A Development and Application of Pavement Deterioration Model on Route 8 in Hokuriku Region

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INTRODUCTION

Pavement management systems (PMS) are a set of methods used for finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition. The final objective of the PMS is to give pavement engineers useful information about when, where and what kind of maintenance work should be applied. Pavement deterioration models are generally used to forecast the changes of pavement performance over some future time period. In PMS procedures, pavement deterioration models are used for pavement maintenance planning, economic analyses and life cost analyses. This study mainly focuses on two objectives: To develop the pavement deterioration models and to apply the pavement deterioration models to PMS procedures.

DEVELOPMENT OF PAVEMENT DETERIORATION MODELS

Markov probabilistic models are used to develop the pavement deterioration model in this study. The Markov probabilistic models use transition probability matrix (TPM) to describe the probability that a pavement in a given condition at a given time will change to some other condition in future. There is an assumption that the probability of changing from one condition to another is a function of the condition and time. The database used in this study is Hokuriku Region Pavement Management Support System. The pavement performance data collections were carried out in 1997 and 2000. It is suitable for applying the Markov probabilistic model to pavement deterioration model of national road of Route 8 in Hokuriku region.

According to the pavement base material types, the last pavement maintenance actions and traffic volumes (one-way daily traffic volume of heavy vehicles is over 3000), the pavement sections are classified into four pavement families as presented in **Table 1**. After the calculation, the pavement deterioration model could be developed as shown in **Fig.1**.The maintenance control index (MCI) is the pavement performance index developed by the Japanese Ministry of Land, Infrastructure and Transport. It is widely used for asphalt pavements of national roads in Japan. From **Fig.1**, it can be seen that MCI values decrease with time. It indicates that pavements deteriorate with age. It is also can be seen that pavements in the same current performance condition deteriorate with different deterioration changes.

When the pavement deterioration models have once been developed, the next step is to consider how to apply the pavement deterioration models to PMS procedures. This study mainly focuses on discussing the applications of the pavement deterioration models.

Table 1 Pavement families developed in the study.

Family	Base material	Action applied
1	Bitumen stabilized base	Overlay
2	Bitumen stabilized base	Reconstruction
3	Granular base	Overlay
4	Granular base	Reconstruction

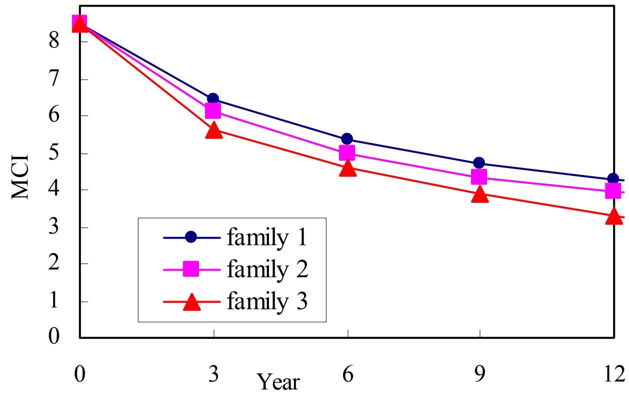

Fig.1 Pavement deterioration models

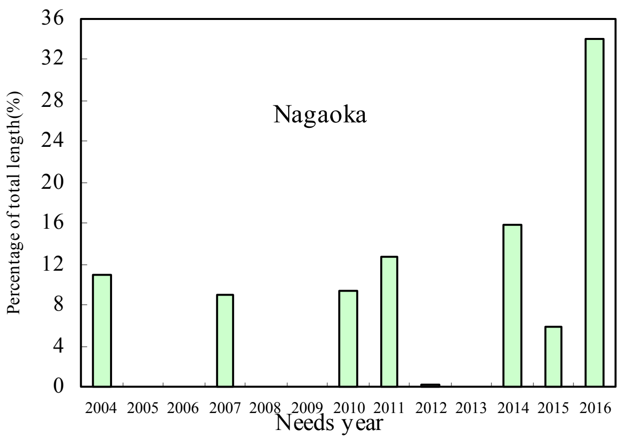

Fig.2 Needs year distribution of Nagaoka city

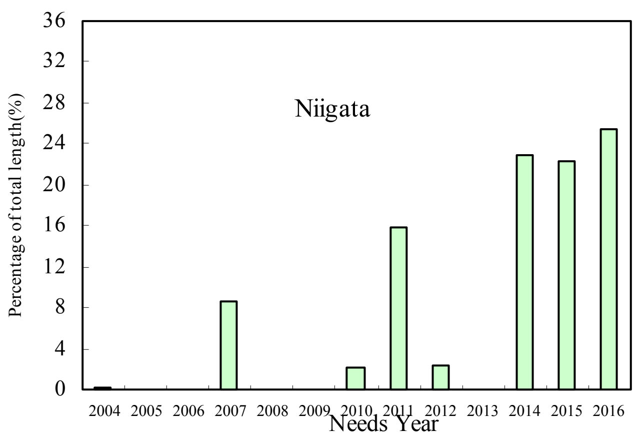

Fig.3 Needs year distribution of Niigata city

APPLICATIONS OF PAVEMENT DETERIORATION MODELS

1. Pavement Needs Year Distribution

The needs year is defined as the year in which the pavement performance index falls to or below a minimum acceptable value. In this study a MCI value of 4.0 was selected as the minimum acceptable value. By using the pavement deterioration models, the needs years can be calculated as presented in **Fig.2** and **Fig.3**. The total lane length of Niigata is about 8 kilometers. The total lane length is about 42 kilometers in Nagaoka city. From those figures, it can be seen that in different areas, the pavement needs years distributions are different. At the same time, the pavement needs years distributions are variable**.** The reason is that the characteristics of pavement are different between Nagaoka area and Niigata area. A needs year map that is convenient for making M&R work planning is also developed.

2. Pavement Distress Type Analysis

The MCI value is defined by three indexes: cracking ratio, rutting depth, and roughness. These index values stand for the following distress types: cracking, rutting and roughness. The MCI values are calculated by using the following four formulas. The smallest value will be assigned to the MCI value of the pavement section.

$$MCI_0 = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2} \quad (1)$$

$$MCI_1 = 10 - 1.51C^{0.3} - 0.30D^{0.7} \quad (2)$$

$$MCI_2 = 10 - 2.23C^{0.3} \quad (3)$$

$$MCI_3 = 10 - 0.54D^{0.7} \quad (4)$$

C: Cracking ratio (%)
D: Rutting depth (mm)
σ: Roughness (mm)

In order to forecast which distress is the main distress form in a given pavement section, checking the MCI formation becomes necessary. In this study, it is assumed that the pavement distress type that the index stands for is the main pavement distress type of the pavement section. By using the above assumption, the percentages of each distress type in Nagaoka area and Niigata area are presented in **Table 2**. It can be seen clearly that the main distress is cracking in both Nagaoka area and Niigata area.

3. Pavement Maintenance and Rehabilitation Options Determination

In order to calculate the pavement M&R cost, M&R options and unit cost of each M&R option are required. There are many M&R options for each pavement distress. According to the experts' opinions, the most common and suitable M&R options to cracking, rutting and roughness are selected as presented in **Table 3.** Unit cost, which is added up as a practical price for real maintenance works includes: direct construction cost, indirect construction cost and general administrative cost. The unit cost shown in **Table 3** is the one used for national road, which has a traffic volume of class D.

4. Pavement Maintenance and Rehabilitation Cost Calculation

The pavement M&R cost for each pavement section is estimated by applying those instructive prices shown in **Table 3**.The pavement M&R cost is calculated by using the following formula:

$$\text{COST} = \text{Unit Cost} \times \text{Lane Area} \times \text{Lane Numbers} \quad (5)$$

The pavement M&R cost was calculated as presented in **Fig.4** and **Fig.5**. The figures indicate how mnay budgets are required yearly from 2004 to 2016. As shown in **Table 4**, it can be seen that the necessary unit cost 2 in Niigata area and Nagaoka area are about the same, but, the necessary unit cost 1 in Niigata city is about as twice as that of Nagaoka. Since the environmental conditions and pavement materials used in both areas are about the same, therefore, one of the reasons might be the lane width of Niigata area is about twice as wide as that of Nagaoka area. Another reason might be the daily traffic volumes are different in Nagaoka city and Niigata city as shown in **Table.5**.

Table 2 Percentage of each distress type

Area	Cracking (%)	Rutting (%)	Roughness (%)
Nagaoka	66	34	0
Niigata	78	22	0

Table 3 M&R option and its unit cost

Distress Type	M&R options	Unit Cost (JPY/100m^2)
Cracking	Reconstruction	11.8×10^6
Rutting	Cut and Cover	2.3×10^6
Roughness	Overlay	1.8×10^6

Table 4 Necessary total cost and unit cost

Area	Total Length (km)	Total Cost (JPY)	Necessary Unit Cost 1(JPY/km)	Necessary Unit Cost 2(JPY/ m^2)
Nagaoka	41.805	$28{,}452\times10^6$	680×10^6	84,530
Niigata	7.790	$10{,}253\times10^6$	$1{,}316\times10^6$	90,122

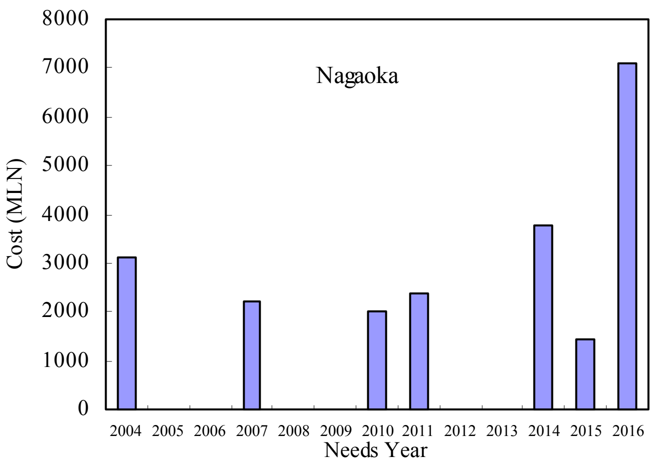

Fig.4 Cost distribution of Nagaoka (Million JPY:MLN)

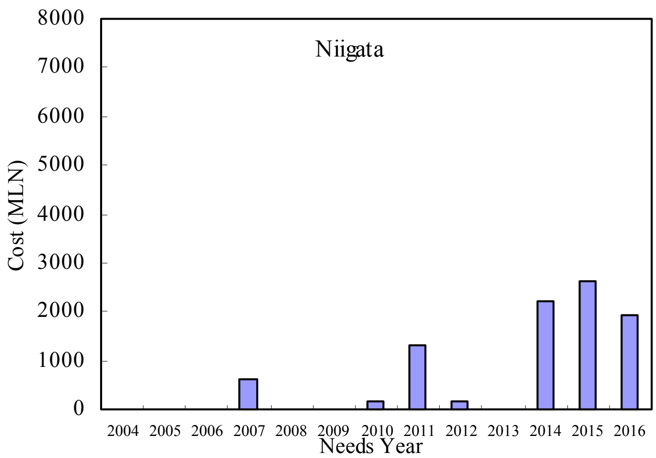

Fig.5 Cost distribution of Niigata

Table 5 Measured traffic volume (Unit : vehicles/day·direction)

Area	Maximum traffic volume	Minimum traffic volume	Average traffic volume
Nagaoka	7,672	3,452	4,569
Niigata	15,324	14,613	14,665

5. Pavement Maintenance and Rehabilitation Optimization

In order to use the limited budget in the most effective way for the pavement M&R and to make the pavement M&R working planning easier, the optimization becomes necessary. Normally, optimization methods approach the problem finding optimal M&R budget constraints, or minimize M&R cost subject to minimum requirements on road conditions. A simple priority decision principle is discussed as the following.

5.1 Pavement MCI value

From the pavement section with smaller MCI value to pavement section with bigger MCI value.

5.2 Pavement traffic volume

From the pavement section with bigger observed data of traffic volume to pavement section with smaller value.

5.3 Pavement distress type

Pavement section with cracking, then pavement section with rutting, the last one is pavement section with roughness.

5.4 Pavement location

From pavement section in urban area to pavement section in rural area.

5.5 Pavement lane length

From the pavement sections with longer lane length to pavement section with shorter lane length.

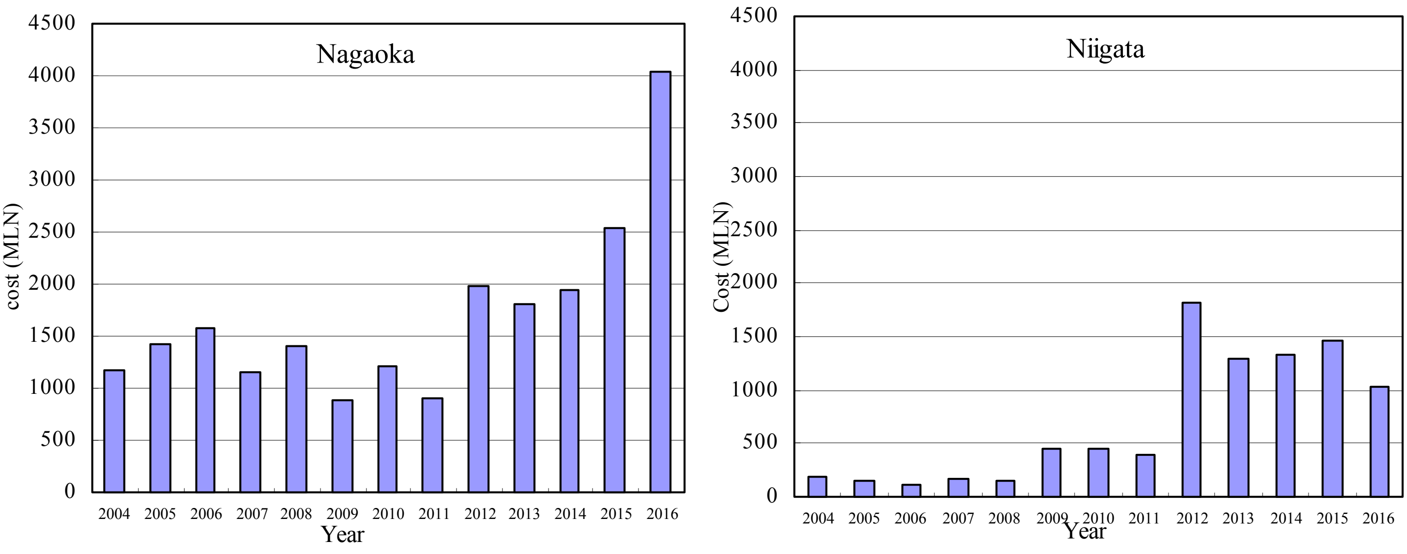

Fig.3.6 Pavement M&R cost distribution of Niigata and Nagaoka-after optimization

Based on the above principles, one of the optimization for the pavement M&R work in Nagaoka city and Niigata city is developed as shown in **Fig.6**. Compared with the original pavement M&R cost distribution as presented in **Fig.4** and **Fig.5**, it became easier to make the pavement M&R budget planning than before. In Nagaoka city, it can be seen that in most of the years, the budgets are from 1000 million JPY/year to 2000 million JPY/year.

CONCLUSIONS

Pavement deterioration models on Route 8 using Markov probabilistic model are developed. Pavement deterioration model applications for PMS procedures are shown and discussed. The necessary budgets of Nagaoka and Niigata for 12 years are predicted. From the figures, it is can be seen that the necessary budgets are variable yearly in both Nagaoka and Niigata. Therefore, for the supervisors, it is necessary to disperse the maintenance work, make an effective maintenance planning and implement it. This will be the next step of this study.