# Road Condition and Maintenance Inputs for Feasibility Studies in Developing Countries

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Guidelines for determining expected road routine and periodic maintenance costs and predicting pavement condition over time are presented. This input is necessary for the economic evaluation of road construction and rehabilitation projects. The developed guidelines, which are presented in the context of a recent project application in Southeast Asia (Rural Infrastructure Fund Project), have direct application in the economic analysis of internationally funded investment projects in developing countries. Proposed techniques and procedures have been adopted from the ones accepted worldwide by international organizations and also according to the authors' experience in the field. One of the objectives was to obtain simple procedures, sensitive to the fast-track nature of road feasibility studies. These guidelines were developed and successfully applied in a project of infrastructure evaluation in the Philippines, sponsored by the United States Agency for International Development.

Road feasibility studies require the forecasting of roadway pavement conditions over time for both the "do" and "do-nothing" alternatives. Pavement condition and, in particular, roughness will determine (together with other factors, such as speed, alignment, cross-section, and traffic) vehicle operating costs (VOCs) (*1,2*). The savings in VOCs between the do and do-nothing alternatives constitute the traffic benefits brought by a project (consumer-surplus approach).

In many instances, roughness, which is a good predictor of pavement condition and has a demonstrated and published relationship with VOCs (*3*), is not measured in the field during fast-track road feasibility studies. More expedient subjective pavement condition surveys are carried out. This paper suggests guidelines for the correlation of roughness and subjective measures of pavement condition by means of a recent application in Southeast Asia [Rural Infrastructure Fund (RIF) Project].

Second to traffic benefits, the other main source of benefits produced by road improvement projects (of all-weather roads) is maintenance savings. Also by means of the RIF example, this paper provides guidelines on how to estimate roadway routine and periodic maintenance costs.

The suggested methodology is simple, quick, and conceptually sound and is particularly appropriate for the economic analysis of road feasibility projects in developing countries.

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## PAVEMENT DETERIORATION CURVES

### Roughness as Indicator of Pavement Condition

Pavement deterioration curves estimate future values of an index related to pavement condition, such as a pavement condition index or roughness, as a function of current values of that index and time or accumulated axle loads.

The authors recommended roughness as the primary indicator of pavement condition because

- Several internationally accepted studies have demonstrated the high degree of correlation between pavement condition [both user defined as per AASHTO (*4*) and distress defined as per United States Army Corps of Engineers' PAVER (*5*)] and roughness.
- There are readily available models for roughness progression prediction that are applicable in the Philippines.
- Roughness relates directly to vehicle operating costs and estimation of project benefits.

Estimates of road roughness with and without the proposed projects over the analysis period are required to estimate cost savings. The authors have projected roughness progression by means of appropriate roughness progression (pavement deterioration) curves for asphalt, concrete, and unpaved roads that are presented in the following sections. A later section presents the authors' estimate of the correlation between pavement conditions (subjective estimation) with roughness levels.

### Asphalt Roads

Because of the recent development, extensive data base, and transferability among developing countries, roughness progression curves derived by the World Bank in its *Highway Design and Maintenance Standards Model* (HDM-III) (*3*) has been selected by the authors.

The World Bank's HDM-III aggregate roughness progression model was developed mainly with data from a United Nations Development Project (UNDP)-funded transportation study in Brazil. The model is based on a relationship between initial roughness, modified structural number, cumulative traffic [in terms of equivalent standard axle loads (ESALs)] and the age of the pavement since construction or last overlay. The relationship is as follows:

$$Rt = [R1 + 725 (1 + SN^1)^{-4.99} * N1] * e^{(0.0153t)} \quad (1)$$

where

- $Rt$ = roughness at time ($t$) in international roughness index (IRI) m/km,
- $R1$ = initial roughness in IRI m/km
- $SN^1$ = modified structural number = $0.0394 * n \sum_{i=1} a_i * H_i + SNSG$
- $N1$ = cumulative standard axles carried since construction or last overlay,
- $t$ = age of pavement (years) since construction or last overlay,
- $a_i$ = strength coefficient of the $i$th layer (from AASHTO guidelines),
- $H_i$ = thickness of the $i$th layer, provided that the sum of thickness ($H_i$) is not greater than 700 mm (mm),
- $n$ = number of pavement layers, and
- $SNSG$ = modified structural number contribution of the subgrade, given by $3.51 \log_{10} CBR - 0.85 (\log_{10} CBR)^2 - 1.43$ where $CBR$ is the California bearing ratio of the subgrade at in situ conditions of moisture and density (percent).

### *Effect of Seal Coats on Roughness*

Following guidelines presented previously (*6*), the authors assumed that a seal coat does not reduce roughness. This is understandable because the coat is a thin layer that follows the contour of the existing pavement. Indeed, if the seal coat is applied badly, roughness may increase.

### *Effect of Overlays on Roughness*

It is useful to know the effect of an asphalt concrete (AC) overlay on road roughness so that the benefit of the overlay may be quantitatively assessed.

Research continuing from the Brazil-UNDP study has related the roughness after overlay to the roughness of the road before overlay as follows:

$$QIA = 19 + (QIB - 19)/(0.602 * H + 1) \quad (2)$$

where

- $QIA$ = predicted roughness after overlay (quarter-car index counts per km),
- $QIB$ = roughness immediately before overlay,
- $H$ = thickness of the overlay,
- $A$ = after the overlay, and
- $B$ = before the overlay.

Note that $QI$ counts/km = 66 mm/km Transportation and Road Research Laboratory (TRRL) roughness units, and 13 $QI$ counts/km = 1 m/km IRI.

Also, an overlay changes a pavement's modified structural number (e.g., the one used in Equation 1) as follows:

$$SN^1A = 0.9 * SN^1B + a_k * D_k \quad (3)$$

where $a_k$ is the overlay strength coefficient and $D_k$ is the overlay thickness in inches.

## Portland Cement Concrete Pavements

The authors suggested the use of the HDM-III roughness deterioration model for paved roads as the model for portland cement concrete (PCC) pavement deterioration. A large structural number has been given to the PCC so that the increase in roughness over the life of the road is very small, as would be expected for a well-constructed, well-maintained road. Initial values of roughness for a newly constructed PCC pavement have been estimated and are presented later.

Using a modified structural number of 5 in the HDM-III model yields an increase in roughness from 2.0 m/km to 3.0 m/km over a 20-year period and the passing of 2.5 million ESALs. This increase corresponds to a condition rating bordering good/fair. If a modified structural number of 15 is used, the roughness increases to 2.72 m/km. Little change occurs in the incremental roughness predicted for modified structural numbers greater than 8. For a modified structural number of 15, the roughness after 40 years is 3.70. This value is considered only fair/poor, whereas, considering good construction and good maintenance practices, one would expect the condition to be in the good/fair zone, (i.e., having an IRI value of 3.0 m/km).

Adapting the HDM-III model for bituminous-paved roads to concrete roads does not entirely fit the expected behavior of concrete. However, the model does allow the comparison of concrete roads with bituminous-surfaced roads; the evaluation will be somewhat biased toward bituminous surfaces since the method appears to overestimate the rate of roughness increase for concrete roads. A modified structural number of 8 has been used for concrete pavements in the analysis of RIF projects.

## Unpaved Roads

### *Routine Grading*

The purpose of routine grading is to improve surface roughness and minimize the loss of gravel material. It is reasonable to base the frequency of grading on the criteria of limiting roughness. If grading is not carried out, the road condition will become very bad within a short period, even for a traffic level of 100 vehicles per day. With such rapid changes in road roughness, it is not appropriate to determine annual roughness values as it is determined for paved roads. It is, however, viable to approximate average annual roughness values, assuming good maintenance, and this has been done in the RIF study.

Annual average roughness increases between regraveling activities despite the grading interventions. This increase is caused by the gradual loss of gravel, which results in a weaker structure and increased subgrade deformation under traffic.

*Regraveling Requirements*

The model adopted by the RIF study for determining regraveling requirements was developed by TRRL (*7*) in the Kenya Maintenance Study for Unpaved Roads. The model relates gravel loss to traffic, rainfall, gravel type, and average gradient as follows:

$$GL_A = f[T_A^2/(T_A^2 + 50)] (4.2 + 0.092T_A + 3.5 R_L^2 + 1.88VC) \quad (4)$$

where

$GL_A$ = annual gravel loss (mm);
$T_A$ = annual traffic (thousands) in both directions;
$R_L$ = annual rainfall (m);
$VC$ = average percentage gradient; and
$f$ = constant: 0.94 for lathyritic gravel, 1.51 for quartzitic gravel, 0.96 for volcanic gravel, and 1.38 for sandstone gravel.

Volcanic gravel is the predominant type of soil found in the Philippines, and a value of $f$ of 0.96 for calculating gravel loss has been assumed accordingly.

*Roughness Progression Between Regravelings*

Variations in gravel road roughness throughout the year are considerable, and only an average annual roughness can be assumed. The annual increase in average roughness is linked to gravel loss. It is assumed that between regravelings the roughness increases as follows:

$$R_t = R_{(t-1)} + 2 \times \frac{GL_A}{100} \quad (5)$$

where

$R_t$ = average roughness for year $t$ (m/km),
$R_{t-1}$ = average roughness for year $t - 1$ (m/km), and
$GL_A$ = annual gravel loss (mm).

## ROUGHNESS AND PAVEMENT CONDITION

Described in this section are the procedures used during the pavement condition surveys and the relationship between pavement condition and roughness.

### Pavement Condition Surveys

The authors recommended a subjective evaluation of the current road condition of all project roads. This subjective estimation was made by project pavement engineers. The survey team was provided with appropriate guidelines and training (to achieve consistency in ratings) to perform the requested road condition evaluation. Given the short time frame for the reconnaissance survey, a three-category rating scheme was used. A description of each category follows:

- Good: Paved roads substantially free of defects, requiring only routine maintenance; unpaved roads needing only routine grading and spot repairs.
- Fair: Paved roads having significant defects, requiring resurfacing or strengthening; unpaved roads needing reshaping or resurfacing (regraveling) and spot repair of drainage.
- Bad: Paved roads with extensive defects, requiring immediate rehabilitation or reconstruction; unpaved roads that need reconstruction and major drainage works.

### Pavement Condition/Roughness Relationships

To translate subjective pavement condition measures from the reconnaissance surveys into pavement roughness in IRI, the authors used previously published relationships (*3,6,9*). A comparison of benchmark roughnesses given in those reports and a point estimation technique were the methods used.

The subjective condition rating data were converted into a numerical scale so that an appropriate comparison of the condition rating categories with published roughness benchmarks could be performed. A point estimation technique exercise (see Figures 1 through 3), in which all pavement raters participated, was applied for the conversion of the subjective category scales used during the field survey on a scale of 0 to 10 (*8*).

The correlation between IRI and pavement condition was derived by a comparison of benchmark roughnesses (e.g., new asphalt, new surface treatment, and new gravel). Since most of the project roads are presently in fair or bad condition, with roughness values generally well over 4 m/km, it is not sufficient to compare pavement condition with measured roughnesses only on new paved roads.

The relationship between pavement condition and roughness at the rougher end of the scale depends on varying and subjective conceptions of pavement condition and failure. For example, the roughness of fair gravel surfaces depends on many factors (such as type of material, its maximum grain size and grading, the time of year, the level of maintenance, the time since the last blading, etc.), and there is no direct way to fix an accurate benchmark for this condition. It is here that the point estimation technique has been useful.

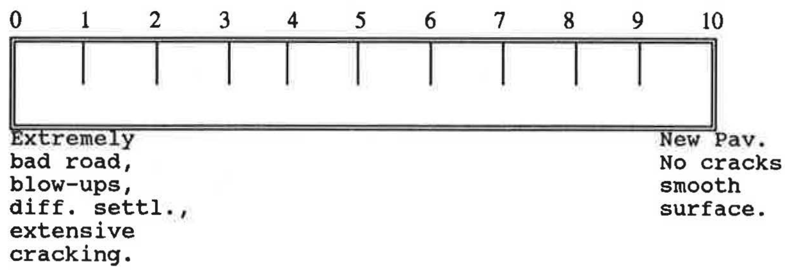
Figure 4 shows the benchmark roughnesses established in the National Roads Improvement Project (*9*) (NRIP) and those in the RFS III study (*10*), measured in in./km, for various surface types and conditions. These benchmarks were compared with the benchmarks established in the World Bank's Brazil study, expressed in IRI. DPWH's pavement condition benchmarks, together with a correlation with roughness values, are presented in Table 1.

The authors estimated the relationships between pavement condition and roughness levels (Tables 2 and 3) based on the relationships presented and the discussion above.

The roughness values assumed for the good, fair, and bad categories for each pavement type in Table 3 fall within the benchmark ranges in Figure 4. Also, the roughness values assumed for failed gravel and earth roads fall within the range of the World Bank's Brazil roughness research data (*3*, Chapter 3, Tables 3 and 4). Values presented in Tables 2 and 3 have been used for pavement deterioration forecasts and for the calculation of vehicle operating costs.

Could you please place an "X" in the following scale at the points that best represent the subjective estimates of pavement condition described below?

PCC ROADS




GOOD: Smooth surface, minor cracking, pavement in good condition, allowing running speeds at design speed.

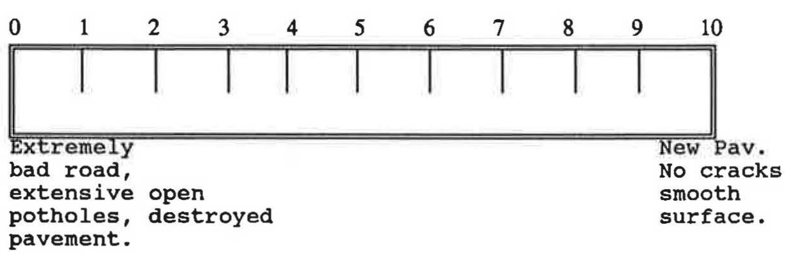
FAIR: Some cracking and joint damage, vehicle running speeds close to design speed.

BAD: Vehicle running speeds are constrained by poor pavement condition. Pavement has failed and is in need of immediate rehabilitation/reconstruction.

**FIGURE 1 Point estimation technique questionnaire: PCC pavements.**

Could you please place an "X" in the following scale at the points that best represent the subjective estimates of pavement condition described below?

ASPHALT AND OTHER BITUMINOUS PAVEMENTS:




GOOD: Smooth surface, minor cracking, pavement in good condition, allowing running speeds at design speed. No potholes.

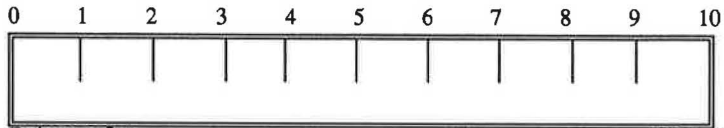
FAIR: Some cracking, vehicle running speeds close to design speed. Few minor open potholes.

BAD: Vehicle running speeds are constrained by poor pavement condition. Pavement has failed and is in need of immediate rehabilitation/reconstruction. Numerous open potholes and surface has disappeared in some sections.

**FIGURE 2 Point estimation technique questionnaire: asphalt pavements.**

Could you please place an "X" in the following scale at the points that best represent the subjective estimates of pavement condition described below?

GRAVEL ROADS




Extremely bad road, impassable trail.

New Pav. with smooth surface.

GOOD: Smooth surface; surface condition allows running speeds at design speed.

FAIR: Tangent speeds of 30 to 50 km/h; surface somewhat rough.

BAD: Road in very poor condition. Uneven surface reduces operating speed to less than 30 and sometimes to only 10 km/h.

**FIGURE 3 Point estimation technique questionnaire: unpaved roads.**

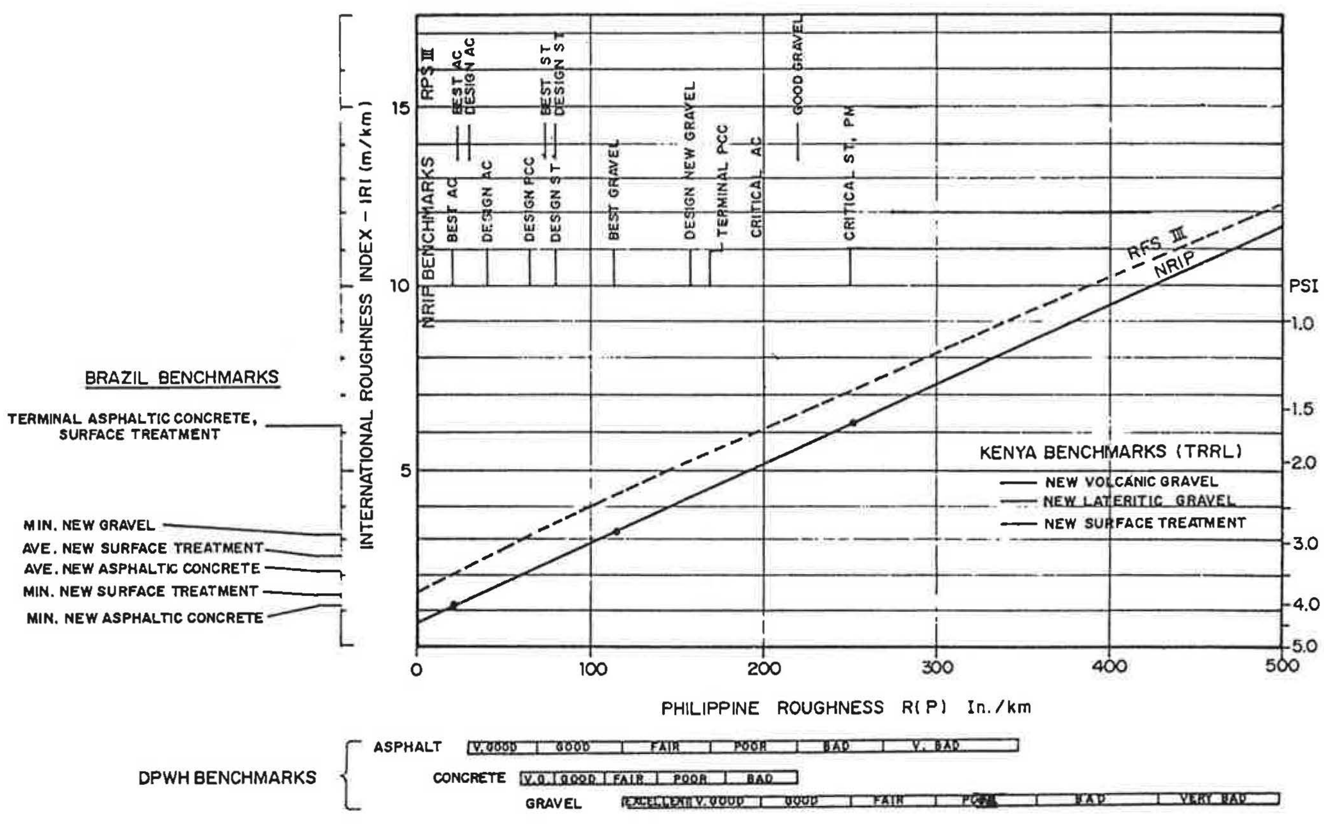



**FIGURE 4 Benchmark roughness versus IRI in the Philippines.**

**TABLE 1 DPWH Pavement Condition Benchmarks**

| Flexible Pavements (AC, BS) | | Roughness (in/km) |
|---|---|---|
| 1 Very Good | No cracks, as new. | < 70 |
| 2 Good | No cracks, low roughness. | 70 - 120 |
| 3 Fair | Some cracks but no developed pattern, slight surface deformation. | 120 - 170 |
| 4 Poor | Developed continuous cracking pattern, no loss of material, moderate surface deformations, few potholes. | 170 - 220 |
| 5 Bad | Extensive cracking pattern with loss of material, large surface deformations, some potholes. | 220 - 270 |
| 6 Very Bad | Highly deformed pavement, extensive potholing, complete failure. | > 270 |
| **Rigid Pavements (PCC)** | | **Roughness (in/km)** |
| 1 Very Good | No cracks, as new. | < 80 |
| 2 Good | Low roughness, cracks < 100m/100m. | 80 - 110 |
| 3 Fair | Slight surface deformation, cracks 100 - 200m/100m. | 110 - 140 |
| 4 Poor | Developed cracking, no loss of material, cracks 200 - 300m/100m. | 140 - 180 |
| 5 Bad | Extensive cracking with loss of material, deformed pavement, cracks 300 - 400m/100m. | 180 - 230 |
| 6 Very Bad | Highly deformed pavement, complete failure, high loss of material, cracks > 400m/100m. | > 230 |
| **Unpaved Surfaces (G, E)** | | **Roughness (in/km)** |
| 1 Very Good | Surface not restrictive to speed. | < 200 |
| 2 Good | Surface slightly restrictive to speed. | 200 - 250 |
| 3 Fair | Slight surface deformations, a few potholes. | 250 - 300 |
| 4 Poor | Deformed surface, frequent potholes. | 300 - 360 |
| 5 Bad | Highly deformed surface, continuous potholes, passable only at low speed. | 360 - 450 |
| 6 Very Bad | Passable only by jeep. | > 450 |

Note: To convert Philippine Roughness (Rp in/km) to Roughness in IRI in in/km, the following equation has been used: Roughness IRI = 0.7 + 0.0215 * Rp.

**TABLE 2 Roughness Values By Pavement Condition and Road Category**

| Pavement Type | Initial | Critical | Terminal |
|---|---|---|---|
| PCC | 2.0[a] (*9*) | — | 4.6 (*9*) |
| AC | 1.5[a] (*9*) | 4.0 (*9*) | 6.0 (*9*) |
| DBST | 2.5[b] (*9*) | 4.5 (*9*) | 6.5 (*9*) |
| Gravel | 4.0 (*9*) | 7.5 (*3*) | 10.0 (*9*) |
| Earth | 4.5 (*9*) | 8.5 (*3*) | 10.0 (*9*) |

NOTE: Values are according to IRI (m/km). Initial = pavement condition right after construction. Critical = pavement condition at which major maintenance is appropriate to reduce life-cycle maintenance costs and VOC costs. Terminal = pavement condition at which reconstruction is warranted.

[a]Under a good construction scenario. In the cases of fair and poor construction, these values are 2.0 and 2.5

[b]Under a good construction scenario. In the cases of fair and poor construction, these values are 2.75 and 3.0.

**TABLE 3 Roughness Values By Pavement Condition and Road Category**

| Pavement Type | Good | Fair | Bad | Failed (Very Bad) |
|---|---|---|---|---|
| PCC | 2.7[a] | 3.6[a] | 4.6[b] | 6.0 (*9*) |
| AC | 2.6[a] | 4.2[c] | 6.0[b] | 9.5 (*3*) |
| DBST | 3.4[a] | 4.5[c] | 6.5[b] | 9.5 (*3*) |
| Gravel | 5.5[a] | 7.5[c] | 10.0[b] | 14.0 (*3*) |
| Earth | 6.0[a] | 8.5[c] | 10.0[b] | 16.5 (*3*) |

NOTE: Values are according to IRI (m/km).

[a]From a point estimation technique exercise, assuming linear variation of roughness between benchmarks (0 = initial value; 5 = fair; 8 = bad).

[b]Terminal values coincide with the midpoint between the bad and very bad categories (*9*).

[c]Mean roughness observed in the World Bank's International Road Roughness Experiment (*3*).

## ROAD MAINTENANCE REQUIREMENTS AND UNIT COSTS

The purpose of this section is to determine appropriate maintenance levels for the project roads under study and, in particular, to determine quantitatively the effect of the various improvement strategies on routine and periodic maintenance expenditures.

### Routine Maintenance

Routine maintenance needs and unit rates have been estimated. Although rates vary somewhat throughout the Philippine islands, within the degree of accuracy possible, it is reasonable to use a standard cost per kilometer of road, irrespective of terrain type or location.

Manual routine maintenance is common to any road irrespective of surface type and includes ditch cleaning, culvert cleaning, and general upkeep of structures. Table 4 includes the financial and economic costs per kilometer for these activities. Financial costs are costs measured in market prices, including taxes, subsidies, custom duties, and other tariffs. Economic costs represent real costs for the economy. Transfers, including taxes, subsidies, and duties, are not included; shadow prices for wages, oil, and foreign exchange are considered. The listed activity cost estimates assume 40 m of culvert and 0.2 structures per km.

#### *Shoulder Maintenance*

Shoulder grading and regraveling are important maintenance activities necessary for maintaining a shoulder's slope and surface course. The authors have assumed that 5-cm-thick full-shoulder-width regraveling is necessary every 4 years. Grading occurs on an average of 2.4 times per year.

Table 5 presents the financial and economic costs of shoulder maintenance as derived from 1988 NRIP cost data updated by means of consumer price indexes (CPI).

#### *Asphalt Pavement Maintenance*

This section presents estimates of routine maintenance costs related to AC and surface treatment (ST) pavements. There are several routine maintenance activities mainly associated with asphalt pavements, such as patching, premix leveling, skin patching, and crack sealing.

Of these activities, shallow patching is the most important in terms of both manpower requirements and cost. Patching is required to repair cracking and potholes. In cases of a

**TABLE 4 Annual Manual Routine Maintenance Costs**

| Activity | Unit | Financial Costs | Economic Costs |
|---|---|---|---|
| Ditch Cleaning | Road Km | 10413.9 | 10413.9 |
| Grass Cutting | Road Km | 2083.4 | 2083.4 |
| Culvert Cleaning | Road Km | 778.1 | 778.1 |
| Minor Structural Repairs | Road Km | 1192.2 | 1192.2 |
| TOTAL (after rounding) | | 14500 | 14500 |

Note: Costs are in February 1990 pesos.

**TABLE 5 Shoulder Maintenance**

| | Economic Unit Cost P/m2 | Financial Unit Cost P/m2 |
|---|---|---|
| Regravelling (10 cm) | 21.82 | 29.60 |
| Regravelling (5 cm) | 10.91 | 14.80 |
| Grading | 0.87 | 1.21 |

Annual Cost (P/yr-km)

| | Shoulder Width 0.50m | 1.0 | 1.5 | 2.0 | 2.5 | 3.0m |
|---|---|---|---|---|---|---|
| Regravelling | 2730 | 5460 | 8190 | 10920 | 13650 | 16380 |
| Grading | 2088 | 4180 | 6270 | 8360 | 10450 | 12540 |
| Total Economic Cost | 4820 | 9640 | 14460 | 19280 | 24100 | 28920 |
| Total Financial Cost | 6600 | 13200 | 19800 | 26420 | 33020 | 39620 |

Note: P = pesos.

**TABLE 6 Annual AC and ST Pavement Maintenance Needs**

| | Roughness Level (IRI - m/mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | <3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | >8 |
| Patching Requirements ($m^2$/km) | 0 | 1.3 | 3.6 | 11.3 | 22.7 | 42.3 | 83.3 |
| Patching Requirements (P/yr-km) | 0 | 110 | 250 | 780 | 1570 | 2930 | 5760 |
| Other Pavement Activities (50% of patching req.) | 0 | 55 | 125 | 390 | 785 | 1465 | 2880 |
| Assumed Total Cost (Economic) (After rounding) | 0 | 0 | 750 | 750 | 3300 | 3300 | 8600 |
| Assumed Total Cost (Financial) (After rounding) | 0 | 0 | 990 | 990 | 4340 | 4340 | 11320 |

Note: The assumed economic cost of patching is P 69.17/m2 and the financial costs of patching is P 91.02/m2. P = pesos.

**TABLE 7 Annual PCC Maintenance Requirements and Costs**

| | Economic Unit Cost | Financial Unit Cost |
|---|---|---|
| Slab Replacement | 279.35 P/m2 | 347.76 P/m2 |
| Joint and Crack Sealing | 15.58 P/m | 18.23 P/m |

| | Roughness Level (IRI - m/km) | | |
|---|---|---|---|
| | <4 | 4-6 | >6 |
| Slab Replacement Requirements | 0% | 0.05% | 0.5% |
| J & C Sealing Requirements | 5% | 15% | 30% |
| Slab Replacement Economic Cost (P/km year) | 0 | 930 | 9,300 |
| J & C Sealing Economic Cost (P/km year) (1) | 1,040 | 3120 | 6,240 |
| Total Economic Cost (P/Km Year) | 1,040 | 4,050 | 15,540 |
| Total Financial Cost (P/Km Year) | 1,220 | 4,810 | 18,880 |

(1) Assuming 20-meter-long 6.70-meter-wide slabs. For example, for roughness < 4 IRI m/km : (6.7 m * 50 joints/km (transverse joints) + 1,000 m/km (longitudinal joint)) * 0.05 / year * 15.58 P/m = 1,039.97 P/km year P = pesos.

**TABLE 8 Annual Gravel Road Maintenance Requirements and Cost**

| | Economic | Financial |
|---|---|---|
| Regrading Unit Cost | P 9.070/km | P 12,361/km |
| Annual Cost (regrade 2.4 times/year) | P 21,770/km yr | P 29,670/km yr |

Source: 1988 NRIP Study, updated by means of CPI indices.

**TABLE 9 1990 Economic Routine Maintenance Costs (pesos/km-yr) (*8,9*)**

| Shoulders (Roughness Shoulders in IRI m/km) | | | | |
|---|---|---|---|---|
| Shoulder Width | <4 | 4-6 | 6-8 | >8 |
| 0.5m | 4820 | 4820 | 4820 | 4820 |
| 1.0m | 9640 | 9640 | 9640 | 9640 |
| 1.5m | 14460 | 14460 | 14460 | 14460 |
| 2.0m | 19280 | 19820 | 19820 | 19820 |
| 2.5m | 24100 | 24100 | 24100 | 24100 |
| 3.0m | 28920 | 28920 | 28920 | 28920 |
| **PCC Pavements** Roughness in IRI m/km | | | | |
| | <4 | 4-6 | 6-8 | >8 |
| | 15540 | 18550 | 30040 | 30040 |
| **DBST/AC Pavements** Roughness in IRI m/km | | | | |
| | <4 | 4-6 | 6-8 | >8 |
| | 14500 | 15250 | 17800 | 23100 |
| **Gravel Roads** Roughness in IRI m/km | | | | |
| Roadway Width | <4 | 4-6 | 6-8 | >8 |
| 6m | 36270 | 36270 | 36270 | 36270 |
| 4m | 29010 | 29010 | 29010 | 29010 |
| **Earth Roads** Roughness in IRI m/km | | | | |
| Roadway Width | <4 | 4-6 | 6-8 | >8 |
| 6m | 36270 | 36270 | 36270 | 36270 |
| 4m | 29010 | 29010 | 29010 | 29010 |

surface treatment or asphalt concrete pavement, potholes develop from raveling, wide cracking, or alligator cracking. Factors controlling the initiation and progression of potholes are diverse.

The World Bank HDM-III model (*3*) is a mechanistic model that relates patching requirements to potholes caused by cracking and raveling and to enlargement of existing potholes.

Although the principles behind the HDM-III deterioration model for patching are sound, they are unwieldy in practice because they attempt to rationalize complicated mechanisms into a less complicated, but still complex, set of relationships. Since the authors are considering theoretical maintenance levels in this study, which will be greatly modified by human intervention in actual practice, there is good reason to adopt a more simplistic approach that still allows quantitative comparisons of various maintenance strategies.

The AC and ST pavement patching and total maintenance requirements were tabulated according to roughness level (pavement condition) (see Table 6). Costs were estimated based on NRIP data (updated by means of CPI indexes), assuming average pavement widths of 6.7 meters and pothole depths of 8 cm. The variation of maintenance needs across pavement conditions was estimated according to Montenegro and Sinha (*8*).

### *PCC Pavement Maintenance*

This section presents estimates of routine maintenance requirements and costs for PCC pavement surfaces. The two most important PCC maintenance activities are slab replacement and joint and crack sealing.

Based on NRIP, Volume II, (*9*) it was assumed that an average of 0.05 percent of the paved area is replaced each year. Based on NRIP, Volume II (*9*), and previous data (*8*) it was assumed that joints are sealed every 6 years and that 15 m of cracks are filled every year.

Table 7 presents the authors' estimate of maintenance unit and total costs for PCC pavements.

### *Gravel Road Maintenance*

Many of the roads under study are gravel surfaced. To evaluate upgrading options, it is necessary to determine future maintenance requirements for these gravel roads without the project. Also, some sections of road were evaluated for improvement to gravel standards only and, for these sections, it is necessary to know the future maintenance costs. These estimated costs are presented in Table 8.

Tables 9 and 10 present summaries of the estimated financial and economic routine maintenance costs by road type and condition.

## Periodic Maintenance

### *Paved Roads*

One way of scheduling seal coats (pavement resealing) is by assigning a level of distress (e.g., percentage of pavement

**TABLE 10 1990 Financial Routine Maintenance Costs (pesos/km-yr) (*8,9*)**

| | Shoulders Roughness in IRI m/km | | | |
|---|---|---|---|---|
| Shoulder Width | <4 | 4-6 | 6-8 | >8 |
| 0.5m | P6600 | P6600 | P6600 | P6600 |
| 1.0m | 13200 | 13200 | 13200 | 13200 |
| 1.5m | 19800 | 19800 | 19800 | 19800 |
| 2.0m | 26420 | 26420 | 26420 | 26420 |
| 2.5m | 33020 | 33020 | 33020 | 33020 |
| 3.0m | 39620 | 39620 | 39620 | 39620 |
| | PCC Pavements Roughness in IRI m/km | | | |
| | <4 | 4-6 | 6-8 | >8 |
| | 15720 | 19310 | 33380 | 33380 |
| | DBST/AC Pavements Roughness in IRI m/km | | | |
| | <4 | 4-6 | 6-8 | >8 |
| | 14500 | 15490 | 18840 | 25820 |
| | Gravel Roads Roughness in IRI m/km | | | |
| Roadway Width | <4 | 4-6 | 6-8 | >8 |
| 6m | 44170 | 44170 | 44170 | 44170 |
| 4m | 34280 | 34280 | 34280 | 34280 |
| | Earth Roads Roughness in IRI m/km | | | |
| Roadway Width | <4 | 4-6 | 6-8 | >8 |
| 6m | 44170 | 44170 | 44170 | 44170 |
| 4m | 34280 | 34280 | 34280 | 34280 |

requiring patching) at which the seal is applied. In practice, few highway departments in developing countries undertake seal coating unless the amount of distress has reached critical levels (this often means that the pavement is beyond saving by application of a simple seal). For the purpose of this study, it was assumed that flexible pavements are seal coated every 8 years.

Pavement structures deteriorate and their roughness values increase over time. At certain critical points, it is appropriate to provide an AC overlay (*11*) to

- Prolong the working life of a pavement by increasing the structural strength, and
- Reduce the surface roughness, and in so doing, to increase the VOC benefits derived from the road improvement.

Although it is a universally recommended procedure, AC overlay is rarely carried out in developing countries, resulting in increased roughness for a given traffic loading, which means higher vehicle operating costs and additional capital expenditures (cost of reconstructing a pavement compared with the cost of an overlay).

**TABLE 11 1990 Periodic Maintenance Unit Costs**

| | Economic Cost | Financial Cost |
|---|---|---|
| Seal coat[a] | 17.39 P/m$^2$ | 21.82 P/m$^2$ |
| | 116,500 P/km | 146,200 P/km |
| Overlay[b] | 2,236.61 P/m$^3$ | 2,856.05 P/m$^3$ |
| | 1,498,530 P/km | 1,913,560 P/km |
| Regravelling | 21.82 P/m$^2$ | 29.60 P/m$^2$ |
| 4-m road | 87,280 P/km | 118,410 P/km |
| 6-m road | 130,920 P/km | 177,610 P/km |

NOTE: Unit costs are based on NRIP data updated by means of CPI indices. P = pesos.
[a]Assuming a 6.70-meter cross section.
[b]Assuming a 6.70-meter cross section and a 10-centimeter overlay.

### *Unpaved Roads*

It is assumed that gravel roads are regraveled every 4 years to replenish the gravel loss caused by traffic and weather. A replenishment thickness of 10 cm has been assumed. Table 11 summarizes the unit periodic maintenance costs assumed in the RIF study.

## APPLICATION OF THE PRESENTED METHODOLOGY

As suggested in the previous sections, the proposed methodology was applied successfully by the authors in the evaluation of road construction and improvement projects in the Philippines (financed by the U.S. Agency for International Development).

The proposed methodology provided a quick, technically sound and sensitive (to policy variables) way of assessing the pavement condition (roughness) and road maintenance needs necessary for the analysis of road feasibility projects.

## SUMMARY AND CONCLUSIONS

The proposed guidelines provide a framework for the estimation of roadway condition and maintenance needs in the context of road feasibility studies. The guidelines, provided by means of a recent example in Southeast Asia, are simple and conceptually sound. One area of direct application is the economic analysis of internationally funded investment projects in developing countries.

This methodology gathered and adapted in the same framework the latest theories in the areas of pavement deterioration and road maintenance needs estimation from previously published material (*3,6*), as well as the authors' experience in the area. Its use in the Philippines proved to be highly successful, giving a useful tool for estimating necessary factors in the economic analysis of road feasibility projects.

## REFERENCES

1. F. M. Montenegro and M. Minc. Economic Evaluation of Urban Transportation Projects in Developing Countries. Presented at

69th Annual Meeting of the Transportation Research Board, Washington, D.C., 1990.
2. F. M. Montenegro and M. Minc. Methodological Considerations in Road Feasibility Studies. Presented at 71th Annual Meeting of the Transportation Research Board, Washington, D.C., 1992.
3. T. Watanada et al. *The Highway Design and Maintenance Standard Model*, Vol. I–V. The World Bank, Washington, D.C., 1987.
4. *Guide for Design of Pavement Structures*. AASHTO, Washington, D.C., 1986.
5. *PAVER*. U.S. Corps of Engineers Research Laboratory, Champaign, Ill.,
6. L. L. Parsley and R. Robinson. *The TRRL Road Investment Model for Developing Countries (RTIM2)*. Laboratory Report 1057. Transportation and Road Research Laboratory, Crowthorne, England, 1982.
7. *A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-tropical Countries*. Road Note 31. Transportation and Road Research Laboratory, London, England, 1987.
8. F. M. Montenegro and K. C. Sinha. Development of a Procedure for Assessing Routine Maintenance Needs of Highways. In *Transportation Research Record 1109*, TRB, National Research Council, Washington, D.C., 1987.
9. Louis Berger International, Inc., and TCI Engineer. *National Road Improvement Project*. Final Report. Republic of the Philippines, Department of Public Works and Highways, Manila, 1988.
10. *Road Feasibility Study III*. United Nations Development Project, Manila, Philippines, 1978.
11. F. M. Montenegro. Pavement Management Systems for Developing Countries. Technical Seminar Memoirs. Universidad Nacional Autonoma de Mexico, School of Engineering, Graduate Department, Aug. 1989.

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