LCC 및 LCA 통합에 근거한 철도시설물 유지관리 필요성 고찰

A Study on the Necessity of Maintenance of Railway Structures based on the Integration of LCC and LCA

진남희* 박준오** 박미연***

Jin, Nam-Hee Park, Joon-Oh Park, Mi-Yun

철도시설물의 유지관리를 위한 전통적인 의사결정 방법은 구조물의 기술적인 측면 즉, 시설물의 안전성과 사용성 등을 만족시키는 조건하에 경제적인 측면 즉, 시설물의 생애주기 비용을 최소화하고자 하는 것이며, 생애주기 비용을 정량화하기 위한 도구로서 LCC 기법이 사용되었다. 그러나, 1990년대 후반 이후로 지구온난화 등의 피해가 부각됨에 따라 선진국들을 중심으로 시설물의 유지관리를 위한 의사결정에 환경적 측면과 사회적 측면을 추가적으로 고려하는 지속가능한 발전 개념을 도입하고 있으며, 환경 부하를 정량화하기 위한 도구로서 LCA를 적용하고 있다.

본 연구에서는 시설물의 유지관리 행위와 관련된 경제적 측면과 환경적 측면을 정량화하는 방법으로서 LCC 및 LCA의 적용 방안을 고찰하고, LCC 및 LCA 결과로부터 시설물 유지관리 최적 방안을 결정하기 위한 의사결정 기법을 제안한다.

국내의 철도시설물에 대한 유지관리 필요성이 증대되고 있으며, 철도시설물의 규모가 커서 유지관리 행위에 따른 경제적 및 환경적 파급효과가 큼을 감안할 때, 본 연구에서 제안된 내용은 경제적이고 환경 친화적인 철도시설물 유지관리 방안을 선정하는데 유용한 방법론으로 활용될 것으로 사료된다

1. Introduction

The traditional approach for the decision making in bridge management is that the decisions should be based on minimum life cycle cost subject to safety or reliability constraints, i.e. minimise the total cost over the remaining service life provided that a reliability or safety value remains above an acceptable/tolerable level. However, from the 1990s onwards, another strategy for decision making, termed sustainable development, is gaining ground among public policy makers. At the heart of sustainable development is the simple idea of ensuring a better quality of life for everyone, now and for generations to come. It means achieving social, economic and environmental objectives at the same time. (Figure1)

The construction industry has a huge impact on achieving sustainability targets because of its tremendous scale of business. Recently, in Korea, the industrial policy that promotes technologies or products which produce low carbon-dioxide is emphasized. With regard to environmental impacts, it is considered that the railway industry could be competitive. However, the superiority of railway industry in terms of environmental aspect has rarely been quantified.

* 책임저자 : 정회원, 코레일트랙(주), 선로시설연구소, 연구소장
E-mail : nhjin70@hanmail.net
TEL : (042)257-9486 FAX : (042)257-9488
** 정회원, 코레일트랙(주), 선로시설연구소,연구부장
*** 정회원, (주)아이엠기술단, 기술연구소, 연구소장

Bearing this in mind, this paper tries to make a decision-making support tool for bridge, one of the main railway structures, management based on sustainable development concept. However, it is difficult to quantify the social criteria influenced by bridge maintenance activities. Social criteria in this context may include different indicators of noise, nuisance, inconvenience and job opportunity, etc for different maintenance activities. More than anything else, there are no objective tools to measure these indicators. A single activity/task may have both a positive and a negative impact, depending upon the individual perspective (e.g. noise vs. job opportunity). Furthermore, individuals may change their mind over time. In view of this, it is currently practically impossible to formulate a social impact score for bridge maintenance activities. Therefore, social impacts arising from bridge maintenance activities are not considered, and only economic and environmental factors are calculated and integrated. In other words, this paper quantify the economical and environmental aspects of the maintenance options of bridge structures by applying LCC and LCA tools and propose how to decide an optimal bridge maintenance plan by applying multi-criteria decision making analysis/Aid (MCDA) tools.

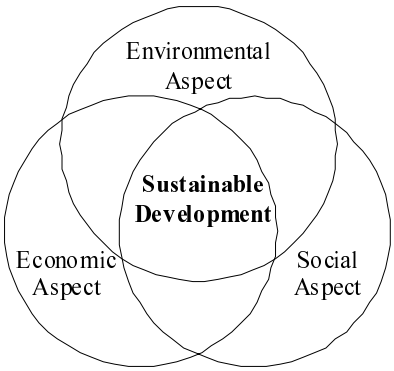

Figure1. Three bottom line approach for sustainable development

2. Development of a methodology

2.1 Decision making framework for sustainable bridge maintenance

As explained above, the main concern of this paper is to develop a decision making support tool which will help in finding preferable bridge maintenance options/plans in terms of sustainability. This aim can be achieved by understanding the general decision making process and applying it carefully to a given situation. The general decision making process is made up of following steps.

- Identifying objectives
- Identifying options for achieving the objectives
- Identifying the criteria to be used to compare the options
- Analysis of the options
- Making choices

Based on the general decision making process, the decision making framework used in this study has been made as presented in Figure2. The details of each step are explained below one by one.

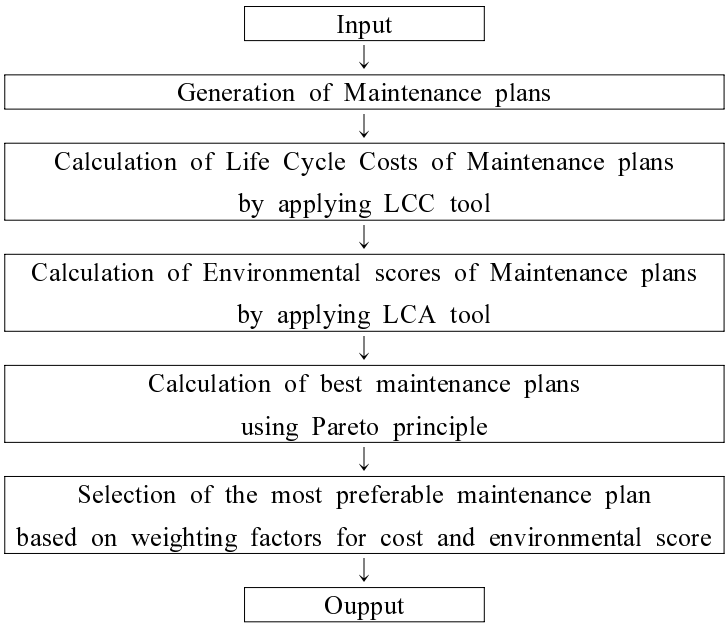

Figure2. Main flow used in this study

2.2 Generation of maintenance plans

The maintenance options available for achieving "sustainable" bridge maintenance are the same as those considered in "traditional" bridge maintenance. Maintenance plans can be generated by considering different maintenance options such as concrete repair, waterproofing, and rehabilitation, etc. and their combination. Different maintenance options vary in respect of required time and materials, have different cost, and produce different improving effects in safety/reliability and durability. Hence, maintenance plans can be generated diversely by combining different maintenance options, and different maintenance plans will result in different economic, environmental and social impacts.

Basically, three approaches can be used in the determination of maintenance plans. They are:

(a) time-based approach: applicable primarily to preventative maintenance actions;
(b) performance-based approach: applicable primarily to essential maintenance actions;
(c) time- and performance-based approach: applicable to both preventative & essential maintenance actions.

The time-based approach uses two variables: time of first application and time of subsequent applications, independently of predicted or measured profiles of any performance indicators (Figure3). In the case of a performance-based approach, maintenance actions are applied when a performance threshold is violated, which implies that some prediction/estimation of performance is needed. Time- and performance-based approach is a mix of these two approaches. Typically, the timing of preventative maintenance actions may be determined by a time-based approach but, in addition, essential maintenance is applied if/when some performance threshold is violated (Figure4).

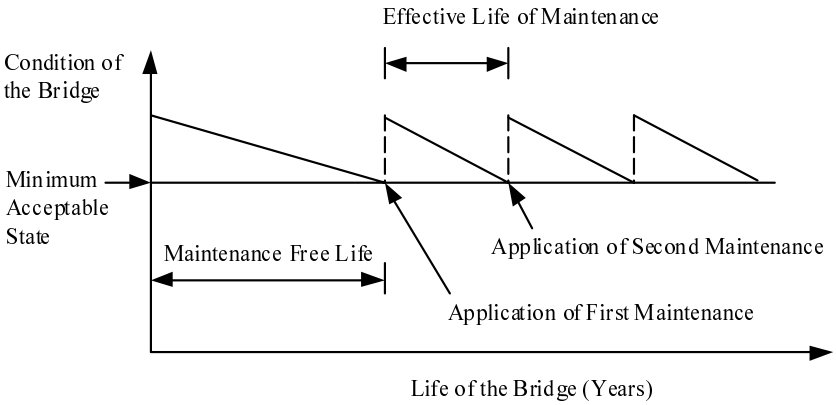

Figure3. Determination of maintenance frequency by effective life concept

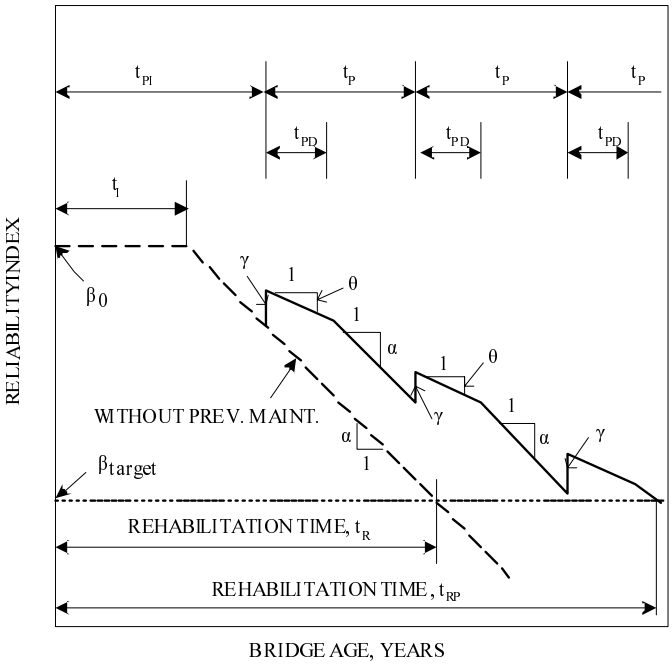

Figure4. Time variation of reliability index with and without preventative maintenance

2.3 Calculation of Life Cycle Costs of Maintenance plans by applying LCC tool

According to Ryall, life cycle costing (LCC) is a way of determining the total cost of a bridge structure from its initial conception to the end of its service life. It attempts to quantify, in present monetary terms, the costs arising from all work undertaken on a certain structure. Future costs are converted into their present value (PV) at a given base year using the expression:

$$PV = \frac{C}{(1+r)^t} \qquad (1)$$

where, C is cost at current price levels; r is the test discount rate (TDR) and t is the time period in years. Alternatively, the term $1/(1+r)^t$ is called the discount factor and determines the discounting ration between future cost and present value.

In fact, expenditure is spread over the service life of bridge structures, hence the cumulated present value of all expenditures becomes:

$$PV = \sum \frac{C}{(1+r)^t} = \frac{C_1}{(1+r_1)^{t_1}} + \frac{C_2}{(1+r_2)^{t_2}} + \ldots + \frac{C_n}{(1+r_n)^{t_n}} \qquad (2)$$

2.4 Calculation of Environmental scores of Maintenance plans by applying LCA tool

In ISO 14040 [4], Life Cycle Assessment is defined as the "compilation and evaluation of the input, outputs and potential environmental impacts of a product system throughout its life cycle." As shown in Figure5, LCA includes definition of goal and scope, inventory analysis, impact assessment and interpretation of results.

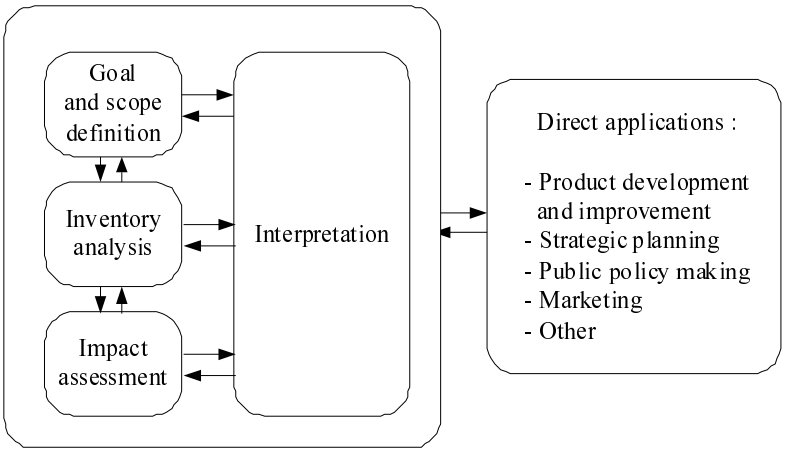

Figure5. The processes of LCA

The goal and scope definition is the phase in which the initial choices to determine the working plan of the entire LCA project are made. Life Cycle Inventory analysis (LCI) involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. Life Cycle Impact Assessment (LCIA) is the phase in which the set of results of the inventory analysis is further processed and interpreted in terms of environmental impacts and societal preferences. Figure6 shows the several mandatory and optional elements of LCIA process. In this study, it is assumed that a single environmental score can be obtained by applying LCIA process and Figure7 shows the environmental scores of four maintenance options when Eco-indicator 99 methodology is used.

2.5 Multi-Criteria Decision Analysis

The results from separate LCC and LCA analyses have different characteristics since economic or environmental quantities are respectively calculated. Multi-criteria decision analysis techniques may be employed to combine them. Pareto analysis and the relative strength of preference and swing weighting concept are chosen herein (see Figure8).

Pareto Analysis

If one represents the two values of life cycle cost and environmental score as a point in a two-dimensional

graph for all bridge maintenance plans, one can draw a non-inferior curve; only points on this curve can represent the best maintenance plans. It means that life cycle cost and environmental performance score of all other points are worse than those of one of the points on the non-inferior curve.

Relative strength of preference and swing weighting

The main idea of 'relative strength of preference and swing weighting' is to construct scales representing preferences for the consequences, to weigh the scales according to their relative importance, and then to calculate weighted averages across the preference scales. In this study, considering that the lowest cost and environmental score best meet the two decision criteria, the most preferred option is assigned a preference score of 0, and the least preferred a score of 100. Scores are assigned to the remaining options so that differences in the numbers represent differences in strength of preference.

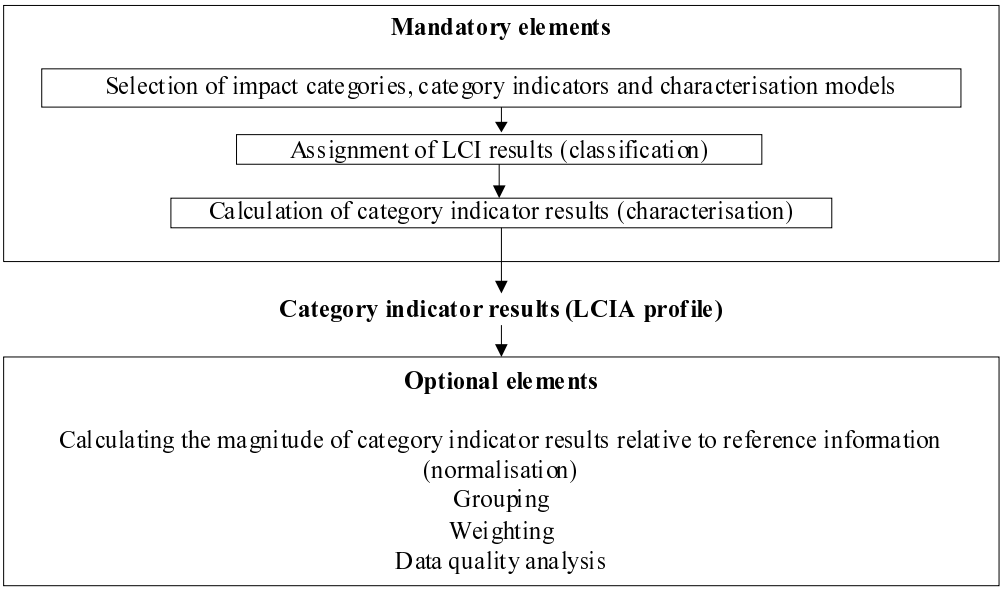

Figure6. Elements of LCIA process

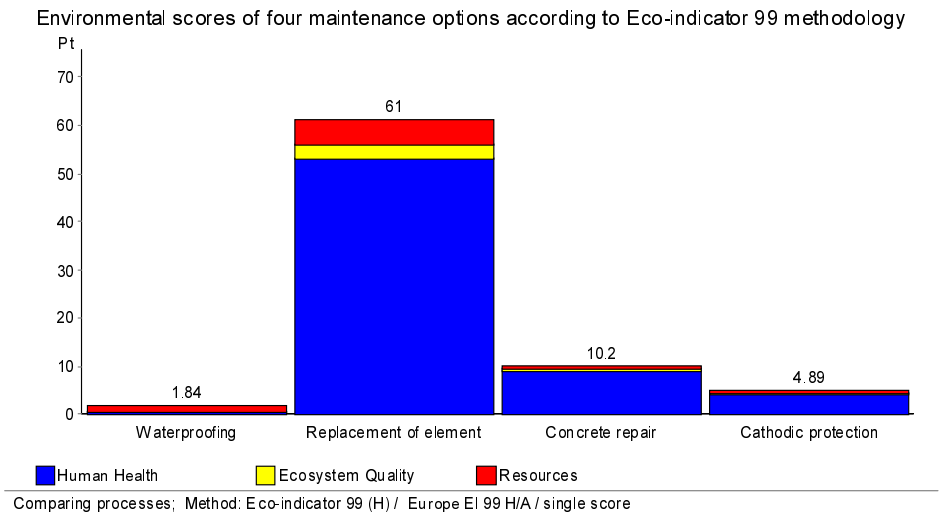

Figure7. Environmental scores of four maintenance options according to Eco-indicator 99 methodology

If a decision-maker determines the weighting factors for environmental score and total cost, then the overall weighted score can be calculated by formula (3) below. Thus, a maintenance plan with the smallest value of S_i becomes the best maintenance plan.

$$S_i = w_E\, s_{Ei} + w_C\, s_{Ci} \qquad (3)$$

where, S_i: overall weighted score for i_{th} maintenance plan

w_E, w_C: weighting factors for environmental score and life cycle cost.

s_{Ei}, s_{Ci}: relative strength of preferences for environmental score and life cycle cost for i_{th} maintenance plan, respectively

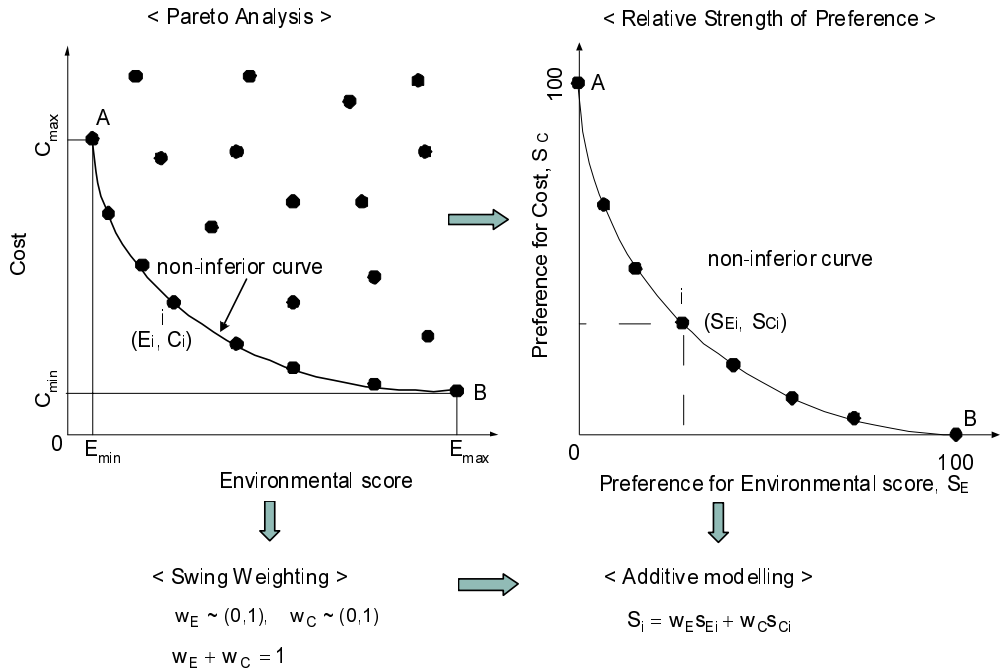

Figure8. MCDA techniques used in this study

3. Conclusion

In this paper, the methodology which integrates LCC, LCA and MCDA tools for determining an optimal bridge maintenance plan has been proposed. As the environmental issue becomes more and more important, it is considered that the LCA tools should be adopted as a tool quantifying an environmental impacts in railway industry and the results should compete with cost when an optimal bridge maintenance plan is chosen in terms of sustainable development concept. The methodology suggested in this paper may give some ideas how to do that.

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