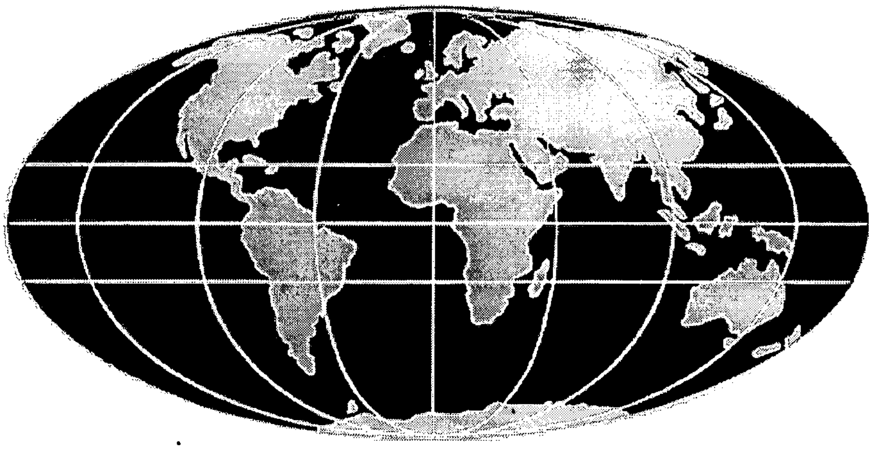
TRANSPORT RESEARCH LABORATORY

DFID Department For International Development

TITLE: Roughness Progressions and Appropriate Maintenance Strategies for Inter-Urban Roads in Indonesia

by: G Morosiuk, A B Sterling and S Mahmud



Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

PA3506/99

PA3506/99 MOROSIUK, G, A STERLING and S MAHMUD (1999). **Roughness progressions and appropriate maintenance strategies for inter-urban roads in Indonesia**. *XXI st World Road Congress, PIARC, Kuala Lumpur, Malaysia, 3 - 9 October 1999.*

ROUGHNESS PROGRESSIONS AND APPROPRIATE MAINTENANCE STRATEGIES FOR INTER-URBAN ROADS IN INDONESIA

by

G Morosiuk, A B Sterling and S Mahmud

1. INTRODUCTION

The accurate prediction of the rates of deterioration of roads is important in scheduling appropriate maintenance activities in road management systems. The Integrated Road Management Systems (IRMSs) project currently being undertaken by the Directorate General of Highways (Bina Marga) is attempting to integrate the various road management systems in use in Indonesia (N D Lea International Ltd, 1997). One of the objectives of the project is to standardise on the road deterioration relationships used in the IRMSs.

The performance of sections of road in Indonesia have been monitored over the past ten years as part of a co-operative research programme between the Transport Research Laboratory (TRL), UK and the Institute of Road Engineering (IRE) in Indonesia. One of the outcomes of one of the TRL/IRE highway engineering projects was the derivation of appropriate calibration factors for Indonesian conditions (Morosiuk and Toole, 1998) for use with the road deterioration relationships in the World Bank's HDM-III model (Watanatada et al, 1987).

This paper reviews the roughness calibration factors derived in the TRL/IRE study and examines the economic implications of using appropriate roughness calibration factors in HDM-III in predicting the deterioration of roads and their effect in determining maintenance strategies. The potential benefits from using appropriate maintenance strategies based on realistic predictions of roughness progressions are also detailed.

HDM-III was used to conduct the economic analysis in this study because HDM-4 is currently being developed and therefore was not available. However, the roughness progression relationship in HDM-4 is fundamentally the same as that in HDM-III and therefore the roughness calibration factors derived in this study are applicable to the HDM-4 model.

The research programme contributed to DFID's aims of increasing the efficiency of national and regional transport systems through better targeting of scarce resources, thus allowing the potential benefits to accrue to wider sections of the community.

2. ROUGHNESS CALIBRATION FACTORS FOR INTER-URBAN ROADS IN INDONESIA

In the TRL/IRE study, twenty five sections of inter-urban road were monitored over a 10-year period. The roughness progressions observed on these sections of road were compared with those predicted by the roughness relationships based on the HDM-III model (Paterson and Attoh-Okine, 1992). The predictive roughness relationships used in the comparison are reproduced below.

For applications in which data or predictions of rutting, cracking and patching are available the recommended model, referred to in this study as the detailed model, is as follows:

Detailed Model

$$RI_t = 0.98\, e^{Kgm\, m\, t}\, RI_o + K_{gp}\, \{0.98\, e^{Kgm\, m\, t}\, [135(SNCK)^{-5}\, NE_t] + 0.143\, RDS_t + 0.0068\, CRX_t + 0.056\, PAT_t\} \qquad \ldots (1)$$

When a general model is required without knowledge of the surface distress, an alternative relationship for predicting roughness, which is referred to as the aggregate model in this study, is proposed as follows:

Aggregate Model

$$RI_t = 1.04\, e^{Kgm\, m\, t}\, \{RI_o + K_{gp}\, 263(1 + SNC)^{-5}\, NE_t\} \qquad \ldots (2)$$

where

RI_t = roughness at pavement age t (m/km IRI)
RI_o = initial roughness (m/km IRI)
t = pavement age since rehabilitation or construction (years)
m = environmental coefficient
NE_t = cumulative esa at age t (millions esa/lane)
$SNCK$ = $1 + SNC - 0.00004(HS)(CRX_t)$ for $(HS)(CRX_t) < 10{,}000$
SNC = modified structural number
HS = thickness of bound layers (mm)
CRX_t = area of indexed cracking at time t (%)
RDS_t = standard deviation of rut depths at time t (mm)
PAT_t = area of patching at time t (%)
K_{gm} = calibration factor for environmental coefficient
K_{gp} = calibration factor for roughness progression

The value of the environmental coefficient 'm' was set to 0.023 and the initial roughness, RI_o, was set to 1.7 IRI in the analysis. Two calibration factors are used to calibrate the roughness progression models. One factor, K_{gm}, is associated with the environmental coefficient, m, and the other factor, K_{gp}, with the remaining terms. In HDM-III the default values of K_{gm} and K_{gp} are 1.0. The average values of the two calibration factors derived from this study, for roads categorised by construction quality, terrain and traffic volumes, are given in Table 1.

Table 1
Average roughness calibration factors by construction quality and traffic

Construction Quality	Traffic (MESA)		Detailed Model		Aggregate Model	
			Kgm	Kgp	Kgm	Kgp
Well constructed roads with average to good asphalt surfacings in flat to rolling terrain and free flowing traffic conditions	Heavy	> 0.75	1.3	0.9	1.3	1.0
	Light - Medium	< 0.75	2.4	1.2	2.6	1.2
Poorly designed/constructed roads, exhibiting failures due to poor road widening and reinstatement prior to overlay, in flat to rolling terrain and free flow traffic conditions	Heavy	> 0.75	1.3	1.1	5.3	1.0
	Light - Medium	< 0.75	1.0	1.2	5.5	1.4
Well constructed roads in mountainous regions with poor asphalt surfacings	All	All	7.0	1.5	7.0	1.5

The figures in Table 1 indicate that the values of K_{gp} are similar for both models and remain relatively constant for all situations. However, the values of K_{gm} cover a much wider range. The values of K_{gm} and K_{gp} for well constructed roads in flat or rolling terrain, surfaced with well designed asphalt mixes and carrying heavy traffic, are approximately 1.0 for both the detailed and aggregate models. This indicates that both models are capable of accurately predicting roughness on these roads without the need for further calibration. When similar roads carry light to medium traffic, the value of K_{gm} increases to approximately 2.5 for both models, indicating that the uncalibrated models under-predict the rate of roughness progression. This suggests that traffic effects may be over-represented in the models, and/or the difference in construction quality between roads carrying heavy and light traffic may be less significant in Indonesia than in the data set from which the model was derived.

On poorly designed or badly constructed roads, the development of roughness tends to be through the growth of specific defects such as cracking, rutting and patching. The detailed model was successful at using the extent of these defects to predict the rate of roughness progression. Hence K_{gm} in the detailed model was close to unity for both heavy and light trafficked roads. However, the value of K_{gm} for the aggregate model had to be increased approximately five fold to compensate for the lack of distress terms.

For roads in mountainous terrain, data were only available for roads with poor asphalt surfacings. The distresses observed on these roads were either plastic deformation or early and very severe cracking. As a result of these distresses, one of the major sources of roughness was the development of transverse corrugations. The detailed model does not include this phenomenon amongst its distress variables, resulting in the model severely under-predicting the rate of roughness progression. Similarly the aggregate model also severely under-predicted the rate of roughness progression. The values of K_{gm} and K_{gp} were 7.0 and 1.5 respectively for both the detailed and aggregate models.

3. ECONOMIC CONSEQUENCES OF APPLYING APPROPRIATE CALIBRATION FACTORS

The monitoring sections used in this study were located on inter-urban roads and therefore the roughness calibration factors listed in Table 1 are applicable for these types of road. The inter-urban road management system (IRMS) employed by Bina Marga uses the aggregate model to predict the progression of roughness. Hence, this investigation centred on the factors derived for the aggregate model.

The HDM-III model was used in this analysis. HDM-III generates a number of economic indicators. The net present value (NPV), defined as the discounted benefits minus the discounted costs over the analysis period, was used as the economic indicator in this investigation. A discount rate of 15 per cent was used for a 25-year analysis period.

Four notional roads were used in the analysis. A flat, straight road at sea level represented roads in flat/rolling terrain. A hilly road, at an altitude of 1500 m with rise and fall of 60 m/km and curvature of 200°/km, typified Indonesia's mountainous roads. The roughness calibration factors derived in this study indicated that construction quality had an important effect on roughness progression. These two types of road were therefore sub-divided into 'good' and 'poor' levels of construction, and labelled as FG (flat/good), FP (flat/poor), HG (hilly/good) and HP (hilly/poor).

The thickness of the bituminous surfacing of all the roads was set at 125 mm with a subgrade CBR of 5 and a structural number of 3.3. The initial roughness of the roads at the start of the analysis period was set at 2 IRI and rainfall was taken to be 200 mm/month.

Five traffic levels were used, AADT's of 1000, 2500, 5000, 10,000 and 20,000, with a growth rate of five per cent per annum. These traffic levels classified by vehicle type are given in Table 2 together with other detailed data used in this analysis. All costs are quoted in US dollars. The vehicle characteristics and optional vehicle parameters listed in were obtained from the IRMSs study (N D Lea International Ltd, 1997).

Table 2

Traffic composition and vehicle characteristics

		Vehicle Type						
		Cars	**Pick-ups**	**Buses**	**Light Trucks**	**Medium Trucks**	**Heavy Trucks**	**Artic Trucks**
AADT	**1000**	400	500	25	23	25	25	2
	2500	1000	1250	63	56	63	63	5
	5000	2000	2500	125	112	125	125	13
	10,000	4000	5000	250	225	250	250	25
	20,000	8000	10000	500	450	500	500	50
GVW		1.3	2.6	8.0	6.0	13.0	27.0	35.0
Equivalence Factor		0	0.1	0.5	0.25	2.5	7.0	9.0
Service life		10	10	10	10	12	12	12
Hours driven per year		600	1500	3000	1500	2000	2000	2000
Km driven per year		15000	30000	100000	40000	50000	50000	50000
Vehicle price		16000	16000	50000	20000	30000	40000	50000
Tyre price		25	30	130	75	130	130	200
Labour costs		1.5	1.5	1.5	1.5	1.5	1.5	1.5
Crew costs		0	1.5	1.7	1.7	1.7	1.7	1.7
Passenger time		2.5	2.5	2.5	2.5	2.5	2.5	2.5
Petrol / Diesel		0.18	0.18	0.18	0.18	0.18	0.18	0.18
Oil		2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table 3

Optional vehicle parameters

Vehicle parameter	Cars	Pick-ups	Buses	Light Trucks	Medium Trucks	Heavy Trucks	Artic Trucks
Payload (tons)	0.2	0.8	3.5	4.9	7.8	17.8	15.0
Aerodynamic drag coefficient	0.45	0.46	0.65	0.7	0.85	0.85	0.63
Projected frontal area	1.8	2.72	6.3	3.25	5.2	5.2	5.75
Driving power (metric HP)	40	43	104	74	109	116	210
Braking power (metric HP)	22	38	160	131	205	250	500
Desired speed (km/h)	95	90	85	85	85	8.5	85
Energy efficiency factor	0.9	0.9	0.9	0.9	0.9	0.9	1.0
Hourly utilisation ratio		0.45	0.65	0.45	0.45	0.45	0.45
Calibrated engine speed	3500	3300	2300	2600	1800	1800	1700
Fuel adjustment factor	1.16	1.16	1.15	1.15	1.15	1.15	1.15
FRATIO0	0.268	0.221	0.233	0.253	0.292	0.292	0.179
FRATIO1				0.128	0.094	0.094	0.023
Recap cost ratio			40	40	40	40	40
Tyre rubber volume (cu dm)			6.85	4.35	7.6	7.3	7.3
Base number of retreads			1.5	1.5	1.5	1.5	1.5
Spare parts C0SP1	23	39	1.34	7.5	3.8	3.9	13.94
Spare parts CSPQ1	6.1	6.1	6.1	25	25	25	15.65
Spare parts QI0SP	17	17	17				
Labour hours C0LH	46.6	77.1	293.4	180.0	242.0	301.0	652.5
Labour hours CLHPC	0.547	0.547	0.517	0.519	0.519	0.519	0.519

The HDM-III model was run with the roughness calibration factors K_{gm} and K_{gp} adjusted to the values for the aggregate model listed in Table 1. In this study no roughness calibration factors were derived for hilly roads in good condition. For these HG roads, the calibration factors for the flat roads in good condition were used in the HDM-III analysis. The calibration factors for light/medium traffic were used for AADT's of 1000, 2500 and 5000; the factors for heavy traffic were used for AADT's of 10,000 and 20,000.

Twelve alternative responsive maintenance policies were used. Each included patching of potholes and the policies required overlays of 30, 40 or 50 mm at roughness intervention levels of 4, 5, 6 or 7 IRI. The costs of these maintenance activities used in the HDM-III analysis are given in Table 4. The base scenario, against which each of these strategies was compared, was routine maintenance which included only patching of potholes.

Table 4

Maintenance operation costs

	Patching per sq m	30 mm Overlay per sq m	40 mm Overlay per sq m	50 mm Overlay per sq m	Routine per km per year
Financial	10	5	6	7	1500
Economic	8	4	4.8	5.6	1275

The NPV for each of the twelve maintenance policies compared with the base scenario was derived for 100 km of each of the four types of road and five levels of traffic. These NPV's relate to realistic rates of roughness progression observed on inter-urban roads in Indonesia and are referred to as the 'timely' NPV's in this paper, indicating the NPV's that would be generated by HDM-III for a range of responsive maintenance strategies that were performed, without delay, once the intervention levels of IRI were reached.

The length of the national and provincial roads in Indonesia is approximately 50,000 km. No reliable data were available on the horizontal and vertical alignment of these roads. It was estimated that 70 per cent of these roads were in flat/rolling terrain and 30 per cent were in mountainous terrain. It was further estimated that there was an even split between 'good' and 'poor' roads in the flat/rolling terrain (ie. 35% in each category) and that most of the mountainous roads were in a poor condition (25% poor, 5% good). The proportions of these four categories of road were further sub-divided by the five traffic levels. The percentages of road for each traffic level are listed in Table 5.

Table 5

Proportions of inter-urban roads classified by condition and traffic levels

Road Condition	AADT					Total
	1000	2500	5000	10,000	20,000	
Flat – Good	5%	10%	10%	5%	5%	35%
Flat – Poor	5%	10%	10%	5%	5%	35%
Hilly – Good	1%	1%	1%	1%	1%	5%
Hilly – Poor	10%	5%	5%	3%	2%	25%

These percentages were then used to derive the 'timely' NPV's for an average 100 km of inter-urban roads in Indonesia for each of the twelve maintenance policies. These NPV's are presented in Table 6.

The figures in Table 6 indicate that delaying maintenance to a higher roughness level reduces the NPV's. The magnitudes of the reductions in NPV's per 100 km by delaying maintenance from an intervention level of 4 IRI to 5, 6 or 7 IRI are given in Table 7 in both absolute and percentage terms.

Table 6

NPV's for timely maintenance

Overlay thickness (mm)	NPV (millions US$ per 100 km)			
	Roughness intervention level			
	4 IRI	5 IRI	6 IRI	7 IRI
30	44.60	38.73	33.03	26.78
40	46.43	41.89	36.99	32.06
50	47.05	43.35	38.74	34.32

Table 7

Loss in NPV due to delayed maintenance from 4 IRI

Overlay thickness (mm)	NPV (millions US$ per 100 km)					
	Roughness intervention level					
	5 IRI		6 IRI		7 IRI	
	NPV	%	NPV	%	NPV	%
30	5.87	13.2	11.57	25.9	17.82	39.9
40	4.54	9.8	9.44	20.3	14.37	31.0
50	3.70	7.9	8.31	17.7	12.73	27.1

The figures in Table 6 and Table 7 show that it is far more effective to provide an overlay at a roughness intervention level of 4 IRI than at 5, 6 or 7 IRI. This is true whether the overlay is 30, 40 or 50 mm thick.

One of the most common maintenance strategies on inter-urban roads in Indonesia is a 30 mm overlay applied when roughness reaches 4 IRI. The figures in Table 7 indicate that there is a loss in NPV of US$5.87 million per 100 km of road in delaying this maintenance policy until roughness reaches 5 IRI. Therefore for the 50,000 km of inter-urban road there is a potential loss in benefits of approximately US$3 billion over a 25-year period. Similarly, the potential loss in benefits rises to approximately US$9 billion by delaying a 30 mm overlay until roughness reaches 7 IRI.

Maintenance activities are usually limited by lack of funds. It is, therefore, important to note that it is more effective to use a 30 mm overlay at an intervention level of 4 IRI than a thicker overlay at a higher roughness level.

The predicted scheduling of the maintenance activities over the 25-year analysis period have been summarised in Table 8 for the four notional roads and five traffic levels. The timing of the first overlay for a particular road and traffic level will be the same irrespective of the thickness of the overlay. The timing of subsequent overlays however will be dependent on the overlay thickness. As the same roughness calibration factors have been used for the FG and HG roads, the maintenance schedule for these two types of road are identical.

Table 8

HDM-III predicted scheduling of maintenance activities

Type of Road	Traffic Level (AADT)	Overlay Thickness (mm)	Roughness Intervention Levels							
			4 IRI		5 IRI		6 IRI		7 IRI	
			Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays
FG & HG	1000	30	11	5	13	4.5	16	3.5	17	3.5
		40		7		7		6		7
		50		9		9		8		9
	2500	30	10	5.5	13	4	14	4	16	3.5
		40		8		6		7		7
		50		9		8		9		9
	5000	30	9	5	12	3.25	13	3.75	15	3
		40		7.5		6		6		5
		50		9		7		8		7
	10,000	30	11	6	13	5.5	15	5	17	4
		40		8		8		8		8
		50		9		10		10		10
	20,000	30	9	5	10	5	12	4.25	13	4
		40		7.5		7.5		7		7
		50		8		9		9		9
FP	1000	30	6	2.75	7	2.5	9	2	10	1.75
		40		4		4		3.75		3.5
		50		5		5		5		5
	2500	30	6	2.5	7	2.25	9	2	10	1.75
		40		4		4		3.5		3.5
		50		5		5		4.75		4.75
	5000	30	5	3	7	2	8	2	9	1.75
		40		4		3.75		3.75		3.75
		50		5		5		5		5
	10,000	30	5	3	7	2.25	8	2	9	1.75
		40		4		3.75		3.75		3.75
		50		5		5		5		5
	20,000	30	5	2.5	6	2.25	7	2	8	1.75
		40		4		4		3.75		3.5
		50		5		5		4.75		4.75
HP	1000	30	5	2	6	1.75	7	1.5	8	1.5
		40		3		3		3		3
		50		4		4		4		4
	2500	30	5	2	6	1.75	7	1.5	8	1.25
		40		3		3		3		3
		50		4		4		4		4
	5000	30	4	2	6	1.75	7	1.5	8	1.25
		40		3.25		3		3		3
		50		4		4		4		3.75
	10,000	30	4	2	5	1.75	6	1.5	7	1.5
		40		3		3		3		3
		50		4		4		4		3.75
	20,000	30	4	2	5	1.5	6	1.5	6	1.25
		40		3		3		2.75		3
		50		4		3.5		3.5		3.75

The figures in Table 8 indicate the consequences of delaying maintenance to a higher roughness intervention level in terms of time. The delays in time to the first overlay being scheduled by delaying maintenance from an intervention level of 4 IRI to 5, 6 or 7 IRI are summarised in Table 9.

Table 9

Time delay in postponing maintenance activities from 4 IRI

Type of road	Traffic Level (AADT)	Time delay (years) Roughness intervention level 5 IRI	6 IRI	7 IRI
FG & HG	1000	2	5	6
	2500	3	4	6
	5000	3	4	6
	10,000	2	4	6
	20,000	1	3	4
FP	1000	1	3	4
	2500	1	3	4
	5000	2	3	4
	10,000	2	3	4
	20,000	1	2	3
HP	1000	1	2	3
	2500	1	2	3
	5000	2	3	4
	10,000	1	2	3
	20,000	1	2	2

In reality, maintenance is frequently not performed on time. The most common reason is budget constraints. HDM can be extremely useful to assist in budget preparation by:

- estimating the years in which maintenance treatments are likely be required
- calculating the cost of delaying maintenance, as an argument in support of the budget request.

However, it is essential that HDM is calibrated for the country/environment/roads in which it is to be used. If HDM-III is used with the roughness calibration factors K_{gm} & K_{gp} set to the default value of 1.0, the predicted maintenance schedule over the 25-year analysis period is as given in Table 10 for the various traffic and roughness intervention levels. The difference in road geometry between the 'flat' and 'hilly' roads did not affect these predicted maintenance schedules.

Comparing the figures in Table 8 and Table 10 clearly shows the difference in maintenance schedules that would be estimated over a 25-year period using an appropriately calibrated HDM-III model (Table 8) and an uncalibrated model (Table 10). For example, on a road with an AADT of 5000, the uncalibrated HDM-III model would estimate an overlay at a roughness intervention level of 4 IRI would be required after 14 years. However, using appropriate roughness calibration factors, HDM-III predicts that at a roughness intervention level of 4 IRI, an overlay would be required after 9 years for well constructed roads and after 4 or 5 years for poorly constructed roads.

Table 10

HDM-III predicted maintenance activities (K_{gm} & K_{gp} = 1.0)

Traffic Level (AADT)	Overlay Thickness (mm)	Roughness Intervention Levels							
		4 IRI		5 IRI		6 IRI		7 IRI	
		Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays	Year of 1st overlay	Years between overlays
1000	30	18	-	24	-	No overlay		No overlay	
	40		-		-	No overlay		No overlay	
	50		-		-	No overlay		No overlay	
2500	30	15	9	20	-	25	-	No overlay	
	40		-		-		-	No overlay	
	50		-		-		-	No overlay	
5000	30	14	7	17	7	20	-	23	-
	40		9		-		-		-
	50		9		-		-		-
10,000	30	11	7	14	6	16	6	18	6
	40		9		8		9		-
	50		10		10		-		-
20,000	30	9	6	11	5	12	5	14	4.5
	40		8		7.5		8		8
	50		9		9		10		9

Note: the symbol '-' indicates that no further overlays were scheduled during the 25-year period

4. SUMMARY

HDM-III roughness calibration factors, appropriate for inter-urban roads in Indonesia, were derived and used in the model to predict roughness progressions over a 25-year analysis period. HDM-III runs were conducted for roads in flat and mountainous terrain, in good and poor condition, for a range of traffic levels using maintenance strategies of overlays of 30, 40 and 50 mm at roughness intervention levels of 4, 5, 6 and 7 IRI.

The NPV's generated by HDM-III for these maintenance strategies compared with a base scenario of routine maintenance were examined. These 'timely' NPV's indicated that it is more cost effective to provide an overlay at a roughness intervention level of 4 IRI than at 5, 6 or 7 IRI, irrespective of the overlay thicknesses that were examined.

A common maintenance policy in Indonesia is a 30 mm overlay applied when roughness reaches 4 m/km IRI. This study indicated that the potential benefits that could be gained by applying this maintenance policy rather than delaying maintenance to a roughness intervention level of 5 IRI was approximately US$3 billion over a 25-year period for the 50,000 km of inter-urban road in Indonesia. The potential loss in benefits was shown to rise to approximately US$9 billion over 25 years by delaying this maintenance policy until roughness reached 7 IRI.

The importance of using appropriate calibration factors in HDM-III to set maintenance schedules was illustrated in this paper. For example, the uncalibrated HDM-III model predicted that an overlay at a roughness intervention level of 4 IRI would be required after 14 years, whereas an appropriately calibrated model predicted an overlay would be required after 9 years on well constructed roads and after 4 or 5 years on poorly constructed roads.

5. ACKNOWLEDGEMENTS

The work described in this paper was carried under a co-operative research programme between the Institute of Road Engineering in Indonesia and the Transport Research Laboratory of the United Kingdom, funded by the World Bank and the Department for International Development, UK.

The work described forms part of TRL's research programme (Programme Director: Mr T Toole) carried out on behalf of the Department for International Development. Any views expressed are not necessarily those of the World Bank, the Department for International Development, the Directorate General of Highways (Bina Marga), or the Institute of Road Engineering.

6. REFERENCES

MOROSIUK G and T TOOLE (1998). Road deterioration modelling of bituminous pavements in Indonesia - interim report. TRL Unpublished Project Report PR/ORC/131/98. Transport Research Laboratory, Crowthorne, Berks, UK.

N D LEA INTERNATIONAL LTD (1997). Revised Road User Cost Model Manual - Working Paper, 11th September 1997. Integrated Road Management Systems (IRMSs). Directorate General of Highways, Jakarta, Indonesia.

PATERSON W D O and B ATTOH-OKINE (1992). Summary Models of Paved Road Deterioration Based on HDM-III. Transportation Research Record 1344, pp 99-105, TRB, National Research Council, Washington, DC.

WATANATADA T, C G HARRAL, W D O PATERSON, A M DHARESHWAR, A BHANDARI and K TSUNOKAWA (1987). The Highway Design and Maintenance Standards Model. Volume 1, Description of the HDM-III Model. The International Bank for Reconstruction and Development, Washington, DC, USA.

KEYWORDS

INDONESIA, MAINTENANCE, HIGHWAY DESIGN, MATHEMATICAL MODEL, RESURFACING, FLEXIBLE PAVEMENT, ECONOMICS OF TRANSPORT, DEVELOPING COUNTRIES,IBRD,