Long-Term Network Level Maintenance Strategy Optimization of Bridge Decks Using Genetic Algorithms

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1. Introduction

With the rapidly increasing requirements of bridge maintenance and the limited budget available for this maintenance, the optimization of the long-term maintenance strategy considering the network-level bridge system under an acceptable deterioration level becomes an important problem. Especially, the bridge deck is an important member of the bridge that is subject to cyclic loading and harsh environmental conditions directly, so it needs maintenance more frequently. However, the total maintenance cost of bridge decks is a function of the deterioration conditions, the maintenance methods, and the planning period. The selection of optimization algorithms has a great effect on the solution of this problem. In this research, the search procedure and optimization technique are presented using a genetic algorithm (GA).

2. Bridge Deck Maintenance Strategy

In this research, four kinds of maintenance methods, i.e. routine maintenance, repair, rehabilitation, and replacement, are available. Only one activity is carried out for every bridge at every year, and at most one rehabilitation or replacement will take place in 5 years. The choice of maintenance methods is related to the deterioration condition of bridge deck. The deterioration model is modified according to a linear model in [1] as shown in Eq. (1) :

$$C_d(t) = C_d(0) + \sum_{j=1}^{t} R_d(A_j, V_j) + \sum_{j=1}^{t} Imp_m(j) \tag{1}$$

where $C_d(t)$ represents the deterioration condition (deteriorated degree) at the end of year t, and has a value between 0 and 1; $C_d(0)$ is the initial deterioration condition; $R_d(A_j, V_j)$ is the yearly deterioration rate, which is related to the bridge age A_j and the traffic condition V_j; $Imp_m(j)$ is the impact on the deck deterioration condition due to maintenance method m at year j.

The total maintenance cost (MC) is determined by Eq. (2), where N is the number of bridges; T is the planning period; r represents the discount rate; $L(i)$ and $W(i)$ indicate the length and width of bridge i; and $UC_m(i,j)$ means the unit area cost of maintenance method m.

$$MC = \sum_{i=1}^{N}\sum_{j=1}^{T} [(1+r)^{-j} \times L(i) \times W(i) \times UC_m(i,j)] \tag{2}$$

Constraints on deterioration conditions ($C_{max}(i,j)$) and the maintenance budget *(B)* are used. The cost of a maintenance strategy, in which deterioration condition is higher than the allowable deterioration condition, or the maintenance cost is higher than the maintenance budget, will be penalized by a penalty cost. The objective function *(F)* is a sum of maintenance cost and penalty costs as shown in Eq.(3), where $C_d(i,j)$ is the deterioration condition of bridge i at year j.

$$F = MC \times (1 + \sum_{i=1}^{N}\sum_{j=1}^{T} \frac{C_d(i,j) - C_{max}(i,j)}{C_{max}(i,j)} + \frac{MC - B}{B}) \tag{3}$$

3. Maintenance Strategy Optimization Using GA

Every GA string consists of substrings representing all bridges in a given order. From left to right, a substring represents the maintenance methods from the first year to the end of the planning period. Routine maintenance, repair, rehabilitation, and replacement are coded by two binary values, 00, 01, 10, and 11, respectively. These couples of bits are called *basic string bits.*

Bridge:	$i-1$		i							$i+1$	
Year:	$T-1$	T	1	2	3	...	$T-2$	$T-1$	T	1	2
String:	1 0	0 1	0 1	1 1	0 0	...	0 1	0 0	1 0	0 1	1 0

Figure 1: Coding Structure for Maintenance Strategy of Bridge Decks

At generation 0, the codes of the basic bits are generated simultaneously, not bit by bit. Furthermore, these two binary values are selected according to the deterioration condition of the previous year, not randomly. The substrings of bridges are generated one by one and compiled to the whole string of the bridge system. This procedure is repeated to make the population pool.

With a specified probability of crossover, two members of the population whose costs are not greater than the average population cost will be selected randomly, and parts of their chromosomes are exchanged. The crossover point is not within the basic bits. Furthermore, the crossover operator happens within every substring. To ensure that the new strings express feasible maintenance strategy plan, the right substring bits of the crossover point will be verified and regenerated if necessary. With a probability of mutation, a pair of basic bits are altered into another two binary values. Similar to crossover, the mutation operator happens within every substring. After the creation of every new generation, by decoding the strings, the solutions can be obtained. The maximum generation number is used as the terminating conditions in this research.

4. Numerical Example

To examine this optimization model, the data of 204 bridges are obtained from the Nagoya City Bridge Inspection Database. The data include lengths and widths of bridges, construction years, and initial deterioration conditions. The planning period is 5 years, and the discount rate (r) is 1.75%. The population size is 50, and the crossover and mutation probabilities are 0.8 and 0.001, respectively. Fig. 2 shows the average and minimum costs of the maintenance strategies from generation 0 to maximum generation 100. The near optimal maintenance cost is 227.12 million Yen. The highest and average deterioration rates are 0.70 and 0.29 among 5 years, respectively.

According to the conventional maintenance policy, routine maintenance is usually the only method until the bridge deck deteriorates very seriously. At that time only, it will be replaced. The maintenance cost of these 204 bridges is found to be 457.03 million Yen for 5 years. The highest and average deterioration rates are 0.88 and 0.39 among 5 years, respectively.

5. Conclusions

(1) The application of GA in long-term network level decks maintenance strategy optimization has been examined, and a near optimal solution has been found. Deterioration conditions, maintenance methods, and maintenance costs can be evaluated using this method.

(2) The numerical example shows that GA optimization can search more economical and reasonable maintenance strategy than the conventional maintenance policy.

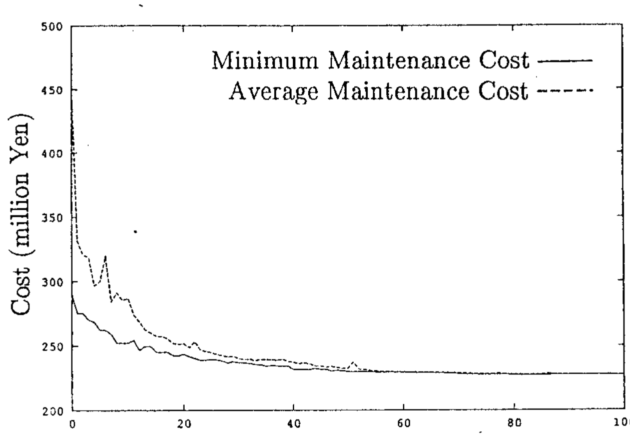

Figure 2: Generation History

References

[1] Jacaobs, T. J.(1992). *Optimal Long-Term Scheduling of Bridge Deck Replacement and Rehabilitation.* Journal of Transportation Engineering, ASCE, Vol. 118, No. 2, pp. 312-322.