BENCHMARKING - AN EFFECTIVE APPROACH TO IMPROVE
VIETNAMESE PAVEMENT MANAGEMENT SYSTEM

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## 1. Introduction

Road network building has been recognized as one of the key infrastructure development in developing country. The technologies in road design and maintenance as well as rehabilitation are thus playing a very important role within the framework of the pavement management system (PMS). There is a fact in developing countries that these technologies are in general borrowed directly from design specifications of industrialized countries. And there is also a fact that the socio-economic conditions between these countries have a wide difference [1)]. It is therefore a need to examine the appropriateness of employed technologies could become vital necessary.

The PMS in Vietnam is having a problem of being characterized with many different technologies both in design and maintenance. The issues of trading-off among technologies along with weak management system due to historical influence have made many difficulties for policy makers in defining the most suitable guideline, standards in the PMS. The objective of this paper is to develop a benchmarking model for selecting the appropriate standard designs for pavement technology with focus on the surface structure. Life cycle cost analysis incorporating hazard model is used to extract the optimal design alternatives and management strategies that becomes important indicators for benchmarking.

## 2. Background of The Research

In the heart of systemic PMS system is the deterioration hazard model and the optimization life cycle cost analysis model. Hazard models allow users to forecast the hazard rates, life expectancies and deterioration curves of highways, roads given the past inspected condition states and other variables concerning various environment impacts such as: traffic volume and surface thickness [2)-4)]. Given the fact that roads exposing under different working conditions bear different hazard rates. Moreover, the rates are also varied according to the dissimilarity of road surface structures and road groups. It is therefore the application of hazard model into these contexts would enable to have a list of hazard rates, predicted life expectancies in associate with different types of road surfaces and conditions.

Beside the consideration of technical results as given from hazard models, road managers often desire to choose the a design and management policies primarily based on its economic performance indicators like expected accumulation life cycle cost or cost benefit ratio. Therefore, for the purpose of benchmarking, it is necessary to make a comparison of life cycle cost for each group of roads as when already having their certain predicted hazard rates and life expectancies. As the consequent, road managers feel confident to make investments in a particular technology (possible the alternative offering minimum expected accumulation life cycle cost) for entire PMS since they are convinced by the

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comparison results of benchmarking. In another word, this approach could effectively support the establishment of suitable surface pavement technologies for PMS in Vietnam.

There are a numbers of hazard models, which can be utilized for benchmarking study. For instance, the hazard model developed by Tsuda et al [4], in which hazard rate is estimated from Markov transition probability given the two set of inspection data, can be used to compare for the group of similar roads to other groups. However, this model has not yet addressed the heterogeneity factors, thus only represent the average hazard rate. Since the PMS of Vietnam is very much affected by heterogeneity factors, it could be more relevant to consider the hazard model, which takes heterogeneity into account.

## 3. Mixture Hazard Model for Benchmarking Study

(1). Heterogeneity Factors and the Benchmarking Framework

It is assumed that the deterioration process of infrastructure can be formulated by Markov transition probability $\pi_{ij}$, hazard rate $\lambda$ and time interval $z$. Here, pair element *(i,j)* represents the finite discrete condition state of infrastructure. Given a fact that, a fool of data consists of information from a huge number of roads (for example *k*). Thus, the hazard rate of each road can be formulated as $\lambda_i^k = \tilde{\lambda}_i^k \varepsilon^k$ $(i = 1,...,I-1; k = 1,...,K)$. The letter $\varepsilon^k$ denotes the heterogeneity parameter, which infers the change of characteristic of a peculiar hazard rate to each type of road *k(k=1,...,K)* In this understanding, the benchmarking study can be illustrated in following framework.

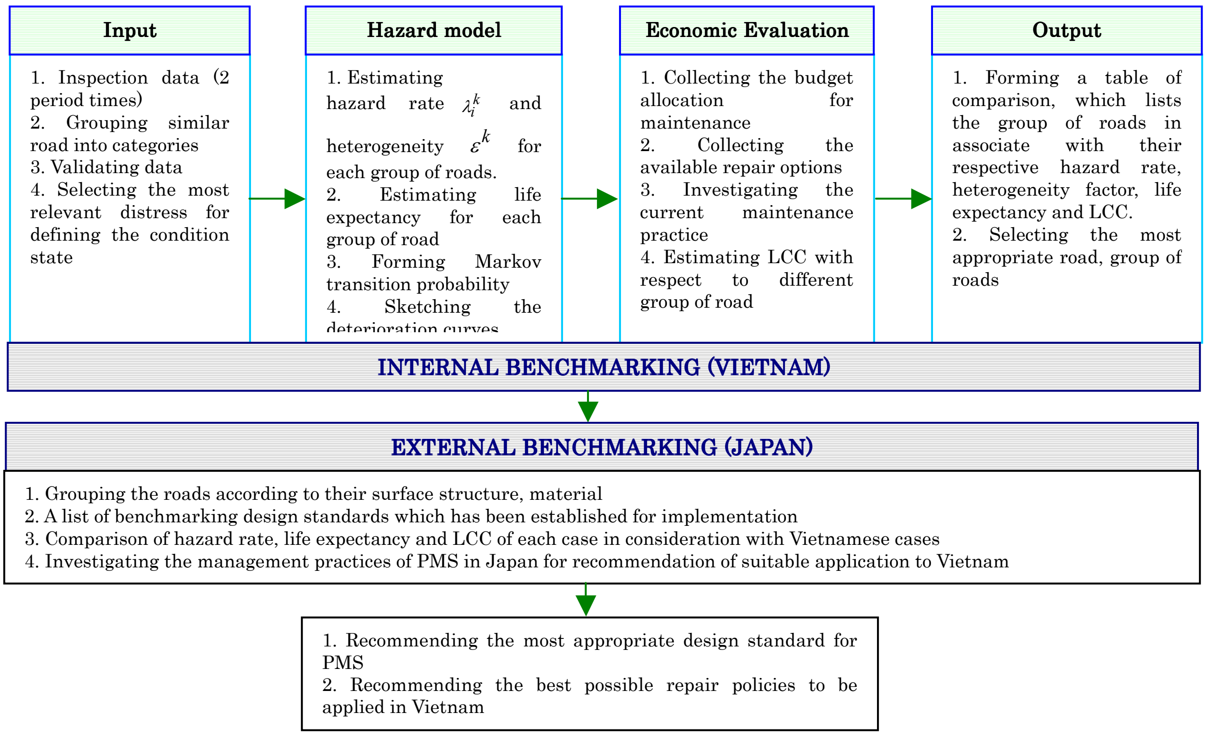


Figure 1: Benchmarking framework for Vietnamese PMS

(2). Markov Transition Probability

The development of hazard rate $\tilde{\lambda}_i^k$ depends very much on the value of $\varepsilon^k$. In this study, it is assumed that the heterogeneity parameter $\varepsilon^k$ to be distributed according to Gamma function $f(\varepsilon^k : \alpha, \gamma)$

$$f(\varepsilon^k : \alpha, \gamma) = \frac{1}{\gamma^\alpha \Gamma(\alpha)} (\varepsilon^k)^{\alpha - 1} \exp(-\frac{\alpha^k}{\gamma}) \qquad (1)$$

The deterioration of pavement can be formulated by Markov transition probability [5] with following characteristics.

$$\pi_{ii}^k(z^k:\overline{\varepsilon}^k)=\exp(-\overline{\lambda}_i^k\overline{\varepsilon}^k z^k) \text{ and } \pi_{ij}^k(z^k:\overline{\varepsilon}^k)=\sum_{l=i}^{j}\prod_{m=i,\neq l}^{j-1}\frac{\overline{\lambda}_m^k}{\overline{\lambda}_m^k-\overline{\lambda}_l^k}\exp(-\overline{\lambda}_l^k\overline{\varepsilon}^k z^k) \tag{2}$$

Where, $(i=1,...,I-1); j=i+1,...,I; k=1,...,K)$ and $\varepsilon^k$ follows Gamma function, further expression can be formed as

$$\tilde{\pi}_{ii}(z)=\frac{\phi^\phi}{(\overline{\lambda}_i\ z+\phi)^\phi} \text{ and } \tilde{\pi}_{ij}(z)=\sum_{l=i}^{j}\prod_{m=i,\neq l}^{j-1}\frac{\overline{\lambda}_m^k}{\overline{\lambda}_m^k-\overline{\lambda}_l^k}\frac{\phi^\phi}{(\overline{\lambda}_l\ z+\phi)^\phi} \tag{3}$$

(3). Estimation Approach

In order to establish the Markov transition probability, the information from two visual inspections is necessary to be recorded $\overline{t}^k$ is time at first inspection *k=(1,...,K)*. Second inspection is at $\overline{\tau}^k=\overline{t}^k+\overline{z}^k$ when time $\overline{z}^k$ passed. The sign $\Xi$ indicates the measurable value in the inspection of *k* roads. $h(\overline{t}^k)$ is corresponding condition rating. Based on the results of inspection, the dummy variable $\overline{\delta}_{ij}^k$ is defined as $\overline{\delta}_{ij}^k=1$ when 1 $h(\overline{t}^k)=i, h(\overline{\tau}^k)=j$ and =0 otherwise. The $\overline{\delta}^k=(\overline{\delta}_{11}^k,...,\overline{\delta}_{I-1,I}^k)$ is dummy variable vector. Furthermore, the structural characteristic and environmental condition of road components that effect the deterioration speed are represented by the row vector $\overline{x}^k=(\overline{x}_1^k,...,\overline{x}_M^k)$, where $\overline{x}_m^k(m=1,...,M)$ shows the observed value of variable *m* for the inspected sample \$k\$. Here, it is noted that the first variable is $x_1^k=1$. The information contains in the inspection of sample *k* can be rearranged as $\varepsilon^k=(\overline{\delta}^k,\overline{z}^k,\overline{x}^k)$ and the entire pool of sample is $\Xi$. The deterioration process of sample *k* can be expressed by using mixture index hazard function $\lambda_i^k(y_i^k)=\tilde{\lambda}_i^k\varepsilon^k$, where $\pi_{II}^k=1, \tilde{\lambda}_I^k=0$. The hazard rate $\tilde{\lambda}_i^k$ depends on the characteristic vector of road component and suppose to change to the vector $x^k$ as $\tilde{\lambda}_i^k=x^k\beta_i^{'}$. Where $\beta_i=(\beta_{i,1},...,\beta_{i,M})$ is a row vector of unknown parameters and the symbol $'$ indicates the vector is transposed. From (3), the standard hazard rate in each rating can be expressed by the standard variance $\phi$ of the probability distribution of hazard rate $\lambda_i^k$ and the heterogeneity parameter $\varepsilon^k$. Average Markov transition probability is expressible by $\tilde{\lambda}_i^k=x^k\beta_i^{'}$ when using row vector $\overline{x}^k$ of road components. In addition, the transition probability also depends on inspection time interval $\overline{z}^k$ when data is observed. Thus, it is $\tilde{\pi}_{ij}^k(\overline{z}^k,\overline{x}^k:\theta)$ with $(\overline{z}^k,\overline{x}^k)$ and $\theta=(\beta_1,...,\beta_{I-1},\phi)$ for average Markov transition probability $\tilde{\pi}_{ij}^k$.

$$\ell(\theta,\Xi)=\prod_{i=1}^{I-1}\prod_{j=i}^{I}\prod_{k=1}^{K}\left\{\tilde{\pi}_{ij}^k(\overline{z}^k,\overline{x}^k:\theta)\right\}^{\overline{\delta}_{ij}^k} \tag{4}$$

From (3), it is possible to express $\tilde{\pi}_{ij}^k(\overline{z}^k,\overline{x}^k:\theta)$ as follows

$$\tilde{\pi}_{ii}^k(\overline{z}^k,\overline{x}^k:\theta)=\frac{\phi^\phi}{(\overline{x}^k\beta_i^{'}\overline{z}^k+\phi)^\phi} \text{ and } \tilde{\pi}_{ij}^k(\overline{z}^k,\overline{x}^k:\theta)=\sum_{l=i}^{j}\prod_{m=i,\neq l}^{j-1}\frac{\overline{x}^k\beta_m^{'}}{\overline{x}^k\beta_m^{'}-\overline{x}^k\beta_l^{'}}\frac{\phi^\phi}{(\overline{x}^k\beta_l^{'}\overline{z}^k+\phi)^\phi} \tag{5}$$

Since $\overline{\delta}_i^k,\overline{z}^k,\overline{x}^k$ are known from inspection, the likelihood functions are functions of $\beta,\phi$. In method of maximum likelihood, $\hat{\theta}=(\hat{\beta},\hat{\phi})$ that maximizes (5) will be presumed. $\theta$ can be obtained by solving the optimality conditions of following equation

$$\ln\ell(\theta,\Xi)=\sum_{i=1}^{I-1}\sum_{j=1}^{I}\sum_{k=1}^{K}\overline{\delta}_{ij}^k\tilde{\pi}_{ij}^k(\overline{z}^k,\overline{x}^k:\theta) \tag{6}$$

When $\hat{\theta}$ is obtained, then heterogeneity parameter $\varepsilon^k$ is given as $\hat{\varepsilon}^k$ by solving for the optimal value of

$$\ln\ell(\hat{\varepsilon}^k:\theta,\varepsilon^k)=\ln f(\varepsilon^k:\hat{\phi})+\sum_{i=1}^{I-1}\sum_{j=i}^{I}\overline{\delta}_{ij}^k\pi_{ij}^k(\overline{z}^k,\overline{x}^k:\hat{\beta},\varepsilon^k) \tag{7}$$

**4. Optimal Repair Strategy and Life Cycle Cost Analysis**

The optimal repair strategy is the one, which offers the least expected life cycle cost. The repair strategy can be expressed by Markov transition probability. In this study, average cost method is proposed since it is the desirable method in LCC analysis [5)]. Let consider the repair action in the period from time *t* to time *t+1*. A rule of repair actions can be expressed as vector $\eta^d = (\eta^d(1),...,\eta^d(K))$, in which, $\eta^d(i) = j$ refers to the change of state from $i$ to $j$ by applying repair action, and $d \in D$ as a serial of rule that specifies the repair action. As the condition state of infrastructure reaches to ultimate level $i=K$, the repair (renewal) action is carried out and condition state returns as $\eta^d(K) = 1$ . In addition, when having repair action the associate cost should be determined. Cost vector $c^d = (c_1^d,...,c_K^d)$ is referred for implemented repaired action $\eta^d$ . When a repair action is carried out, it changes the infrastructure to better condition state. Thus, the property of transition matrix $p_{ij}$ is supposed to change accordingly as $P^d = Q^d P$ ( $Q^d$ is repair dummy matrix). It is noted that since repair action $d$ is to prevent condition state $K$ to be happened at time $t+1$, thus the dimension of matrix $p^d$ is $(K-1)(K-1)$). Let assume that the condition state $i$ is observed at time $t=0$, the expected accumulation life cycle cost $u_i^d(n)$ is the expected value concerning the sum of total life cycle generated from initial condition state $i$ at time $t=0$ to time $t=n$ under repair $d \in D$ . Since repair action $d$ is applied in the horizontal management span. Following regression expression is used to calculate expected LCC (See Otazawa[6]).

$$u_i^d(n) = e_i^d + \sum_{j=1}^{K-1} p_{ij}^d u_j^d(n-1) \quad (i = 1,...,K-1) \tag{8}$$

Road managers try to control and maintain the facilities from $t=0$ to a particular fiscal future year $t(t=0,1,...)$ with aim to minimize the average cost from the very beginning. Thus, when applying the average cost $u_i^d(n)/n$ scheme in $n$ years with repair strategy $d$ (as $n$ can be infinity), the average cost, here defined as $w^d(i)$ and the best repair action $d*$ (minimum LCC), can be obtained by satisfying the following equations.

$$w^d(i) = \lim_{n\to\infty} \frac{u_i^d(n)}{n} \text{ and } w^{d*}(i) = \min_{d\in D} \left\{ \lim_{n\to\infty} \frac{u_i^d(n)}{n} \right\} \tag{9}$$

## 5. Conclusion

In this study, it is proposed the benchmarking approach improve the current situation of Vietnamese PMS. The study requires at least two sets of inspection data in different period of time that enable to determine the condition state of road system. In addition, mixture hazard model incorporating heterogeneity factors is used to forecast the deterioration process of the roads. Roads are grouped in different categories according to their surface characteristics and working condition. By comparing the expected life cycle cost among different group of roads, it is possible to obtain the best design standard and management policies that offer the minimum life cycle cost. As the consequence, for the benefit of the entire PMS, result from benchmarking study help to establish the design standards and management practices that suits to Vietnamese environment.

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