I -365

LONG-TERM MAINTENANCE PLANNING OF BRIDGES USING GENETIC ALGORITHM

Nagoya University, Student Member, ○Chunlu Liu
Nagoya University, Member, Amin Hammad
Nagoya University, Member, Yoshito Itoh

1. Introduction

Because of the rapidly increasing requirements of bridge maintenance, maintenance planning is an important issue to get the optimal long-term maintenance strategy of a bridge system. In this research, using the bridge deck as an example, maintenance planning optimization is performed for a given planning period T using Genetic Algorithms (GA). Three maintenance policies are compared from the point of view of maintenance cost and deterioration degree.

2. Maintenance Strategy of Bridge Deck

In this research, four kinds of maintenance methods are available for bridge decks. These methods are routine maintenance, repair, rehabilitation, and replacement. The choice of maintenance methods is related to the deterioration degree that is determined by

$$D(t) = D(0) + \sum_{j=1}^{t} \mu \times R(A_j, Tr_j) - \sum_{j=1}^{t} I_m(j) \tag{1}$$

where $D(t)$ is the deterioration degree at the end of year t with a value between 0 (new deck) and 1 (failure condition); $D(0)$ is the initial deterioration degree. The factor μ reflects the deterioration property of different deck material. $R(A_j, Tr_j)$ is the annual deterioration rate related to the bridge age A_j and the traffic condition Tr_j at year j; $I_m(j)$ is the impact on the deterioration degree due to maintenance method m. The maintenance cost C is determined by Eq. (2), where N is the number of bridges; T is the planning period; r is the discount rate; $L(i)$ and $W(i)$ are the length and width of bridge i, respectively; and $c_m(i,t)$ is the unit area cost of maintenance method m adopted for bridge i at year t. The objective function is the maintenance cost plus two penalty costs for exceeding the budget and the allowable maximum deterioration degree $D_{max}(A_j)$.

$$C = \sum_{i=1}^{N} \sum_{t=1}^{T} ((1+r)^{-t} \times L(i) \times W(i) \times c_m(i,t)) \tag{2}$$

3. Maintenance Planning of Bridge Deck Using Genetic Algorithm

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. At generation 0, these values are generated simultaneously according to the deterioration degree of the previous year. With a probability of crossover, two members of the population whose costs are less than or equal to the average population cost are selected randomly, and the right parts to the crossover points are exchanged. To ensure that the new strings express feasible maintenance strategy, the right parts will be verified and regenerated if necessary. With a probability of mutation, a couple of bits are altered into another two values. The mutation operator also happens within every substring. After the creation of every new generation, the maintenance strategy can be obtained by decoding the strings.

In this study, two maintenance policies using GA (Policy 1 and Policy 2) are compared with the conventional maintenance policy (Policy 3) for the future 25 years. Policy 1: The maintenance planning is taken for $T = 25$ years; Policy 2: The maintenance planning is taken for five sequential planning periods with $T = 5$; and Policy 3: Only routine maintenance or replacement is applied, depending on whether the deterioration degree is less or greater than $(D_{max}(A_j))$, respectively. Applying these three policies, the maintenance planning of 287 bridges of Nagoya City is made using $D_{max}(A_j) = 0.8$. From sensitivity analyses, the population size of 50, crossover probability of 80%, mutation probability of 0.1%, and maximum generation number of 100 are adopted. The discount rate is fixed and the inflation effect on the unit costs is not considered. Fig.1 shows an example of the change in the deterioration degree of a bridge deck according to the three maintenance policies. This bridge was constructed in 1968 and its $D(0)$ is 0.5. The maintenance costs of the coming 25 years for the three policies are 4704, 5433, and 7508 Million Yen, respectively. Because the planning period in policy 2 is 5 years, the cost at the first year of every planning period is high as shown in Fig.2. Furthermore, for policy 3, the maintenance cost fluctuates. This means that policies 2 and 3 are difficult to implement and the traffic will be affected by the large number of bridges to be replaced or rehabilitated in one year. Policy 1, on the contrary, needs lower budget, and gives a stable cost per year of about 200 Million Yen. Fig.3 shows that the average deterioration degrees of policies 1 and 2 increase gradually toward $D_{max}(A_j)$ at the end of the planning period. The average deterioration degree of policy 3 is more steady. However, its cost is prohibitive and the resulting strategy is far from rational.

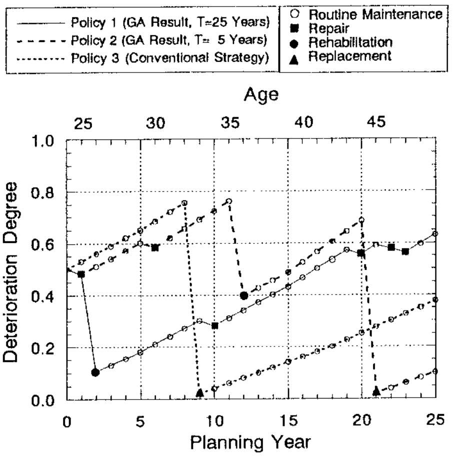

FIG. 1. Example of the Change in the Deterioration Degree

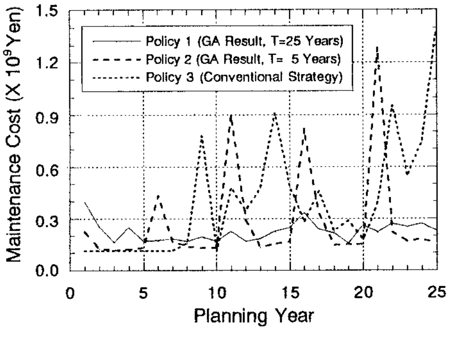

FIG. 2. Maintenance Cost

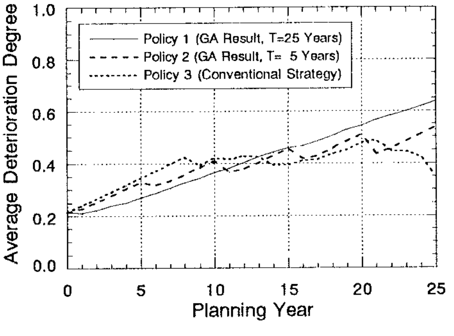

FIG. 3. Average Deterioration Degree

4. Suggestion for Selecting Maintenance Policy

From the previous results, it can be noticed that the maintenance cost can be roughly estimated according to several factors including: (1) the economic life span of the bridge S, (2) the planning period T, (3) the annual deterioration rate R and the maximum allowable deterioration degree D_{max}, (4) the unit costs c_m and impacts I_m of the maintenance methods, and (5) the discount rate r. Considering a fixed discount rate, the average maintenance cost of the deck unit area per year c' can be written as a simple linear function of the previous parameters and a coefficient α:

$$c' = \alpha \times \frac{S}{T} \times \frac{R}{D_{max}} \times \sum_{m=1}^{4} \frac{c_m}{I_m} \tag{3}$$

5. CONCLUSIONS

It was demonstrated that GA can deal with the long-term maintenance planning of a network-level bridge system. By a comparison with the conventional maintenance strategy, GA optimization could find long-term near-optimum planning of maintenance budget of the bridge system. In addition, a simple formula was suggested to estimate the average cost per unit area per year considering the key parameters of the maintenance planning policy.