Road Maintenance and Repair Strategy with Benchmarking Methodology

ROAD MAINTENANCE AND REPAIR STRATEGY WITH BENCHMARKING METHODOLOGY

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***ABSTRACT*:** Road pavements are often designed to accommodate two important functions. The first function is to make suitable surface characteristics, which provide safety and comfortable driving for road users. The second function is to ensure a certain level of structural durability for its performance over a long period of time. These two functions need to be considered carefully in view of maintenance and management. Without a proper maintenance and management plan or strategy, the functionality of road pavements will not be assured. In view of maintenance and repair (M&R), temporary M&Rs are often implemented in practices, only to restore its condition states and satisfy the immediate performance. Current M&R methods are not significantly improve the durability of pavement structures. This practice can be regarded as a limitation in the field. This paper is developed with aim to give an answer to this limitation. In a glance, the paper proposes an innovative approach by combination of Markov hazard model and Mixture Hazard Model to trigger an optimal M&R strategy in a long-term planning view. The deterioration speeds of road sections are comparatively evaluated. Based on the results of obtained deterioration speeds, a further investigation on structural performance can be tested. We conduct an empirical study on a set of monitoring data for 71.140 km national roads in Japan to verify the usefulness of the proposed methodology.

KEYWORDS: benchmarking, road repair and maintenance planning, asset management

1. INTRODUCTION

One of the main roles for road administrators is to provide a certain level of service to road users. This task is crucial important and become challenging nowadays as they face a number of emerging issues. For example, the stock of large-scale infrastructure is continuously increasing while there is less money being allocated for M&R activities due to governmental budget constraints, tax reduction, etc. Another challenging task comes from the road users, the demands of road users keep diversifying with time and location, sometimes being sophisticated, thus require additional work forces for road administrators. Therefore, in order to accommodate those matters, road administrators are required to develop an efficient management system in a long-term perspective.

There are two important functions of road pavements, which deem as important factors. The first function is about its surface characteristics. Surface characteristics must give safety and comfortable driving for road users. The second function is about its structural properties. Structural properties of road must be durable with time, carrying loads, and environmental impacts. This durability ensures a long-term serviceability. These two functions need to be considered carefully in view of maintenance and management. Without a proper maintenance and management plan or strategy, the functionality of road pavements will not be assured.

In actual practices, the damage to the surface of road pavements is observed by means of visual inspection and monitoring activities. Gathered information includes cracking, rutting, flatness, etc. This information is then examined by road engineers for determining a set of M&R methods.

In most of the cases, the M&R methods are proposed to focus only on immediate repair, which recover the condition states of road surfaces, but neither genuinely emphasize on preventive M&R activities (overlay or cutting overlay) nor durability of pavement structure (crack sealing). These practices are mainly by limitation of expenditure in managerial term. As the matter of course, the immediate and temporarily M&R strategies do not always improve the structural performance of pavements. As a result, the duration of service after temporarily M&R actions is not significantly improved. This is due to the fact that the deterioration of structure performance has a high influence on the overall performance of the road pavements.

This paper proposes a new approach to overcome the limitation of current optimization problems in road planning for M&R strategies. We apply consecutively Markov hazard model and Mixture hazard model in the approach. At first, the deterioration speeds of road sections will be comparatively evaluated. Secondly, the structural performance of road sections will be analyzed. Section 2 provides a background literature as a favor for this study. Section 3 discusses the benchmarking method using two hazard models and planning for M&R strategies. An empirical study is explained in section 4 with highlighted estimation results. Finally, section 5 gives a conclusion of the study.

2. BACKGROUND OF STUDY

2.1 Overview of study background.

The Markov transition probability model is proposed as a statistical prediction deterioration model of social facilities. In particular, the development of Markov deterioration hazards model (hereafter abbreviated as Markov deterioration model) dramatically improved the accuracy and applicability to real data to estimate Markov transition probability.

Markov transition probability prediction method is able to divide into 1) an aggregate prediction method and 2) a disaggregate prediction. The one method is based on data about the occurrence in the transition state between the ratings in a certain period of observation, which aims to directly estimate the Markov transition probability. The simplest method defined transition probability rate with counting the transition state of real inspection data in each rating. On the other hand, the method of maximum likelihood method to estimate the transition probability has also been proposed. Markov transition probability depends on the time interval to define the transition probability.

The data which inspected in practice often have various data in different duration. In this case, it will be required to compensate the effects of time differences were observed between the actual data. Sugisaki et al (2006) suggested a way to aggregate the estimated Markov transition probability using visual inspection data with different length of observation period. However, these aggregate degradation prediction method are limits that can poor-modeled the relationship has been placed in the environment and facilities between the structural and functional characteristics and transition probability

On the other hand, disaggregate prediction method is based on information about individual social facilities deterioration processes, and statistical methods to estimate the regularity of the underlying deterioration process. In such way, Kaito et al. (2007a & 2007b) discussed on prediction method of average deterioration process based on the deterioration speed of Bridges using visual inspection data in New York City. The other has been proposed for prediction of Markov transition probabilities that use the history of the last inspection which is deterioration speed as a random variable. After this improvement applied Hazard model, the disaggregate prediction method have undergone a dramatic development.

In a series of this improvement, Michalani and Madanat (2002) proposed to express the exponential hazard model using a Markov transition probability intended only as two adjacent single rating. On a parallel with the improvement, Tsuda et al. proposed a two stage multi-hazards model to represent the index in the transition state between any two or more rating has proposed a general Markov deterioration model to estimate the Markov transition probability. Then those improvements continue to propose the studies as Multi-stage Weibull deterioration hazard model which Markov transition probability predicts non-homogeneous Markov transition probability with past memories, and Hierarchical exponential hazard model to represent transition probabilities between different deterioration processes.

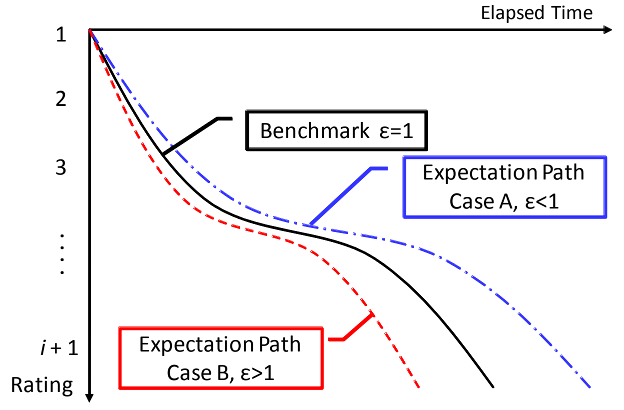
As far the prediction of Markov transition probability, it proposed the Bayesian methods to predict the Markov transition probability combined information of engineer's experiment and road inspection data with very small stage inspection data, and the deficit bios calibration method to calibrate the deficit of inspection data caused by preservation repairing of the pavement.

However, there are limits that can not consider the heterogeneity of individual facility-specific hazard rate, these hazards model using either deterministic hazard function. Realizing this limitation, Kaito et al. (2008) suggested Mixture Weibull hazard model considering the deterioration of the hazard rate heterogeneity, and it has been applied to the management of traffic control system. However, it expressed the state of system deterioration where 2 represents of variable value the presence or absence of fault, the framework is not to evaluate the heterogeneity of degradation rates can be expressed using multiple ratings. Therefore, Obama et al (2008) formulated the Mixture Markov hazard model considering the heterogeneity of hazard rate on multiple exponential hazard model that focused on setting of benchmarking deterioration curve on the social facilities, and comparative validation and judgment of deterioration speed, proposed the methodology to prepare the index of comparative validation on benchmarking deterioration curve and speed. Based on above-mentioned background, this study will discuss a new approach for road maintenance plan using the existing Benchmarking technology.

3 BENCHMARKING AND REPAIRING PLANNING

3.1 Benchmarking and Comparative Evaluation.

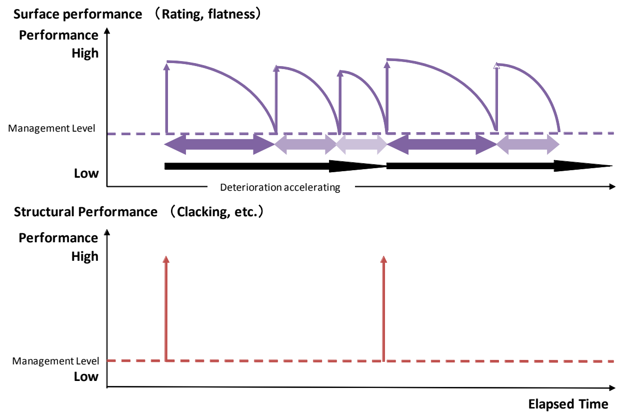
For more information on benchmarking model,



Note:

ε = 1 of the solid line represents the benchmark degradation curve. The degradation curve is located below the curve is rapidly degraded than the average progress, and located above means that progress is slow deterioration.

Figure 1 Benchmarking and Comparative Evaluation.



Note:

The deterioration of surface pavement is faster than the cycle of performance of the road structure, and being recover its performance to repair each time.

In addition, the deterioration speed of surface becomes faster due to the deterioration of road structure.

Figure 2 Pattern of pavement deterioration

Obama et al (2008) is further discussed in the paper, this paper may state that the basic concept of benchmarking for comparative evaluation.

This paper considers the comparative evaluation in a group of elements that comprise social facilities and system, which is divided into K groups. The empirical analysis in this paper applies the issue relative to the speed rating of the group of pavement deterioration. In such case, each unit of pavement would be set as one group. A pavement type to configure one group of pavement is positioned 1 element configured in same group. In this case, the comparisons in deterioration of each group become possible.

The evaluation on comparativeness of deterioration speed has been studied in several infrastructure facilities. For example, comparison of deterioration speed on bridges also is carried out as the base for formulating an comparative evaluation of deterioration speed. In this case, Mixture Markov hazard model plays an important role for comparative evaluation. Mixture Markov deterioration model is applied to evaluate the comparative deterioration process based on the heterogeneity case. The average degradation curve of pavement type in different group can express as a function of time as shown in Figure 1. The pavement group of study should be considered in all the same characteristics of structural materials and the terms and conditions. Average deterioration curve of solid line shown in figure1 indicates the average deterioration curve of target pavement group. The pavement group A, where dotted curve is located below the average curve judges to deteriorate faster than the average.

In a contrast, deterioration curve of group B is located above the average has lower speed of deterioration than the average deterioration curve. The average degradation curve, which is the standard

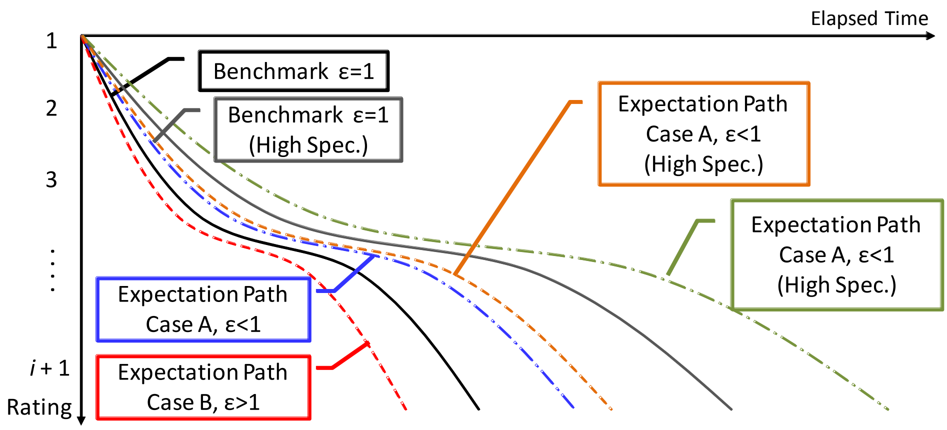


Figure 3 Benchmark in Deferent Pavement Performance and Expectation Path of Each Heterogeneity Parameters.

between speeds of pavement deterioration, applies the word of this curve to Benchmark deterioration curve or Benchmark curve in this study. Mixture Markov deterioration model is able to represent the deference with heterogeneity parameter between each deterioration speed which has homogeneous characters if apply it. In this case parameter prediction. This heterogeneity parameter ε is to represent the difference between random variables indicated the degradation rate. In this to indicate the benchmark degradation curve, the heterogeneity parameter ε should be one (1). Furthermore, in case of ε> 1, the degradation curve is faster degradation than the Benchmark curve and in case of ε <1, the evaluation can be a slow compared with the Benchmark.

For these evaluations, if the deterioration speed of some group is indicated considerably higher than other groups, road administrator is required to be clarified specifically reason to cause the change. In this way, Mixture Markov hazard model is able to provide convenient information for sophisticated and advanced asset management of pavement in road network by evaluating each group relative to the speed of pavement deterioration. Additionally, Mixture Markov hazard model installed heterogeneity parameter has several advantages that measures comparative evaluation in non-homogeneous pavement groups of deferent road types, characters, and environments. Therefore, this model allows drawing the Benchmark deterioration curve by individual type of pavement deterioration in pavement group consisted of different type of pavement and developing the comparative evaluation model to estimate the deterioration speed.

3.2 Relation of pavement structure and comparative evaluation.

The performance of pavement after beginning in service started the deterioration due to heavy traffic and so on. There are several indexes to assess the pavement performance, especially, the index which cracking rate etc. evaluate the state of pavement structure, rutting and flatness evaluate to affect the safety and comfort for road user are typical. Another is the percolating volume index of draining water permeability for porous pavement and so on. When the pavement performance reach to a level, the pavement should raise the performance back same as new construction by preservation maintenance, or conduct the repairing or reconstruction to improve the performance. Figure 2 is shown the management level as target level of performance that is required to carry out repairing or reconstruction.

The process of pavement deterioration, 1) decrease in surface characteristics, 2) decreased as the structural integrity of the pavement, considering there are roughly the performance of the cycle track was fast from the slow degradation of the structural integrity of the pavement, repairing each time to recover its function. The process of pavement deterioration is able to divide into 1) Deterioration in surface performance only, and 2) Deterioration of pavement structural performance. The speed of 1) Deterioration in surface performance only should be faster than 2) Deterioration of pavement structural performance. Furthermore, the cycle of road performance becomes faster deterioration of pavement due to structural deterioration. Consequently, if the same surface features in the surface, the speed of deterioration in performance is considered that the surface condition depends on the deterioration of the road structure.

Meanwhile, the comparative evaluation of road deterioration based on Benchmarking methodology has formulated to be comparative model for each pavement group, so that it becomes suitable technology to grasp the condition under surface pavement if it certifies the assumption. This phenomenon is considered as same even the pavement designed high specification.

4. EMPIRICAL ANALYSIS

4.1 Overview.

Using proposed the methodology, this study conducted the comparative evaluation of deterioration speed based on Markov hazard model and Mixture hazard model.

In order to analyze with Benchmarking methodology, this study focuses on the national roads under the control of the national road maintenance office in the vicinity of the Ministry of Land, Infrastructure, Transport and Tourism. The total length of observed road is approximately 71.140 km in its length. Data for analysis is consisted of index of MCI (Maintenance Control Index) from road inspection data and road repairing durations. The MCI data is prepared based on inspection on crack rate, rutting, and flatness observed in the year 2006.Furthermore, in order to analyze the deference of deterioration speed, it acquired the road characteristics and spatial information. In the information, the analysis of Markov hazard model was applied the road mixture type data such as dense grade asphalt pavement, permeable asphalt pavement, cement pavement, and other factors evaluate with the heterogeneity parameters of Mixture hazard model.

4.2 Markov Hazard Model.

This study tries to predict the life expectation using database mentioned in section 4.1. This database is classified into 6 MCI ranks. The Markov hazard model which Road mixture type selected as explanatory valuables in each rating predicts the hazard function. Among those parameters, the model was selected the combination of explanatory valuables, which satisfied the sign conditions and the likelihood ratio test. We select three characteristic variables of road mixture type including dense grade asphalt pavement, permeable asphalt pavement, and cement pavement. As a result, following equation of hazard function is defined:

$$\tilde{\lambda}_i = \exp\left(\beta_{i,1} + \beta_{i,2}x_2 + \beta_{i,3}x_3\right) \qquad (i = 1,\cdots,6)$$

Table 1 Prediction of Parameters with Markov Hazard Model

Rat -ing	Const. βi,1	Permeable asphalt βi,2	Dense grade asphalt βi,3	E[θ]	Life expectancy
1	0.0933	0.5035	0.1712	0.339	2.949
	(14.62)	(25.10)	(20.94)		
2	1.2522	-0.8461	-	1.029	0.972
	(19.60)	-(12.81)	-		
3	0.0539	0.2147	0.6407	0.533	1.876
	(14.82)	(12.06)	(21.46)		
4	0.1551	0.1531	-	0.196	5.114
	(29.00)	(4.34)	-		
5	0.15	-	0.0803	0.203	4.928
	(5.67)	-	(2.70)		
log likelihood				-13433.7392	

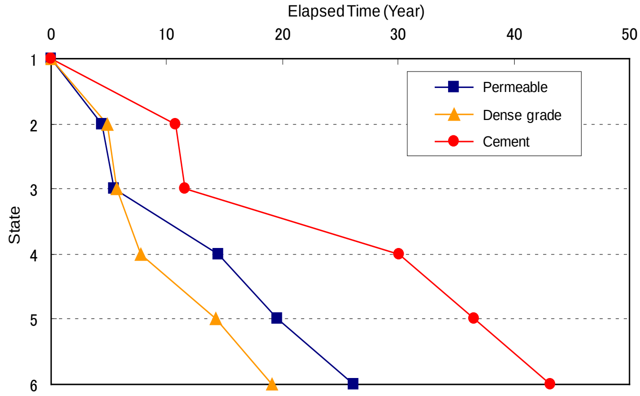


Figure 4 Deterioration Curve with Markov Hazard Model (Road Mixture Type).

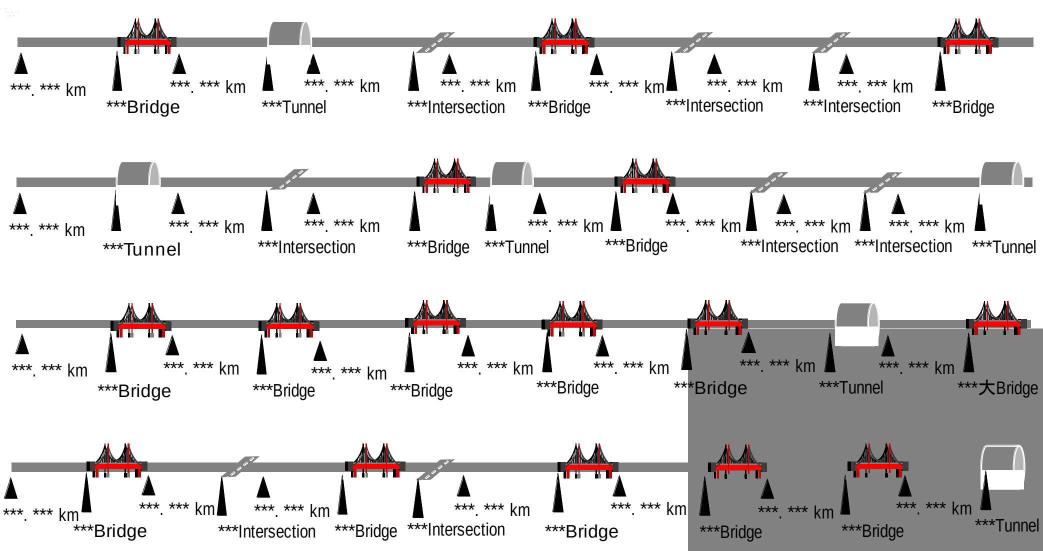


Figure 5 Groups by Sections (Example)

Data of road mixture type is qualitative data and further being associated with dummy variable.

In case of permeable asphalt pavement,
$x_2 = 1 \quad x_3 = 0$
In case of dense grade asphalt pavement,
$x_2 = 0 \quad x_3 = 1$
In case of cement pavement,
$x_2 = 0 \quad x_3 = 0$

Table 1 displays the estimation values of parameters, while Figure 4 illustrates the deterioration path of each road mixture type using life expectancy in each rating of Table 1. Those figures show that the cement pavement has the longest life expectancy and faster deterioration speed than in order from grade asphalt pavement, and permeable asphalt pavement.

4.3 Mixture Markov Hazard Model.

Mixture Markov hazard model captures the heterogeneity factor of each pavement group. Following equation describes the integration

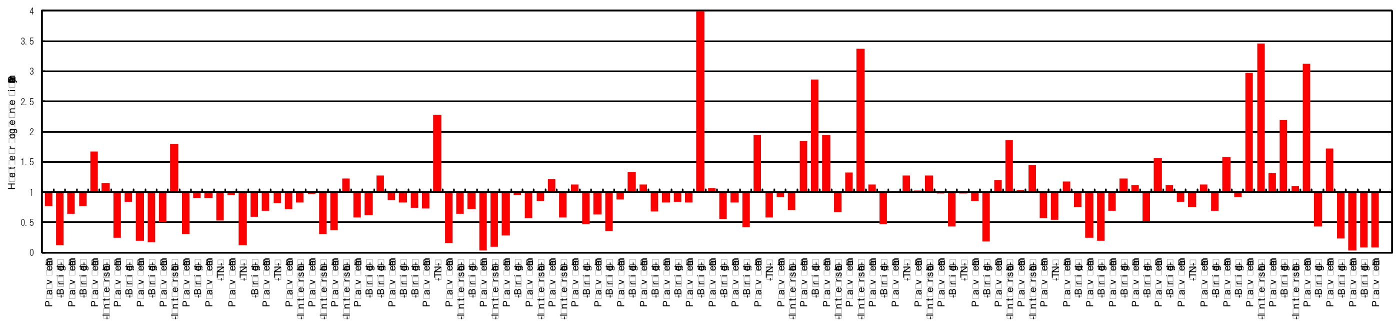


Figure 6　Heterogeneity Parameters in Groups

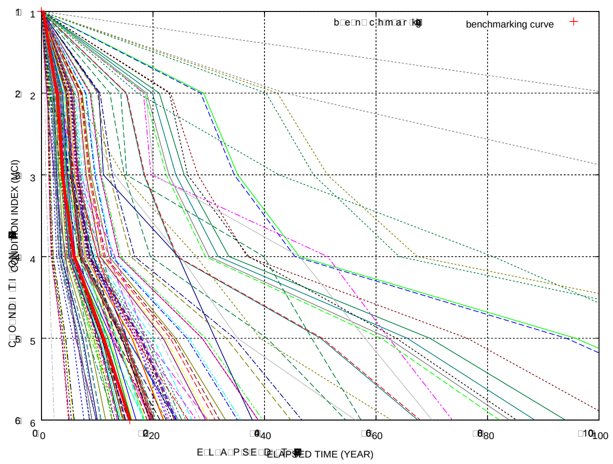


Figure 7　Expectation Path of Section Groups.

of heterogeneity factor in hazard function.

$$\lambda_i^k = \exp\left(\beta_{i,1}^k + \beta_{i,2}^k x_2 + \beta_{i,3}^k x_3\right)\varepsilon^k \qquad (i = 1,\cdots,6)$$

The ε^k is a heterogeneity factor, which indicates deterioration characteristics in group k $(k = 1,\cdots,K)$. Group k shown in Figure 5 is an example corresponding to area group, which are divided into a road facilities such as bridges, tunnels and intersections.

Figure 6 represents the change in the heterogeneity parameters of groups in consecutive sections. Figure 7 shows the life expectancy for each targeted group. Additionally, in Figure 7, the solid line of bold red color shows the benchmark curve in the whole group.

5. CONCLUSION

This paper has presented an approach using benchmarking technology for comparative evaluation of deterioration speed and structural performance of each pavement group. It emphasizes on detecting condition state of lower asphalt surface structure when upper surface exposing to fast deterioration. We recommend applying Falling Weight Deflectometer (FWD) test to reveal the condition of lower structure in case of necessity. The long-term view toward future management of road pavement should always consider the optimal M&R strategies. In order to achieve this objective, benchmarking methodology and economic evaluation with life cycle cost analysis are recommended.

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