# PAVEMENT REHABILITATION MANAGEMENT: PERFORMANCE MODELING AND REHABILITATION PROGRAMMING

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## INTRODUCTION

Damage to the pavement begins from the first day of utilization; thus, timely and suitable maintenance and rehabilitation are required to prevent substantial pavement damage and premature loss. Pavement management systems are used to developing efficient policies to monitor, maintain and rehabilitate deteriorating pavements. These systems consist of pavement inventory and condition information, pavement performance models, and pavement maintenance and rehabilitation optimal programmes.

This paper develops a pavement performance model, and the maintenance and rehabilitation optimal programme at a network level. The performance model is a non-linear empirical whose parameters are estimated from in-service pavement data. The shuffled complex evolution method is used to develop the optimum programming of the maintenance and rehabilitation at a network level. In both cases, the Kanagawa prefecture road network inventory and condition survey data were used.

## PAVEMENT PERFORMANCE MODEL

The deterioration of pavement is dependent on the combined influence of traffic and environment; it also depends on the pavement strength, subgrade condition, and maintenance and rehabilitation history. Therefore, a sound model should incorporate these factors in its formulation. Pavement strength is governed by pavement thickness and material characteristics. The pavement section is made up of layers with different characteristics of material, and maintenance and rehabilitation history, a formulation that generalizes this situation was developed. In this study the pavement structure consists of four layers (i.e. asphalt surface, bituminous base, mechanically stabilized base and crusher run subbase), see **Fig.1**. Including the influence of traffic prior to M&R action captures the different of ages of layers in the pavement structure.

The AASHO model (AASHTO, 1993) governs the strength of the pavement structure formulation. The strength depends on equivalent thickness of the section structure and is given by Eq. 1

$$ET = \left[(T_{0i}S_i^{\alpha_0} + \alpha_1 T_{1i} + \alpha_1 \exp(N_{1i}\beta_0)T'_{1i} + \alpha_2 \exp(N_{2i}\beta_1)T_{2i} + \alpha_3 \exp(N_{3i}\beta_2)T_{3i} + \alpha_4 \exp(N_{4i}\beta_3)T_{4i}\right]^{\alpha_5} \quad (1)$$

Specification for traffic loading and its effect to pavement performance in this study is governed by Manual for Asphalt Pavement of Japan Road Association, (JRA, 1989). In this manual traffic load is given in terms of total number of wheel load converted to the number of 5-ton wheel load. Further, the vehicles are classified as heavy or light depending on whether their wheel loads are greater or less than 5 tons respectively. The equivalent traffic load (ETL) given by Eq. 2 is adapted to reflect the vehicle classification as well as the available data which, contains the average annual daily number of light and heavy vehicles. The equivalent damage caused by the traffic load assumes the *power law* (AASHTO, 1981); consequently Eq. 3 gives damage (Dg) to pavement due to traffic load. L and H in Eq. 2 and 3 represent cumulative light and heavy traffic respectively.

$$\text{ETL} = \alpha_6 L + \alpha_7 H \quad (2)$$

$$Dg = (\alpha_6 L + \alpha_7 H)^{\alpha_8} \quad (3)$$

The final pavement performance model is given by combination of the initial MCI, the pavement structure strength, and traffic load damage. The initial MCI represents the pavement condition soon after construction or rehabilitation action, Eq. 4 gives the expression for the complete mode.

$$MCI_{ti} = MCI_{0i} - ET(\alpha_6 L + \alpha_7 H)^{\alpha_8} \quad (4)$$

Where;

$MCI_{ti}$ = pavement MCI for section $i$ at time $t$

$MCI_{0i}$ = pavement initial MCI (construction, rehabilitation)

ET = pavement structure strength (Eq. 1)

$T_{0i}$ = section thickness between lowest part of subbase and 2m depth

$S_i$ = design CBR of the section $i$ subgrade

$T_{1i}$ = surface thickness for pavement section $i$

$T_{2i}$ = bituminous stabilized base thickness for pavement section $i$

$T_{3i}$ = mechanically stabilized base thickness for pavement section $i$

$T_{4i}$ = subbase thickness for pavement section $i$ (crusher run)

$L_i$ = cumulative light traffic since construction or rehabilitation

$H_i$ = cumulative heavy traffic since construction or rehabilitation

$N_{ji}$ $(j=1,2,...,4)$ = cumulative heavy traffic (in millions) between the construction or reconstruction and the current action for unchanged pavement layers $T_j$

$N_{2i}$ = cumulative heavy traffic (in millions) between the construction or reconstruction and the current action for unchanged bituminous stabilized base

$N_{3i}$ = cumulative heavy traffic (in millions) between the construction or reconstruction and the current action for unchanged mechanically stabilized base

$N_{4i}$ = cumulative heavy traffic (in millions) between the construction or reconstruction and the current action for unchanged crusher run subbase

$\alpha_0$ to $\alpha_8$ and $\beta_0$-$\beta_3$= model parameters to be estimated

The salient features of the model includes: it captures the effect of subgrade condition; differentiates the effect of bituminous stabilized base with the mechanically stabilized base; and eases the obstacle of obtaining traffic load data by using traffic volume categorized into vehicle and light vehicles. The model is non-linear in parameters; therefore, a non-linear model in the econometric LIMDEP software (Greene, 2003) was used to estimate the parameters of the model. The estimated parameters and statistics of Eq. 1 are given in Table 1. The asymptotic-$t$ value in Table 1 shows that all parameters are statistically significant from zero at a 5% degree of confidence and all parameters have the expected signs.

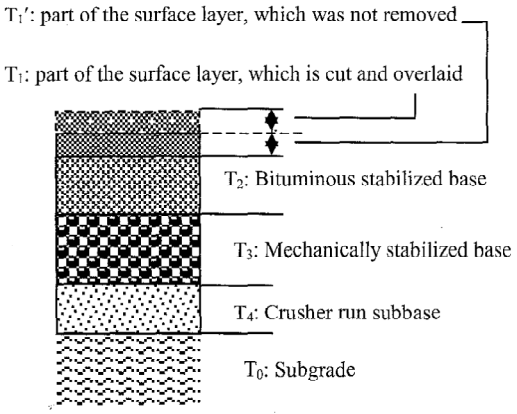



**Fig. 1** Typical thick pavement section

**Table 1**: Model Parameter Estimates

| Parameter | Estimate | Error | t-ratio |
|---|---|---|---|
| $MCI_0$ | 8.74 | 0.4325 | 20.2081 |
| $\alpha_0$ | 1.349 | 0.2073 | 6.5075 |
| $\alpha_1$ | 5.857 | 0.6826 | 8.5804 |
| $\alpha_2$ | 3.555 | 0.1124 | 31.6281 |
| $\alpha_3$ | 1.483 | 0.3322 | 4.4642 |
| $\alpha_4$ | 0.638 | 0.1076 | 5.931 |
| $\alpha_5$ | -1.361 | 0.2519 | -5.4039 |
| $\alpha_6$ | 0.534 | 0.1356 | 3.9381 |
| $\alpha_7$ | 2.171 | 0.1244 | 17.4518 |
| $\alpha_8$ | 0.458 | 0.0567 | 8.0762 |
| $\beta_0$ | -0.0248 | 0.0034 | -7.2941 |
| $\beta_1$ | -0.011 | 0.0018 | -6.1111 |
| $\beta_2$ | 0.0121 | 0.0014 | 8.6429 |
| $\beta_3$ | 0.0013 | 0.0005 | 2.4074 |

## MAINTENANCE AND REHABILITATION PROGRAMMING

During planning for maintenance of a road network, engineers are faced with the decision to determine which road segment to repair, when to repair, and what treatment to use. Optimisation techniques have commonly been used in making such decisions. In this paper, shuffled complex evolution method is demonstrated as a maintenance and rehabilitation programming tool at network level.

The Shuffled Complex Evolution Method (SCEM) is a general-purpose global optimisation program (Duan, 1993,1994). The SCEM is a hybrid of four types of optimisation approaches, consisting of a combination of random and deterministic approaches, the concepts of clustering, the concept of a systematic evolution of a complex of points spanning the space in the direction of global improvement, and the concept of competitive evolution. It is largely based on a controlled random search algorithm developed

by Price (1987). Evolution algorithms are metaheuristics that emulate the process of evolution in which a population of solution is created, and new solutions are found through probabilistic combination and mutation of solutions in the population. The SCEM expands on this concept by dividing the solution space into several complexes. New solution points in each complex are generated using Nelder Mead Algorithm reflections and contractions in combination with evolutionary methods.

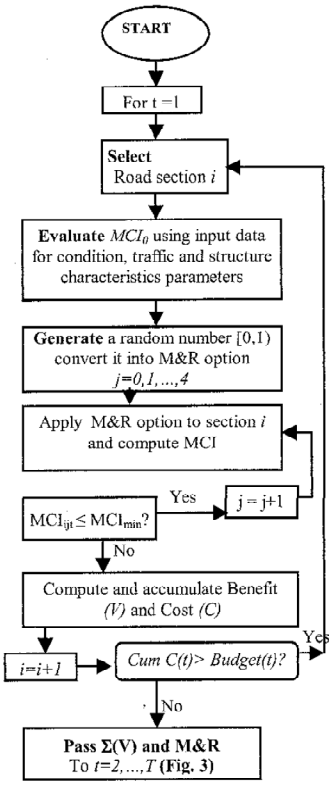



**Fig 2** feasible solution space algorithm for year 1

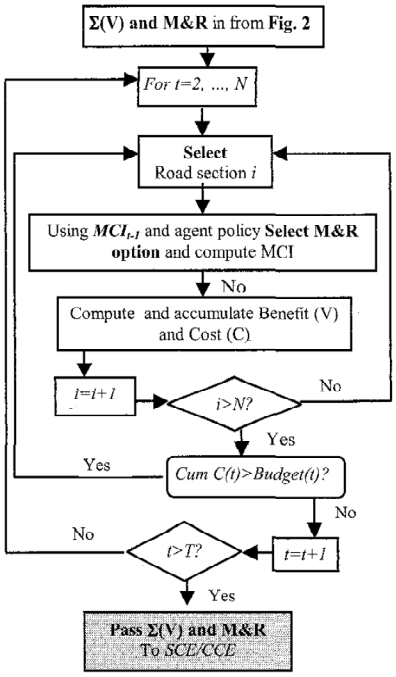



**Fig 3**. feasible solution space algorithm for years 2,..., T

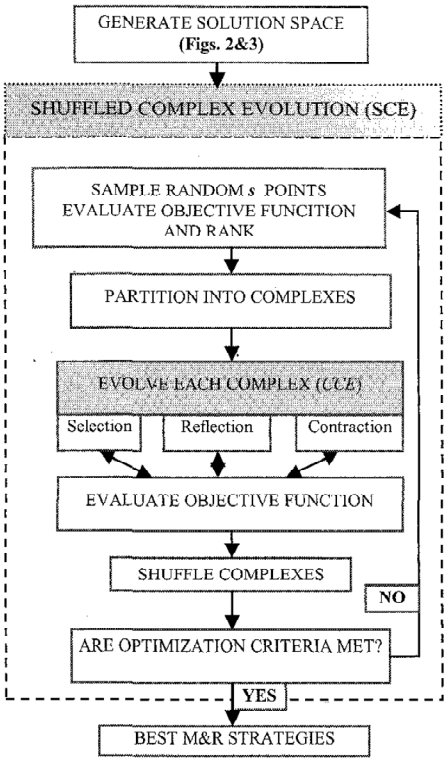



**Fig. 4** Shuffled Complex Evolution algorithm

The overall scheme of the SCEM algorithm as used in optimisation of maintenance and rehabilitation actions in the road network is depicted in **Fig. 4.** It has two main parts, the initial solution population space formulation, **Figs. 2** and **3**, and the shuffled complex evolution (SCE) algorithm which has a competitive complex evolution (CCE) algorithm embedded in it. The algorithms SCE and CCE are coded according to Duan et al. (1993, 1994). The outline of the SCEM six main steps includes: generation of feasible solution population space; randomly selecting a "population" of points from the feasible solution population space; partitioning the selected population into several complexes, each with $2n + 1$ points, where $n$ is the number of parameters to be optimized; evolving independently each complex based on the downhill simplex method (Nelder Mead Algorithm); periodically shuffle the complexs to share information; repeat the evolution and shuffling algorithms until the convergence criteria are satisfied

The road network used to demonstrate the application and performance of this optimisation Formulation consists of 10 pavement segments, which constitute a 1 km stretch of Route *467* in Kanagawa Prefecture. The characteristics and other problem formulation are shown in **Table 2**. The Japan Road Association Manual (JRA, 1989) policy was used to govern the choice of M&R options. Objective function of this optimisation program is to maximize the benefits that are reaped from applying maintenance or rehabilitation actions on the pavement segment during the planning horizon. In this study, benefit is defined as the product of the improvement attained during the programming horizon as a result of applying maintenance or rehabilitation option to a pavement segment and the traffic that travels onto that section.

The complete programming formulation is expressed mathematically as follows:

Maximize: $\sum_{i=1}^{N}\sum_{j=1}^{S}\sum_{t=1}^{T} X_{ijt} * V_{ijt}$ ..... (5)

Subject to: $\sum_{i=1}^{N} X_{ijt} < 1$ for i = 1,2,3,..., N .... (6)

$\sum_{i=1}^{N}\sum_{j=1}^{k} X_{ijt} * C_{ijt} \le B_t$ for t = 1,2,3,..., T .....(7)

$X_{ijt} \ge 0$ .....(8)

Where,

$X_{ijt}$ = section $i$ with alternative $j$ in year t
$V_{ijt}$ = Total benefits of section $i$, with alternative $j$ built in year $t$

$C_{ijt}$ = the M&R cost of section $i$, with alternative $j$ built in year $t$,
$B_t$ = total budget for year $t$

**Table 2** parameters used in M&R programming

| Parameter Category | Parameter Adopted |
|---|---|
| *Network parameters* | 10 road segments |
| *Planning Period* | 15 years |
| *Budget* | 0.11Billion Ycn |
| *Minimum MCI* | 3..5 |
| *Routine Maintenance cost* | (105Yen/m$^2$) |
| *Rehabilitation cost* | |
| Scrap and overlay | 309.4Yen/m$^2$per unit depth in cm |
| Asphalt layers reconstruction | 251.5Yen/m$^2$ per unit depth of bituminous base plus the scrap and overlay cost |
| Reconstruction | 177.8Yen/m$^2$ per unit dept of mechanical base (in cm) and the asphalt concretc layer cost |

| | PROGRAM YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SECT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | 4 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 2 | 2 | 1 | 5 | 1 | 1 | 1 |
| 2 | 4 | 3 | 1 | 2 | 5 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 3 | 2 | 3 | 1 | 2 | 4 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 | 1 | 3 |
| 4 | 3 | 3 | 1 | 2 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 3 | 1 | 2 |
| 5 | 3 | 4 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 | 5 | 1 | 1 | 1 | 1 |
| 6 | 1 | 4 | 1 | 1 | 1 | 3 | 1 | 2 | 3 | 1 | 2 | 2 | 1 | 4 | 1 |
| 7 | 3 | 4 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 2 |
| 8 | 4 | 3 | 1 | 2 | 5 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 4 | 1 |
| 9 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 2 |
| 10 | 1 | 5 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 4 | 1 | 1 | 1 | 3 |

**Fig. 5** Programmed M&R options

The resulting M&R programme suggested by the SCEM algorithm that uses the developed performance model is given as Fig 5. In this figure, "1" is do nothing, "2"is routine maintenance, "3" is cut and overlay, and "4" is asphalt layers reconstruction. It can be observed that, there is a good agreement between combination of these actions as suggested by this study and the actual engineering practice.

## CONCLUSION

This paper presented the formulation of a pavement management system through development of a deterioration model and programming for network maintenance and rehabilitation using shuffled complex evolution method. The demonstration example has shown that a well-specified deterioration model, that used available in-service data from condition surveys and pavement inventories when used with a global optimisation algorithm could be used to develop an efficient pavement management system with minimum cost. The results of the example have shown good agreement of the combination of the assigned M&R option with those actually practiced by engineers.

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