

# A Simplified Pavement Maintenance Cost Model

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This paper presents a summary of an effort to develop a simplified pavement maintenance cost model for the Roads and Bridges Authority (RBA) of Egypt. The model was based primarily on modeling maintenance costs as a function of pavement condition. The study site included the highway network of the East-Delta district as well as several individual highways in the Delta region. The data collected for this study included information on pavement condition in terms of distress type and class. Pavement condition data were obtained from a previous large-scale study conducted in Egypt. Maintenance practices and unit costs were obtained from RBA's files, as well as from extensive interviews with experts from highway construction companies. The results indicated a significant sensitivity of maintenance costs to pavement condition at a certain condition range. It was determined that substantial savings in maintenance costs can be obtained by keeping pavement condition from reaching this condition range or at least by prolonging the period before this range is reached. In addition, it was recommended that the presence of such maintenance cost models can draw the attention of top management, particularly in developing countries, to the importance of the systematic monitoring of pavement condition as well as to the fact that maintenance budget allocation should not always follow the rule of "the worst is first."

Pavement maintenance management (PMM) is the process of coordinating and controlling a comprehensive set of activities to maintain pavements. Simply stated, it enables the best use of available resources by minimizing costs and maximizing benefits (1).

A successful PMM scheme should include a maintenance cost model that is sensitive and responsive to pavement condition. Reliable cost estimates can then be obtained based on actual factors affecting pavement condition (such as materials, design, quality control, and policies).

In some U.S. highway departments and in Egypt, as well as in several other developing countries, pavement maintenance cost estimates are often based primarily on previous experience. This usually leads to a wide gap between the estimates and actual project costs. It is believed that the use of a successful cost model can reduce this gap. A cost model can quantify the consequences of different pavement maintenance activities. In addition, it can specify those condition regions at which pavement maintenance costs are most sensitive to pavement condition. Policies can be set to keep pavements from reaching these critical regions or at least to prolong the period before they are reached.

This study was initiated to develop a simplified pavement

maintenance cost model to be used by the Egyptian Roads and Bridges Authority (RBA) in the development of a Maintenance Management System (MMS). The model presented in this paper employs condition data (represented by the most common method of pavement evaluation—pavement surface condition assessment) and detailed costing of different maintenance activities and practices.

## DEVELOPMENT OF MAINTENANCE COST MODEL

### Purpose of Model

The main purpose of the maintenance cost model is to determine the costs required to restore pavement surface condition to its "as-constructed state" for various levels of serviceability. This information is important as feedback for planning, design, and construction. The type and degree of maintenance can influence the rate of serviceability loss of pavement. The maintenance cost model can help pavement managers plan, direct, and control maintenance activities so an acceptable level of service, consistent with the class of pavement, can be achieved. In addition, it can assist in evaluating the methods and materials used in maintenance so that efficient, economical practices can be developed.

### Network and Section Identification

The network considered in the development of this model included all paved highways in the East-Delta District as well as a set of individual highways representing different areas of the overall Delta paved network. The network length was 1592 km, of which 1547 km were managed by RBA and 45 km by the Ministry of Reconstruction. The network was divided into 327 homogeneous sections on the basis of the following factors:

- Pavement types and age,
- Layer types and thicknesses,
- Traffic volumes,
- Geometric characteristics (such as number of lanes, lane width, and shoulders), and
- Highway class.

Table 1 shows the highway network links considered in this study, while Figure 1 presents a map of the study network.

TABLE 1 HIGHWAY NETWORK LINKS

Highway Name	Length (km)	Authority	District Name
Cairo-Alex. (Agriculture)	204 x 2 (2-Way)	RBA	146km C. Delta Dis. 126km M. Delta Dis. 200km W. Delta Dis.
Cairo-Alex (Desert)	205	RBA	90.5km C. Delta Dis. 114.5km W. Delta Dis.
Cairo-Ism. (Desert)	98	RBA	34.0km C. Delta Dis 64.0km I. Delta Dis
Cairo-Suez	118	RBA	40km C. Delta Dis. 78km I. Delta Dis.
Bnha-Mansoura Damietta	149	RBA	East-Delta
Damietta-Dibh	45	Ministry of Reconstruction	-----
Dibh-Port Said	18	RBA	East-Delta
Banha-Zagazig - Salehia	106	RBA	East-Delta
Hawata-Sherbin- Blqas	79	RBA	East-Delta
Talkha-Sherbin- Damietta	90	RBA	East-Delta
Abu Hammad-Zagazig -Mit Ghamr	53	RBA	East-Delta
Belbis-Mansoura	75	RBA	East-Delta
Abu Kebir-Senbe Ilawen	28	RBA	East-Delta
Dekerness-Mansoura	28	RBA	East-Delta
Faqous-Hessenia	25	RBA	East-Delta
Talkha-Blqas	18	RBA	East-Delta
Esbt Bata - Daheria	49	RBA	East-Delta

Total=1592  
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### Condition Data

The data included in this study were based on a condition survey conducted in the Delta Study (2) in 1981. In this study, the most common distress types in Egypt were found to be

- Cracking (longitudinal, transverse, map cracks),
- Surface damage (holes, bleeding, crumbling edge), and
- Deformations (rutting, unevenness).

The distress types and their codes are shown in Table 2.

The Texas condition survey method (3) was used in the Delta Study. The original Texas method defined the distress by its type, severity, and density. However, in the Delta Study, the distress severity and the distress density were combined

and called the distress class (in other words, the distress was defined by its type and class only). Pavement distress class ranged from 0 to 3, where 0 meant no distress, 1 meant low density, 2 meant medium density, and 3 meant high density. Table 3 shows the percentages of deteriorated areas (densities) corresponding to each distress (type and class), known as the density matrix.

In the research described in this paper, the 327 sections were evaluated separately, and a condition rating index (CRI) was calculated. The CRI followed the survey method used in the Delta Study.

On the basis of professional judgment, the Texas "scores" were modified as shown in Table 4. The CRI can be calculated by summing the score for each distress (in the same section) and determining a general rating for the section (see Table

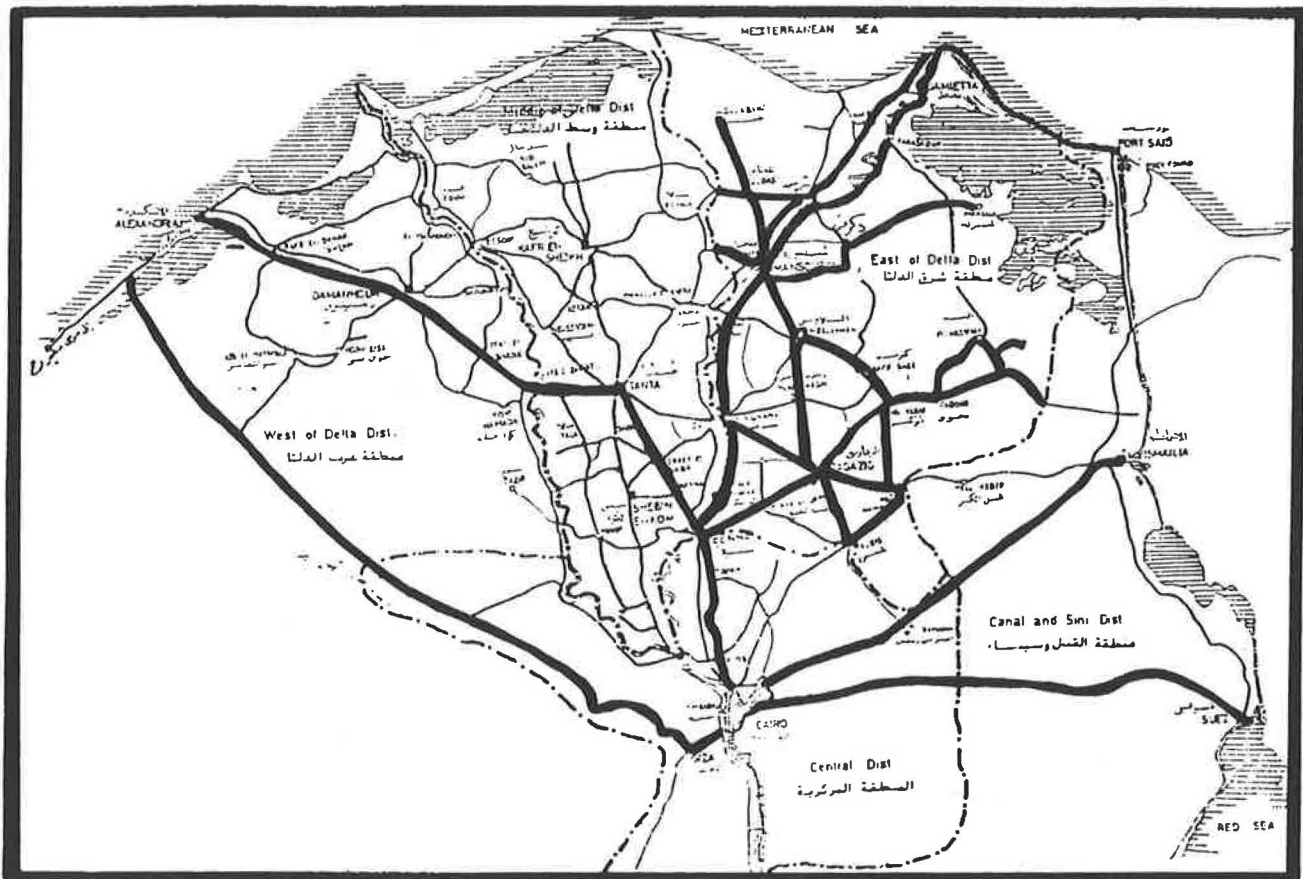


FIGURE 1 Highway network links.

TABLE 2 DISTRESS TYPES AND CODES

Distress Code	Distress Type (Name)
1	Longitudinal cracks
2	Transverse cracks
3	Map cracks
4	Potholes
5	Bleeding
6	Crumbling edges
7	Longitudinal unevenness
8	Rutting

TABLE 3 DENSITY MATRIX

Distress Code <sup>a</sup>	Density by Distress Class <sup>b</sup>			
	0	1	2	3
1	0	10%	15%	20%
2	0	10%	15%	20%
3	0	5%	15%	25%
4	0	0.03%	0.15%	0.3%
5	0	10%	17.5%	25%
6	0	10%	20%	30%
7	0	10%	20%	30%
8	0	10%	20%	30%

<sup>a</sup>Refer to Table 2.

<sup>b</sup>The distress classes are as follows: 0 = no distress, 1 = low density, 2 = medium density, and 3 = high density.

5). For example, if the condition survey results of a section were as follows,

Distress Code	Distress Class
1	1
2	1
3	2
4	1
5	0
6	3
7	1
8	3

then, using the scores given in Table 4, the CRI is

$$CRI = 10 + 7 + 15 + 15 + 0 + 10 + 5 + 7 = 69$$

where the score corresponding to distress 1/class 1 equals 10, distress 2/class 1 equals 7, and so on, as indicated in Table 4.

The CRI score of 69 means that the section's general rating is fair (see Table 5). A high CRI score represents a poor condition, and a low score represents a good condition.

**Maintenance Activities and Unit Costs**

Interviews with experienced highway engineers in Egypt, as well as results of previous studies (2,4), indicated that the most common maintenance activities in Egypt are

- Sealing cracks,
- Scarifying,

TABLE 4 WEIGHTING FACTORS FOR DIFFERENT DISTRESS TYPES

Distress Code <sup>a</sup>	Modified Score by Distress Class <sup>b</sup>			
	0	1	2	3
1	0	10	15	20
2	0	7	12	15
3	0	10	15	25
4	0	15	20	25
5	0	2	5	7
6	0	5	7	10
7	0	5	7	10
8	0	2	5	7

<sup>a</sup>Refer to Table 2.

<sup>b</sup>The distress classes are as follows: 0 = no distress, 1 = low density, 2 = medium density, and 3 = high density.

TABLE 5 SECTION RATINGS

CRI	Section Class
≤30	Very good
30–60	Good
60–70	Fair
70–85	Poor
≥85	Very poor

TABLE 6 AVAILABLE MAINTENANCE ACTIVITIES

Maintenance Activity Code	Maintenance Activity Name
X1	Sealing cracks
X2	Scarifying
X3	Seal coating
X4	Skin patching without applying wearing surface
X5	Skin patching
X6	Deep patching without applying wearing surface
X7	Deep patching
X8	Overlay

- Seal coating,
- Skin patching,
- Deep patching, and
- Overlaying (see Table 6).

Unit cost computation approaches for each of these activities are briefly described in the following sections.

#### Sealing Cracks

**Cracks Less Than 3 mm in Width** The common practice is to fill cracks less than 3 mm wide with a rapid-curing cutback liquid asphalt (RC-5) or with an asphalt cement (60/70 or 80/100 penetration grades). The rate of application used is approximately 0.25 kg/m<sup>2</sup>.

**Cracks Wider Than 3 mm** Two methods are commonly used for cracks wider than 3 mm. In the first method, a liquid asphalt or an asphalt cement is applied, then clean sand is spread over the cracked area. The second method uses a sand mix to fill the cracks. The unit cost calculation for this activity is based on an average condition; therefore, the cost is calculated for an application of 0.25 kg/m<sup>2</sup> of asphalt cement and 0.5 cm of clean sand.

#### Scarifying

Scarifying is defined as spreading a fine aggregate (sand) during hot weather and then scarifying this aggregate using a scraper. The cost calculation is based on the cost of spreading the sand (at an average depth of 2 cm) and the cost of scarifying the sand.

#### Seal Coating (Surface Dressing)

Two alternatives are given for seal coating:

1. Sand coat (1 cm sand + 1.5 kg/m<sup>2</sup> of liquid asphalt), and
2. Seal coat (1 cm crushed stone + 1.5 kg/m<sup>2</sup>) of liquid asphalt.

#### Skin Patching

Skin patching is defined as removing the top 5 cm of the deteriorated surface and replacing it with a new asphalt concrete surface mix. Cost calculations are based on three items:

1. Cost of removing, loading, and transporting the top 5 cm of the old surface,
2. Cost of tack coating the vertical sides of the cut with asphalt (0.5 kg/m<sup>2</sup>), and
3. Cost of securing, placing, and compacting the new asphalt concrete surface mix.

#### Deep Patching

In Egypt, deep patching is defined as the removal of the full pavement depth (surface, binder, base course layers, and 15 cm of the upper portion of the subgrade) and the placement of new courses. Cost items include the following:

- Cost of removing, loading, and transporting the full depth of pavement (approximately 45 cm thick),
- Cost of tack coating the vertical sides of the cut with asphalt (0.5 kg/m<sup>2</sup>),
- Cost of securing, placing, and compacting 20 cm of pit-run gravel as a base course,
- Cost of prime coating the base course surface with a liquid asphalt (1.5 kg/m<sup>2</sup>),
- Cost of securing, placing, and compacting 5 cm of an asphalt concrete binder course mix,
- Cost of tack coating the binder course surface with a liquid asphalt (0.5 kg/m<sup>2</sup>), and
- Cost of securing, placing, and compacting 5 cm of an asphalt concrete surface course mix.

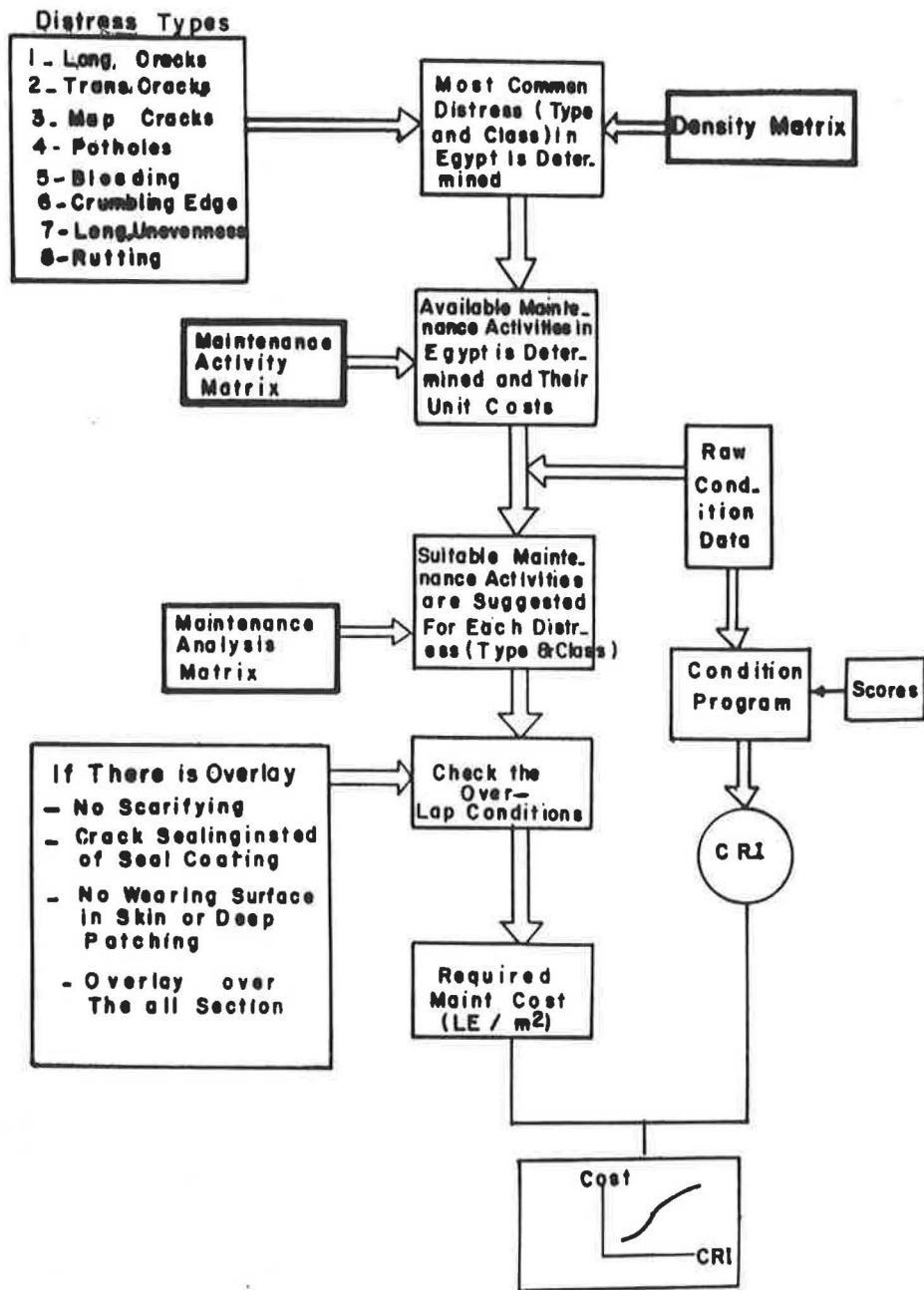


FIGURE 2 Maintenance cost model.

### Overlaying

The overlay includes two layers: a 5-cm premixed macadam and a 3-cm asphalt concrete mix for the surface. It is suitable for pavements that have relatively even surfaces and low traffic volumes.

### Maintenance Cost Model

As mentioned earlier, the main purpose of the maintenance cost model (MCM) was to determine the cost (per square meter) required to restore pavement surface condition to its as-constructed state. Six steps were followed to develop this model (see Figure 2):

1. The most common distresses (types and classes) in Egypt were identified on the basis of the results of the Delta Study (2) and meetings with the East-Delta district engineers (see the previous section on Condition Data).

2. For each distress (type and class), a maintenance activity was suggested (considering that distress as the only one in the section). Table 7 shows the suggested maintenance activities for the different distress types and classes.

3. After identifying the suggested maintenance activities individually, the overlap between these activities was considered.

4. To prevent any overlap between maintenance activities on a section, the following conditions were established:

a. If the section required an overlay, other maintenance activities over this section would be specified as follows: (1)

TABLE 7 SUGGESTED MAINTENANCE ACTIVITIES FOR EACH DISTRESS (TYPE AND CLASS)

Distress Code <sup>a</sup>	Maintenance Activity Code by Distress Class <sup>b</sup>			
	0	1	2	3
1	None	X1	X1	X3
2	None	X1	X1	X3
3	None	X5	X5	X8
4	None	X7	X7	X7
5	None	None	X2	X2
6	None	None	X5	X5
7	None	X5	X5	X5
8	None	None	X5	X5

<sup>a</sup>Refer to Table 2.

<sup>b</sup>The distress classes are as follows: 0 = no distress, 1 = low density, 2 = medium density, and 3 = high density.

TABLE 8 MAINTENANCE ACTIVITY UNIT COSTS

Maintenance Activity Code <sup>a</sup>	Maintenance Activity Cost (£E/m <sup>2</sup> )
X1	0.18
X2	0.20
X3	0.92
X4	1.15
X5	5.30
X6	7.50
X7	22.50
X8	6.90

<sup>a</sup>Refer to Table 6.

no scarifying would be conducted; (2) sealing cracks would replace seal coating; and (3) skin or deep patching would be applied without a wearing surface.

b. The overlay would be carried over the entire section (density equals 1.0).

The mathematical representation of these conditions is as follows:

If there is X8, then

$$X2 = 0$$

$$X3 = X1$$

$$X5 = X4$$

$$X7 = X6$$

$$D_8 = 1.0$$

5. The maintenance activity costs (Egyptian pound £E/m<sup>2</sup>) were obtained from the East-Delta district files and were verified by the Arab Contractors Company engineers. Table 8 shows the unit cost (£E/m<sup>2</sup>) associated with the different maintenance activities.

6. The section maintenance cost (£E/m<sup>2</sup>) was then calculated as follows:

$$C_T = \sum D_i * c_i$$

where

$C_T$  = total unit cost (£E/m<sup>2</sup>) of the entire section,

$D_i$  = density of the  $i$ th distress type class (from Table 3), and

$c_i$  = maintenance unit cost corresponding to the  $i$ th distress type class (from Table 8).

### Application of the MCM

The application of the MCM can be best illustrated through examples. The two examples provided below include actual condition cases. In each example, the distress data (type and class) are presented first. The steps described above are applied in a systematic manner to determine the section maintenance unit cost.

#### Example 1, Highway 5, Station 38.6

Distress Code	Distress Class
1	3
2	3
3	3
4	1
5	2
6	2
7	2
8	1

The maintenance cost was calculated as in Table 9. Because there was an X8 maintenance activity code, X2 = 0, X3 = X1, X5 = X4, and X7 = X6, and the density of X8 = 1.0 (overlap condition).

#### Example 2, Highway 50, Station 159

The distress class was 1 for all distress codes. The maintenance cost was calculated as shown in Table 10. There was no X8 maintenance activity code (overlap condition).

### RELATIONSHIP BETWEEN PAVEMENT CONDITION AND MAINTENANCE COST

Although a pavement condition rating can provide the decision maker with a clear picture of how the network is behaving, it does not indicate how much it will cost to repair the network. Without a clear model of the relationship between pavement condition and repair cost, the ultimate goal of pavement condition assessment cannot be achieved.

The purpose of this study, therefore, was to develop the relationship between the CRI and the corresponding repair and maintenance cost based on the MCM. The following procedure was used to develop this relationship:

1. Each of the samples stored in the condition data base was considered.
2. The existing distresses and their corresponding classes were identified, and the CRI was calculated.
3. The identified distresses were processed through the



TABLE 9 CALCULATION OF MAINTENANCE COST FOR EXAMPLE 1: X8 (OVERLAP) CONDITION PRESENT

	Distress Code							
	1	2	3	4	5	6	7	8
Class	3	3	3	1	2	2	2	1
Density (from Table 3)	20%	20%	25%	0.03%	17.5%	20%	20%	10%
Maintenance activity (from Table 7)	X3	X3	X8	X7	X2	X5	X5	—
Modified density (according to overlap condition)	0.20	0.20	1.0	0.0003	0.175	0.2	0.2	0.1
Modified maintenance activity (according to overlap condition)	X1	X1	X8	X6	—	X4	X4	—
Modified maintenance activity unit cost (according to overlap condition)	0.18	0.18	6.9	7.5	—	1.15	1.15	—
Modified density * modified maintenance activity unit cost	0.036	0.036	6.9	0.002	—	0.23	0.23	—

NOTE: All costs £E/m<sup>2</sup>. Because there is X8, X2 = 0, X3 = X1, X5 = X4, X7 = X6, and the density of X8 = 1.0. Total maintenance cost = 0.036 + 0.036 + 6.9 + 0.002 + 0.23 + 0.23 or 7.434 £E/m<sup>2</sup> (CRI for this section = 96).

TABLE 10 CALCULATION OF MAINTENANCE COST FOR EXAMPLE 2: NO X8 (OVERLAP) CONDITION

	Distress Code							
	1	2	3	4	5	6	7	8
Class	1	1	1	1	1	1	1	1
Density (from Table 3)	10%	10%	5%	0.03%	10%	10%	10%	10%
Maintenance activity (from Table 7)	X1	X1	X5	X7	—	—	X5	—
Modified density (according to overlap condition)	0.1	0.1	0.05	0.0003	0.1	0.1	0.1	0.1
Modified maintenance activity (according to overlap condition)	X1	X1	X5	X7	—	—	X5	—
Modified maintenance activity unit cost	0.18	0.18	5.3	22.5	—	—	5.3	—
Modified density * modified maintenance activity unit cost	0.018	0.018	0.265	0.007	—	—	0.53	—

NOTE: All costs £E/m<sup>2</sup>. Total maintenance cost = 0.018 + 0.018 + 0.265 + 0.007 + 0.53, or = 0.84 £E/m<sup>2</sup>. (CRI for this section = 56).

MCM, and the most suitable maintenance action was identified.

4. The cost of applying the selected maintenance activity was determined.

5. The maintenance cost for a particular sample with a known CRI was determined.

6. By repeating the first five steps for all samples in the condition data base, a set of observations was obtained, containing CRI values and their corresponding maintenance costs.

7. The average maintenance cost for each CRI class (as indicated in Table 11) was calculated.

Figure 3 is a graphical representation of the maintenance cost versus CRI relationship developed on the basis of the results presented in Table 11. This figure indicates several important results:

1. The cost versus CRI relationship can be divided into three basic regions with respect to the rate of the cost increase. In the first region (CRI < 60—good condition), the maintenance cost increases very slowly as the CRI increases (i.e., gets worse). In the second region (60 < CRI < 95—medium condition), the maintenance cost increases sharply as the CRI increases. Finally, in the third region (CRI > 95—bad con-

TABLE 11 PAVEMENT CRI GROUPS AND CORRESPONDING MAINTENANCE COSTS

Condition Group	CRI Range	Average Maintenance Cost (£E/m <sup>2</sup> )
1	<10	—
2	10–20	0.67
3	20–30	0.68
4	30–40	0.71
5	40–50	0.88
6	50–60	1.16
7	60–70	2.03
8	70–80	3.53
9	80–90	5.79
10	90–100	7.65
11	100–120	7.86

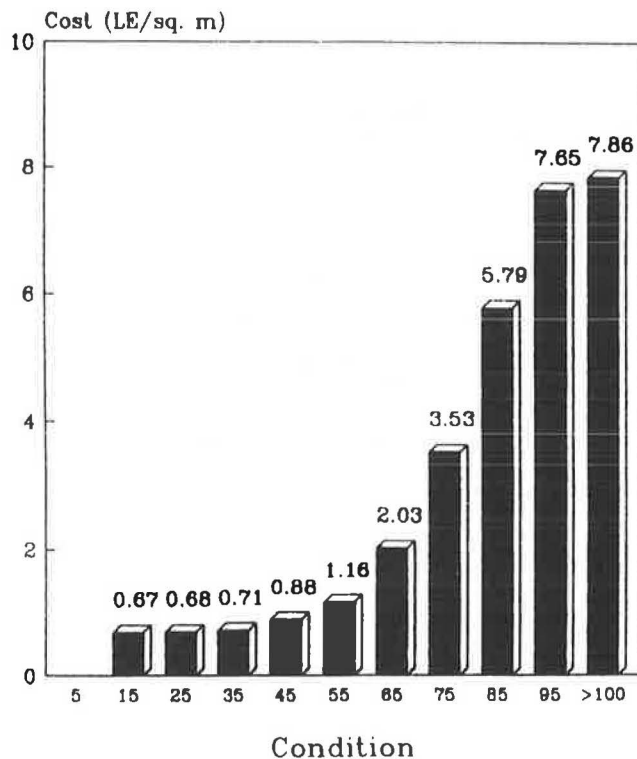


FIGURE 3 Relationship between maintenance costs and pavement CRI groups.

dition), the rate of the maintenance cost increase becomes small again. Mathematically, these three rates can be considered as follows:

$$R = \frac{C_2 - C_1}{CRI_2 - CRI_1} \quad (\text{£E/m}^2/\text{CRI point})$$

where

- $R$  = rate of maintenance cost increase due to 1-point increase in CRI,
- $C_1$  = required maintenance cost at the first stage,
- $CRI_1$  = CRI at the first stage,
- $C_2$  = required maintenance cost at the second stage, and
- $CRI_2$  = CRI at the second stage.

Thus, the rate of the maintenance cost increase in the first region is equal to

$$\left( R_1 = \frac{1.16 - 0.67}{55 - 15} \right) = 0.012 \quad \text{£E/m}^2/\text{CRI point}$$

Similarly, the corresponding rates of increase in the second and third regions are  $R_2 = 0.162$  and  $R_3 = 0.014$ , respectively. These rates are graphically displayed in Figure 4.

2. According to the rates described above, the following can be used as a guide when developing a maintenance program:

- To avoid a sharp increase in maintenance cost, pavements should not be allowed to reach the second stage of deterioration, if possible. This emphasizes the importance of conducting preventive maintenance to prolong the period before the pavement reaches the critical stage.
- If the pavement CRI does reach the second stage, the appropriate maintenance must be carried out immediately, because any delay in maintenance causes a sharp increase in the corresponding maintenance cost.
- Maintenance of pavements in the third stage can be delayed, particularly for roads carrying low volumes or having low strategic importance, without a considerable maintenance cost increase.

3. The highway maintenance priority (from a maintenance cost point of view) can be ranked as follows (see Figure 5):

- 1st—Highways at the end of the first stage or in the second stage,
- 2nd—Highways in the first stage, and
- 3rd—Highways in the third stage.

## CONCLUSIONS

On the basis of the research described in this paper, it was concluded that a successful maintenance program cannot be applied without a pavement monitoring program, at least for pavement surface condition. This is particularly important in developing countries, where maintenance programs usually follow an ad hoc approach and the predominant rule in priority setting is "the worst is first." The results of this study indicate that this rule is not always valid.

In addition, the results strongly suggest the use of a network ranking approach rather than a section-by-section approach. This can be illustrated through a very simple example. If the section-by-section approach is followed, then a section in the third (worst) stage may be selected for repair with approximately 7 £E/m<sup>2</sup>. If, however, a network ranking approach is used, the repair of these sections might be deferred and other sections just approaching the critical stage (stage 2) might be selected. In this case, the average cost to repair the selected sections would be about 1 £E/m<sup>2</sup>. In other words, with the same budget as that allocated to the badly deteriorated section, seven other sections (each with the same area as the badly deteriorated one) can be repaired, their condition can be preserved, and the period before they reach the critical stage can be delayed. Undoubtedly, this would lead to a better network condition.



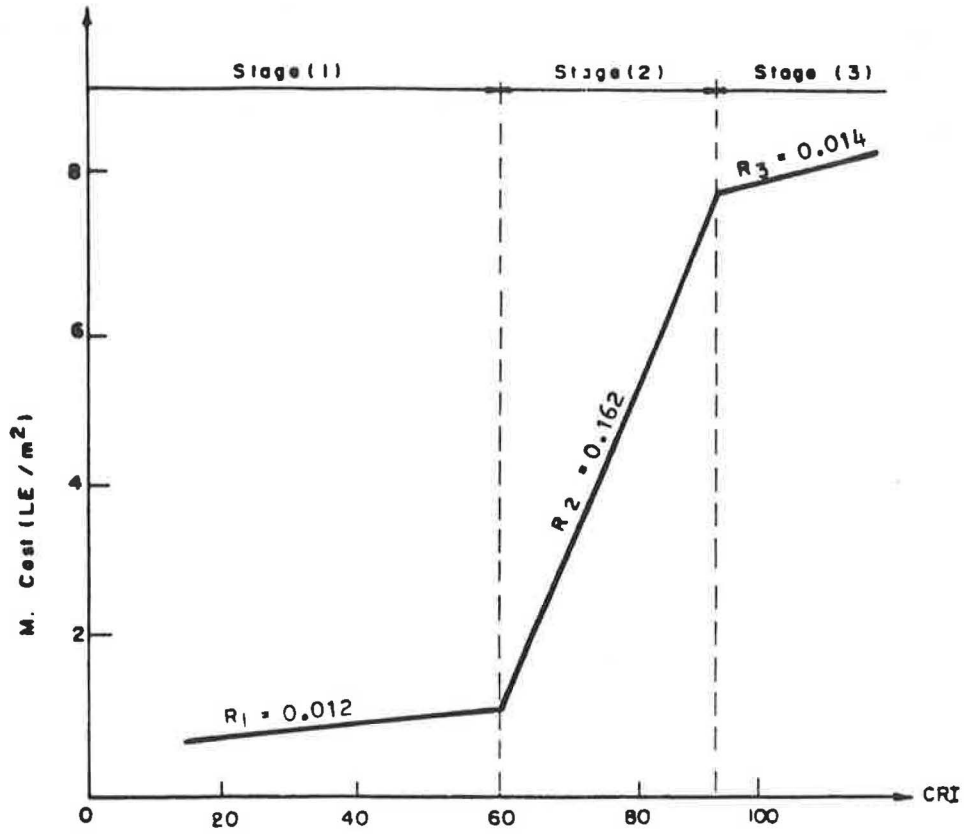


FIGURE 4 Relationship between rate of maintenance cost increase and CRI change.

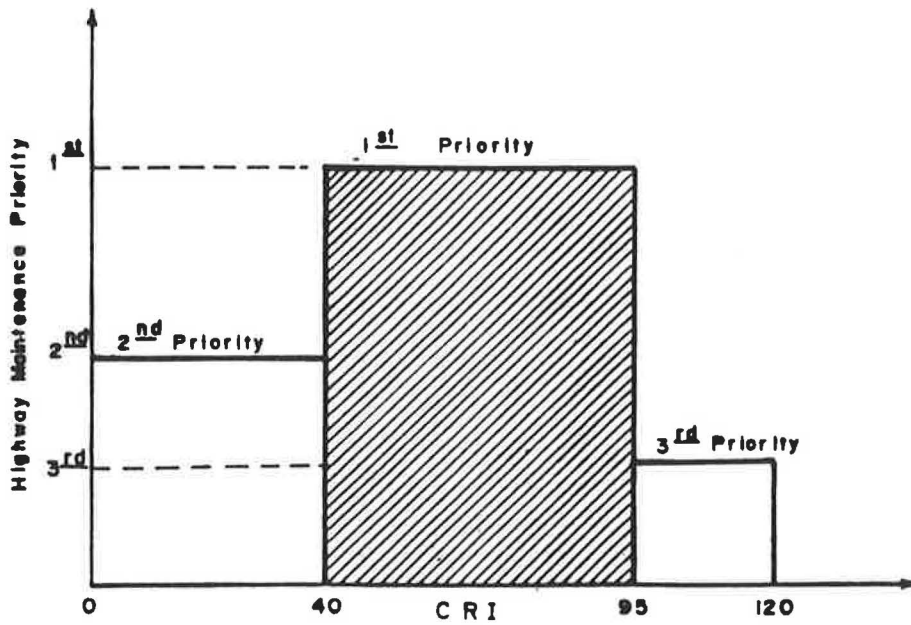


FIGURE 5 Highway maintenance priority.

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*Publication of this paper sponsored by Committee on Maintenance and Operations Management.*