ADAPTING THE HDM-4 TO EXPRESSWAYS IN JAPAN

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ABSTRACT

This paper discusses calibration of the HDM-4 models for adapting it to expressways in Japan. It focuses on a calibration analysis of the HDM-4 rut depth, road user effects and social and environmental effects models by using Japanese expressway data and automobiles, socio-economic and environmental data. After appropriate calibration, it was found that the HDM-4 models of both road user effects and social and environmental effects gave a satisfactory representation of the observed data in Japan. The rut depth model produced an acceptable result as well, but it was observed that further validation of the model was needed to improve the precision of the model prediction. Furthermore, the HDM-4 was applied to study the rut management level for repair of expressways. The optimum rut management level to minimize the lifecycle cost predicted by the HDM-4 nearly agreed with the current rut management criterion. Further study should involve application of the HDM-4 to research on the entire road network and to issues relating to road traffic policy study.

KEY WORDS

HDM-4 / PAVEMENT / ROAD USER COSTS / MAINTENANCE / LIFE CYCLE COST (LCC)

1. EXPRESSWAYS AND PAVEMENT MANAGEMENT IN JAPAN

The Japan Highway Public Corporation (JH) was established in April 1956 for the purpose of promoting highway construction and improvement and ensuring smoother traffic, by comprehensive construction, management and maintenance of toll highways including expressways through a nationwide organization on behalf of the national government. Construction of expressways spanning 11,520 km is planned in the scope of the National Development Arterial Expressway Construction Law. Expressways totaling 7,112 km in length had been opened to traffic as of January 2003 since the service start of the Meishin Expressway (71 km) in July 1963.

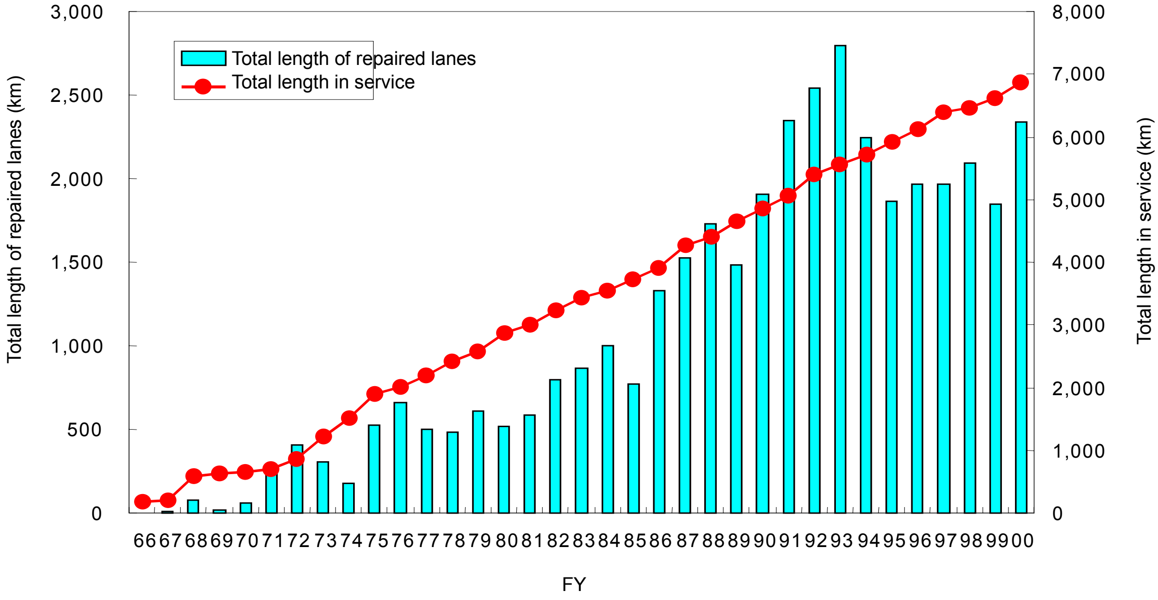

Figure 1 - Trend of length of repaired pavement

Today about 4.02 million vehicles are on the expressways per day, and the volume of cargos transported through the expressways accounts for 40% of the total cargo transport by road. As shown by these statistics, expressways are an essential element of the infrastructure vital for economic activities and daily life in Japan. However, there are approximately 900 km of expressways, which have been in use for 30 years or more, that have deteriorated, and we are now in the period requiring large-scale maintenance for ensuring traffic safety in high-speed operation and effective functions of major arterial highway network. More effective management of expressways with reduced maintenance cost has become essential for society.

Under these circumstances, the length of expressways where the aged pavement is repaired or improved increases as the total length in service increases as shown in Figure 1. The main causes for improvement were rutting due to wear or flow of asphalt mix, but recently improvement due to cracking has been increasing. This shows the effectiveness of measures taken against rutting. As a result, improvement due to cracking accounts for 40% of the total.

Taking this situation into full consideration, the JH is committed to a wide spectrum of investigations aimed at optimized life cycle relating to the pavement maintenance, including study on pavement materials and mixing (physical aspect), and road surface management techniques (intellectual aspect).

The HDM-4, which was developed by ISOHDM under the leadership of PIARC and the World Bank, is used in such investigations. It enables evaluation of the pavement surface performance and economic analysis. We verified the applicability of the HDM-4 as a PMS (pavement management system) tool for expressway pavement.

2. OUTLINE OF THE HDM-4 CALIBRATION

In the study, aimed at effective application of HDM-4 to Japanese expressways, we worked on “improvement of input data quality” and “output calibration” according to the HDM-4 calibration manual (A Guide to Calibration and Adaptation, Bennet et al, 2001).

These are the data and models to be calibrated.

- Collection of basic data (traffic volume characteristics, road alignment characteristics, composition of vehicle classes/vehicle characteristics, climatic conditions, etc.)
- Pavement deterioration/maintenance and rehabilitation model
- Road user cost model
- Traffic accidents and vehicle emission model

With respect to the vehicle class composition (one of basic data sets), we set the following eight vehicle classes by referring to the recommended vehicle classification in the HDM-4 manual and comprehensively assessing the damaging effect to pavement and road user costs, social and environmental costs, classification of vehicle types for expressway tolls, and classification of vehicle types for traffic volume prediction. It should be noted however that, considering the content of collected data, we performed calibrations based on a reduced number of vehicle types.

- Passenger car
- Small truck (gasoline)
- Small truck (diesel)
- Medium truck
- Medium bus
- Large truck
- Large bus
- Trailer

3. CALIBRATION OF THE PAVEMENT DETERIORATION MODEL

3.1. Rutting prediction model of HDM-4

The rutting prediction model of HDM-4 is composed of four parts: (1) initial densification/ consolidation after service start (RDO), (2) structural deformation including failure of base course or lower portion (ΔRDST), (3) plastic deformation of asphalt layer (ΔRDPD), and (4) wear of surface course from studded tires (ΔRDW). Since the use of studded tires is prohibited in Japan, the rutting progression model is adapted as follows (Odoki et al, 2001).

$$\Delta RDM = RDO + \Delta RDST + \Delta RDPD$$

where:

ΔRDM rutting progression in analysis year, in mm
RDO rutting due to initial densification, in mm

$$RDO = K_{rid} [a_0 (YE4\ 10^6)^{(a1 + a2\ DEF)} SNP^{a3} COMP^{a4}]$$

ΔRDST total incremental increase in structural deformation in analysis year, in mm

$$\Delta RDST = K_{rst} (a_0 SNP^{a1} YE4^{a2} COMP^{a3})$$

ΔRDPD incremental increase in plastic deformation in analysis year, in mm

$$\Delta RDPD = K_{rpd} CDS^3 a_0 YE4\ Sh^{a1} HS^{a2}$$

SNP average annual adjusted structural number of the pavement
DEF Benkelman beam deflection, in mm
COMP relative compaction, in per cent
CDS construction defects indicator for bituminous surfacing
HS total thickness of bituminous surfacing, in mm
YE4 annual number of equivalent standard axles, in millions/lane
Sh speed of heavy vehicles, in km/h
ai model parameters
Ki calibration factors

The rut progression is ΔRDM = RDO + ΔRDST for the first year after a new construction or reconstruction that involves the construction of a new base layer and ΔRDM = ΔRDST + ΔRDPD otherwise.

3.2. Sections involved in calibration

Roads and sections meeting these conditions were selected for the study. Table 1 shows the total length and number of sections selected on the basis of the following criteria.

- Earth work sections with dense-graded asphalt pavement and porous asphalt pavement
- Sections with high traffic where rutting progresses relatively significantly
- Sections not repaired, or for which the rehabilitation history is known.
- Only the outer lane is included.
- Considering climatic impact, three regions are set up: ordinary, wearing and quasi-wearing regions.
  - Wearing region: region where wear due to chains, etc. is prominent
  - Quasi-wearing region: region where both wear in winter and flow in summer exist.
  - Ordinary region: region where flow is prominent.
- The measurement interval is set at one to three years depending upon the rutting progression.

Table 1 - Sections selected for calibration of the rutting model

Pavement type	Region class	Total length (km)	Number of sections
Dense-graded asphalt	Ordinary	544.6	43
	Quasi-wearing	318.8	27
	Wearing	72.8	6
Porous asphalt[1]	Ordinary	10.4	31
	Quasi-wearing	7.9	23

Note: 1) The data collected of porous asphalt do not include those for wearing region.

3.3. Results of calibration

The HDM-4 estimation divides the rutting progression into that for the first year of service and that for the succeeding years.

The first service year rutting: $\Delta RDM = RDO + \Delta RDPD$
Subsequent annual progression: $\Delta RDM = \Delta RDST + \Delta RDPD$

Table 2 - Results of calibration of the HDM-4 rutting progression model

Pavement type	Region class	RDO Krid	RDST Krst	RDPD Krpd	Number of data sets		R
					First year	Succeeding year	
Dense-graded asphalt	Ordinary	3.21	4.78	0.44	39	166	0.94
	Quasi- wearing	3.37	14.00	-1.97	26	143	0.87
	Wearing	3.57	-0.13	18.54	9	27	0.96
Porous asphalt	Ordinary	2.63	8.76	0.03	37	84	0.65
	Quasi- wearing	3.33	16.94	0.03	25	66	0.68

Table 2 shows the calibration coefficients of the HDM-4 rutting progression model, determined by regression analysis. The graphs in Figure 2 illustrate the relationship between measured rut depth and that predicted by the HDM-4 model.

When looking at the relationship as a whole including ruts both for the first year and subsequent years, the correlation coefficient is rather high. However, when studying separately the relationship for the first year and that for the succeeding years, the correlation coefficient is rather low. We conclude from this fact that the HDM-4 rut progression model fails to satisfactorily predict the measured rut progression. Some results are meaningless, since Krpd and Krst take on negative values in the quasi-wearing and wearing regions respectively, representing that as the traffic volume increases, the rut progression due to plastic flow of asphalt layer decreases. The measured rut progression varies considerably depending upon the construction and detailed climate conditions, even with the same route, same traffic volume and same pavement structure.

4. CALIBRATION OF THE ROAD USER COST MODELS

4.1. Outline of the calibration

The calibration of the road user cost model of HDM-4 is composed of collection of input data in each model and calibration of model output. In this study, according to the calibration manual, we collected the vehicle characteristic data for each vehicle type. Using the collected data, next, we compared the results of tentative calculation by the HDM-4 model with the road user costs in Japan. Then, for the items with significant difference between calculated result and collected data, we calibrated the internal models of the HDM-4. Figure 3 shows the calibration procedures for the road user cost model. An outline of the calibration of the road user cost model is shown below.

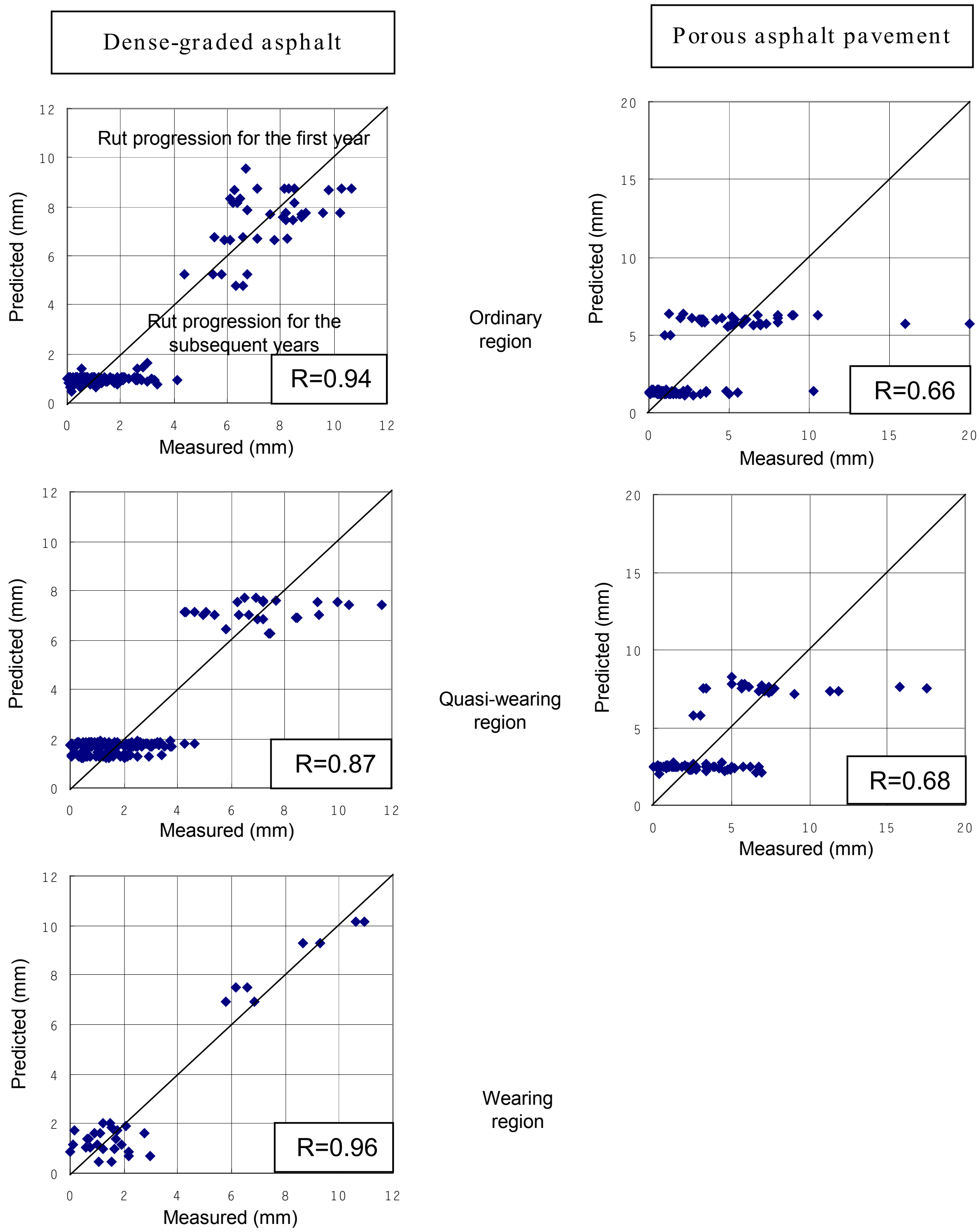

Figure 2 - Comparison between rut progression predicted by HDM-4 model and measurements

4.2. Collection of basic data

Basic data include the following.

- Physical characteristics of vehicles (vehicle dimensions, number of wheels, number of axles, passenger car space equivalents, operating weights, equivalent standard axle load factors, tire characteristics, etc.)
- Vehicle use characteristics (annual mean distance and time traveled, mean service life, passenger car ratio, average number of passengers)
- Vehicle resources (new vehicle price, tire price, fuel cost, oil cost, annual overhead, wage for vehicle crew, etc.)

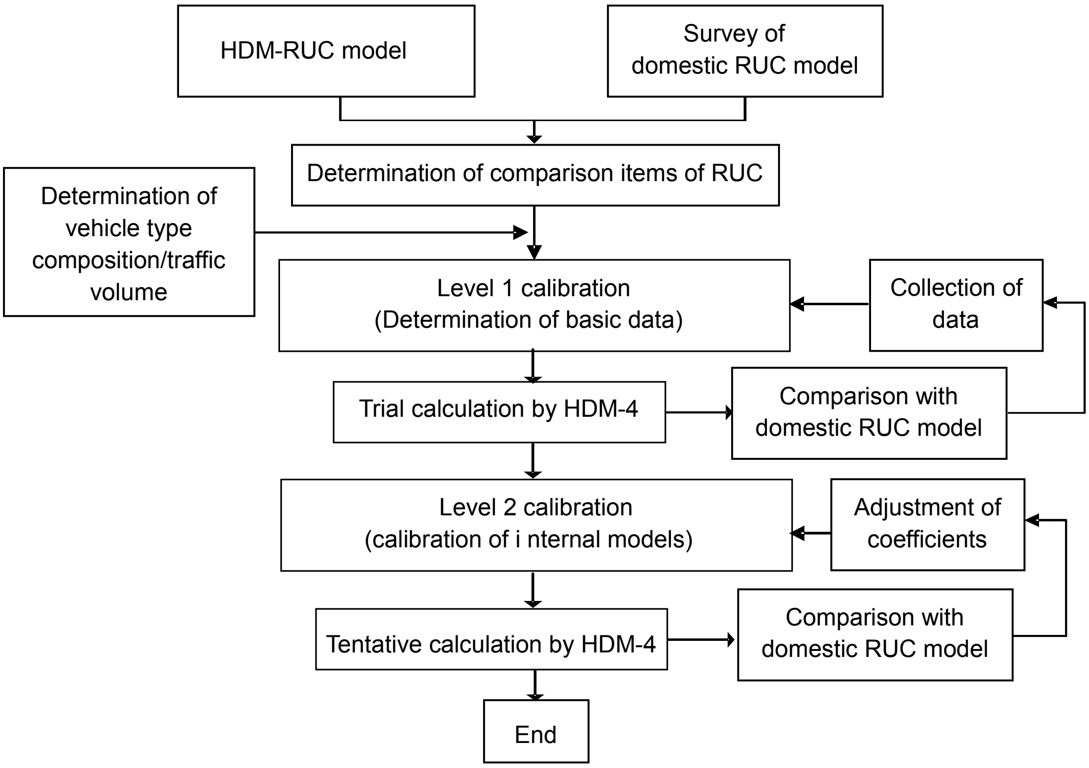

Figure 3- Flow of calibration for the road user cost model

- Time value data (time value of business passengers, time value of non-business passengers, time value of cargos, etc.)

In this study, for level 1 calibration, we collected various data mentioned above based on published materials from automobile makers, automobile-related associations, the Ministry of Infrastructure, Land and Transport, and the results of interview research.

Basic data arranged for each vehicle type are inputted into HDM-4, to make a trial calculation by HDM-4 for expressway sections 10 km long. The results thus obtained were compared with the road user costs in Japan (vehicle operating cost and travel time cost for each item). As a result of this comparison, a great difference was found for the vehicle maintenance cost of trucks and buses, and for the fuel cost of vehicles except buses. We therefore made level 2 calibration for the vehicle maintenance cost model and fuel consumption model.

4.3. Calibration of vehicle maintenance cost model

The vehicle maintenance cost model of HDM-4 is composed of the cost of vehicle parts consumption and cost for maintenance labor hours (Odoki et al, 2001).

Parts consumption:

$$PC_{kp} = K0pc * \left[CKM^{KP} * (a0 + a1 * RI_{adj}) + K1pc\right]\left(1 + CPCON_k * dFUEL_{kp}\right)$$

where

PC_{kp} parts consumption/1000veh-km, expressed as a fraction of average new vehicle price

CKM average cumulative number of kilometers driven per vehicle type (km)

KP the age exponent in parts consumption model
RI_{adj} the adjusted road roughness (IRI m/km)
$CPCON_k$ incremental change factor in parts consumption due to vehicle speed change cycles effects (default =0.10)
$dFUEL_{kp}$ additional fuel consumption factor due to vehicle speed-change cycles
a0□a1 model parameters
K0pc, K1pc calibration factors (default value K0pc =1.0, K1pc=0)

Maintenance labor hours:

$$LH_{kp} = K0lh * \left[a0 * PC_{kp}{}^{a1} \right] + K1lh$$

where
LH_{kp} number of labor hours per 1000veh-km of vehicle type k during traffic flow period p
a0□a1 model parameters
K0lh, K1lh calibration factors (default value K0lh =1.0, K1lh =0)

Since vehicle maintenance cost data of Japan is not broken down as in HDM-4, we calibrated the model so that the total of both costs of HDM-4 would agree with the domestic vehicle maintenance cost, as shown in Table 6. The calibration procedures are shown in Figure 4 and the results of calculations after calibration are listed in Table 3.

Table 3 – Calibration of the HDM-4 vehicle maintenance cost model

(yen/km-vehicle)	Passenger car	Small truck G	Small truck D	Medium truck	Large truck	Trailer	Medium bus	Large bus
Kp value	0.230	0.230	0.280	0.280	0.280	0.280	0.483	0.483
(a) HDM-4 output: maintenance (parts)	0.980	0.677	1.201	3.888	5.698	10.898	14.924	39.040
(b) HDM-4 output: maintenance (labor)	2.611	1.434	7.797	10.589	10.138	14.893	15.281	17.284
(c) Estimated maintenance cost: (a) + (b)	3.591	2.111	8.998	14.477	15.837	25.791	30.205	56.323
(d) MRI model: maintenance cost	5.940	6.690	6.690	5.560	5.560	5.560	5.760	5.760
Ratio (c)/(d)	0.605	0.316	1.345	2.604	2.848	4.639	5.244	9.778
K0PC	1.654	3.169	0.743	0.384	0.351	0.216	0.191	0.102
a1 for labor	0.547	0.547	0.519	0.519	0.519	0.519	0.517	0.517
K0LH	1.256	1.686	0.867	0.631	0.604	0.478	0.449	0.332
MRI model: maintenance cost	5.94	6.69	6.69	5.56	5.56	5.56	5.76	5.76
HDM-4: total maintenance cost	5.94	6.71	6.68	5.55	5.55	5.56	5.75	5.73
HDM-4: maintenance cost (parts consumption)	1.62	2.15	0.89	1.49	2.00	2.35	2.85	3.98
HDM-4: maintenance cost (labor hours)	4.32	4.56	5.79	4.06	3.55	3.21	2.90	1.75

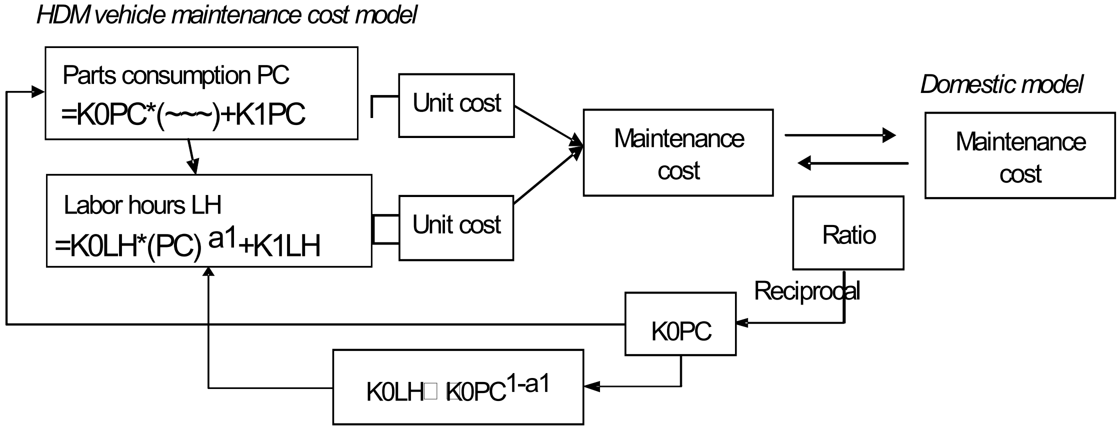

Figure 4 - Flow of calibration of the vehicle maintenance cost model

4.4. Calibration of the fuel consumption model

The HDM-4 model determines the fuel consumption by computing the instantaneous fuel consumption (IFC), that is consumption per second, as a function of the vehicle driving condition. IFC is given by the following equation. The model calibration focuses on ZETAB and EHP.

IFC = ZETAB*PTOT***Erreur !**

where

IFC instantaneous fuel consumption (ml/s)
PTOT total power requirement of the vehicle (kW)
ZETAB base fuel-to-power efficiency factor (ml/s/kW)
EHP decrease in engine efficiency when producing higher power
PRAT maximum rated power of the vehicle (kW)

The data for calibrating the fuel consumption model is shown in Figure 5. This graph is based on the regression formula obtained from actual vehicle driving data, in the scope of investigation by the Publics Works Research Institute of Japan. The values of ZETAB and EHP were estimated, according to the HDM-4 calibration manual. The values of these parameters thus determined are given in Table 4. Figure 6 illustrates a comparison between IFC based on measured data and IFC outputted by the HDM-4 model. As demonstrated by these table and figure, the correlation is high enough between measurement and HDM-4 output. We can conclude therefore the HDM-4 model simulates the actual fuel consumption satisfactorily.

Table 4 - Values of parameters calibrated in the fuel consumption model

Parameter	Passenger car	Small Truck G	Small Truck D	Medium truck	Large Truck	Trailer	Medium bus	Large bus
EHP	0.4802	1.4626	-0.1284	-0.1863	0.0262	-0.0580	-0.1044	0.4734
ZETAB	0.0406	0.0714	0.0446	0.0568	0.0677	0.0795	0.0863	0.0534
R	0.9980	0.9979	0.9866	0.9834	0.9930	0.9903	0.9847	0.9957

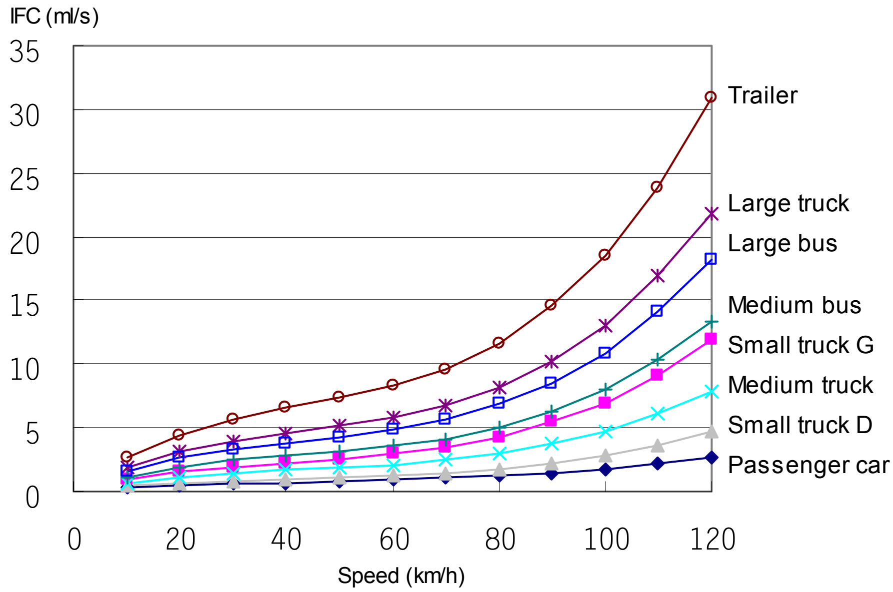

Figure 5 – Data for calibration of the HDM-4 fuel consumption model

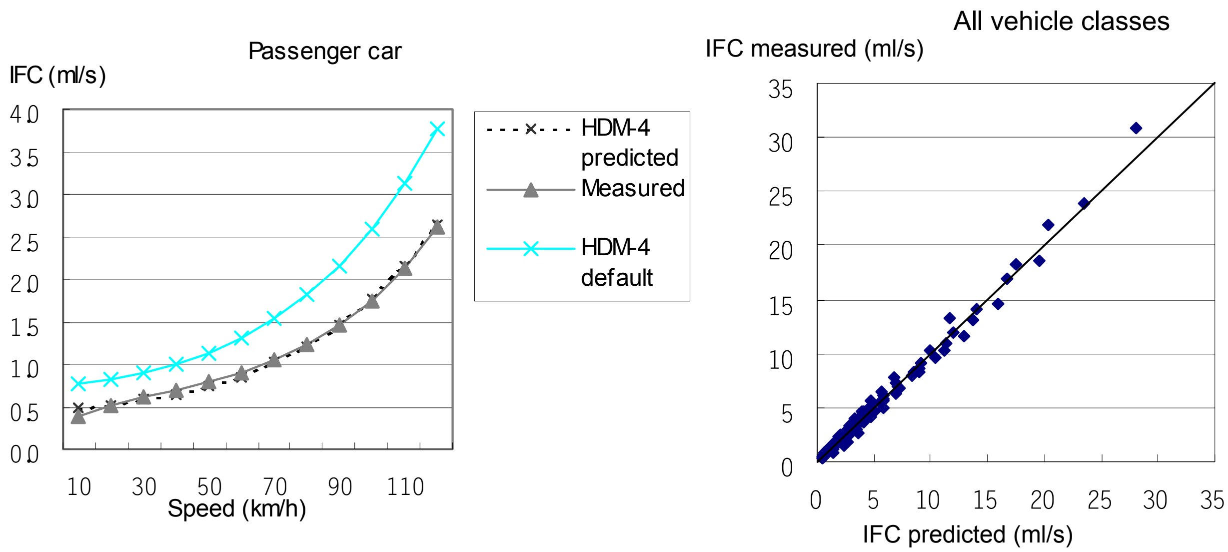

Figure 6 - Comparison of IFC between measurement and HDM-4 prediction

4.5. Summary of the calibration results

A trial run was made of the HDM-4 using all the parameters calibrated as discussed above, to calculate the road user costs (vehicle operation cost VOC and travel time cost). The results are shown in Table 5. For comparison, the road user costs (vehicle operation cost and travel time cost) given by the domestic MRI model are listed in Table 6.

Comparison between HDM-4 and MRI models in terms of the road user costs is shown in Figure 7 (vehicle operating cost) and Figure 8 (travel time cost). As seen in these figures, the results by the calibrated road user cost model of HDM-4 well agree with those by the domestic MRI model.

Table 5 - Road user costs calculated by the HDM-4 model

(yen/vehicle-km)

Detail of prediction by HDM-4		Passenger car	Small Truck G	Small truck D	Medium truck	Large truck	Trailer	Medium bus	Large Bus
Vehicle operating cost	Fuel	3.25	12.04	3.17	5.65	12.27	19.19	10.14	11.00
	Lubricants	0.33	0.78	0.97	1.06	2.14	2.39	1.32	1.77
	Tire	0.64	1.16	1.17	1.24	2.89	4.52	1.47	2.15
	Parts consumption	1.62	2.15	0.89	1.48	1.99	2.40	2.84	3.90
	Maintenance	4.33	4.57	5.80	4.03	3.52	3.25	2.90	1.72
	Depreciation	12.82	4.66	4.77	3.67	10.17	8.61	8.65	18.63
	Total	22.98	25.36	16.77	17.12	33.00	40.36	27.32	39.18
Travel time cost	Crew	0.00	0.00	0.00	0.00	0.00	0.00	20.46	21.31
	Overheads	0.00	27.49	28.17	14.57	16.05	14.06	20.36	21.20
	Business travel cost	25.61	0.00	0.00	0.00	0.00	0.00	414.69	431.98
	Non-business travel cost	20.12	0.00	0.00	0.00	0.00	0.00	138.23	143.99
	Cargo keeping	0.00	25.38	26.01	31.94	55.32	60.40	0.00	0.00
	Total	45.73	52.87	54.18	46.51	71.37	74.46	593.73	618.49
Total cost		68.71	78.23	70.95	63.64	104.37	114.82	621.05	657.67

Table 6 - Road user costs calculated by the MRI model

(yen/vehicle-km)

Vehicle type/speed	Passenger car	Small truck		Ordinary truck		Bus
Vehicle classification for HDM-4	Passenger car	Small truck G	Medium truck	Large truck	Trailer	Coach
Fuel, lubricants	3.06	3.93		8.29		11
Tire, tube	2.34	1.71		4.68		5.56
Maintenance	5.94	6.69		5.56		5.76
Depreciation	3.34	13.53		16.08		21.54
Total of vehicle operating cost	14.68	25.86	25.86	34.62	34.62	43.85
Total of travel time cost	36.5	25.6	31.9	55.3	60.2	561.0
Total cost	51.1	51.5	57.8	89.9	94.8	604.9

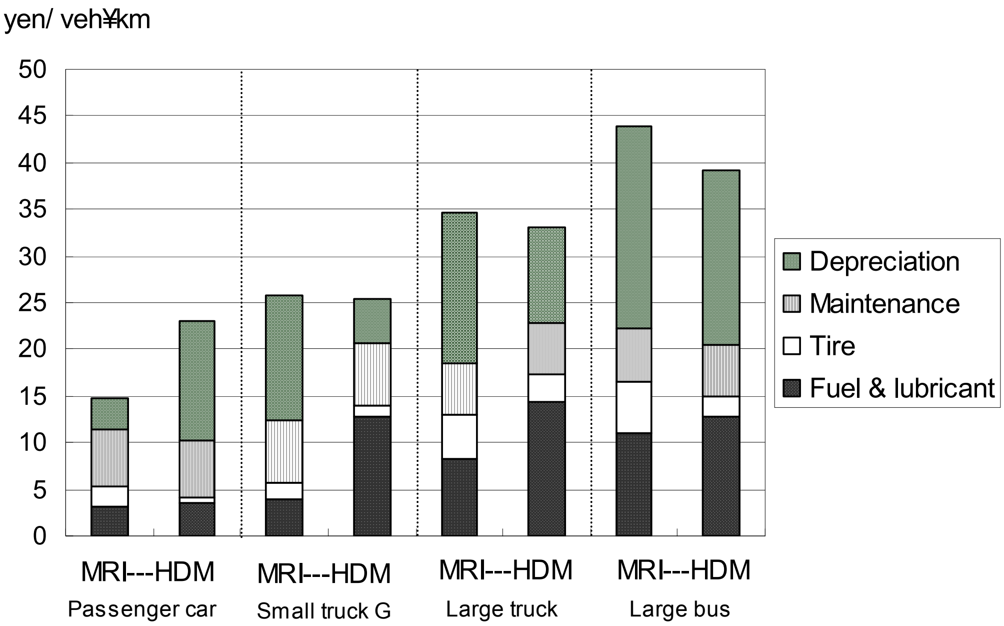

Figure 7 – Comparison between vehicle operating cost (VOC) by HDM-4 and MRI

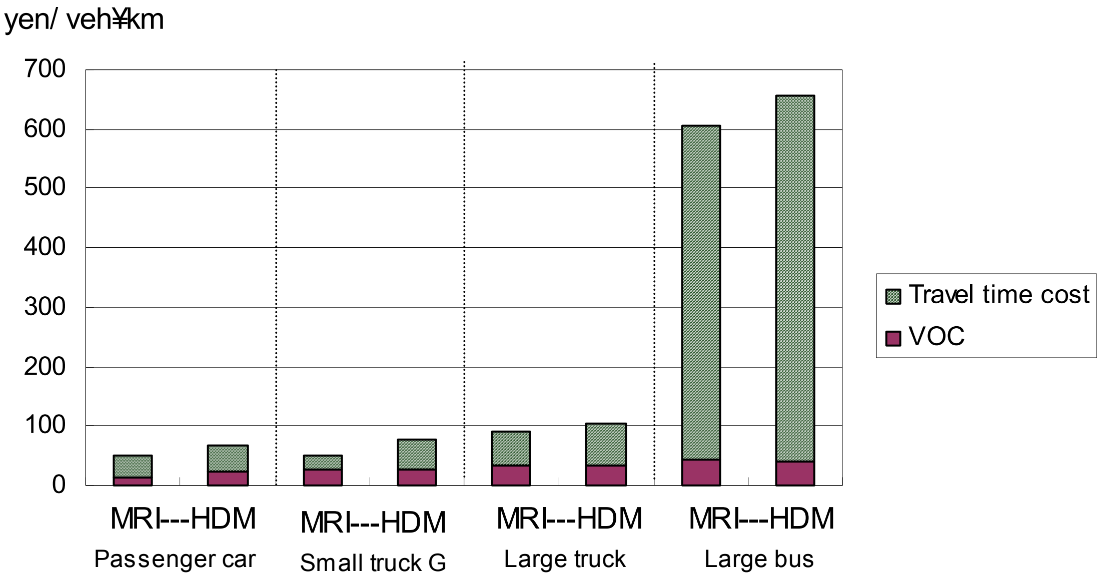

Figure 8 – Comparison between road user cost by HDM-4 and MRI

5. CALIBRATION OF THE ENVIRONMENTAL EFFECTS MODEL

The equations in HDM-4 to estimate vehicle emissions are as follows (Odoki et al, 2001). For lead (Pb), we did not calibrate the model because measured data was not available.

NOx: $E\_NOx = 3.6*Kenox0*(a0 + a1*Kenox1*IFC)*(1 + 0.5*a2*LIFE)*10^3/S$

CO: $E\_CO = 3.6*Kec0*(a0 + a1*Keco1*IFC)*(1 + 0.5*a2*LIFE)*10^3/S$

PM: $E\_PM = 3.6*Kepar0*(a0 + a1*Kepar1*IFC)*10^3/S$

SO_2: $E\_SO_2 = 3.6*Keso0*a0*a1*IFC*10^3/S$

CO_2: $E\_CO_2 = 3.6*Keco0*a0*IFC*10^3/S$

HC: $E\_HC = 3.6*Kehc0*(a0 + a1*Kehc1*IFC)*(1 + 0.5*a2*LIFE)*10^3/S$

where

E_XX	XX (CO, NOx, PM, SO_2, CO_2, HC) emissions (g/veh-km)
S	vehicle speed (km/h)
a0□a2	model parameters
Ki	calibration factors (default = 1.0)
LIFE	vehicle service life (years)
IFC	instantaneous fuel consumption (ml/s)

Using measured data from the Tokyo metropolitan government, we calibrated the model for each of the vehicle emissions by regression analysis. The results are summarized in Table 7. As an example, Figure 9 compares the measurements with the HDM-4 prediction of the CO_2 amounts for large trucks and those for all vehicle classes as a whole. The correlation coefficient is high, 0.8 or more in most cases. In some cases, however, it is low partly because the curve given by the HDM-4 is convex downward and the curve of measurement is convex upward in some cases.

Table 7 - Result of calibration of the vehicle emission model

Emission	Coef.	Passenger car	Small truck G	Small truck D	Medium truck	Large truck	Trailer	Medium bus	Large bus
NOx	Kenox0	0.055	-0.010	-0.100	0.229	-0.546	-0.037	-0.584	-2.015
	Kenox1	2.203	-8.991	-1.540	0.796	-0.647	-6.307	-1.375	-0.386
	R	1.00	0.99	0.99	0.99	0.95	0.95	0.92	0.89
CO	Kec0	0.197	0.006	-0.012	0.145	0.137	-0.362	0.135	-0.154
	Kec1	0.592	3.982	-4.051	7.138	2.324	-3.867	5.518	-4.635
	R	0.66	0.77	0.79	0.79	0.98	0.98	0.96	0.95
PM	Kepar0	-5.380	3.947	1.521	0.153	-0.012	0.034	-0.034	1.228
	Kepar1	-3.103	0.767	3.730	2.940	-37.564	30.893	-30.775	0.794
	R	0.88	0.48	0.52	0.53	0.88	0.88	0.84	0.81
SO_2	Keso0	1.464	4.365	3.835	2.274	1.783	1.287	4.240	2.807
	R	0.99	0.99	0.96	0.96	0.97	0.97	0.95	0.98
CO_2	Keco0	1.114	0.387	0.977	0.580	0.370	0.267	0.864	0.571
	R	0.99	0.99	0.97	0.96	0.98	0.97	0.95	0.98
HC	Kenox0	0.026	-0.053	0.080	-0.040	0.093	-0.071	0.104	0.097
	Kenox1	1.534	0.007	-94.085	182.801	18.328	0.028	1.430	-27.055
	R	0.99	0.99	1.00	0.99	1.00	0.99	0.99	1.00

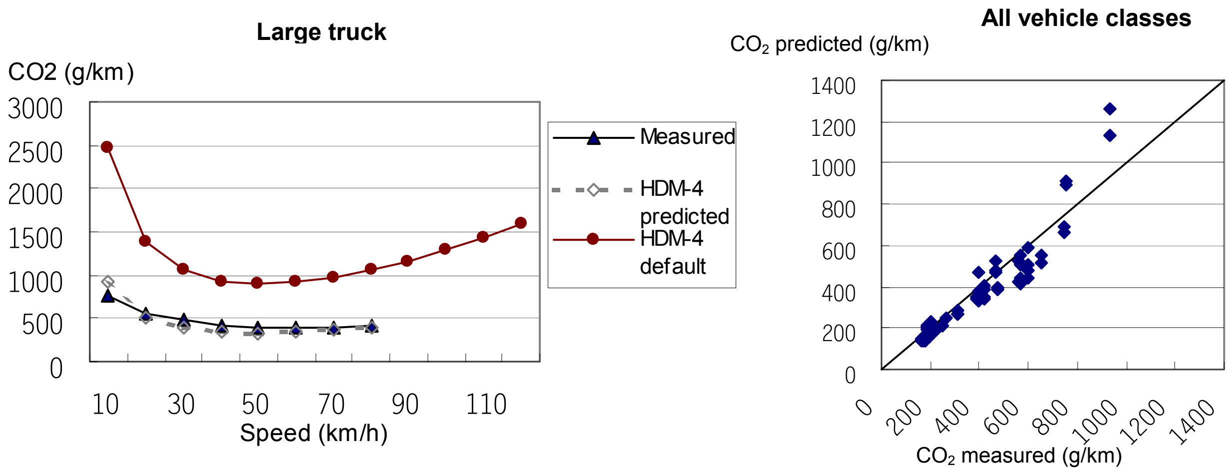

Figure 9 - Result of calibration of the vehicle emission model (CO_2)

6. ESTIMATION OF RUT MANAGEMENT LEVEL BY HDM-4

By changing the rut management level (rut depth) for repair by the use of the HDM-4 model, we calculated the total social cost integrating the road administrator cost and road user cost, to estimate the optimal rut management level such that the total social cost is minimized.

6.1. Overview

We can calculate the social cost (road work cost and road user cost) of each model by running the HDM-4. In the pavement deterioration model, cutting-overlay is implemented when the rut depth exceeds the management level. By changing this rut management level that determines the timing of rehabilitation, it is possible to know how the social cost changes accordingly.

This study considered a section between Katsunuma IC and Ichinomiya-misaka IC of the Chuo Expressway (the westbound outer lane, 2.0 km long between 92.1 - 94.1kp (kilometer post)). Changing the rut management level for cutting-overlay at intervals of 5 mm from 10 to 35 mm, we calculated the social cost (road administrator cost and road user cost) for each value of management level. Other conditions involved are discount rate of 4%, 40 mm thick surface layer of asphalt pavement, and analysis period of 40 years after service start (from 1982 to 2021).

6.2. Procedures

For project analysis of the HDM-4, we prepared six rut rehabilitation alternatives for the section, as shown in Table 8. In addition, we set up a base case where only routine maintenance is done and ruts are not repaired. The alternatives were evaluated by comparison with the base case.

Table 8 - Alternatives and unit cost for rehabilitation works

Rut depth as management level (mm)	10	15	20	25	30	35
Cutting-overlay thickness (mm)	40	40	40	40	40	40
Unit cost (yen/m^2)	2300	2300	2300	2300	2300	2300

6.3. Calculation results

Table 9 and Figure 10 show the results of a preliminary calculation by the HDM-4.

Now we compare the net present value (NPV) (net benefit) due to the rehabilitation work for each case. The net benefit of the base case being 0.0, the maximum net benefit of 844 million yen is obtained with the rut management level of 15 mm from the viewpoint of maximizing the NPV, followed by 839 million yen with 20 mm. Compared with the case of the rut management level of 10 mm, a difference of about 25 million yen is expected with 15 mm, and of 160 million yen with 35 mm.

By minimizing the total social cost including road user cost and road administrator cost, it takes on the lowest value with the rut management level of 15 mm (11.01 billion yen), followed by 20 mm (11.02 billion yen) and 10 mm (11.04 billion yen).

Based on the two evaluation criteria mentioned above, the optimum rut management level for rut rehabilitation is 15 to 20 mm. However, it should be noted that the current version 1.30 of HDM-4 does not consider cost for congestion due to rehabilitation work (The future version 2.0 will probably consider it). In the analysis period, the repair is made nine times with Rut10mm, and four times with Rut15mm. The loss cost due to congestion would be therefore significant. If the congestion from repair work were integrated in the framework of analysis, the road user cost of alternatives accompanying frequent repair would become larger. This suggests that the optimum rut management level would be 20 to 25 mm, which will agree with the current rut management criterion in JH.

Table 9 - Comparison of alternatives in terms of cost

(Ichinomiya-misaka IC - Katsunuma IC: westbound 92.1 - 94.1kp, outer lane, analysis period: 40 years)

Computation items (in million yen, based on the price in 2000)	No repair	Rut10	Rut15	Rut20	Rut25	Rut30	Rut35
(value converted to price in 2000)	Ref. case	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Road administrator cost: RAC	0.0	74.0	37.6	22.7	14.7	12.0	7.3
Increase in road administrator cost: C	0.0	74.0	37.6	22.7	14.7	12.0	7.3
Road user cost: RUC	11,857	10,964	10,976	10,997	11,036	11,106	11,167
Social cost: *RAC + RUC*	*11,857*	*11,038*	*11,014*	*11,020*	*11,051*	*11,118*	*11,174*
Benefit due to reduction in RUC: B	0.0	893	882	861	822	752	691
Other benefits: E	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net present value: □*NPV*□*B+E-C*□	*0.0*	*819*	*844*	*839*	*807*	*740*	*683*
(Reference) B/C	0.0	12.1	23.5	38.0	56.1	62.5	95.1
(Reference) NPV/RAC	0.0	11.1	22.5	37.0	55.1	61.5	94.1

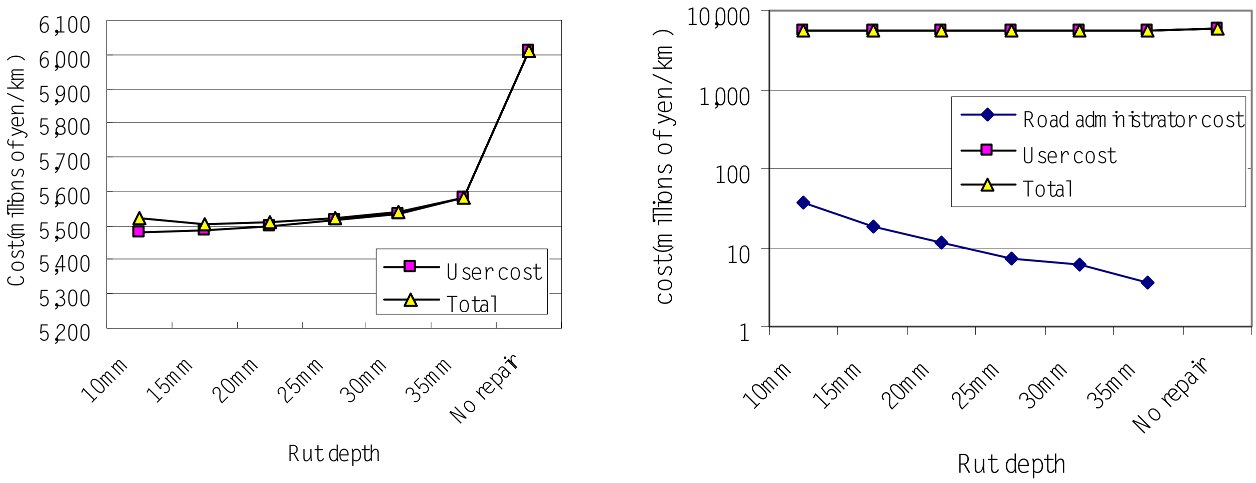

Figure 10 - Comparison of alternatives in terms of cost

7. CONCLUSION

This paper discusses calibration of the HDM-4 models for adapting it to expressways in Japan. It focuses on a calibration analysis of the HDM-4 rut depth, road user effects and social and environmental effects models by using Japanese expressway data and automobiles, socio-economic and environmental data. After appropriate calibration, it was found that the HDM-4 models of both road user effects and social and environmental effects gave a satisfactory representation of the observed data in Japan. The rut depth model produced an acceptable result as well, but it was observed that further validation of the model was needed to improve the precision of the model prediction. Furthermore, the HDM-4 was applied to study the rut management level (rut depth limit) for rehabilitation of expressways. The optimum rut management level to minimize the lifecycle cost predicted by the model nearly agreed with the current rut management criterion in JH.

A future study subject should be calibration of the HDM-4 models for damages other than rutting, such as cracking, and for other types of pavement including composite and concrete pavement. Other topics should be application of the HDM-4 to research on the entire road network and study on issues relating to road traffic policy.

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