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Numerical Simulation for Lifecycle Environmental Impact and Cost of Highway Bridges

Nagoya University Student Member ○ Laxman Sunuwar
Nagoya University Fellow Yoshito Itoh

1. Introduction

Besides the lifecycle cost analysis of bridges needed to predict the investment in a bridge, environmental impact is an important part of lifecycle performance. Among various environmental effects from bridge construction, maintenance and demolition activities, the global environmental impact is one major effect. With increasing interest in the research of global environmental impact, a system was prepared at Nagoya University to evaluate the global environmental impact of various bridge types for the purpose of selection of bridge types in the preliminary design process[1]. Later, an evaluation system was developed for the prediction of lifecycle environmental impact and cost of bridges[2]. Carbon-dioxide (CO_2) emission is considered as the indicator of the global environmental impact. In this study, numerical simulation is used to predict environmental impact and cost of different bridge types with probabilistic treatment of various uncertain parameters.

2. Bridge Lifecycle and Assumptions during Maintenance Stage

Among construction, maintenance and demolition stages of bridge lifecycle, several manuals and databases are available for the estimation of resources and cost of the construction stage of bridges. The resources and cost for demolition stage can be found with some assumptions of demolition method. However, the maintenance stage of bridges last for a longer duration with various uncertainties. The maintenance stage is dependent upon various parameters like traffic volume, surrounding environment and so on. To deal with the uncertaities, several assumptions are needed to find out the effect of maintenance stage. Bridge service life and maintenance frequencies are considered to follow Weibull distribution and log-normal distribution respectively in this study. The lifecycle environmental impact and cost is calculated by combining various probability distributions considered for lifecycle parameters.

For the illustration purpose, four bridge types are considered to show the evaluation procedure. These bridges are 120m in length and 12m in width with three equal spans. Table 1 shows the bridge types considered with environmental impact and cost for various activities of bridge lifecyle. The first two bridge types are pre-stressed concrete (PC) bridges and the other two types are steel bridges. These bridges will be referred as Bridge1, Bridge2, Bridge3 and Bridge4 in the subsequent discussions. The environmental impact and cost for various activities are calculated by the use of systems prepared for bridge type selection[1] and lifecycle environmental impact and cost[2]. The mean value of bridge service life is considered as 60 years. The mean and standard deviation (SD) values for maintenance frequencies are shown in Table 1. The frequencies for most common maintenance activities are adopted from the result of available literature and interview carried out with bridge engineers. The standard deviation value is decided by taking the difference of fastest and slowest frequency values and dividing by a constant to consider confidence interval. More details about this is found in the other paper by the the authors [2].

Table 1 Maintenance Frequencies and Environmental Impact and Cost from Each Stage

Designation			Bridge1		Bridge2		Bridge3		Bridge4	
Bridge type			PC T-Girder (RC Deck)		PC Box Girder (PC Deck)		Steel I-Girder (RC Deck)		Steel Box Girder (Steel Deck)	
	Frequency Value		Impact	Cost	Impact	Cost	Impact	Cost	Impact	Cost
	Mean	SD	(tC)	(10^6 Y)	(tC)	(10^6 Y)	(tC)	(10^6 Y)	(tC)	(10^6 Y)
Construction	60	7.0	393.13	611.83	329.71	429.78	369.22	684.41	458.41	686.06
Maintenance										
Pavement	12	3.75	3.79	12.28	3.79	12.28	3.79	12.28	3.79	12.28
Painting	10	2.0	0	0	0	0	3.56	40.70	6.45	68.36
Deck Rehabilitation	20	2.5	24.38	50.12	8.24	27.84	24.38	50.11	8.24	27.84
Deck Repalcement	40	5.0	75.08	277.82	0	0	75.06	277.82	149.25	347.04
Joint	12	3.75	14.12	9.6	14.12	9.6	14.12	9.60	14.12	9.60
Bearing	25	3.75	3.30	117.31	3.30	117.31	13.66	99.78	1.52	87.88
Demolition	60	7.0	11.19	355.58	11.19	325.44	4.64	296.64	5.36	398.88

Key words: bridge lifecycle, environmental impact, lifecycle cost, maintenance, simulation
Furo-cho, Chikusa-ku, Nagoya 464-8603, Tel.: 052-789-2737, Fax: 052-789-3734.

3. Analysis of Bridge Lifecycle Environmental Impact and Cost

To derive the combined probability distributions for lifecycle environmental impact and cost, a numerical simulation method is applied in this study. Probabilistic models of lifecycle environmental impact and lifecycle cost are prepared by considering assumptions made for maintenance stage. The model is prepared in the risk analysis software @RISK[3]. Latin Hypercube Sampling method is adopted to simulate the probablistic values. Latin Hypercube is a stratified sampling technique in which the probability scale of the cumulative distribution curve is divided into an equal number of probability ranges[4]. The number of ranges is equal to the number of iterations performed in the simulation. The current model for four bridge types consists of 28 probabilistic input variables (bridge service life and 6 maintenance frequencies for each bridge type) and 8 output variables. The number of samples were checked for stable output distribution with several simulation runs and finally 25,000 sampling points were taken as appropriate.

Figure 1(a) shows the probability distributions of lifecycle CO_2 emissions for four bridge types considered for one lifecycle. Steel bridges have higher mean values than the PC bridges. The spread of lifecycle emission value is within the order of 200 tC. The steel bridges include painting activity which is not included in the PC bridges. Figure 1(b) shows the probability distribution of lifecycle cost for one lifecycle. An annual discount rate of 2% is considered for the maintenance and demolition costs. The ranges of lifecycle cost values for steel bridges are more than that of PC bridges. The range of lifecycle cost is spread in the order of 200 million yen for the PC bridges. For the steel bridges, the range is spread in the order of 300 million yen. The steel bridges have more maintenance activities and the cost of single maintenance activities are also higher than that of the PC bridges. This result shows that if number of parameters is more for the output variable it will show more wider variation.

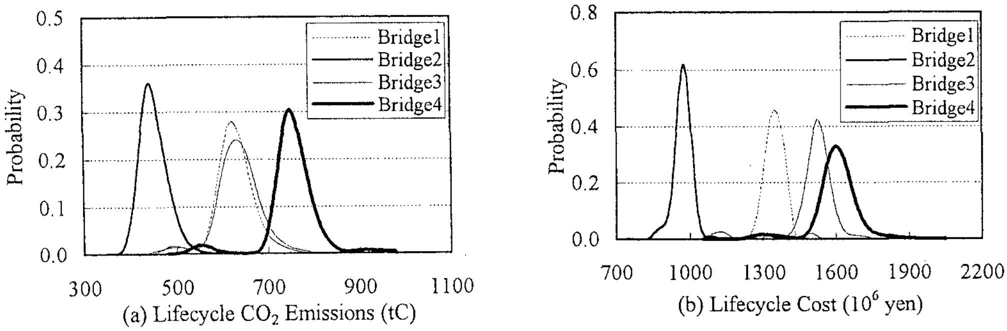

Fig. 1 Probability Distributions

4. Conclusions

This study presented the methodology of combining various probabilities associated with lifecycle parameters to single probability distribution. Following conclusions can be stated from the current study of bridge lifecycle: (1) Numerical simulation of probalistic models of lifecycle environmental impact and cost can give these values in a range with probability values. (2) The lower number of probabilistic parameters results smaller range of lifecycle environmental impact and cost. Since steel bridges have normally more number of maintenance items, the lifecycle cost varies in wider ranges than concrete bridges in this study.

References

[1] Itoh, Y., Hirano, T., Nagata, H., Hammad, A., Nishido, T., and Kashima, A., "Study on Bridge Type Selection System Considering Environmental Impact," *Journal of Construction Management and Engineering,* JSCE, No 553/VI-33, 1996, pp. 187-199 (in Japanese).

[2] Sunuwar, L., Itoh, Y., and Nagata, H., "Evaluation System for Lifecycle Environmental Impact and Cost of Bridges," *Journal of Civil Engineering Information Processing,* JSCE, Vol. 6, 1998, pp. 137-144.

[3] Palisade Corporation Homepage, http://www.palisade.com/html/, 1997.

[4] McKay, M. D., Beckman, R. J., and Conover, W. J., "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code", *Technometrics,* 21(2), 1979, pp. 239-245.