricity and communication 10.29%, machinery 15.38%, and outdoor subsidiary facility 5.17%), with construction cost increased almost threefold and that of machinery and electricity and communication increased almost twofold. Although the construction cost index does not largely influence the initial construction cost, the difference between each cost item determined when the cost is counted up using present values is significant.

The ratios of each work type for 20-year and 65-year LCC are compared in Fig. 3. Both LCC20yr and LCC65yr are surveyed to have a high ratio of construction and machinery work. In LCC20yr, the repair/replacement cost is little higher than the initial cost, but the initial cost of LCC65yr is 1/3 times higher than the repair and replacement cost.

The cost of LCC20 is 5 years, and it is 42.15% of total LCC in 20 years. If you are considering 20 years of use, it is important to reduce costs by increasing the number of years of use in the case of replacement after 15 years.

In LCC60 years, large repair and replacement costs occur every ten years, depending on the number of years of use. It can be seen that the number of years of the system included in the building is 10 years, and it is considered that it will take a lot of cost in 10 years. Therefore, it is necessary to repair or replace items with high priority in consideration of aging, necessity and influence. It is necessary for the school facility manager to establish a medium- and long-term plan considering the LCC.

Fig. 4 shows the maintenance and replacement ratios by year.

4.2 LCC Leveling Model

The availability of prediction models for each condition, e.g., for reflected/non-reflected construction

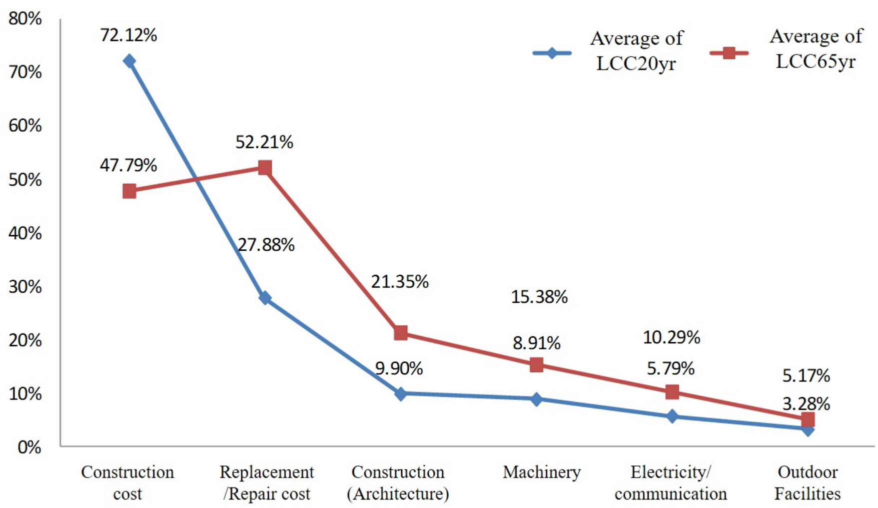

Fig. 3 The ratio of each work type for LCC20yr & 65yr.

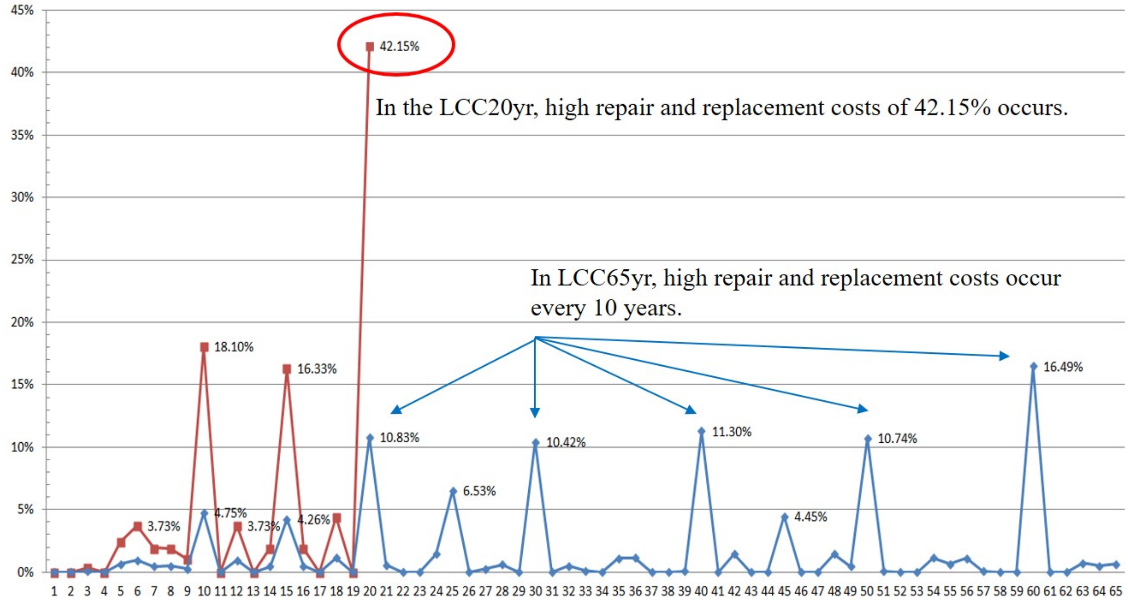

Fig. 4 Contributions of repair and replacement costs by years.

cost index, present/fixed value index, large, medium, and small city size, and elementary/middle/high school allows a prediction model suitable for the desired LCC to be selected and used.

Additionally, the LCC prediction model for each condition is provided for each unit area or year, and, for prediction models by year, LCC-20-year and LCC-65-year scenarios are provided. The LCC-20-year prediction model is used only when analyzing LCC during the lease period, such as BTL, with the LCC-65-year prediction model being applicable to all projects, such as publicly financed, new construction, or remodeling ones.

The existing LCC prediction formula is calculated by adding up the initial investment cost corresponding to the total construction cost and the sum of the maintenance and energy ratio that occurs for 65 years from the first year after completion. Predicting LCC at the initial stage of the project, when work type details were not provided, was challenging, since repair, replacement, and energy costs could be obtained only when the detailed system of each work type along with the initial investment cost equivalent to the total construction cost were known. However, the LCC prediction model proposed in this study is accurate and useful because it is a model based on statistics of life cycle cost within error rate ± 5% among LCC case studies.

When LCC is calculated by year, the school facility LCC leveling model prioritizes repair cost accordingly, so that it is changed on the basis of the school facility budget. As illustrated in Fig. 4, the maintenance budget is standardized by year. The above model standardizes annual budget equalization by iteratively optimizing the predicted LCC value, so that an equal maintenance budget fraction is used each year over the entire maintenance period, without allowing the budget to be concentrated on a specific year by introducing a preventive maintenance strategy based on school facility LCC by year and work type.

In detail, LCC leveling can be derived from the life cycle cost of work type and each year in school facilities. For example, the LCC prediction model is extracted through life-cycle cost cases and statistical analysis data, and modeled so as to be consistent with actual year-to-year actual values, thereby calculating a life cycle cost prediction value for each year. In the LCC leveling model, the leveling adjustment is made within 20% of the life cycle cost of the year. At this time, the life cycle cost of each year is calculated by

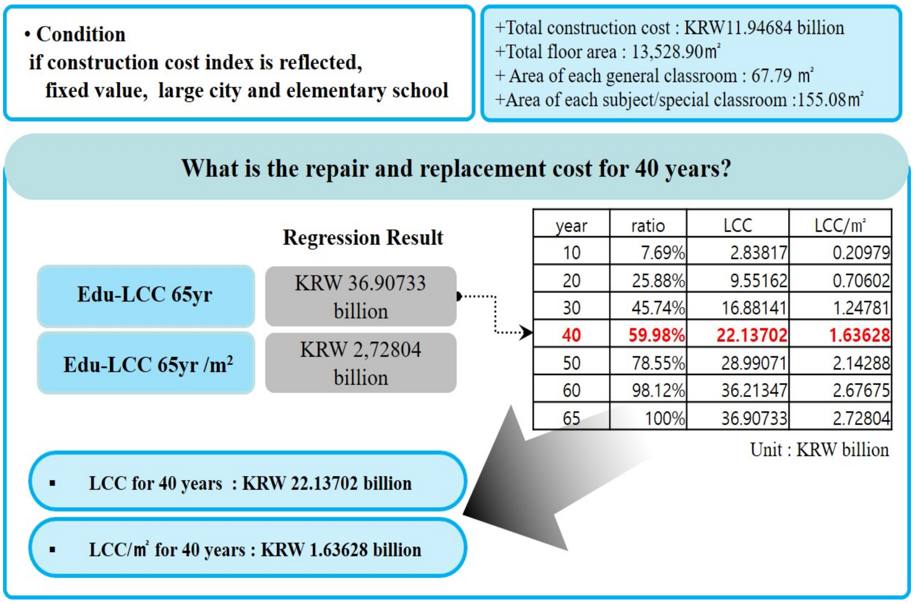

Fig. 5 Sample of LCC backtracking method.

using the corrected coefficient according to whether the cost index is reflected and whether the value index of the unchanged or the present value is reflected in the time series index.

4.3 LCC Backtracking

The LCC backtracking method utilizes the ratios by the ratio of work type and the number of years elapsed. For example, in case of the condition shown in Fig. 5, the LCC value of 65 years is regarded as 100%, and the ratio of LCC value of 40 years is 59.98%, which is equivalent to KRW 22.13702 billion.

5. Conclusions

Herein, variables were extracted by performing a literature review and seeking advice from an expert group, with 59 cases of school facility BTL projects announced in 2009~2011 analyzed and variable significance confirmed by correlation analysis. A statistical analysis program was used to establish a regression model based on the key elucidated variables, i.e., city size, school grade, total construction cost, area of general classroom per square meter, and total floor area. Verification was performed by determining errors relative to the original plan, with the absolute values of Alt 1 and Alt 3 (fixed values) shown to be within 6%. The high error observed in the case of Alt 2 was explained by the twofold correction utilized, since the construction cost index was not included and the present value was used.

In the future, the developed model is expected to evolve into a practical system for managing facility maintenance cost prediction, being suitable for room characteristics, comparing actual input costs with planned ones, and establishing a firm base for maintenance work at the time of planning the management budget of school facilities, reflecting their diverse variables (number of classes, facility, area and class function).

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