CALIBRATING HDM-4 RUTTING MODEL ON NATIONAL HIGHWAYS IN JAPAN

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ABSTRACT

This study mentions results of calibrating HDM-4 rutting model on Japanese national highways and comparing HDM-4 rutting model with rutting prediction model included in MLIT-PMS (Pavement Management System developed by Ministry of Land, Infrastructure, and Transportation of Japan). It is found that as far as rut model is concerned, HDM-4 is more applicable to real phenomenon than MLIT-PMS in both dense-graded asphalt concrete pavement and porous asphalt pavement. However it is necessary to perform further verification of HDM-4 models together with continuing accumulation of relevant field data.

KEY WORDS

HDM-4 / PAVEMENT / PMS / MAINTENANCE / RUT MODEL.

1. INTRODUCTION

The Pavement Management System (PMS) is designed to analyze the relationship of cost versus effects in the three aspects of road administration, road users and environment, with the goal to maximize economic effects from pavement investment. The World Bank and the World Road Association (PIARC) originally developed HDM-4 (Highway Development and Management Tools). Currently, in the domain of PMS, HDM-4 is considered as the most practical tool for economic assessment of road investment projects.

This paper reports first of all the calibration of the HDM-4 rutting model we conducted to learn whether this model is applicable or not to ordinarily highways in Japan. We also attempted to apply it to national highways. Secondary, we discuss the details of comparison between HDM-4 and MLIT-PMS (Pavement Management System which is currently used by the Ministry of Land, Infrastructure and Transport).

2. COMPARISON OF HDM-4 AND MLIT –PMS

Here we first introduce the framework of MLIT-PMS and then compare it with HDM-4 in terms of their applicability at the stages of road construction, maintenance and policy study.

2.1 Outline of MLIT-PMS

The Ministry of Land, Infrastructure and Transport provides a pavement management system (MLIT-PMS), composed of a pavement databank, a short-term repair plan system at project level and a long-term repair plan at network level as shown in Figure 1.

The pavement databank is a core system of MLIT-PMS whose purpose is to effectively manage the data relating to road surface attributes, maintenance control data, and pavement composition data, and to produce processed data as figures, graphs, charts, etc.

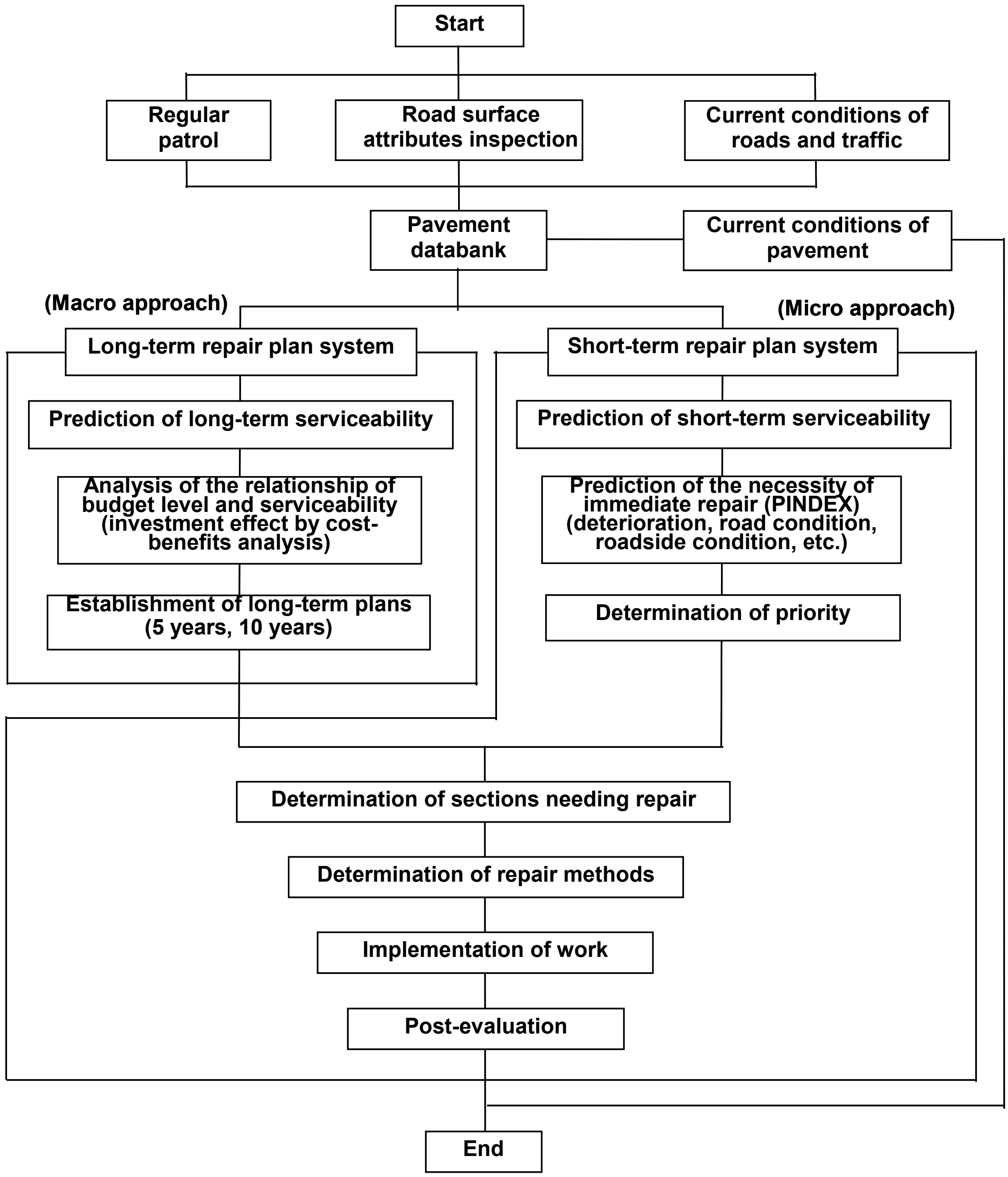

Figure 1 - Basic Flow of MLIT-PMS

The short-term repair plan system (Figure 2) is also a core model of MLIT-PMS able to make judgment about repair locations and work types, using the information from the pavement data bank. It also has a sub-system for determining priorities with which to decide repair priority sections, and a repair process-determination system.

The purpose of the system for determining repair priorities is to classify roads from 1 to 3 in terms of repair priority, with PINDEXs (priority index), which is the scored level of repair priority. This index is determined from the maintenance control index of MLIT-PMS, after being corrected with road category and roadside conditions. Score 1 indicates roads needing urgent repair, score 2 those for which repair is desirable, score 3 those not needing immediate repair.

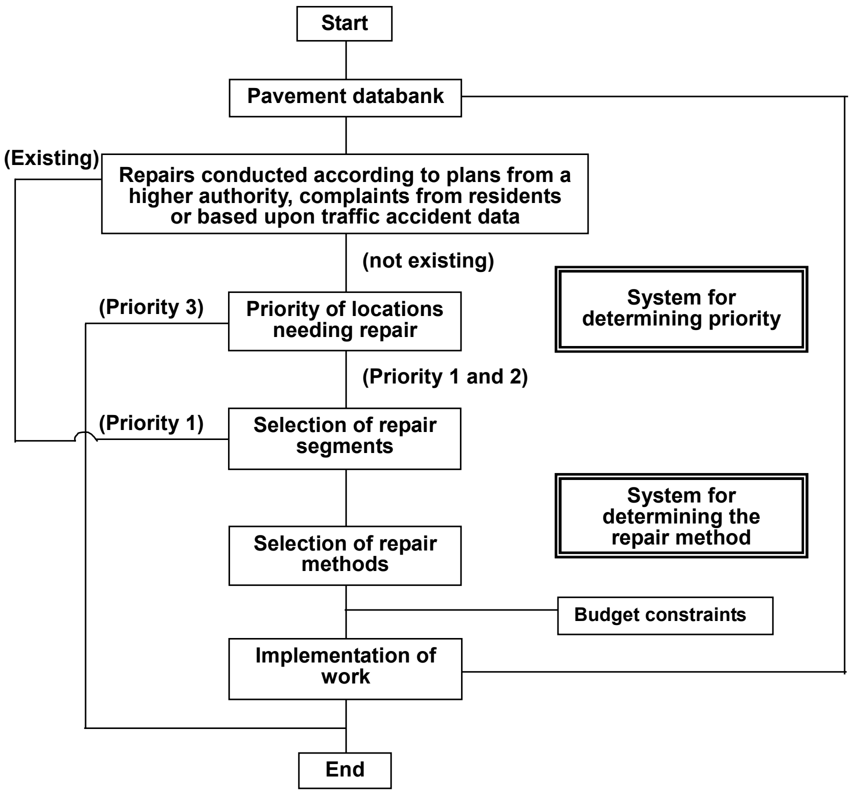

Figure 2 - Basic Flow of the MLIT-PMS's Short Term Repair Plan System

The system for determining repair priorities is designed to select the most suitable repair method for road locations that are identified to need maintenance and repair (priority scores 1 and 2).

First, road surface attributes, pavement composition, service history and traffic conditions of existing pavements are evaluated for the structure of pavement, so that the road concerned is judged to be subject to maintenance or repair.

For each of these two approaches, applicable construction methods should be set up on the agenda, based upon road surface attributes and roadside conditions, and analyzed in terms of economy and feasibility to finally select the most suitable construction method.

The MCI (Maintenance Control Index) of MLIT-PMS is given by the following expression;

$$MCI = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$$

where C : amount of cracking (%)
D : rut depth (mm)
σ : longitudinal roughness (mm)

The management criteria of MCI in actual road management are as follows;

MCI	Management level
More than 5	not needing repair (desirable management level)

3 to 5	needing repair
Less than 3	needing immediate repair

The formulas for predicting cracking and rutting are as follows;

Dense-grade asphalt concrete

Crack $C_i+1 = 0.40+1.16C_i$

Rut $D_i+1 = -0.03+1.03D_i$

Porous asphalte pavement

Crack $C_i+1 = 0.40+1.1C_i$

Rut $D_i+1 = 0.78 +0.99D_i$

where i represents the number of years in service.

These prediction equations are empirically obtained from measurements.

The long-term repair plan system (Figure 3) is provided in order to create an optimized repair plan through the systematic combination of pavement management level, MCI-measured pavement serviceability, repair cost and user benefits according to MCI, covering not only prediction of demand for repair, estimate of investment effects (macro evaluation) but also selection of repair locations, repair methods and repair timing (micro evaluation).

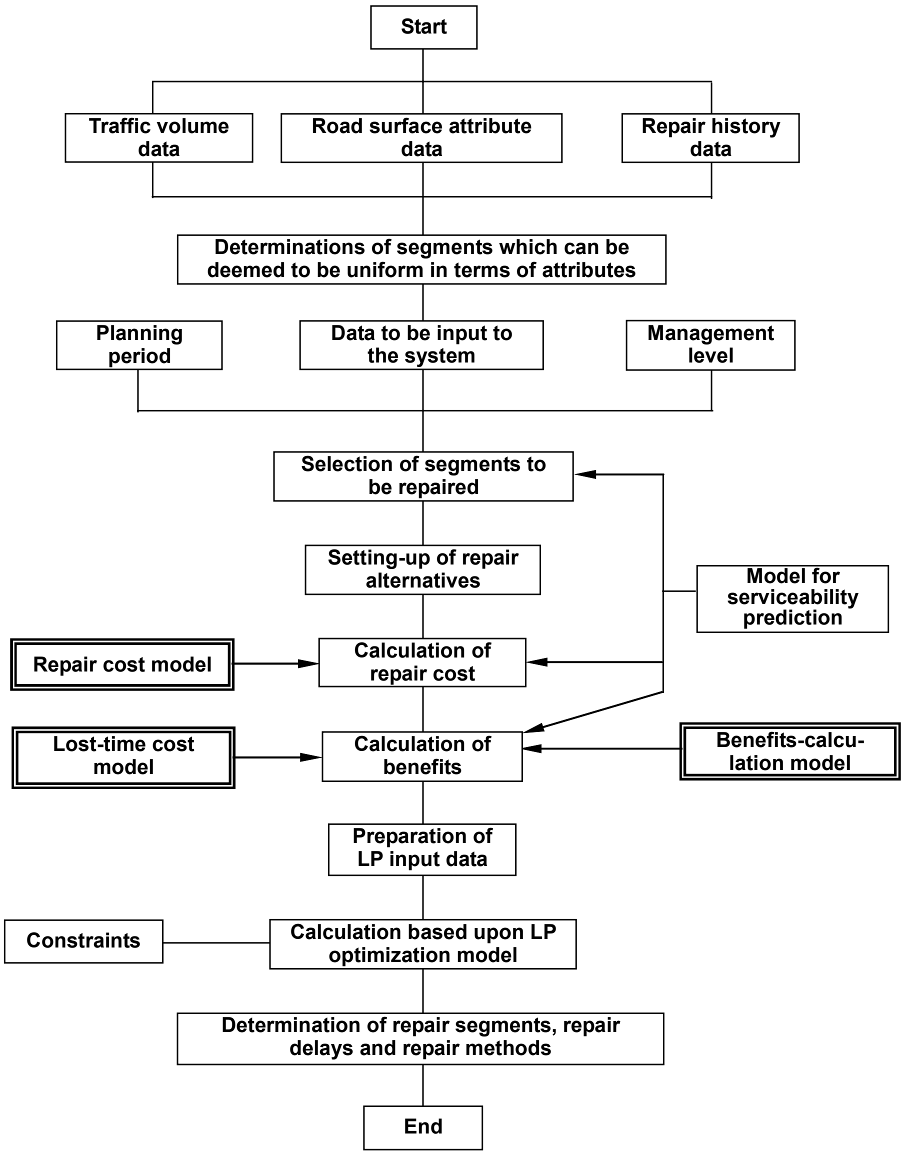

Figure 3 - Basic Flow of the MLIT-PMS's Long Term Repair Plan System

2.2 Comparison of HDM-4 and MLIT-PMS

HDM-4 is an economic evaluation tool for investment of different construction and maintenance options, while MLIT-PMS is a maintenance system for road pavements. In both systems, the items relating to road management, such as pavement short-term repair plans, middle- and long-term maintenance and repair plans and budget estimates are approximately the same. However, one remarkable difference is that HDM-4 estimates the vehicle operating cost with the index of IRI as effects of road surface attributes, while MLIT-PMS uses MCI.

Furthermore, HDM-4 can, in addition to road management, be applied to review of road development and road traffic measures that MILT-PMS does not cover.

3. CALIBRATION OF THE HDM-4 RUTTING MODEL

3.1 Preparation of calibration data

(1) Selection of segments

In this paragraph, data was collected as shown below, by setting up the conditions for data selection.

- Three segments selected should differ from each other in type, with the condition that other attributes be almost the same.
  - Segment A: dense-graded asphalt pavement with AADT of about 50,000 vehicles/day.
  - Segment B: dense-graded asphalt pavement with AADT of about 20,000 vehicles/day
  - Segment C: porous asphalt pavement (not dependant upon traffic volume)

- The three segments are 2-3 kilometers long of earthwork sections, with almost the same road width, shoulder width, composition of lanes, traffic volume, and service history (in years). For each segment, maximum rut measured is taken for calibration.

- Since HDM-4 provides an analysis period of about 10 years, this calibration also sets up ten years as service time from the construction or re-pavement.

- They need to have undergone restoration at least one time after the service commenced.

- In principle, they should be selected from road segments, which exist in the management area under the authority of the Utsunomiya National Highway Office. If there are no sections meeting the above conditions, a segment (s) belonging to other areas may be used.

AADT / Pavement type	High traffic (approx.50,000 vehicles/day)	Low traffic (approx.20,000 vehicles/day)
Dense-graded asphalt pavement	Segment A	Segment B
Porous asphalt pavement	Segment C (not dependant on traffic volume)	

(2) Selection of representative vehicles

Since road user modeling involves difficulties in determining vehicle operation cost per vehicle, it is necessary to use representative vehicle types to make it possible to consider vehicle characteristics for each of the types.

Here, taking account of the traffic composition, functions of different vehicle types, data availability, we assume that the following five types of vehicles operate on the sections.

- Light car
- Ordinary passenger car
- Medium truck
- Large-sized truck
- Large-sized bus

(4) Conditions for input data

The conditions for input data are summarized below.

1) The data used shall be that collected in the period from 1988 through 1999 for each of the routes.
2) Pavement on the road sections being studied shall have received a process of cutting-overlay.
3) Collection of traffic volume shall be made for five types of vehicles, using the road traffic census data.
4) The rutting depth shall be 30 mm as management reference. For the rutting depths exceeding the management reference, they should be subject to the process of cutting-overlay.

3.3 Results of calibration

Measurements and calculations ΔRDO, ΔRDST and ΔRDPD of ruts for each of the road sections are shown on the next page. Since Sections A and B are dense-graded asphalt pavements and Section C is a porous asphalt pavement, calibration was made for each type of pavement. By using these data, we implemented multiple regression analysis to determine the calibration coefficient K as regression parameter.

$$\Delta RDM = K_{rid}\,[a_0\,(YE4\;10^6)^{(a1\,+\,a2\,DEF)}\;SNP^{a3}\;COMP^{a4}] + K_{rst}\,(a_0\;SNP^{a1}\;YE4^{a2}\;COMP^{a3}) + K_{rpd}\,CDS^3 a_0\;YE4\;Sh^{a1}\;HS^{a2}$$

- Dense-graded asphalt pavement

K_{rid}=3.26 K_{rst}=3.11 K_{rpd}= 0.59 (R^2=0.1617)

- Porous asphalt pavement:

K_{rid}=2.96 K_{rst}=5.73 K_{rpd}= -2.5 (R^2=0.8636)

This means that when $K_{rpd}<0$, the plastic deformation rate in layer As decreases as the years of service pass. It dose not represent reality. Therefore, with an assumption of K_{rpd} =0, we obtained the following values;

K_{rid}=1.48 K_{rst}=0.83 K_{rpd}=0 (R^2=0.7273)

The calibration results for the rutting model are shown in Figure 4.

In the case of the dense-graded pavement, the rutting values were recalculated by using the determined calibration coefficient, and plotted in a graph so that they could be compared with the measurements. From this, we learn that since the RMSE (root mean square error) prior to calibration is 6.49, and 3.72 after calibration, the calculation becomes closer to the measurement.

where RMSE = $\sqrt{\sum_{i=1}^{n}\frac{(\Delta R_i - \Delta R_i')^2}{n}}$

ΔR : rut measurement
ΔR' : rut calculation
n : number of samples

With respect to the porous asphalt pavement, for which the amount of actual data available is relatively small, there is a significant disagreement between calculated rut depths and measured depths before calibration. The RMSE was 0.58 after calibration, instead of 4.23 before calibration. This demonstrates that, as with the case of dense graded pavement, the calculated values became closer to the measurements after calibration,

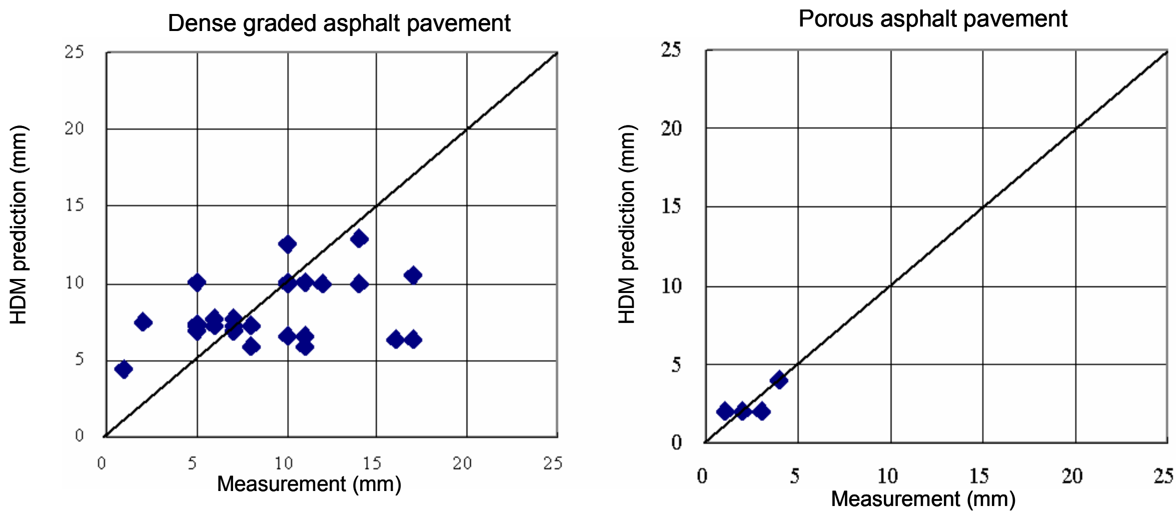

Figure 4 - Comparison between Predicted and Measured Rut Depths

4. COMPARISON OF RUT OUTPUT BETWEEN HDM-4 AND MLIT-PMS

Using the calibration coefficient determined in the previous chapter, we ran the HDM-4 model to compare the road surface attributes obtained by this model with those by the pavement management system (MLIT-PMS).

Three sections were involved in this study. The overview of the trial running of HDM-4 is as follows.

1) Study sections
- Section with high traffic and dense-graded asphalt pavement: A
- Section with low traffic and dense-graded asphalt pavement: B
- Section with porous asphalt pavement: C

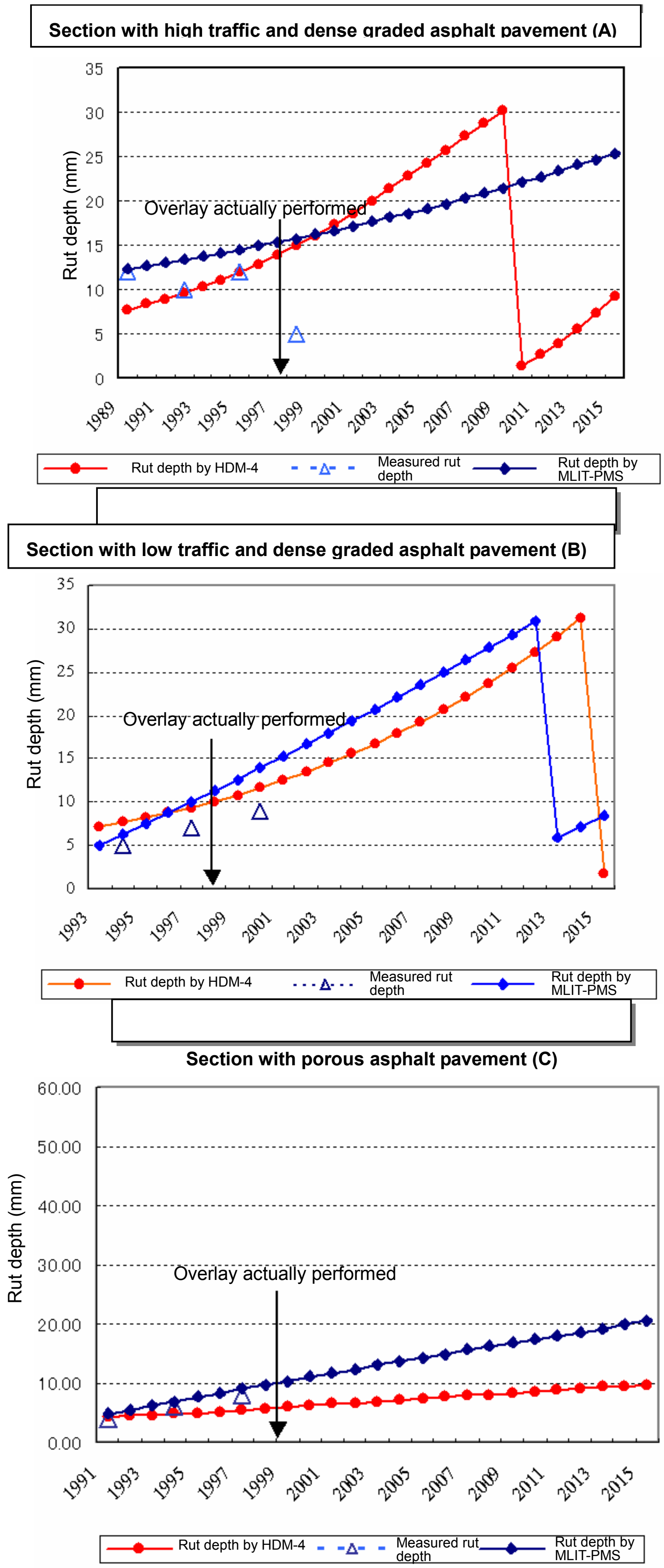

Figure 5 - Comparison of Rut Depths Using HDM-4 and MLIT-PMS

2) Damage type and management criterion
- Rutting: cutting-overlay when the rut depth exceeds 30 mm

3) Prediction period
From 2001 through 2015

4) Outputs of the model in the trial running
Representative elements of these three sub-models were output.
- Road Deterioration and Works Effects model
- Road User Effects Cost model
- Safety, Energy and Environmental effects

The calculation results of road surface attributes for each study case (section) are shown in the graphs in Figure 5. The graphs represent the calculated rut depths on all the three sections, with measured values, from the initial road construction time to the year 2015.

As illustrated by these results, the rut depths calculated by HDM-4 better coincide with the measurements, than those by MLIT-PMS. Results from both HDM-4 and MLIT-PMS generally demonstrate similar progression tendencies. However, for the time of overlay, both prediction results significantly differ from the time when overlay was actually implemented. This disagreement is due to the fact that the execution of overlay at sites is not merely based on the rut depth, but on the maintenance control index (MCI) that is an integrated index defined by cracking rate, rutting and longitudinal roughness.

5. CONCLUSIONS

This study used the internal analytical models of HDM-4 to collect necessary data on twelve road sections. In this scheme, each model was calibrated and a trial run was performed. A comparison of the results of HDM-4 and those of MLIT-PMS demonstrated that the accuracy of HDM-4 is equivalent or superior to MLIT-PMS.

The following topics should be studied in the future for effectively applying HDM-4 to Japanese roads.

- Among the pavement deterioration models, this study only calibrated the rutting model because of the limited amount of data available. It will be necessary to calibrate the models for cracking, roughness and skid resistance coefficients. In addition to flexible pavement, we must study concrete pavement and composite pavement.

- It is essential to study the applicability of HDM-4 at the network level, more specifically the applicability to formulation of multi-year repair plans, to estimation of medium- and long-term road investment budgets and road performance, and to research on road traffic policies.