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INTEGRATED LIFE-CYCLE COST ANALYSIS CONSIDERING ENVIRONMENTAL COSTS: A HIGHWAY PROJECT CASE

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ABSTRACT: Concerns over the environment have spawned a number of research studies in the construction industry, as the construction of built environments and large infrastructures involves diverse environmental impacts and loads of hazardous emissions. Many researchers have attempted to quantify these environmental loads, including greenhouse gases, carbon dioxide, nitrogen dioxide, and sulfur dioxide, to name a few. However, little research has been conducted regarding integrating the life-cycle assessment (LCA) of environmental loads with the current life-cycle cost analysis (LCCA) approach. This study aims to estimate the environmental loads as a monetary value using the European Climate Exchange (ECX) rate and, then, to integrate those impacts with the pure construction cost. Toward this end, this study suggests an integrated approach that takes into account the environmental effect on the evaluation of the life-cycle cost (LCC). The bill of quantity (BOQ) data of a real highway project are collected and analyzed for this purpose. As a result, considering the environmental loads in the pavement process, the total LCC increased 16% from the traditional LCC cost. This study suggests an integrated approach that will account the environmental effect on the LCC. Additionally, this study is expected to contribute to better decision-making, from the perspective of more sustainable development, for government as well as for contractors.

Keywords: Life Cycle Assessment (LCA); Life Cycle Cost Analysis (LCCA); Sustainability; Environmental Loads; Highway project; European Climate Exchange (ECX)

1. INTRODUCTION

The lifecycle cost (LCC) concept, which includes diverse expenditures related to planning, design, construction, operations, maintenance, and demolition, is an important concept for the economic appraisal of infrastructure facilities [16]. Therefore, previous research has investigated diverse perspectives related to LCC, e.g., comparison of alternatives, assessment of an appropriate discount rate, estimation of user costs, and other subjects [1, 2, 12, 13]. LCC has become one of the most significant indices of decision-making, and the majority of owners even require contractors to provide an LCC analysis in their request for proposals. In the meantime, the construction of built environments and large infrastructures involves diverse environmental loads emissions. With the growing concern about the environment, a great deal of research has thus dealt with estimating environmental loads, such as the emission of greenhouse gases, carbon dioxide, nitrogen dioxide, and so on, during the whole lifecycle; this is known as lifecycle analysis (LCA). After the ratification of the Kyoto Protocol in 1992, these concerns have been more rapidly increasing. Moreover, depending upon each country's needs, these concerns motivated to develop exchange markets for trading emission rights. For this reason, a number of trading centers were established and the European Climate Exchange (ECX) trading amount has became one-thousand million tons in 2007. Nevertheless, little research has been conducted to integrate the LCA with the current LCA approach; instead, most previous LCC research has focused on the initial investment, including construction and maintenance costs. This study aims to estimate the environmental loads of a construction project during the construction, operation/maintenance, and demolition phases. Then, this study combines these estimations with the LCC analysis. From an extensive literature review on LCC and LCA, items those need to be considered in estimating environmental loads and relevant estimation methods are identified. On the basis of this framework, a case application with a highway pavement project in Korea is conducted to demonstrate the benefit of a proposed approach.

2. RESEARCH APPROACH

For the purposes of ascertaining current research trends, this study starts with a literature review on LCC, LCA, and LCA programs. The considerable components of LCCA (life cycle cost analysis) and LCA were also identified. We then extract the environmental terms of the LCA analysis and define the Integrated LCCA framework by a combination of the aforementioned results. After that, a case application of a highway pavement project in Korea is performed using a project lifecycle cost approach. This study concludes with implications for the sustainable planning of construction projects from the government's perspective as well as contractor's view. Figure 1 shows the research procedure:

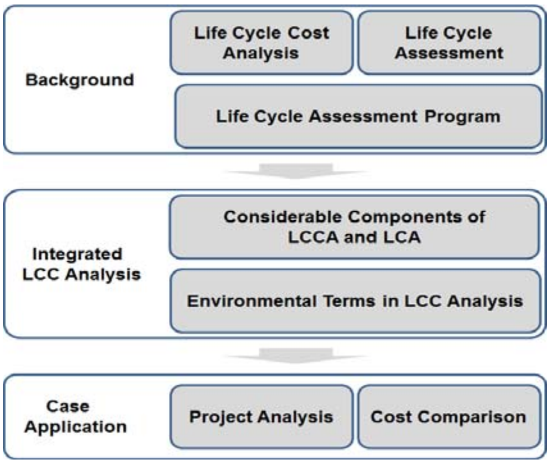

Fig. 1. Research Procedure

3. BACKGROUND

According to the Federal Highway Administration (FHWA)[3], life cycle cost analysis is defined as "a process for evaluating the total economic worth of a useable project segment by analyzing initial costs and discounted future costs…over the life of the project segments." Therefore, LCCA generally covers initial investment (including planning, design, procurement, and construction costs), operating costs, maintenance costs, demolition costs, financial costs, and other expenses. A traditional project management approach sees cost, schedule, and quality as the most important elements in construction projects. However, with the growing concern over sustainability and economic efficiency, LCCA has become the essential condition for project planning and decision-making. Thus, for a more detailed analysis of LCC, a number of studies have been widely conducted. Some researchers have used agency costs and user costs in cost/benefit analysis, and then sub-divided the terms. Agency costs usually include construction, rehabilitation, and maintenance costs. Additionally, engineering or administration costs are partly included. The same is true for investment costs. Facilities consider user costs as either inconvenient or disadvantageous. Thus, factors such as travel time, car accidents, and vehicle air emissions are included [5, 14]. However, the estimation of user costs is too difficult and uncertain. Similarly, the estimation of reasonable and accurate discount rates and future expenditures are also important issues in the LCCA field. Therefore, several studies have proposed discount rate estimation and optimization methods [1, 2, 12]. Meanwhile, apart from cost elements related to the characteristics of the facility type, most studies have adopted a similar LCC structure, and no research has dealt with environmental loads as cost elements.

The concept of LCA was first defined by the Society of Environmental Toxicology and Chemistry (SETAC)[11] and covered inventory investigation, impact assessment, and improvement assessment. Later, ISO14040 [8] stipulated the LCA procedure as encompassing four phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and life cycle interpretation. Since most of the environmental loads of construction projects are generated during the construction phase, and the amount of loads varies depending on the material, most LCA research in the construction field has focused on lifecycle inventory analysis and life cycle impact assessment. Furthermore, while some research has focused on an essential element—CO_2 emission [6, 8]—research has also covered the diverse elements SO_2, CO_2,, and NOX, as well as many other elements, including greenhouse gases [15]. Duraijai et al. proposed eco-cost terms in their environmental LCC model, but this cannot be suitable in a general LCC framework [17].

Forseberg et al. conducted a comparison of various assessment tools for the built environment [4]. They showed the importance factors related to environmental consideration for each tool. Although previous research and tools are efficient in estimating environmental loads, attempts to quantify them, in terms of cost, and to include LCCA elements, are still insufficient. For this reason, this study uses the SimaPro life cycle assessment software program, which is an LCA analysis tool. This software can automatically calculate environmental loads, based on the material properties and the amount of material consumed, using databases of previously completed projects [7, 9]. SimaPro was developed by Pre Consultants in Holland. SimaPro has some advantages for LCA analysis. First, this program allows a great amount of freedom when it comes to defining and analyzing projects. Thus, users can easily input their own items. If users are unable to input these items, SimaPro provides a library search that enables users to find the same items. This program only requires the same items and quantities. Secondly, SimaPro provides very fast calculation for the analysis. Thus, users can save time and determine the results of each process from a single calculation. Thirdly, SimaPro can be applied in various methodologies. Consequently, users can choose the desired method. Finally, SimaPro analysis data can be saved in Microsoft Excel files [9]. However, users cannot access these Excel files without the SimaPro program.

Despite the efforts of aforementioned research studies, researches on converting the environmental loads to monetary terms or comparisons of environmental costs are still insufficient. For example, Ari et al.analyzed environmental damages, and its impacts, by conducting air pollution costs and government policies [10]. Mette et al. analyzed the variation of CO_2 emission rates by environmental tax changes in Denmark [18]. Nevertheless, these research results do not apply to general construction projects.

3. INTEGRATED LCCA APPROACH

3.1 Considerable Cost Components of LCCA and LCA

The planning and design phases of a project should take into account the environmental cost factors in an organized way. But environmental factors of each step are widely variable and its impacts are also different. Accordingly, potential environmental emissions could be reduced in each step through investigating alternative construction methods and selecting appropriate materials. Actually, the procurement stage uses many material or equipment transporters. These transporters lead to a load of environmental emissions. Moreover, material production processes are the most critical when it comes to environmental emission factors. The construction, operations, and maintenance steps all use operating equipment. This equipment leads to environmental emissions by heavily consuming energy. The operation and maintenance steps also use new materials and transporters. However, the environmental impact of these two steps is considered smaller than that of the procurement phase. In the demolition step, no more new material is used, but, the demolition step also relates to emissions, because the operating equipment and the transportation of wastes create emissions.

In reference to the SimaPro database, concrete, for example, can relate to more than 30 different kinds of emission factors, including SO2, CO2, and NOX, and many other elements, even greenhouse gases [9]. Table 1 shows the important factors that must be considered in a construction project. Since construction projects use a lot of materials and equipment along the life cycle, some guidelines are required for simplifying LCC analysis that can handle a wider variety of factors and additional environmental costs by those factors.

Table 1. Important Factors in Construction Projects

Project Phase	Sources	Factors
Planning & Design	Environmentally Sound Alternatives	New techniques; Material Changes
Procurement	Material-production; Transportation	Emissions in production; Emissions by Fuel
Construction	Equipment	Emissions by Fuel
Operation & Maintenance	Material production; Transportation; Equipment	Emissions in production; Emissions by Fuel
Demolition	Equipment; Transportation	Emissions by fuel; Emissions by fuel

3.2 Environmental Terms in LCC Analysis

Through the literature, several major environmental sources (material, transportation, and construction) are categorized. These source components can be valued in most LCC steps. As planning and design does not actually use material or equipment source, this phase only includes such factors as alternatives and material change, etc. (see Table 1). In order to evaluate environmental costs, this study first calculates the material loads through taking off actual consumptions from the bill of quantity (BOQ). These actual material amounts can be then converted to emissions in the material production process. Secondly, it requires converting transportation loads into the amount of fuel. These kinds of emissions are generated when the materials manufactured are delivered to the construction site. Thirdly, this study estimates equipment loads in the same way as the fuel costs related to the equipment on site. In these ways, this paper considers environmental loads by assessing and analyzing the amounts of materials and fuel that are presumably consumed in a given construction project.

Another perspective to be considered is related to environmental impact factors. As previously mentioned, there are too many environmental factors to cover all of environment assessments. For the purposes of this research, we primarily focus on greenhouse gases, such as CO2, because greenhouse gases constitute a large portion of environmental loads and also can be accurately converted to monetary terms using the carbon-tax method or Certified Emission Reduction (CER).

3.3 Integrated LCCA Procedure

For identifying the environmental impact with respect to construction LCC, preferentially, we defined the general procedure. Step 1 involves calculating the total quantity of actual resource consumption for the construction project. Table 2 displays an example of the total quantity of the highway project. For the analysis, we grouped materials and equipment with sub-grouping related activities that can be found under the Name column in Table 2.

Table 2. Major materials and equipment usages in a highway project

Group	Name	Related Activity	Quantity
Material	Asphalt	Surface layer; Sub-base layer; ……	23,104M^2
	Concrete	Lean base layer;, Concrete slave; …..	13,850M^3
	Steel	Site processing; Site	395 Ton

		fabrication; …..	
	…..	…..	…..
Equipment	Dump truck	Material transport; ……	21,902M^3
	Concrete roller	Compaction …..	4,469 M^3
	…..	…..	…..

Generally, LCC is calculated from the planning phase to the demolition phase. Project planning and design cost definitions are too broad to estimate all the components and there also exist many uncertainties to assess them. Therefore, direct CO_2 emission is calculated from the procurement to the demolition phase. For the integrated LCCA, users are requested to define materials and equipment usages from the procurement phase to the demolition phase. In Step 2, environmental impact is calculated using CO_2 emissions. Currently, there are various methods for calculating these emissions. In this research, we use the IPCC 2007 coefficient embedded in the SimaPro program [9, 19]. The LCC is comprised of cost or monetary terms. Therefore, for the cost comparison, we convert the CO_2 emissions to monetary terms in Step 3, using the ECX rate. In Step 4, we finally analyze the cost comparisons. To verify the environmental impact, we compared existing LCCs with the integrated LCCAs. Fig. 2 shows the step-by-step procedure for this end.

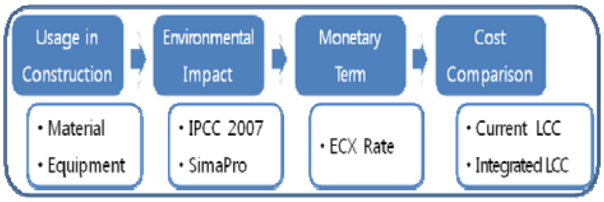

Fig. 2. Integrated LCCA Procedure

4. CASE APPLICATION

4.1 Project Analysis

On the basis of the integrated LCCA framework, a case application with a highway pavement project in Korea is conducted to demonstrate the benefit of a proposed approach. This case study uses data for a highway construction project located in South Korea. The case project is a four-lane, asphalt-paved road that is 10.2 km length. For the analysis, we defined both the process and the assumptions. First, the whole costs are categorized into procurement, construction, operation and maintenance, and demolition costs. The planning and design steps are excluded in the project's LCC, as these stages do not generate heavy CO_2 emissions. Secondly, we used the main materials and fuel for transportation or equipment usages in the BOQ to analyze the LCA. Construction projects require a great deal of materials and equipment. Thus, specifying all of these sources would be a waste of time and effort. Therefore, it is necessary to limit the driving materials and equipment taken into account for cost analysis in relation to environmental factors. Thirdly, this study covers materials from production to installation. For the production of materials, various raw resources are consumed. Moreover, with regard to installation, materials must be delivered from the manufacturing factory to the construction site. Thus, each process needs to consider all these processes. Finally, this paper uses the Intergovernmental Panel on Climate Change method (IPCC) [19], within a period of 20 years, to calculate the CO_2 emissions. For the calculation of net present value (NPV), we assumed a discount rate as a fixed value of 6%. Under this assumption, according to the LCC Table, PW (P/F, 6%, 10year) = 0.5584, PW (P/F, 6%, 20year) = 0.3118 and PW (P/F, 6%, 30year) = 0.1741.

4.2 Integrated LCCA approach

STEP 1. Usage in Construction

Procurement and Construction Phase

In terms of procurement and construction costs, this study categorizes two elements. We first divide construction costs into three subcategories (material costs, labor costs, other expenditures). The other major category is environmental costs (Table 7 and Table 8). In terms of material production process, this paper considered asphalt, cement, steel, and diesel. Diesel, however, was not directly connected to the other construction materials per sea, as it was only used for transportation fuel.
This road project required 23,252 tons of asphalt, 105,100 tons of concrete, and 395 tons of steel. For the delivery of these materials, 0.7 tons of diesels were calculated to be used by BOQ. For the environmental emission analysis, this paper adopts the IPCC 2007 method in SimaPro. Information from the SimaPro input screen is displayed in Table 3. The SimaPro calculate CO_2 emissions as a total of 24,460 tons. As shown in Table 6, the asphalt production process induced the primary emissions factor of 16,800 t CO_2 eq.

Table 3. Material Input for the Procurement and Construction Phase

Method	Item	Amount	Unit
IPCC 2007	Asphalt	23,252	Ton
	Concrete	105,100	Ton
	Steel	394.91	Ton
	Fuel (diesel)	7372	Kg

Operation and Maintenance Phase

In terms of operation and maintenance costs, this study categorized two terms. The first is operation and maintenance costs, which is divided to three elements (material costs, labor costs, and other expenditures), as mentioned above. The other category is environmental costs (Table 7 and Table 8). In road maintenance, particularly in the paving process, only one procedure (cutting and extra coating) is required every 10 years, which only consumes asphalt material. Thus, 3,751 tons of asphalt, and 0.5 tons of diesel fuel, were considered for this phase. Information from the input SimaPro screen is shown in Table 4. The SimaPro calculations show a CO_2

emissions total of 2,710 tons. The life-cycle of this case project is assumed 30 years; thus, the procedure of cutting and extra coating will be conducted twice (See Table 6).

Table 4. Material input for the Operation and Maintenance Phase

Method	Item	Amount	Unit
IPCC 2007	Asphalt	3,751	Ton
	Fuel (diesel)	487	Kg

Demolition Phase

This phase identified two types of costs, demolition costs and environmental costs (Table 7 and Table 8). The demolition costs are also divided into material costs, labor costs, and other expenditures. The demolition process does not use new materials; it only requires equipment to crush and remove the existing pavement. In road projects, not all of the elements are removed at the end of the service life. Materials can be renewed using new technology or can be recycled in another way. Thus, it is estimated that only 0.3 tons of diesel is required for equipment fuel for this stage using crusher fuel efficient. Information from the SimaPro input screen is shown in Table 5. The SimaPro calculation shows a CO_2 emissions total of 0.931 tons (See Table 6).

Table 5. Material Input for Demolition Phase

Method	Item	Amount	Unit
IPCC 2007	Fuel (diesel)	3277	Kg

STEP 2 and 3. Environmental Impact and Monetary Terms

Conversion of environmental loads to monetary terms

This paper calculated the environmental costs by a conversion to CO_2 equivalents. According to the European Climate Exchange (ECX), the transaction rate is found 14.13 euro per 1 ton of CO_2 emission rights (Dec. 5, 2009). The currency exchange rate of 1 euro is 1,735 Korean Won as of Dec. 5, 2009.

Table 6. Environmental Impact (CO_2 Equivalent Emissions, Ton)

Project Phase	Asphalt	Cement	Steel	Diesel	Sum
Procurement & Construction	16,800	7,260	398	2	24,460
Operation & Maintenance	2,710	-	-	0.138	2,710
Demolition	-	-	-	0.931	0.931

Calculation of LCC with Environmental Costs

The initial costs for procurement and construction stage are estimated 2,064,052 Euros. The environmental costs of CO_2 emissions, in the procurement and construction phases, amount to 345,619 Euros. This means that there is a 16% increase in costs, compared with the initial expenditure. The operation and maintenance costs are 282,750 Euros, while the environmental costs in these phases are 38,292 Euros. Lastly, the demolition cost is 305,910 Euros; the environmental cost, brought about by the demolition process, is assessed 13 Euros. Table 7 and Table 8 provide the detailed calculations. The general LCC cost is calculated as 2,363,359 Euros. This includes the initial cost, two repetitions of operation and maintenance costs, and the cost of demolishing. Moreover, the environmental costs, calculated using SimaPro and the ECX rate, are 378,942 Euros. Road pavement processes alone generate an additional cost of approximately 16%, compared to the existing LCC value.

STEP 4. Cost Comparison

The total CO_2 emission amount is 27,171 tons. These emissions cannot be considered in current LCC structures. Especially, 24,460 Ton of CO_2 was estimated in procurement and construction phase. It means that procurement and construction phases occupied 87% of entire emission. In the same manner, emission by materials source was calculated to 24,458 Ton of CO_2. It is interesting to note that only 2 ton of CO_2 was emitted by construction equipment (Table 6). It signifies that most of CO_2 emission was brought by such driving materials as asphalt, concrete and etc., particularly during procurement and construction phase. By converting to monetary term, environmental cost in procurement and construction phase was calculated to 345,619 Euros. Thus, it can be noted that over the 90% of environmental cost was originated in this phase (Table 7 and Table 8).

These results represent that procurement and construction phase is critical in environmental emission and its cost. Thus, in order to reduce or control environmental impacts, it is suggested to focus more in procurement and construction phase. Especially, construction materials consumed during procurement and construction phase are considered most critical.

Moreover, the environmental cost is at least 378,942 Euros, representing 16% of the total construction costs in the typical LCC approach. If the government takes account this cost in the LCC, this can change the budget allocations and priority for investments to pay for their environmental impact.

5. CONCLUSION

Although there are increasing concerns over the environmental effects of construction projects, there have been relatively few attempts to analyze environmental issues in terms of life cycle costs. This paper identified important items that should be considered in estimating environmental loads. We presented an example of such an analysis, using a highway pavement project in Korea. . As a result, a total of 27,171 tons of CO_2 emissions were estimated. The total LCC was calculated to 2,363,359 Euros, and the environmental cost was gauged to be 378,942 Euros.

Table 7. NPV Calculation (Euro) – General LCC

Project Step	Material costs	Labor costs	Other expenditures	Total	NPV
Procurement & Construction	1,049,606	653,015	361,431	2,064,052	Same
Operation & Maintenance (10 year)	141,375	90,480	50,895	282,750	157,887
Operation & Maintenance (20 year)	141,375	90,480	50,895	282,750	88,161
Demolition (30 year)	152,955	97,891	55,064	305,910	53,259
Total Construction Cost					2,363,359

Table 8. NPV Calculation (Euro) – Environmental Costs

Project Step	Ton (CO2 eq.)	ECX rate	Sum	NPV
Procurement & Construction	24,460	14.13	345,619	Same
Operation & Maintenance (10 year)	2,710		38,292	21,382
Operation & Maintenance (20 year)	2,710		38,292	11,939
Demolition (30 year)	0.931		13	2
Total Environmental Cost				378,942

This means that an additional 16% of costs were presumed if we cover the environmental impact. Through such a case application, this paper identified environmental load amounts and introduced the costs of each construction phase; these data could be used to support environmentally friendly decision-making. However, this study has several limitations: 1) The extent of specificity of the life cycle cost structure is not sufficient; 2) the use of material and equipment data for the analysis was limited; and 3) only CO2-converted environmental loads were recognizable because of the proposed software method (IPCC 2007); and 4) cost comparisons were only made between the site construction and environmental costs of the road project, using NPV. This was not enough to determine the impact of the LCCs upon the environmental costs. Despite the current limitations, however, this paper attempted to give a quantitative analysis using bill of quantity to generate data that are more reliable. So far, the results can be used as fundamental references for rational and sustainable project decisions and to support the government's environmental policies. By introducing environmental cost concept to the LCCA, LCC can be estimated with higher precision. For owners, this will allow them to allocate budgets more efficiently and make appropriate decisions in long-term view. Also, the conversion of environmental impact into monetary value makes it possible for owners and contractors to judge the environmental impacts of several alternatives quantitatively and make objective comparison between them. Future research will focus on more detailed cost breakdown structures, in relation to LCCA and LCA concepts, as well as consideration of various environmental factors.

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