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EXAMINATION OF MEDIUM AND LONG TERM EXPRESSWAY MANAGEMENT POLICY FOR IMPLEMENTATION

Y. YAMADA, K. OBAMA, and K. KAITO

Graduate School of Engineering, Osaka University, Osaka, Japan

In recent years, deterioration of expressways is the serious problem, and it is necessary to plan the medium and long term management policy. In this study, the authors examine the medium and long term management policy, using the accumulated enormous inspection data of road surface conditions. The future condition of road pavement is significantly different by the management system such as the budget, personal distribution or repair method, etc. The authors quantitatively evaluate the relation between the future condition of road pavement and the management system, of which the authors specially take up preventive repair by penetration repair agent. Then, the risk evaluation and the life cycle cost (hereinafter referred to as LCC) analysis can be conducted in deferent repair strategies by stochastic simulation. By using stochastic simulation as the method of these two evaluations, the comprehensive analysis can be conducted, considering the possible change of management surroundings in the medium and long term and various examinations for optimization.

Keywords: Pavement repair policy, Mixed Markov deterioration hazard model, Risk, LCC.

1 INTRODCTION

In management of expressway pavement, more effective and economical pavement repair policies are demanded because of rapid deterioration of pavement or a reduced budget. In these social backgrounds, the repair policy based on significant increase of budget is unrealistic and, more multilateral examination of management policy is essential. In this study, the authors focus on the preventive repair by penetration repair agent introduced in recent years. In this repair method, crack or gap of asphalt pavement is filled by sealing agent and, massive damages are prevented. Road administrator can effectively prolong life of pavement by using this preventive repair method, because this method is easy and economical to be conducted, and more widespread execution is expected. However, enough time has not elapsed yet since this repair method was in practical, administrator don’t have accurate information about the prolonged years by this repair method. The authors evaluate the risk and LCC of management policies adopting the preventive repair, assuming more than two patterns of the prolonged years, and examine the decrease of LCC by the preventive repair. Chapter 2 explains about statistical deterioration prediction method, mixed Markov deterioration hazard model. Chapter 3 explains the stochastic simulation. Chapter 4 carry out empirical analysis that is based on the road surface condition survey data acquired from the expressway during service.

2 MIXED MARKOV DETERIORATION HAZARD MODEL

In this study, the authors used mixed Markov deterioration hazard model proposed by Obama *et al.* (2008) for the relative evaluation of deterioration speed. The authors explain this model simply. Moreover, assume that group $k(k=1,\cdots,K)$, determined each combination of management offices and routes (simply "route k"). Let us introduce a parameter ε^k (hereinafter referred to as "heterogeneity parameter") that represents the variation characteristics of hazard rate unique to route $k(k=1,\cdots,K)$. At this time, the hazard rate of deterioration rating $i(i=1,\cdots,I-1)$ of group k is expressed by the mixed exponential hazard function:

$$\lambda_i^k = \exp(\mathbf{x}^k \boldsymbol{\beta}_i')\varepsilon^k = \tilde{\lambda}_i^k \varepsilon^k \quad (i=1,\cdots,I-1; k=1,\cdots,K) \tag{1}$$

where $\tilde{\lambda}_i^k$ represents the average hazard rate of group k has in rating i (hereinafter referred to as "standard hazard rate"). The standard hazard rate can be expressed by characteristic variable vector $\boldsymbol{x}^k$ and unknown parameter vector $\boldsymbol{\beta}$. The heterogeneity parameter ε^k is a random variable representing the degree of deviation from the standard hazard rate $\tilde{\lambda}_i^k$ of group k, and it is assumed that $\varepsilon^k \geq 0$. As the heterogeneity parameter ε^k is larger, the deterioration speed of all structures in the group k is higher than the standard hazard rate. Here, assume that the heterogeneity parameter ε^k is the probability sample extracted from the gamma distribution with a mean of 1 and a variance of $1/\phi$ is assumed,

$$\bar{f}(\varepsilon:\phi) = \frac{\varphi^{\phi}}{\Gamma(\phi)}\varepsilon^{\phi-1}\exp(-\phi\varepsilon) \tag{2}$$

Markov transition probability $\pi_{ij}^k(z)$, that a transition in the condition state from i to j occurs in the inspection span z, can be formulated, using the mixed hazard rate (1), as:

$$\pi_{ij}^k(z) = \sum_{a=i}^{j}\prod_{m=i}^{a-1}\frac{\lambda_m^k}{\lambda_m^k - \lambda_a^k}\prod_{m=a}^{j-1}\frac{\lambda_m^k}{\lambda_{m+1}^k - \lambda_a^k}\exp(-\lambda_a^k z) \tag{3}$$

Average Markov transition probability can be expressed substituting ε^k=1 for Eq. (3). Unknown parameter vector and heterogeneity parameters can be estimated by maximum likelihood estimation.

3 SIMULATION

The deterioration process of pavement is stochastically expressed by using the Markov transition probability calculated from mixed Markov hazard model. In this study, the authors conduct the stochastic simulation based on the Markov transition probability and calculate LCC. By this simulation the authors can evaluate the management policy considering the repair action under the budget limitation and the change of deterioration process caused by the shift of pavement type, from dense graded asphalt pavement to porous asphalt pavement. In this study, the general simulation model is constructed, in which deterioration level is evaluated by 2 different indexes, crack rate and IRI. In addition, repair action vectors $\boldsymbol{\eta}^c$ and $\boldsymbol{\eta}^r$ are expressed as follows:

$$\boldsymbol{\eta}^c = \left(\eta^c(1), \cdots, \eta^c(C)\right) \tag{5-a}$$

$$\boldsymbol{\eta}^r = \left(\eta^r(1), \cdots, \eta^r(R)\right) \tag{5-b}$$

$\eta^c(c)$ and $\eta^r(r)$ express rating after the repair action to crack rate and IRI with rating c and r. These vectors include the repair actions, "any repair action isn't conducted", expressed by $\eta^c(c)=c$, $\eta^r(r)=r$. Moreover, the authors consider that the effect of corrective repair is observed in both crack rate and IRI commonly, and can express the deterioration and repair process. Rating transition about crack rate and IRI of each road sections are expressed by sample passes generated from Markov transition probability and repair action vector. Here, in sample pass $p(p=1,\cdots,P)$, $c_d^{y,p}\left(c_d^{y,p}=1,\cdots,C\right)$ and $r_d^{y,p}\left(r_d^{y,p}=1,\cdots,R\right)$ represent rating of crack rate and IRI observed on road section d (d=1,・・・,D) when y (y=1,・・・, Y) years passed from y_0, D shows the number of road sections. Furthermore, let us define the repair cost matrix $\boldsymbol{E}$, whose component of cth row and rth column, $\boldsymbol{E}(c,r)$, expresses the repair cost needed when rating of crack rate and IRI are c and r. LCC to all road section D through Y years is calculated by the mean of all sample pass P:

$$LCC = \frac{\sum_{p=1}^{P}\sum_{y=1}^{Y}\sum_{d=1}^{D}\mathbf{E}\left(c_d^{y,p}, r_d^{y,p}\right)}{PY} \tag{6}$$

In addition, let us define the risk related to the safety of road users as follows,

$$\Xi^y = \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\delta_d^{p,y}}{PD} \tag{7}$$

In this study, risk expresses the ratio of length which administrator have to repair immediately. Dummy variable $\delta_d^{p,y}$ shows which the road section d needs to be repaired when y years passed from y_0, and it is defined as follows:

$$\delta_d^{p,y} = \begin{cases} 1 & \left(\hat{c}_d^{p,y} = C \quad or \quad \hat{r}_d^{p,y} = R\right) \\ 0 & \left(\hat{c}_d^{p,y} \neq C \quad and \quad \hat{r}_d^{p,y} \neq R\right) \end{cases} \tag{8}$$

4 CASE STUDY

4.1 Outline of Data

The authors conduct deterioration prediction and evaluation of risk and LCC by using the data in Kinki region in Japan. The data used in this case study had been accumulated in the road surface measurement that had conducted targeting crack rate and IRI in 22 routes for 8 years, since 2006 until 2013. Total length of 22 routes is 3,400km and data are obtained in lane units. Table 1 shows the definitions of crack rate and IRI rating. The authors divide the all database into 4 parts according to the kind of pavement material because of empirical views that fundamental differences occur in deterioration process by kind of pavement material.

Table 1. Rating Rank.

rating	Crack rate：Cr (%)	IRI (mm/m)
1	0≦Cr＜1	0≦IRI＜1.0
2	1≦Cr＜5	1.0≦IRI＜2.0
3	5≦Cr＜10	2.0≦IRI＜3.0
4	10≦Cr＜15	3.0≦IRI＜4.0
5	15≦Cr＜20	4.0≦IRI＜5.0
6	20≦Cr	5.0≦IRI＜6.0
7	-	6.0≦IRI＜7.0
8	-	7.0≦IRI

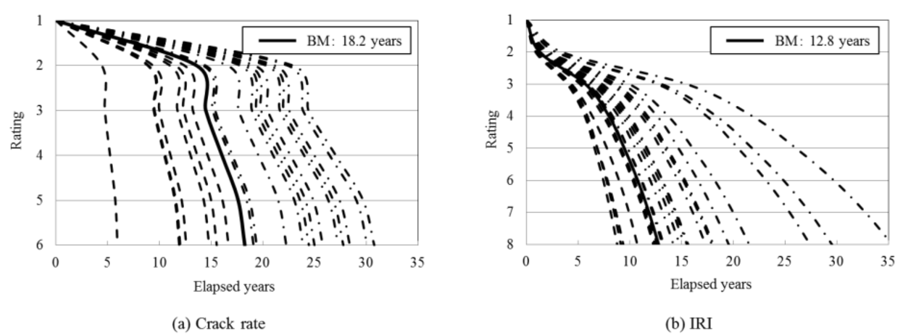


Figure 1. Performance Curves each roads (embankment).

4.2 Result of Statistical Deterioration Prediction

First, the authors evaluate the deterioration factors of pavement quantitatively, by using Markov deterioration hazard model to each 4 database (crack rate*dense graded asphalt pavement, IRI*dense graded asphalt pavement, crack rate*porous asphalt pavement and IRI*porous asphalt pavement). Candidates of characteristic variables are line division (up-line or down-line), lane division (a slow lane or overtaking lane), road structure (embankment or bridge), heavy vehicle traffic volume (continuous volume), heavy vehicle traffic volume rank (discrete value). By *t*-test and comparison of AIC (Akaike's Information Criterion), the optimum model (the optimum combination of characteristic variables) is examined. In this study, in all 4 databases road structure dummy (embankment sections=1, bridge sections=0) is commonly adopted as characteristic variables. In addition, in crack rate of dense graded asphalt pavement (crack rate*dense grade asphalt) heavy vehicle traffic volume rank, in crack rate*porous asphalt and IRI*porous asphalt heavy vehicle traffic volume, and in IRI* dense grade asphalt lane division dummy is adopted respectively. Secondly, the authors conduct the benchmark evaluation by the mixed Markov deterioration hazard model, to correctly evaluate the deterioration speed to each route. Heterogeneity parameters are set basically every combination of routes and management offices considering the actual management system in which a road managed by more than two management offices. In this case study, there are 22 routes and 11 offices, and the number of heterogeneity groups becomes 30. Figure 1 shows performance curves and BM curves (solid curves) to respective roads about porous asphalt as an example. About road structure, embankment is adopted.

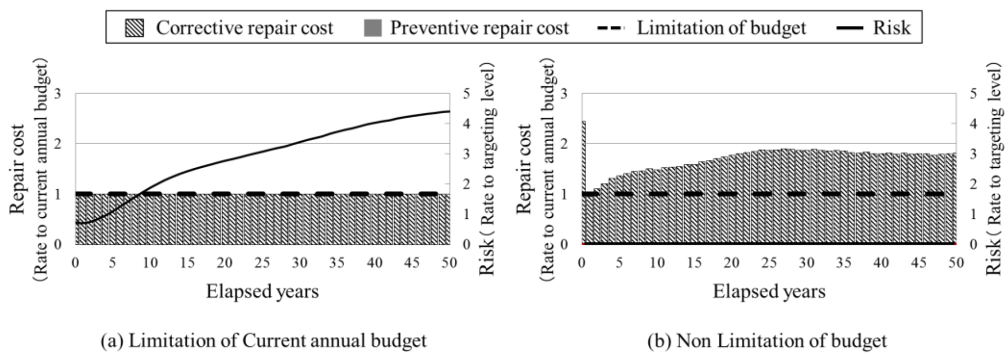


Figure 2. Transition of repair cost (Corrective repair method).

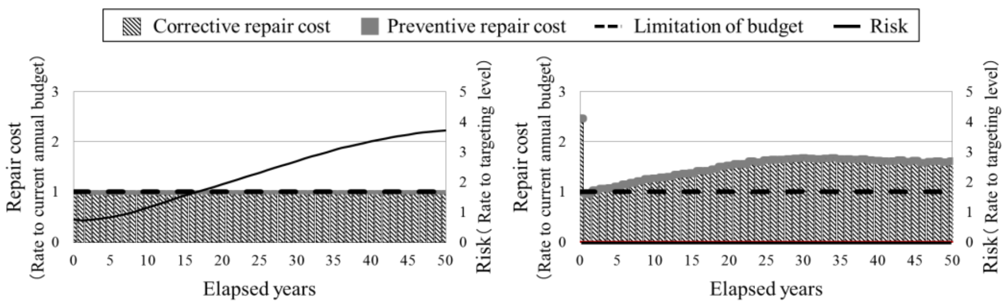
4.3 Stochastic Simulation

4.3.1 *Outline of simulation*

The authors evaluate the management policy quantitatively, by conducting the simulation based on Markov transition probability calculated from the result of mixed Markov deterioration hazard model. In this study, start year of simulation is 2013, when latest survey was employed, and management term is 50 years. Road sections are repaired in the limitation of annual budget. Furthermore, every year, each management offices cannot repair more than limited amount because the number of worker or ability of preparing the material isn't enough. In this simulation, the limitation of annual budget and the construction ability of each office are both considered.

4.3.2 *Result of simulation*

First, the authors examine the current management policy in which pavement sections are repaired mainly by corrective repair method, cut-overlay method. Figure 2 shows transition of repair cost through 50 years. In this study, repair cost is expressed by rate to current limitation of annual budget, and if the repair cost rate is larger than 1, it is said that the annual budget is not enough to the demand of repair. The risk is also shown by red line in Figure 2 (a), as the rate to targeting risk level. According to Figure 2, the risk rate in 2013 is around 1, however after 50 years the risk is about 4.4 times as large as targeting risk level. Shortage of annual budget is indicated in safety of road users. Secondly, the authors conduct simulation without the limitations of annual budget and the construction ability of each office, and show the result in Figure 2 (b).



(a) Limitation of Current annual budget

(b) Non Limitation of budget

Figure 3. Transition of repair cost (Both of preventive and corrective repair method).

4.3.3 *Examination about preventive repair*

As mentioned above, in this study the authors propose the management policy with preventive repair by penetration repair agent. Prolonged effect is expressed by recovering of rating. Timing when this repair method is conducted is crack rate rating 2 (crack rate: 1%) and the recover level is rating 1 (crack rate: 0%). Here, prolonged effect isn’t clearly, and to examine the safety or economic change by preventive repair, the acceleration of deterioration speed after preventive repair is considered by 3 patterns, 1, 1.25, 2. Prolonged years are respectively 13.6 years, 10.9 years, 6.8 years. In this paper, the authors show the result about pattern in which prolonged years is 6.8 years. Figure 3 (a) shows transition of repair cost under the current limitation of annual budget. Risk is 3.7 times as large as targeting risk level, and it is said that risk decrease by introduction of preventive repair.

5 CONCLUSION

The authors conducted deterioration prediction based on accumulated enormous pavement inspection data by utilizing the mixed Markov deterioration hazard model. Moreover, the deterioration process simulation was carried out considering the deterioration prediction result in order to quantify the LCC and the risk. Finally, reduction of LCC and risk is examined by adopting preventive repair method.

References

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