Simple Procedure for Selecting Best Maintenance Alternatives in Developing Countries

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A simple procedure for economically evaluating pavement maintenance alternatives and for selecting the most economical one is presented. The procedure includes several simple models that relate various cost and benefit items to pavement condition. Visual inspection is selected to represent pavement condition because it is the most common, and in most cases the only, method of pavement evaluation in developing countries. Cost items include (a) fixed initial cost, which depends on the type of maintenance alternative to be applied and the current unit costs of different resources, (b) variable initial cost (surface preparation) as a function of the condition of the existing pavement, and (c) annual routine (recurrent) maintenance as a function of pavement condition of the proposed maintenance alternative through its service life. Benefits, on the other hand, are considered in terms of savings in vehicle operating cost (VOC) resulting from applying maintenance alternatives. VOC is also related to pavement surface condition. A detailed example is presented to illustrate the procedure's step-by-step application. The results strongly indicate that ignoring one or more of the above-mentioned cost or benefit items can lead to considerable losses. This factor is particularly important in developing countries in which maintenance decisions are typically based on minimum initial cost without much attention given to other cost and benefit items.

A network level procedure for selecting the best maintenance alternative and calculating its associated costs and benefits for different pavement types at different levels of pavement condition is presented. This work is an extension of efforts initiated in late 1984 by Purdue University and the Construction Engineering Research Laboratory to develop a model that relates maintenance and repair costs to pavement surface condition (*1–6*).

The major addition to the original procedure is the inclusion of vehicle operating cost (VOC) in determining the best maintenance and repair alternative. This procedure is similar to the World Bank's procedure reported by NCHRP (*7*), except that it is simpler and requires fewer data.

The procedure has been initiated as a recommendation of the Expert Group Meeting of the Economic and Social Commission for Western Asia, United Nations, held in Cairo, Egypt, in 1989. The procedure, therefore, has been developed to serve the countries in this region in the first place; however, all efforts have been made to make the procedure flexible enough to allow its use in other developing countries.

In developing this procedure, several considerations have been taken into account:

1. The procedure should be simple so that it can be used by different management levels.
2. The procedure should be comprehensive to include different factors that may affect maintenance decisions.
3. The procedure should be applied with minimal dependence on sophisticated equipment and with maximum use of human resources, typically available in developing countries.
4. The procedure should be capable of producing results that address both costs and benefits associated with different maintenance alternatives so that rational approaches can be used when selecting the best alternative.
5. The procedure should be flexible enough to be applied in different environments.

The procedure is primarily based on the identification of pavement condition. Pavement condition can be evaluated through different techniques ranging from very simple ones to rather complicated ones that require considerable investment. In selecting the pavement condition assessment method for use in this procedure, the following two factors were considered:

1. The evaluation process should be simple and easily applied by different countries in the region.
2. The results of evaluation should provide information that address both structural and functional performance of pavements.

Therefore, visual inspection of pavement condition has been used in this procedure. From among several methods for visual pavement inspection, the pavement condition index (PCI) has been selected. This well-known method was originally developed by the U.S. Army Corps of Engineers (*8*). It depends on the detailed inspection of pavement and covers up to 19 different pavement distresses. Each distress is defined by its type, severity level (see Table 1), and extent (density) on the pavement area. The names of these distresses are presented in Table 2. The final rating of the pavement condition is based on the calculation of the PCI value. The PCI, a scale from 0 to 100 with 100 being excellent, is determined on the basis of measured type, severity, (see Table 2) and extent of different distresses. The PCI procedure is widely used in the United States, Europe, and in several countries in the local region, including Saudi Arabia, Jordan, and Egypt.

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TABLE 1 DISTRESS SEVERITY LEVELS

Severity code	Severity Level
1	Low
2	Medium
3	High

The following section includes a step-by-step description of the procedure, and an example using the procedure.

FAMILIES OF PAVEMENT SECTIONS

The network under consideration is classified into families of pavement sections. Each family includes a group of pavement sections that are subjected to the same general conditions, such as traffic, location, structural history, and pavement surface type.

As an example, agricultural roads with high traffic level and water sources (canals and drains) surrounding them should be differentiated from desert roads with low traffic level, etc. In this way, groups of nearly equivalent pavement sections are obtained. Pavement evaluation can be done through the PCI procedure by applying appropriate sampling techniques so that each family is adequately presented (*8*).

PAVEMENT CLASSIFICATION

Pavement sections are grouped within each family on the basis of their structural type. Generally, there are numerous categories of pavement structural types, but typically they can be divided into the following types, particularly in the region under consideration:

1. Asphalt concrete;
2. Surface treatment;
3. Thin overlay (normally, less than 5 cm thick);
4. Thick overlay (normally, more than 5 cm thick); and
5. Rigid pavements.

Rigid pavements are not commonly used in paving roads in the region under consideration and therefore have been excluded from the procedure.

MAINTENANCE AND REPAIR ACTIVITIES

Maintenance and repair activities should be grouped into a number of discrete activities that are commonly applied at different levels of pavement condition. Typical activities in the region are routine (or recurrent maintenance), surface treatment, thin overlay, thick overlay, and reconstruction.

PCI RANGES

Because maintenance decisions are discrete in nature, pavement condition, represented by PCI values in this procedure, is also divided into discrete ranges. Typical ranges are

1. PCI = 80 to 100,
2. PCI = 60 to 80,
3. PCI = 40 to 60,
4. PCI = 20 to 40, and
5. PCI = 0 to 20.

At this point, the network is classified into families (categories) of sections. The objective is to select the most cost-effective maintenance and repair alternative for each of those categories at the various PCI ranges. This cost-effective approach is based on a comparison of alternatives using a life cycle costing calculation. Life cycle costing is typically based

TABLE 2 DISTRESS TYPES FOR ASPHALT CONCRETE PAVEMENTS

Distress Code	Distress Name
1	Alligator Cracking
2	Bleeding
3	Block Cracking
4	Bumps and Sags
5	Corrugation
6	Depression
7	Edge Cracking
8	Reflection Cracking
9	Lane/Shoulder Dropoff
10	Longitudinal and Transverse Cracking
11	Patching and Utility Cut Patching
12	Polished Aggregate
13	Potholes
14	Railroad Crossing
15	Rutting
16	Shoving
17	Slippage Cracking
18	Swell
19	Weathering and Ravelling

on two types of data: performance data and cost-benefit data. In the remainder of the procedure, these two categories of data are described for each pavement family.

PERFORMANCE CURVES

Performance curves are those relations that describe the rate of change in pavement condition over time, under certain level of use (traffic), and subject to specific environmental factors such as rainfall, underground water, and temperature. The level of use (amount of traffic) and environmental factors are included in the original classifications of pavement section families. Therefore, this procedure suggests simple performance curves that relate PCI values to the age of pavement. This is typically done by collecting data on PCI values as well as obtaining information on pavement age (usually, from construction history files). Sets of PCI and age values can be easily obtained for sections in each family. This is followed by applying some statistical techniques (typically, regression analysis) to construct the relation between PCI and pavement age. Although several forms of such a relation can be expected, the one used in this procedure is as follows:

$$C = 100 - b * x^{m} \qquad (1)$$

where

C = PCI value,
x = pavement age in months measured from the date of last application of major activity,
b = slope coefficient, and
m = value that controls the degree of curvature of the performance curve.

A set of statistical models, similar to that of Equation 1, can be developed for different pavement families. The importance of these model relations stem from the following:

1. They provide a tool for estimating the pavement condition in the future during the pavement's service life.
2. They can be used to estimate the service life of a pavement category. The service life is defined as the period after which the pavement reaches a certain terminal condition level described by the terminal PCI value. In this case, the model can be used in a reverse manner, that is, estimating the age of the pavement given a terminal PCI value.

COSTS AND BENEFITS

One of the key principles of this procedure is to relate both costs and benefits to pavement condition. Unbiased comparison between different alternatives can be applied. Using this procedure, only direct costs and benefits are included. Indirect costs such as air pollution, noise, and other social costs are not included but could be easily incorporated if they were converted to the proper monetary form. Also, indirect benefits such as value of land, employment, and other social effects are not considered but could be incorporated if they were converted to a proper monetary form.

Direct costs considered in this procedure are the typical ones of initial costs (activity construction costs), and routine (or recurrent) maintenance during the service life. The salvage value is considered to be zero at the end of pavement service life. The direct benefits as considered in this procedure are those resulting from savings in vehicle operating cost (VOC). The VOC savings are presented in this procedure as follows:

$$\text{VOC savings at a specific period (year)} = (\text{VOC})_t - (\text{VOC})_c \qquad (2)$$

where

$(\text{VOC})_t$ = VOC at the terminal level of pavement condition, and
$(\text{VOC})_c$ = VOC at the current level of pavement condition.

That is, the VOC savings resulting from the application of an alternative equal the difference between VOC values when not applying the alternative and that when applying the alternative. Alternatives with higher performance (longer service life or lesser rates of deterioration) are expected to produce higher VOC savings during their service lives and may be selected in spite of their relative higher initial costs. This is particularly important because of the general tendency among highway top management to select the alternatives with the least initial cost.

Initial Cost

Initial cost includes the following two components:

1. Surface preparation cost associated with the repairs of defective areas of the existing surface before applying the maintenance alternative itself. This cost is directly related to the condition of the existing pavement at the time of maintenance alternative application.
2. Maintenance alternative application cost that does not depend on pavement condition and only depends on current prices of different labor, material, and equipment elements used in the application of the particular maintenance alternative.

Recurrent Maintenance Cost

Recurrent maintenance activities are day-to-day activities such as crack sealing and pothole patching. The cost of applying these activities is a function of pavement condition at the time of repair.

VOCs

VOCs are the costs required to run a vehicle. They include depreciation, fuel, lubrication, time, maintenance, and so on. Although the mechanism for calculating these costs will not be described, VOC dependence on pavement condition is a key element in the procedure. Otherwise, it would be impossible to indicate the benefits of maintenance activities (the reduction of VOCs caused by improving pavement condition).

In order to identify these benefits, the following steps were performed during the testing of this procedure, and it is believed that they could be replicated easily in any other environment:

1. Necessary information was collected about the most common vehicle types using the considered road network—for example, representative vehicles for passenger cars, small trucks, combination trucks, and articulated trucks. Then, the necessary mechanical properties and unit costs were estimated, on an average basis. The purpose of this step was to obtain the necessary information required to run the World Bank's VOC model, which estimated the total VOC for each vehicle type at different pavement conditions. This model is based on data from several countries and has proven to be accurate enough to estimate VOCs for different vehicle types (*9*).
2. After the model was run, the following equations were obtained:

$$(\mathrm{VOC})_{\mathrm{PC}} = e^{(5.624 + 0.06814 \cdot \mathrm{IRI})} \tag{3}$$

$$(\mathrm{VOC})_{\mathrm{ST}} = e^{(6.337 + 0.06516 \cdot \mathrm{IRI})} \tag{4}$$

$$(\mathrm{VOC})_{\mathrm{MT}} = e^{(6.465 + 0.06766 \cdot \mathrm{IRI})} \tag{5}$$

$$(\mathrm{VOC})_{\mathrm{AT}} = e^{(6.899 + 0.05116 \cdot \mathrm{IRI})} \tag{6}$$

where

$(\mathrm{VOC})_{\mathrm{PC}}$ = estimated vehicle operating cost for a passenger car (L.E. per 1,000 veh-km);
$(\mathrm{VOC})_{\mathrm{ST}}$ = estimated vehicle operating cost for a small truck (L.E. per 1,000 veh-km);
$(\mathrm{VOC})_{\mathrm{MT}}$ = estimated vehicle operating cost for a medium truck (L.E. per 1,000 veh-km);
$(\mathrm{VOC})_{\mathrm{AT}}$ = estimated vehicle operating cost for an articulated truck (L.E. per 1,000 veh-km); and
IRI = International roughness index, an index that represents the degree of unevenness of a pavement section, which is highly correlated to VOC.

Equations 3–6 represent the condition of Egypt (*10*). However, similar equations can be easily developed for other countries in the region when appropriate vehicle and roadway characteristics are used.

The values of IRI are typically obtained using roughness measurement equipment. In this procedure, a simplified approach has been used to avoid using roughness equipment. Surveying measurements were used on about 60 sections, and the IRI was calculated for each section (*11*,*12*). Detailed visual inspection was also completed on the same sections, and PCI values were determined. A set of PCI, IRI data pairs was available; regression analysis was applied resulting in the following simple model:

$$\mathrm{IRI} = 0.15(100 - \mathrm{PCI})$$

$$R^2 = 0.81 \tag{7}$$

Figures 1 and 2 show scatter plots for IRI and PCI values and the observed versus predicted values, respectively. The IRI values can be easily estimated from the PCI values using Equation 7.

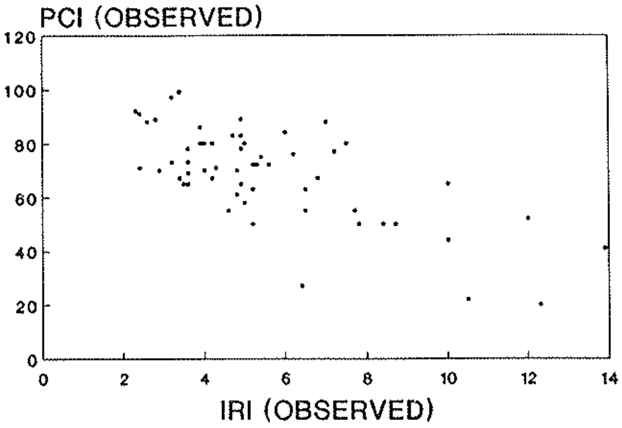

FIGURE 1 Scatter plot for observed values of IRI and PCI measurements.

Calculation of VOCs can best be illustrated through another simple example, assuming the following data:

- A highway section is of 10-km length and 7.5-m width;
- Its average daily traffic (ADT) is 10,000 veh/day with 70 percent passenger cars, 10 percent small trucks, 10 percent medium trucks, and 10 percent articulated trucks; and
- Its current PCI level is 80.

In order to calculate the total VOC, Equations 3–6 are first used to determine the VOC values for passenger car (PC), small truck (ST), medium truck (MT), and articulated truck (AT), respectively. In the application of these equations, the value of IRI calculated using Equation 7 is $0.15(100 - 80) = 3$. For this case,

$$(\mathrm{VOC})_{\mathrm{PC}} = 339.8 \text{ L.E. per 1,000 veh-km} \tag{8}$$

$$(\mathrm{VOC})_{\mathrm{ST}} = 678.1 \text{ L.E. per 1,000 veh-km} \tag{9}$$

$$(\mathrm{VOC})_{\mathrm{MT}} = 786.8 \text{ L.E. per 1,000 veh-km} \tag{10}$$

$$(\mathrm{VOC})_{\mathrm{AT}} = 1{,}155.7 \text{ L.E. per 1,000 veh-km} \tag{11}$$

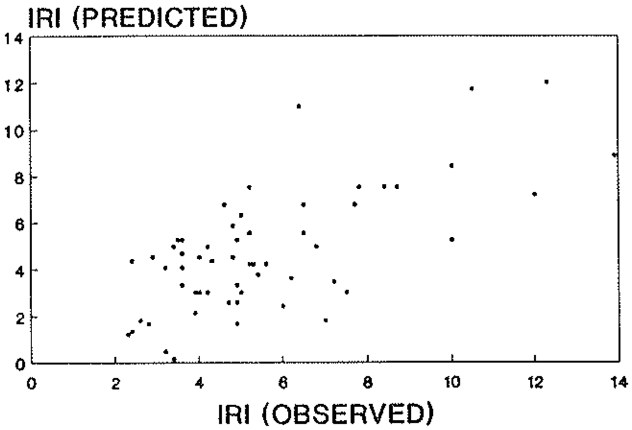

FIGURE 2 Observed versus predicted values of IRI using simplified relation between IRI and PCI.

The average VOC is then calculated using the percentages of the different vehicles, as follows:

$$(\mathrm{VOC})_{\mathrm{average}} = 0.7 * 339.8 + 0.1 * 687.1 + 0.1 * 1{,}155.7 \text{ L.E. per } 1{,}000 \text{ veh-km}$$

$$= 500.8 \text{ L.E. per } 1{,}000 \text{ veh-km}$$

Total VOC on this section is 500.8 * total veh-km/1,000 = 500.8 * 10 * 10,000/1,000 = 50,080 L.E. per unit area of road, VOC/m^2 = 50,080/(10,000 * 7.5) = 0.668 L.E./m^2. The cost per area per year, (VOC/m^2)/year = 0.668 * 360 = 240.5 (L.E./m^2)/year.

The last value allows direct comparison between total VOC and maintenance cost [which is normally calculated in terms of (L.E./m^2)/year].

As mentioned, both the surface preparation part of the initial cost and the routine (recurrent) maintenance costs during the service life of an alternative are dependent on PCI value. In order to determine such costs as a function of PCI, one may think of the required repair cost as the defective area multiplied by the unit area cost of repair. Thus, if at any PCI level, the average defective area and the corresponding required repair action and cost are estimated, then the surface preparation or recurrent maintenance at the PCI level can be easily estimated.

This process led to the development of the density matrix for each pavement category under consideration. A distress density is defined as the percent of section area indicating that specific distress type. The density matrix of a specific pavement category summarizes the average density values for each PCI range by distress type and severity level combination. Figure 3 shows a typical density matrix. For instance, in Figure 3, the average density of low-severity (Severity Code 1) alligator cracking (Distress Code 1) is 9.64 percent at PCI range 0 to 20, whereas the average density of high-severity (Severity Code 3) weathering and raveling (Distress Code 19) is 23.47 percent for PCI range 0 to 20. For this pavement category, at PCI range 0 to 20, there is, on the average, about 9.46 percent of a section area with low-severity alligator cracking and 23.47 percent weathering and raveling.

If the repair method for each distress and severity level is defined, then the required repair costs for the various PCI ranges can be estimated. These values, in turn, lead to the development of the surface preparation policy matrix and recurrent maintenance policy matrix. A surface preparation policy matrix contains the necessary surface preparation actions for different distress-severity level combinations, whereas the recurrent maintenance policy matrix contains the necessary recurrent maintenance actions for different distress-severity level combinations.

Distress Code	Severity Code	Average Density (%) by PCI Range				
		81-100	61-80	41-60	21-40	0-20
1	1	0.32	1.15	5.54	11.36	9.46
1	2	0.13	0.20	1.80	10.24	14.09
1	3	0.03	0.04	0.39	10.05	14.02
.	.	.	.	.	.	.
.	.	.	.	.	.	.
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19	1	4.49	12.44	17.15	19.57	11.25
19	2	0.56	1.18	6.60	10.84	17.31
19	3	0.06	0.08	0.42	6.04	23.74

FIGURE 3 Portion of a typical density matrix (3).

Figure 4 shows a typical surface preparation matrix. The recurrent maintenance matrix is similar to the surface preparation matrix except that the repair policies of the recurrent maintenance matrix differ from those of the surface preparation. The repair policies associated with recurrent maintenance are relatively of lower standard if compared to those of surface preparation.

With the density matrix, surface preparation policy matrix, and annual recurrent maintenance policy matrix, the following equations are used to calculate required surface preparation or annual recurrent maintenance costs at any PCI range:

$$(\mathrm{SP})_k = (\mathrm{D}_{ij})_k * (\mathrm{C}_{ij})_{\mathrm{sp}} \tag{12}$$

$$(\mathrm{RM})_k = (\mathrm{D}_{ij})_k * (\mathrm{C}_{ij})_{\mathrm{rm}} \tag{13}$$

where

$(\mathrm{SP})_k$ = surface preparation cost at the kth PCI range,
$(\mathrm{RM})_k$ = recurrent maintenance cost at the kth PCI range,
$(\mathrm{D}_{ij})_k$ = average density of the ith distress type with the jth severity level combination at the kth PCI range (from the density matrix of the pavement category under consideration),
$(C_{ij})_{\mathrm{sp}}$ = unit cost of the required surface preparation action for the jth severity level of the ith distress type (from the surface preparation policy matrix), and
$(C_{ij})_{\mathrm{rm}}$ = unit cost of the required recurrent maintenance action for the jth severity level of the ith distress type (from the recurrent maintenance policy matrix).

SUMMARY OF PROCEDURE APPLICATION

The purpose of this procedure is to select the most cost-effective maintenance alternative at a specific pavement condition state (PCI range). In order to achieve that, different cost and benefit elements are calculated for each alternative and the one with the highest net equivalent uniform annual cost is considered to be the most cost-effective alternative. In the following section is a summary of cost and benefit elements as considered in this procedure.

Initial Cost

Fixed Cost

Fixed cost, which has no relation to the condition of the existing pavement, can be estimated from the most current similar contracts.

Distress Type	Severity	Preparation Method	Unit	Unit Cost
1- Alligator Cracking	H	Deep Patch	SF	2.32
	M	Skin Patch	SF	0.55
3- Block Cracking	H	Skin Patch	SF	0.55
4- Bumps / Sags	H	Skin Patch	SF	0.55
5- Corrugation	H	Deep Patch	SF	2.32
6- Depressions	H	Deep Patch	SF	2.32
7- Edge Cracking	H	Deep Patch	LF	3.48
	M	Deep Patch	LF	2.9
9- Lane/Shoulder Dropoff	H	Add Aggregate and Grade	LF	0.14
10- Long./Trans. Cracking	H	Shallow Patch	LF	1.65
	M	Crack Fill	LF	1.00
11- Patching and Utility	H	Deep Patch	SF	2.32
13- Potholes	H	Deep Patch	ea	7.29
	M	Shallow Patch	ea	1.82
	L	Pothole Filling	ea	0.79
14- Railroad Crossing	H	Deep Patch	SF	2.32
15- Rutting	H	Deep Patch	SF	2.32
	M	Skin Patch	SF	0.39
16- Shoving	H	Deep Patch	SF	2.32
17- Slippage Cracking	H	Skin Patch	SF	0.55
18- Swell	H	Deep Patch	SF	2.32

FIGURE 4 Typical surface preparation policy matrix (*3*).

Surface Preparation Cost

Surface preparation cost is directly related to the condition of the existing pavement at the time of application activity. It is estimated using Equation 12 taking into consideration the PCI range of the existing pavement.

Annual Maintenance Cost

Annual maintenance cost is directly related to the condition of the pavement for each year within the service life of the proposed alternative. It is estimated using Equation 13 taking into consideration the PCI range during each year of the alternative service life (Equation 1 is used to estimate PCI for each year). For the alternative under consideration, the service life is calculated using Equation 1 with the appropriate terminal PCI value and the appropriate value for coefficient *b*.

Vehicle Operating Cost

VOC is directly related to the condition of the pavement, represented in terms of the IRI value. The IRI value is calculated using Equation 7. The VOC value is then estimated using Equations 3–6.

Savings and Benefits

Savings are the difference between the VOC value in a specific year with a specific IRI value and the VOC value at the terminal IRI value. This calculation is done for each year within the service life of an alternative. The IRI values for each year are estimated using Equation 7 after estimating the PCI value for each year using Equation 1.

EXAMPLE OF PROCEDURE APPLICATION

A simple example of the use of the procedure is given in this section. The purpose of this example is to illustrate the step-by-step application of the procedure to select a best maintenance alternative among several alternatives. In addition, several important conclusions based on this example are discussed in the following section.

Input Data

- Pavement section length = 30 km.
- Pavement section width = 7.5 m.
- ADT = 5,000 veh/day.
- Percentage of passenger cars = 70 percent.
- Percentage of small trucks = 10 percent.

- Percentage of medium trucks = 10 percent.
- Percentage of articulated trucks = 10 percent.
- Current PCI level = 30.
- Terminal PCI level = 30.
- Existing pavement type = thin overlay.
- Surface preparation cost of existing pavement (at current PCI) = 8.5 L.E./m^2 (from appropriate density matrix).
- Maintenance costs of different alternatives at different PCI ranges are as follows (from appropriate density matrices):

	PCI Range				
Alternative	*0–20*	*21–40*	*41–60*	*61–80*	*81–100*
Surface dressing	7.70	2.20	0.80	0.50	0.13
Thin overlay	7.00	2.00	0.70	0.35	0.13
Thick overlay	4.00	1.00	0.60	0.30	0.07
Reconstruction	4.40	1.30	0.65	0.33	0.07

- Performance equations of different maintenance alternatives are as follows:

$\mathrm{PCI} = 100 - 0.0319(\mathrm{age})^{1.5}$ for surface dressing.

$\mathrm{PCI} = 100 - 0.0158(\mathrm{age})^{1.5}$ for thin overlay.

$\mathrm{PCI} = 100 - 0.0129(\mathrm{age})^{1.5}$ for thick overlay.

$\mathrm{PCI} = 100 - 0.0104(\mathrm{age})^{1.5}$ for new asphalt and reconstructed pavement.

- Inflation-adjusted discount rate = 6 percent.

Procedure Steps

- The initial cost of each available maintenance alternative is presented in Table 3. It consists of the fixed part and the surface preparation part (which is a function of the PCI value of the existing pavement with thin overlay). The surface preparation cost is calculated using the appropriate density and surface preparation policy matrices, as described earlier.
- The expected service lives of different maintenance alternatives are calculated using the performance equations (by substituting PCI = terminal value of 30). The resulting service lives are presented in the last column in Table 4.

- Table 5 presents the calculation of the equivalent uniform annual cost (EUAC) of the initial costs of different maintenance alternatives.
- The performance equations are then used to calculate the PCI values at each year within the service life of an alternative. Several steps follow the calculation of the PCI value in a specific year. The results of these steps are presented in Table 6 for surface dressing. Similar tables are developed for other alternatives. Each table consists of 12 columns, as follows:

Column 1. Year number within the service life of the alternative.

Column 2. PCI value as calculated from the performance equation.

Column 3. Annual maintenance cost (L.E./m^2). This cost is determined by first converting the PCI value to its corresponding range (0–20, 20–40, etc.). Then, the associated annual maintenance cost is determined from the table given in the input data.

Column 4. The single payment present worth factor (sppwf) corresponding to the year (n) under consideration.

Column 5. The present worth value of the annual maintenance cost = Column 3 * Column 4.

Column 6. EUAC of annual maintenance cost = [capital recovery factor (CRF)] * [present worth value (PWV) of annual maintenance costs].

Column 7. IRI estimated by Equation 7 as a function of PCI value (Column 2).

TABLE 3 INITIAL COSTS

	INITIAL COST		
ALTERNATIVE	FIXED	SURFACE PREPARATION	TOTAL
SURFACE TREATMENT	1.58	8.5	10.08
THIN OVERLAY	3.76	8.5	12.26
THICK OVERLAY	5.07	8.5	13.57
RECONSTRUCTION	20.70	0.0	20.70

TABLE 4 PERFORMANCE MODELS AND SERVICE LIVES

ALTERNATIVE	PERFORMANCE CURVE	SERVICE LIFE AT PCI = 30
SURFACE TREATMENT	$\mathrm{PCI} = 100 - 0.0319(\mathrm{age})^{1.5}$	14
THIN OVERLAY	$\mathrm{PCI} = 100 - 0.0158(\mathrm{age})^{1.5}$	22
THICK OVERLAY	$\mathrm{PCI} = 100 - 0.0129(\mathrm{age})^{1.5}$	25
RECONSTRUCTION	$\mathrm{PCI} = 100 - 0.0104(\mathrm{age})^{1.5}$	29

TABLE 5 EUAC OF ALTERNATIVE INITIAL COSTS

	MAINTENANCE ALTERNATIVE			
	SURFACE DRESSING	THIN OVERLAY	THICK OVERLAY	RECONSTRUCTION
i	6	6	6	6
n	14	22	25	29
CRF	0.1075	0.0830	0.0780	0.0739
INITIAL COST	10.08	12.26	13.57	20.70
EUAC (I.C.)	1.08	1.02	1.06	1.53

RF : Capital Recovery Factor
UAC: Equivalent Uniform Annual Cost

TABLE 6 SURFACE DRESSING

n	PCI	A.M.C	sppwf	PWV	EUAC	IRI	VOC AT CURRENT	VOC AT PCI= 30	VOC SAVINGS	PWV	EUA BENEFIT
1	98.67	0.13	0.943	0.122		0.2	101.84	197.80	95.96	90.49	
2	96.20	0.13	0.889	0.116		0.57	104.25	197.80	93.55	83.53	
3	93.10	0.13	0.840	0.109		1.04	107.21	197.80	90.59	76.09	
4	89.00	0.13	0.790	0.103		1.65	110.20	197.80	87.60	69.20	
5	85.00	0.13	0.750	0.098		2.25	116.02	197.80	81.78	61.34	
6	80.00	0.50	0.710	0.360		3.00	121.70	197.80	76.10	54.03	
7	75.00	0.50	0.670	0.340		3.75	127.60	197.80	70.20	47.03	
8	70.00	0.50	0.630	0.320		4.50	133.92	197.80	63.88	40.24	
9	64.00	0.50	0.590	0.295		5.40	141.84	197.80	55.96	33.02	
10	58.00	0.80	0.560	0.450		6.30	150.25	197.80	47.55	26.63	
11	51.62	0.80	0.526	0.420		7.26	159.60	197.80	38.20	20.09	
12	44.88	0.80	0.496	0.397		8.27	170.10	197.80	27.70	13.74	
13	37.84	2.20	0.468	1.030		9.32	182.70	197.80	15.10	7.07	
14	30.50	2.20	0.442	0.970		10.43	195.30	197.80	2.50	1.11	
Σ				5.130	0.55					623.60	67.03

AMC : Annual Maintenance Cost
SPPWF : Single Payment Present Worth Factor
PWV : Present Worth Value
EUAC : Equivalent Uniform Annual Cost

TABLE 7 COMPARISON OF COST ELEMENTS OF ALTERNATIVES

	MAINTENANCE ALTERNATIVE			
	SURFACE TREATMENT	THIN OVERLAY	THICK OVERLAY	RECONSTRUCTION
EUA (I.C)	1.08	1.02	1.06	1.53
EUA (AMC)	0.55	0.35	0.23	0.25
EUA (IC+AMC)	1.63	1.37	1.29	1.78
EUA (BENEFITS)	67.03	71.68	73.18	75.12
EUA (NET)	65.40	70.31	71.89	73.34

TABLE 8 BEST ALTERNATIVE AND ASSOCIATED MINIMUM COSTS UNDER DIFFERENT CURRENT CONDITION CASES

	CURRENT PCI = 30		CURRENT PCI = 60		CURRENT PCI = 80	
	i=6	i=12	i=6	i=12	i=6	i=12
SELECTION BASED ON INITIAL COST	THIN OVERLAY (1.02)	SURFACE DRESSING (1.52)	THIN OVERLAY (0.89)	SURFACE DRESSING (1.20)	SURFACE DRESSING (0.42)	SURFACE DRESSING (0.50)
SELECTION BASED ON INITIAL + MAIN. COST	THICK OVERLAY (1.29)	THIN OVERLAY (1.86)	THICK OVERLAY (1.09)	THIN OVERLAY (1.43)	SURFACE DRESSING (0.60)	SURFACE DRESSING (0.67)
SELECTION BASED ON BENEFITS	RECONST (73.34)	RECONST. (78.93)	RECONST. (30.06)	THICK OVERLAY (33.38)	THICK OVERLAY (12.26)	THIN OVERLAY (13.10)

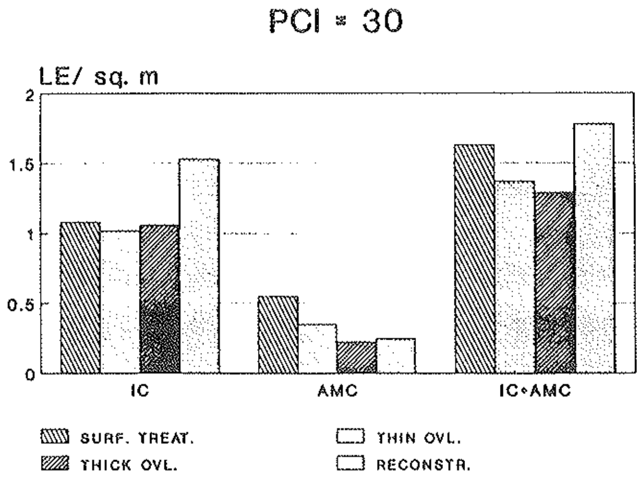

FIGURE 5 EUAC values for different maintenance alternatives under different cost consideration policies.

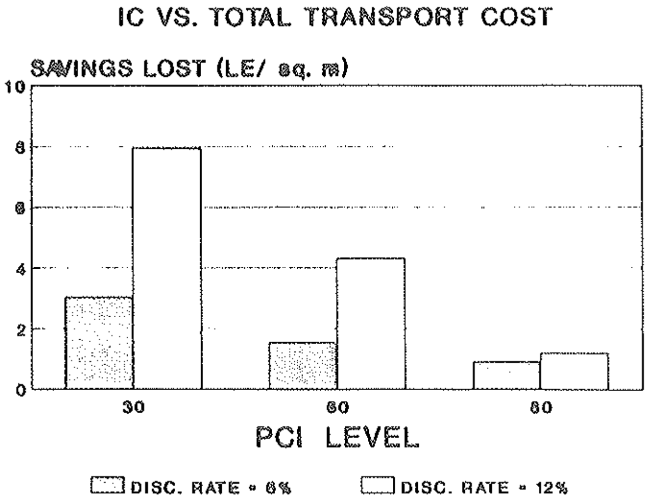

FIGURE 7 Savings lost from not considering both annual maintenance cost and VOCs.

Column 8. VOC calculated using earlier procedure, represented in units of L.E./m^2 to allow direct comparison of VOC and maintenance costs.

Column 9. VOC at terminal PCI value (30 in this example), using procedure of previous example.

Column 10. VOC savings (benefits) resulting from applying the alternative under consideration = Column 9 − Column 8.

Column 11. PWV of VOC savings (benefits) = Column 4 − Column 10.

Column 12. Benefits expressed in EUAC form = CRF * PWV of benefits.

SUMMARY

A procedure was developed for helping decision makers in developing countries in selecting the best maintenance alternative among several available, taking into consideration initial and annual maintenance costs associated with each available alternative in addition to the associated VOC during the service life of each alternative. VOC savings are used to represent the benefits of applying a maintenance alternative. VOC calculations are based on the World Bank's models (*10*).

The procedure is based on relating both the agency costs (initial and maintenance costs) and user costs (VOCs) to the pavement surface condition. Pavement surface condition is presented in this procedure in terms of the PCI value. A life cycle cost analysis is then applied and the alternative with the minimum EUAC is considered to be the best one.

An example is presented that describes a step-by-step application of the procedure. The main results for this example are presented in Tables 7 and 8 and in Figures 5–8.

Table 6 and Figures 5 and 6 indicate the EUAC values associated with different maintenance alternatives under different cost item considerations. For instance, if the initial cost is the only criterion for selecting the best alternative, then thin overlay will be selected as the best alternative, with an EUAC value of 1.02 L.E./m^2. On the other hand, thick overlay will be selected (with EUAC of 1.29 L.E./m^2) if the

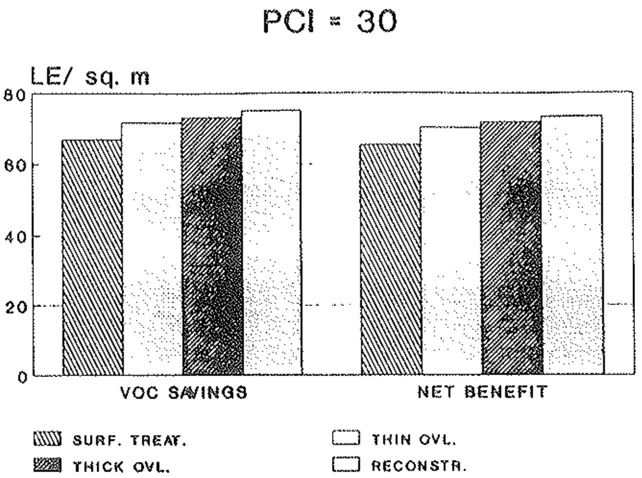

FIGURE 6 EUAC values for VOC savings and net benefits associated with the selection of different maintenance activities.

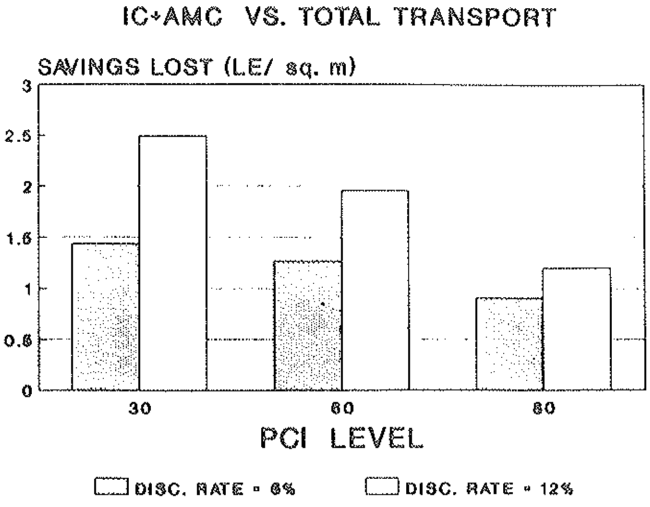

FIGURE 8 Savings lost from not considering VOCs.

criterion of selection is based on both minimum initial and annual maintenance cost; and reconstruction will be selected if the criterion is based on maximum benefits (VOC savings = 75.12 L.E./m^2) or maximum net benefits (73.34 L.E./m^2).

The selected alternative and its associated costs are significantly dependent on the selection criterion. This, in turn, implies that considerable savings could be lost if the selection criterion neglects one or more of the cost categories (VOC, in particular). This particular point is further analyzed and presented in Table 8 and Figures 7 and 8 where different PCI levels (current and terminal) are used (PCI = 30, 60, and 80) and two levels of the inflation-adjusted discount rate (6 and 12 percent) are used. Table 8 lists the selected best alternative under each criterion for the different cases of current PCI values and discount rates as described earlier. Figure 7 shows the corresponding savings lost after neglecting both the annual maintenance and VOC and basing the selection on the initial cost only, which is the case in most countries in this region. Figure 8, on the other hand, shows the values of savings lost after neglecting VOC only. These two figures indicate an extremely important issue, particularly in developing countries in which decisions, in most cases, are based on minimum initial cost plus some indications about the performance of different maintenance alternatives. Finally, the results strongly recommend alternatives with higher initial costs to obtain maximum benefits.

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