Estimation for Pavement Performance Curve based on Kyoto Model : A Case Study for Highway in the State of Sao Paulo

***Kazuya AOKI**, PASCO CORPORATION, Yokohama, JAPAN, Email : kiakzo6013@pasco.co.jp*
***Octávio de Souza Campos**,*
Public Services Regulatory Agency of Transportation Delegates of the State of Sao Paulo, Brazil
***Carlos Yukio Suzuki**, PLANSERVI Engineering, Sao Paulo, Brazil*
***Fatima Tostes**, BASE aerofotogrametria e projetos S.A., Sao Paulo, Brazil*

ABSTRACT

This paper focuses upon a case study to conduct the estimation for pavement performance curve using the archived highway pavement data in the state of Sao Paulo. One of the most important issues for the pavement asset management is to keep the accuracy of estimation for a deterioration prediction model. The deterioration prediction model, based on the Kyoto Model, formulates the regularity of the deterioration process of pavement using hazard model and represents the deterioration probabilities as Markov Transition probabilities. This study experiments the estimation for deterioration performance based on Kyoto Model using archived data of pavement inspection carried out for Highway in the State of Sao Paulo and the practical availability was investigated.

Keywords: pavement management, deterioration forecasting, PDCA cycle, Kyoto Model

INTRODUCTIONS

Recently, the idea of the asset management for an optimal maintenance work on the infrastructure system in which a huge stock is formed is promoted and a vast amount of studies about infrastructure asset management have been reported. Asset management has been achieved by continuous accumulation of a variety of knowledge data generated from annual maintenance works. Especially, the development of the inspection technology which gathers information about deterioration of infrastructures contributed greatly. Furthermore, knowledge database, including deterioration data and repair record, improved PMS functions and made it possible to provide useful information for pavement management.

For infrastructure asset management implementation, it is important to formulate a deterioration forecasting model of infrastructure facility. In the case of road pavement management, automatic data acquisition system to collect the pavement condition data in a quantitative way has been introduced, therefore, it is possible to acquire huge inspection data quickly. The statistical methodology to forecast a deterioration model of road pavement condition using archived inspection data has been used widely.

Various methodologies for estimation of deterioration forecasting model have been proposed. In this paper, above all, the methodology, named “Kyoto Model”, is used to estimate a deterioration forecasting mode. Kyoto Model formulates the regularity of the deterioration process of pavement using hazard model and represents the deterioration probabilities as Markov Transition probabilities using archived inspection and repair data. In addition, the case study using Kyoto Model is described for the highway in the State of Sao Paulo.

RESEARCH FUNDAMENTALS

Outline of the research

A large number of studies were conducted to develop the methodologies for estimating the deterioration prediction model of infrastructure facilities. For example, HDM-4 is one of the world-famous pavement management systems. HDM-4 requires several input data in order to calibrate deterioration prediction curve suitable for actual road conditions.

The methodology, called as Kyoto Model, is proposed to statistically estimate a deterioration performance curve using archived data including past inspection and repair history data. The deterioration prediction model, based on the Kyoto Model, formulates the regularity of the deterioration process of pavement using hazard model and represents the deterioration probabilities as Markov Transition probabilities. The special feature of Kyoto model is that it aims at evaluating pavement performance and supplies the feedback for next planning; therefore Kyoto Model has high affinity with PDCA(PLAN – DO – Check - Action) cycle for pavement management.

This study experiments the estimation for deterioration performance based on Kyoto Model using archived data of pavement inspection carried out for Highway in the State of Sao Paulo and the practical availability was investigated.

In this research, it was concluded that the Kyoto Model is capable to estimate a sufficient and practical performance curve using the minimum data. Also, we described that a continuous accumulation of archived data is important for evaluating the performance based on PDCA cycle.

Highway in the State of Sao Paulo

In Federative Republic of Brazil, the total length of road is approximately 1.6 million km, and the road of 0.12 million km is paved. The way of road maintenance is divided into two type, one is direct control and the other is concession contract. Concession contract will be introduced strongly especially for main highway with large traffic. In the management of State road, concession contract will be popular as well. In the State of Sao Paulo, the paved road in 5,000 km of the total road in 23,000km managed by the State of Sao Paulo is managed on concession contract. ARTESP(Public Services Regulatory Agency of Transportation

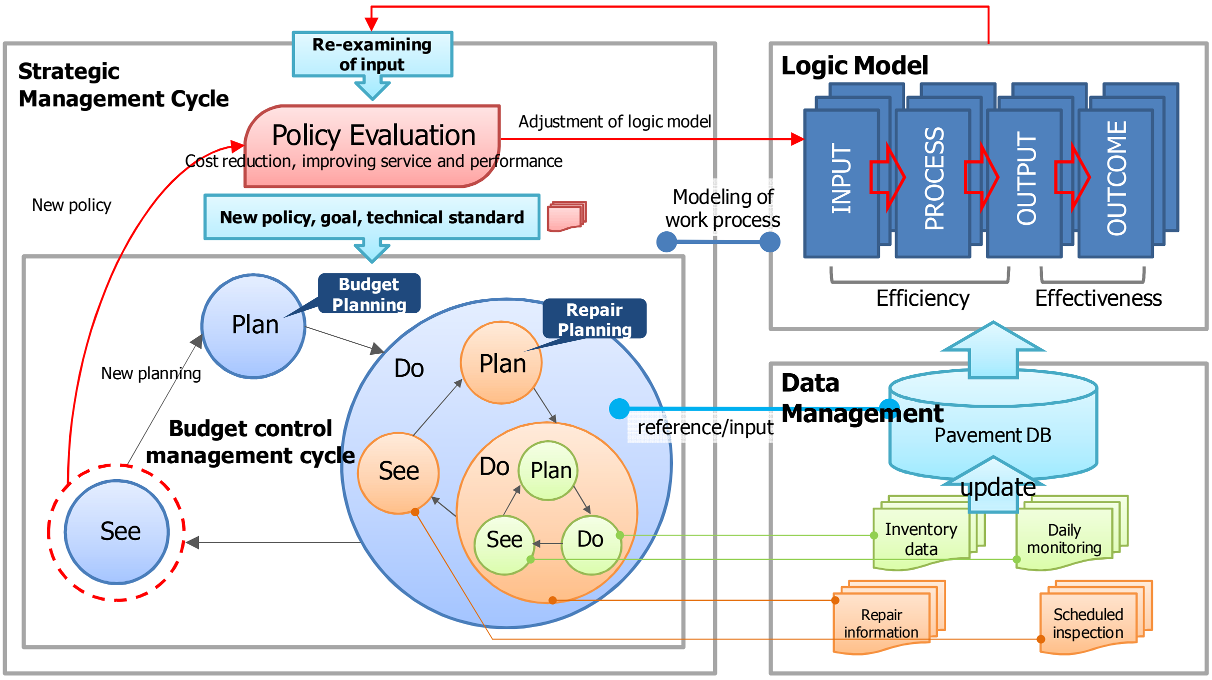

Fig. 1 Whole Structure of Kyoto Model Pavement Management System

Delegates of the State of Sao Paulo) has a responsibility of management of concession contract in this State and has periodical inspection data of managed road.

Kyoto Model

Kyoto model which is the methodology to be used in the case study is described simply. Kyoto model has a hierarchal structure involving the management cycle for budget control and the strategic management cycle. The management cycle for budget control supports daily maintenance work. On the other hand, the strategic management cycle aims to control daily work by monitoring from the view point of strategic level and point out for improvement of management work based on PDCA cycle. Road pavement management work is described by this hierarchal management cycle and that whole process of management work is formulated by logic model. On the other hand, various kind of data required by daily maintenance work is accumulated into pavement database and they are referred for decision making in maintenance work and are used as evaluation index of logic model for assessment. The one of the most important function of Kyoto Model is the methodology to estimate a deterioration forecasting model using actual inspection and repair archived data.

Deterioration Forecasting Model

The methodology to estimate a deterioration forecasting for road pavement conditions is explained briefly.

Markov Transition Probabilities

The deterioration process of road pavement can be formulated as Markov transition probabilities. The deterioration process of pavement is uncertain and forecasting future states cannot be accomplished deterministically. The Markov transition probability is used to represent the uncertain transition of the condition state of a pavement segment during two points in time.

The observed condition state of the pavement segment at time t_A is expressed by using the state variable $h(t_A)$. If the condition state observed at time t_A is i, then the state variable $h(t_A)=i$. A Markov transition probability, given a condition state $h(t_A)=i$ observed at time t_A, defines the probabilities that the condition state at t future time (t_B for example) will change to $h(t_B)=j$. That is

$$\text{Prob}[h(t_B = j \mid h(t_A)] = \pi_{ij} \tag{1}$$

The Markov transition probabilities matrix can be defined by using the transition probabilities between each pair of condition state *(i , j)* as

$$\prod = \begin{pmatrix} \pi_{11} & \cdots & \pi_{1J} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ} \end{pmatrix} \tag{2}$$

From the definition of transition probability $\pi_{ij}=0$ $(i>j)$. Then, it holds for the Markov transition probability

$$\begin{aligned} &\pi_{ij} \geq 0 \\ &\pi_{ij} = 0(when \quad i > j) \\ &\sum_{j=1}^{J} \pi_{ij} = 1 \end{aligned} \tag{3}$$

And in this case $\pi_{JJ}=1$.

Multi-Stage Exponential Hazard Model

By using the exponential hazard function, it is possible to represent a deterioration process of a pavement segment that satisfies the Markov property (independency from past history).
The Markov transition probabilities $\pi_{ij}=(z)$ that a transition in the condition state from i to j ($j>i$) occurs between the inspection time points t_A and $t_B=t_A+z$ becomes

$$\begin{aligned} \pi_{ij}(z) &= \Pr ob[h(\tau_B) = j \mid h(\tau_A) = i] \\ &= \sum_{m=i}^{j} \prod_{s=i}^{m-1} \frac{\lambda_s}{\lambda_s - \lambda_m} \prod_{s=m}^{j-1} \frac{\lambda_s}{\lambda_{s+1} - \lambda_m} \exp(-\lambda_m z) \end{aligned} \tag{4}$$

Here the following notation rule is given.

$$\prod_{s=i}^{m-1} \frac{\lambda_s}{\lambda_s - \lambda_m} = 1 \qquad (when \quad m = i)$$
$$\prod_{s=m}^{j-1} \frac{\lambda_s}{\lambda_{s+1} - \lambda_m} = 1 \qquad (when \quad m = j)$$

The hazard rate characterizing the deterioration process of a pavement segment is considered to change in relation to the vector $\mathbf{x}$ as follows:

$$\lambda_i = \mathbf{x}\boldsymbol{\beta}_i' \tag{5}$$

where $\boldsymbol{\beta}_i'$ is a row vector of unknown parameters. And also, using the parameter ε^k which indicates variability characteristic of hazard rate, comparative assessment of deterioration speed can be formulated using mixture hazard model theory as follows:

$$\lambda_i^k = \lambda_i \varepsilon^k \tag{6}$$

where λ_i is the average hazard rate of group a k and heterogeneity parameter ε^k is a stochastic variable which expresses the degree of dissociation from average hazard rate.

CASE STUDY

Archived Inspection Data for Estimations

In this case study, the performance curve of pavement condition was estimated by using the inspection data of the highway managed by ARTESP in Sao Paulo. Inspection archived data managed by ARTESP has condition data, such as IRI (International Roughness Index) and QI (Quarter-car Index), of each pavement segment collected by periodical inspection. Condition inspection is conducted every year and its data is evaluated every 200m of pavement segment.

As data for estimation of performance curve in this research, inspection data collected from 2007 to 2010 on the roads of SP150 (Rodovia Anchieta), SP160 (Rodovia dos Imigrantes) and SP 248(Rodovia Cônego Domenico Rangoni) was used. The target condition index was IRI.

In order to estimate a performance curve, two time inspection data are required. Unknown parameters for calculation of Markov transition probabilities is estimated using sample data involving a pair of inspection data and the information of inspection interval. Some sample data of the section where the condition rank of IRI is improved are excluded because it can be

Fig. 2 Route map and location of the target route

assumed that that segment was repaired. Finally, the number of sample data for estimation is 3,707.

Estimation Results

Table. 1 shows the definition of condition ranking of IRI and the estimation result of the hazard parameters in the case of bench-marking. Furthermore, the estimation result of heterogeneity parameters by each target route is described in Table. 2 and the performance curves(expected life length of pavement surface) of bench-marking and each route is drawn in Fig. 3.

The average life length of pavement surface of IRI to condition rank 6 (IRI $\geq$ 5) is approximately 24 years. The deterioration speed in the initial stage of deterioration is faster. On the other hand, the deterioration speed after the condition of rank 5 (IRI $\geq$ 4) is rapidly increasing.

The comparison of deterioration speed among routes shows that the deterioration speed of route SP150 is faster rather than the bench-marking case(ε^k =1.21) and the heterogeneity parameter of route SP160 is 0.83, which means that the deterioration speed of route SP160 is gradual.

Table. 3 and Fig. 6 describes the results of the comparison of deterioration speed among lanes. In this results, there are no differences of deterioration speed among routs. Generally, deterioration speed of pavement surface is affected by some characteristics, such as traffic volume, surface type, pavement structure, etc. In this research, these factures are not included in data to estimate the deterioration performance. Actuary marginal lane has some pavement segments which surface type is segment concrete. The issue that remains is the impact analysis of these characteristics of each pavement segment.

Table. 1 Estimation Result (Bench-Marking Case)

IRI (mm/m)	Condition Ranking	Hazard Rate
$0 \leq IRI \leq 1$	1	0.9826
$1 \leq IRI \leq 2$	2	0.2025
$2 \leq IRI \leq 3$	3	0.1623
$3 \leq IRI \leq 4$	4	0.1202
$4 \leq IRI \leq 5$	5	0.4893
$5 \leq IRI$	6	-

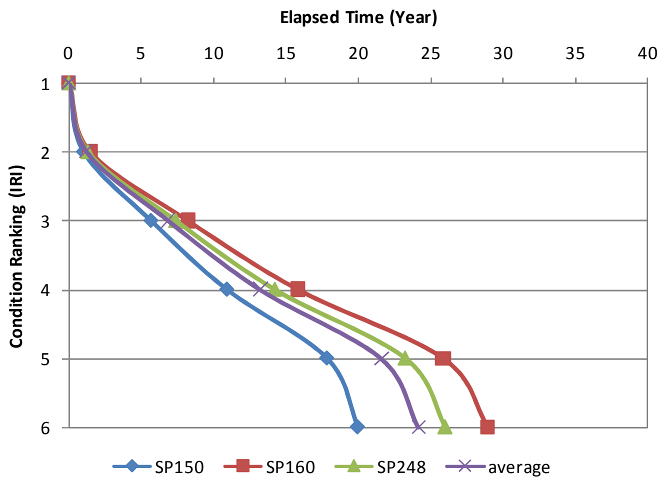

Fig. 3 Performance Curve (Bench-Marking and Each Route)

Table. 2 Estimation Result (Comparison among Routes)

Route Name	Epsilon
SP 150	1.21
SP 160	0.83
SP 248	0.93

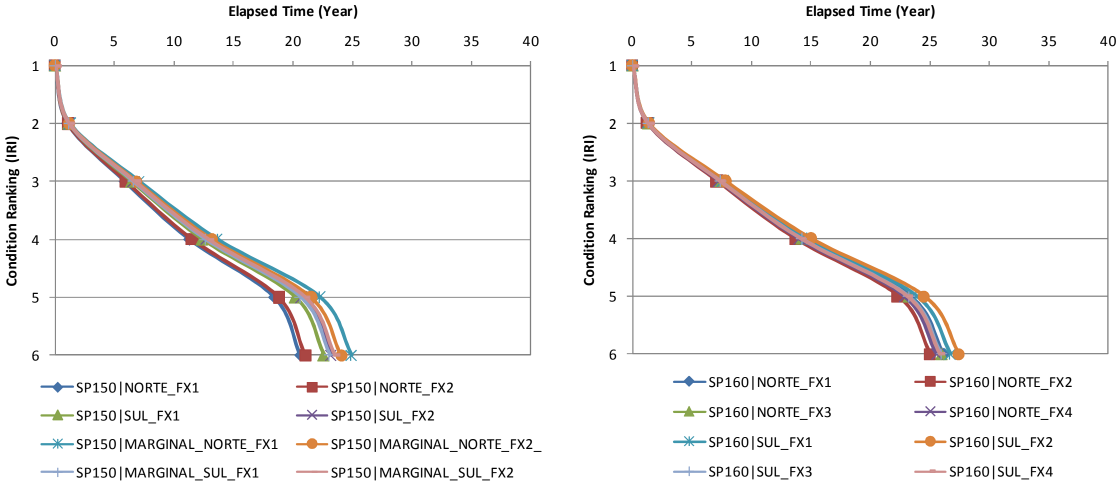

Fig. 4 Performance Curve of SP150 and SP160 (Comparison among Routes & Lanes)

Fig. 5 Pictures of SP150 and SP160

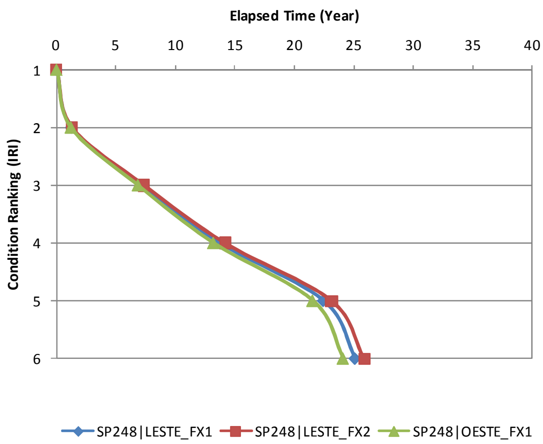

Fig. 6 Performance Curve of SP248 (Comparison among Routes & Lanes)

Table. 3 Estimation Result (Comparison among Routes & Lanes)

SP 150		SP 160		SP 248	
Lane Name	Epsilon	Lane Name	Epsilon	Lane Name	Epsilon
NORTE_FX1	1.17	NORTE_FX1	0.92	LESTE_FX1	0.96
NORTE_FX2	1.15	NORTE_FX2	0.97	LESTE_FX2	0.94
SUL_FX1	1.07	NORTE_FX3	0.93	OESTE_FX1	1.00
SUL_FX2	1.04	NORTE_FX4	0.95		
MARG._NORTE_FX1	0.97	SUL_FX1	0.91		
MARG._NORTE_FX2	1.01	SUL_FX2	0.88		
MARG._SUL_FX1	1.05	SUL_FX3	0.93		
MARG._SUL_FX2	1.03	SUL_FX4	0.94		

CONCLUSIONS

This paper shows the importance of deterioration performance evaluation using inspection data to achieve effective road asset management. The paper is a case study to estimate the deterioration performance by using inspection data of the highway in Sao Paulo. In this case study, the deterioration performance of IRI was estimated and the pavement segments which has the deterioration speed greater deviating from the bench mark case based on the comparison of deterioration speed among routes and lanes are discovered. The methodology proposed by this research is a part of the evaluation of the PDCA cycle of road asset management.

It was shown that unusual segments of deterioration speed can be identified. The results derived are useful information for maintenance planning. By changing the evaluation segments, it is possible to find out a variety of problematic road segments. It is important to improve the management system continuously for the implementation of effective road asset management. The research results suggests a solution for carrying out the continuous improvement based on the PDCA cycle.

REFERENCES

Tsuda, Y., Kaito, K., Aoki, K. and Kobayashi, K. (2006): Estimating Markovian Transition Probabilities for Bridge Deterioration Forecasting, Journal of Structural Eng./Earthquake Eng., JSCE, Vol.23, No.2, pp.241s-256s.

Kaito, K. and Kobayashi, K. (2009): Disaggregated Hazard Rates Evaluation and Bench-marking for Infrastructure Asset Management, International Seminar on Urban Infrastructure Management, The Univ. of Tokyo.

Aoki, K. (2012): Road Performance Assessment – Kyoto Model, Kyoto University – UTC Joint Summer Course of Road Infrastructure Asset Management, Hanoi.

Aoki, K., MORI, H. and OKADA, K. : Effect of Pavement Service Level Upon Operation Timing of Periodical Inspection Policy, 7th ICPT, Bangkok, Thailand, 2011.

Aoki, K.: Pavement Inspection System and Measuring the Deterioration Performance for Pavement Management, Proc. of International Seminar on Asset Management Implementation in Asian Countries, Kuala Lumpur, 2009.