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The Road Pavement Condition Index (PCI) Evaluation and Maintenance: A Case Study of Yemen

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Abstract: The pavement condition index (PCI) is a simple, convenient and inexpensive way to monitor the condition of the surface of roads, identify maintenance and rehabilitation (M-and-R) needs as well as ensure that road maintenance budgets are spent wisely. In this research, the pavement condition was evaluated in terms of the surface distresses existing at the time of the field evaluation. The PCI procedure was used in this research because it deals with the subject of pavement distress identification most comprehensively and is based on a sound statistical technique of pavement sampling.

Because of limited maintenance fund availability in Yemen, timely and rational determination of M-and-R needs and priorities are very important factors. The PAVER™ (1982) condition rating procedure, as described in the *Technical Manual TM 5-623*, *Pavement Maintenance Management*, which is based on the PCI, was used in this study to evaluate a major heavy-traffic road corridor connecting Aden city (the commercial capital of Yemen) with major cities located in the northern region of the country. Based on the PCI of the road sections, the necessary maintenance or rehabilitation procedure is suggested.

Keywords: asphalt pavement evaluation, visual inspection, pavement condition index (PCI)

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1 Introduction

Pavement distresses are classified into two different categories. The first is known as functional failure. In this case, the pavement does not carry out its intended function without either causing discomfort to passengers or high stresses to vehicles. The second, known as structure failure, includes a collapse of pavement structure or the breakdown of one or more components of the pavement with such magnitude that the pavement becomes incapable of sustaining the loads imposed upon its surface (Smith et al. 1979). In some cases, one type of failure may be caused by the other type, but mostly there is only one type of failure.

Functional failure depends primarily on the degree of surface roughness. Structure failure in a flexible pavement may be a result of fatigue, consolidation or shear, developing in the subgrade, sub-base, base course or surface (Yoder and Witzak 1975).

Road pavements require continuous maintenance and rehabilitation (M-and-R) works to prevent deterioration caused by repetitive traffic loading and environmental factors. However, with the limited fund allotted for pavement work, there is a need to use the available funds as effectively as possible. To accomplish this, a systematic procedure for scheduling M-and-R works to optimize the benefits to road users and minimize costs to the agency responsible for pavement management is recognized as a useful measure. Known as the Pavement Management System (PMS), such a system would allow administrators and engineers to allocate funds, personnel, resources, etc. most effectively (Hall et al. 1992). The Pavement Condition Index (PCI) is normally determined annually in order to evaluate changes that occur in the road network system.

The PCI rating of a roadway is based on the observed surface distresses. The PCI rating is not a direct measure of structural capacity, skid resistance or road roughness; however, it is an objective tool for assessing the M-and-R needs of a roadway section with respect to an entire pavement system (Hajj et al. 2011).

Some uses and benefits of PCI include the identification of the need for immediate M-and-R (Galehouse et al. 2003) of roads; development of a road network, preventive maintenance strategies and budgets; and evaluation of pavement materials and designs.

2 Description of study area

In this study, an attempt was made to evaluate and suggest suitable M-and-R works for a major road corridor connecting Aden city (the commercial capital of Yemen), located in the south, with major cities located in the northern region; this road is used for transporting goods and people, with a large percentage of heavy vehicles moving on it. This road is the Al-Fiush Road, which is 10.84 km (6.74 miles) long. It is a two-lane road, with one lane in each direction, and it is an asphalt pavement road, constructed 8 years earlier. The daily traffic moving on this road in the north direction includes 8,704 vehicles, with 58% heavy vehicles, while in the south direction, the traffic comprises 8,494 vehicles, with 45% heavy vehicles. Figure 1 shows the study area.

3 Study methodology

The pavement maintenance management system PAVER™ (1982) was used to evaluate and maintain road sections in this study. This manual was strictly followed for the purpose of evaluation and for the framing of maintenance policy.

Road classification (A, B, C, etc.) based on the traffic volume moving on sections of Al-Fiush Road was obtained as per *Technical Manual TM5-822-2* (1987).

Similarly, the traffic evaluation of vehicles moving on Al-Fiush Road sections was done as per *Technical Manual TM5-822-2* (1987). Based on the information available in this manual, the traffic category was obtained, and knowing the traffic category and road classification, the pavement design index was established. By knowing the pavement design index and California bearing ratio (CBR) values of the subgrade and base materials, the pavement's load-carrying capacity was obtained as per *TM 5-623* (PAVER 1982); this step indicates whether the pavement sections under consideration are structurally strong enough for load carrying or are structurally failed and incapable of carrying the traffic loads imposed and therefore need structural rehabilitation or reconstruction.

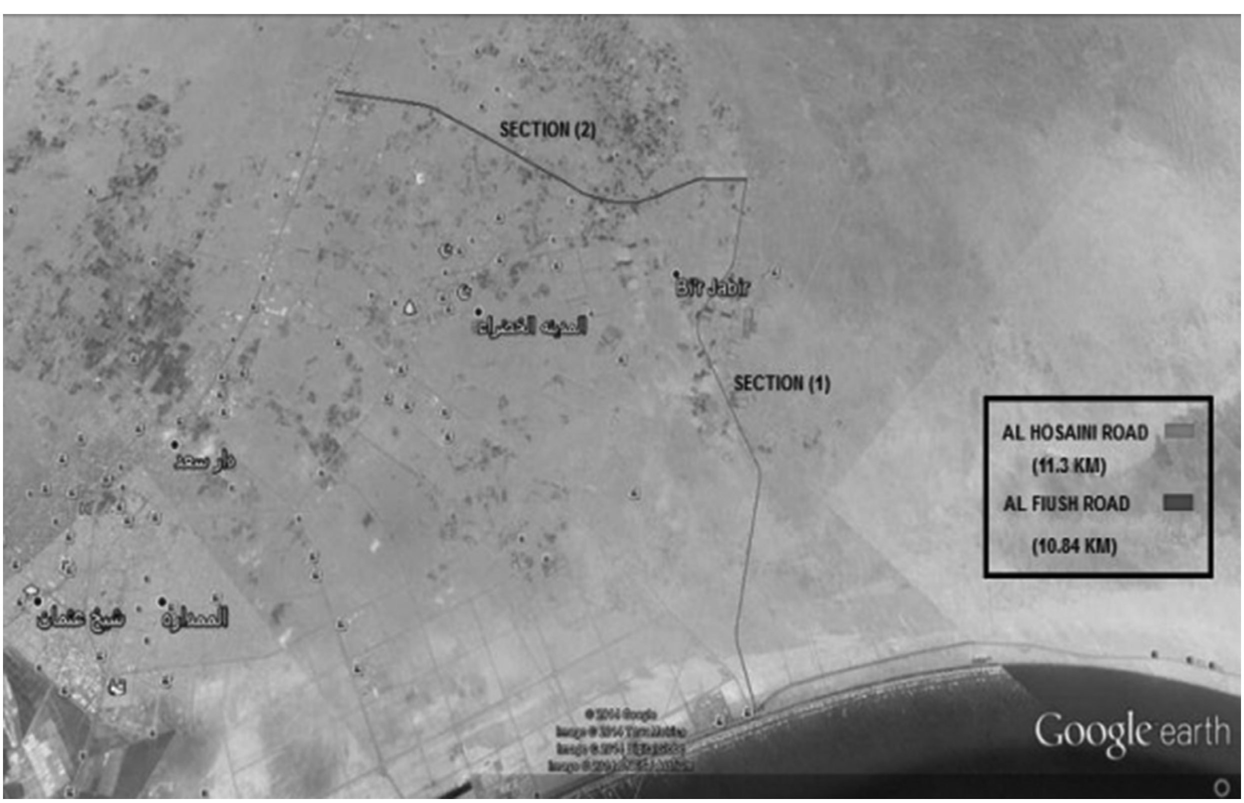


Fig. 1: The study area.

4 PCI determination procedure

A visual inspection of the pavement surface can provide valuable information. Visual inspection data can be used to evaluate the current pavement condition, predict future pavement performance, determine and prioritize pavement M-and-R needs, estimate repair quantities and evaluate the performance of different M-and-R techniques and materials.

The PCI procedure is the standard used by the road industry and the military to visually assess the current pavement condition. The procedure is described in the references in PAVER (1982), American Society for Testing and Materials (ASTM) D6433-09 (2009) and Shahin (1997) and it has been used in this study. During a PCI survey, visible signs of deterioration are recorded and analyzed. The final calculated PCI value is a number from zero to 100, with 100 representing a pavement in excellent condition.

The pavement condition rating is determined from a correlation that presents pavement condition rating as a function of the PCI value. Table 1 shows the PCI ratings.

When interpreting the collected visual condition data, three different aspects of the collected data are of interest: the composite index, the type of distress present and the rate of deterioration. The PCI value itself provides a general idea of the pavement condition and the magnitude of work that will be required to rehabilitate the pavement. Pavements at the upper end of the scale are more likely to be candidates for maintenance and minor rehabilitation, while those in the lower ranges are more likely to require structural rehabilitation or reconstruction.

To evaluate a pavement, first of all, the pavement network should be divided into branches (such as streets, parking areas, etc.) and each branch should be divided into sections that have certain consistent characteristics throughout their area or length, such as structural composition, construction history, traffic and pavement condition. A sample unit is any identifiable area of the pavement section. It is the smallest component of the pavement network. Each pavement section is divided into sample units for the purpose of pavement inspection. Then the steps for performing the condition survey and determining the PCI rating are conducted as per literature (PAVER 1982; ASTM D6433-09 2009; Shahin 1997):

1. Inspect sample unit, determine distress type and severity level and then measure the density
2. The deduct values are determined from the deduct value curves for each distress type and severity.
3. A total deduct value (TDV) is computed by summing all individual deduct values.
4. Once the TDV is computed, the corrected deduct value (CDV) can be determined from the correction curves. When determining the CDV, if any individual deduct value is higher than the CDV, the CDV is set equal to the highest individual deduct value.
5. The PCI is computed using the relation PCI = 100 – CDV.

If all surveyed sample units are selected randomly, the PCI of the pavement section is determined by averaging the PCI of its sample units. If any additional sample units are inspected, a weighted average must be used. The weighted average is computed by using the following equation:

$$\mathrm{PCI_f} = \frac{(N-A)}{N}\,\mathrm{PCI_1} + \frac{A}{N}\,\mathrm{PCI_2} \tag{1}$$

where $\mathrm{PCI_f}$ = PCI of pavement section, $\mathrm{PCI_1}$ = average PCI of random samples, $\mathrm{PCI_2}$ = average PCI of additional samples, N = total number of samples in the section, and A = number of additional samples inspected.

Density of the distresses, measured in square metres (m^2) or square feet (ft^2), is calculated as follows:

$$\text{Density} = \frac{\text{Distress amount in m}^2\ (\text{ft}^2)}{\text{Sample unit area in m}^2\ (\text{ft}^2)} \times 100$$

Density of distresses measured in linear feet or metres (bumps, edge cracking, joint reflection cracking, lane/shoulder drop-off as well as longitudinal and transverse cracks) is calculated as follows:

$$\text{Density} = \frac{\text{Distress amount in linear m (ft)}}{\text{Sample unit area in m}^2\ (\text{ft}^2)} \times 100$$

Density of distresses, as measured by the number of potholes, is calculated as follows:

$$\text{Density} = \frac{\text{Number of potholes}}{\text{Sample unit area in m}^2\ (\text{ft}^2)} \times 100$$

After the density of distresses for each distress type/severity combination is calculated, the deduct values are

Tab. 1: PCI rating

PCI	Rating
85–100	Excellent
70–85	Very good
55–70	Good
40–55	Fair
25–40	Poor
10–25	Very poor
00–10	Failed

determined from the appropriate distress deduct value curves (PAVER 1982). The CDV is then determined, as explained later.

4.1 Evaluation of road sections in the study area

Al-Fiush Road, described earlier, is divided into sample units; the number of sample units to be inspected is determined as per specifications and then randomly selected. Each of the randomly selected sample unit is then surveyed to derive the PCI and the average PCI of each section is determined. Based on the PCI value of the section, the necessary maintenance or rehabilitation procedure is suggested.

4.2 PCI values of Al-Fiush Road sections

First, the sample size should be selected properly because the pavement includes a two-lane road; the total width of the pavement is 7 m (23 ft). It was decided to select the sample size as 7 m wide × 30.5 m long (or 23 ft × 100 ft), with area equaling 213.5 m^2 (2,300 ft^2). The second step is to determine the number of samples to be chosen for inspection.

The number of total samples N in a branch is obtained by dividing the length of the branch by the length of the sample, as shown below:

$$N = \frac{\text{length of the section}}{\text{length of the sample}} = \frac{10{,}800\ \text{m}\ (35{,}564\ \text{ft})}{30.5\ \ \text{m}\ (100\ \text{ft})} = 355\ \text{samples}$$

The curves shown in Figure 2 are used to select the minimum number of sample units that must be inspected. When performing the initial inspection, the PCI range for a pavement section (i. e. PCI of the lowest sample unit subtracted from the PCI of the highest sample unit) is assumed to be 25 for asphalt concrete (AC) surfaces. However, if the PCI range of the samples considered was found to be >25 for a flexible pavement, it would be necessary to go back to Figure 2, start on the N scale again, proceed vertically to the curve for PCI range >25, read the number of samples to be inspected on the n scale and determine the additional samples to be included.

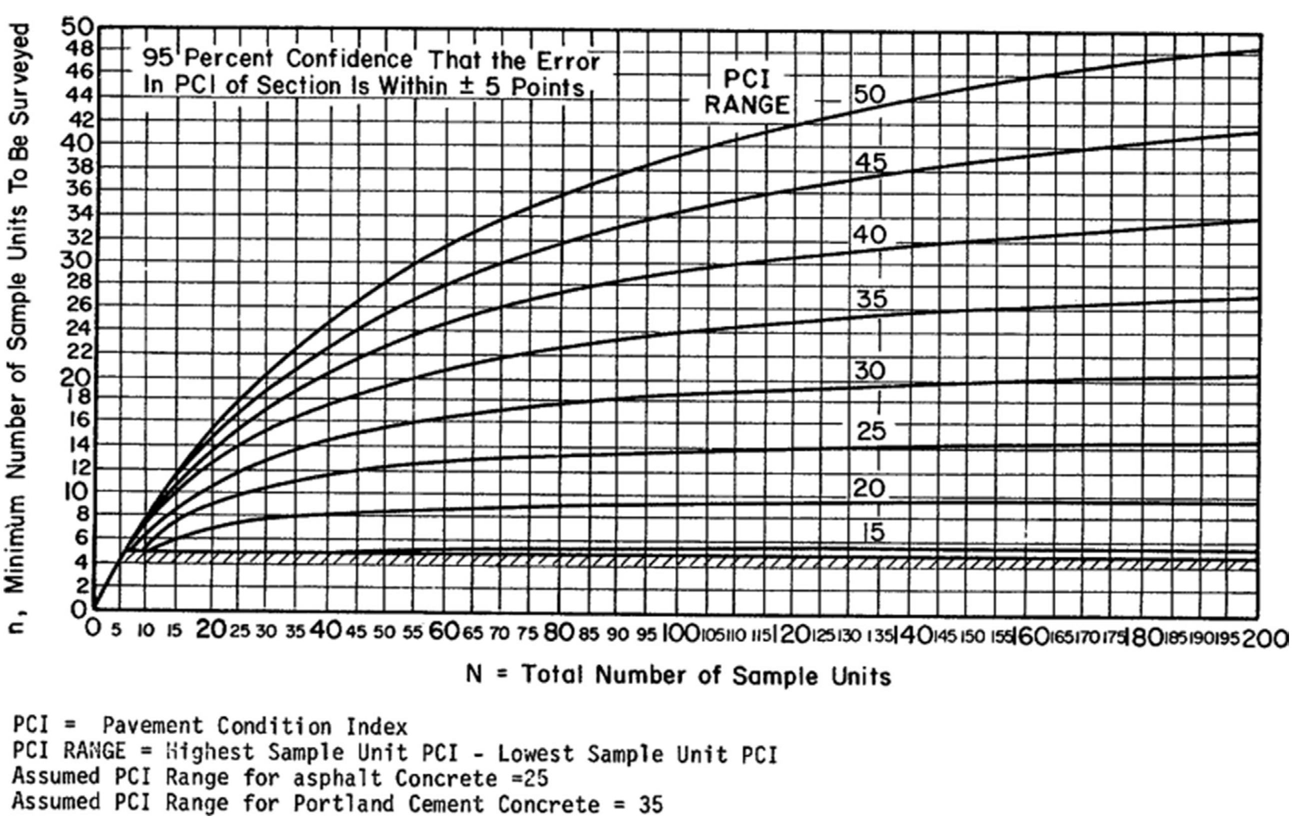


Fig. 2: Determination of minimum number of sample units to be surveyed.

To find the sample size for Al-Fiush Road, start at 355 on the N scale (Figure 2), proceed vertically to the appropriate curve (PCI range = 25) and read 15 on the n scale. This means that 15 sample units should be surveyed.

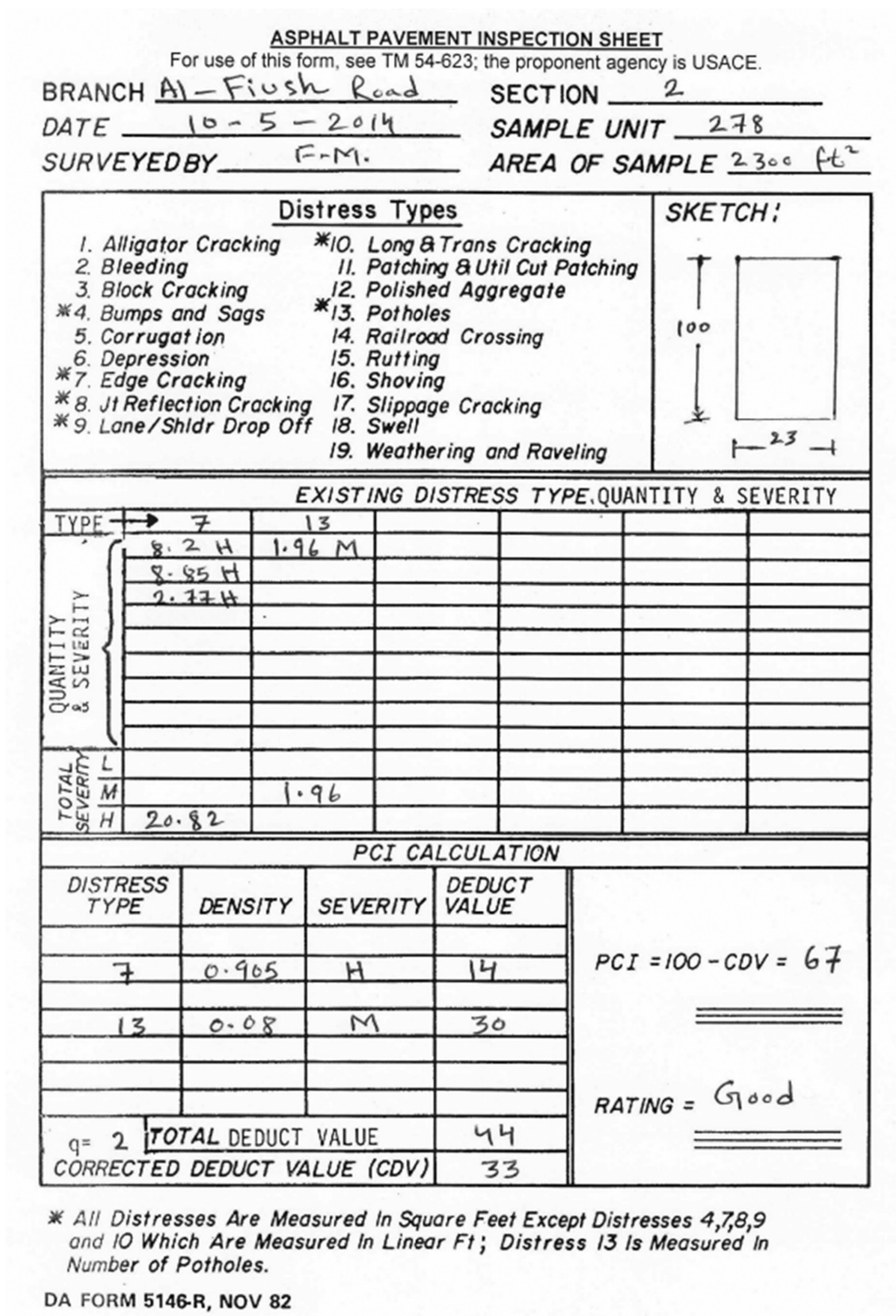
The spacing interval i of the units to be selected is computed from the following equation:

$$i = \frac{N}{n} \tag{2}$$

where i, N and n are defined earlier.

$N = 355$ samples, $n = 15$ samples and $\mathrm{i} = \frac{355}{15} \approx 23.$

All the sample numbers within a feature are numbered, and those that are multiples of the interval i (23) are selected for inspection. The first sample unit to be inspected should be selected at random between one and i sample units. In this section, we selected the first sample to be Sample 2; therefore, the remaining 14 samples are



ASPHALT PAVEMENT INSPECTION SHEET
For use of this form, see TM 54-623; the proponent agency is USACE.

BRANCH Al – Fiush Road SECTION 2
DATE 10 – 5 – 2014 SAMPLE UNIT 278
SURVEYED BY F.M. AREA OF SAMPLE 2300 ft²

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

SKETCH: 100, 23

EXISTING DISTRESS TYPE, QUANTITY & SEVERITY

TYPE	7	13				
QUANTITY & SEVERITY	8.2 H	1.96 M				
	8.85 H					
	2.77 H					
TOTAL SEVERITY L						
TOTAL SEVERITY M		1.96				
TOTAL SEVERITY H	20.82					

PCI CALCULATION

DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE
7	0.905	H	14
13	0.08	M	30
q= 2	TOTAL DEDUCT VALUE		44
CORRECTED DEDUCT VALUE (CDV)			33

PCI = 100 – CDV = 67

RATING = Good

* All Distresses Are Measured In Square Feet Except Distresses 4,7,8,9 and 10 Which Are Measured In Linear Ft; Distress 13 Is Measured In Number of Potholes.

DA FORM 5146-R, NOV 82

Fig. 3: Asphalt pavement inspection sheet for Sample No. 278, Al-Fiush Road.

2 + 23 = 25 and 25 + 23 = 48, 71, 94, 117, 140, 163, 186, 209, 232, 255, 278, 301 and 324, respectively.

5 Field survey work for Al-Fiush Road sections

The actual survey of the section was carried out on 10 May 2014. By visual inspection of the section, it was found that there are a few depressions of medium and high severity, a few edge cracks of high severity, some medium-severity potholes and a few low- to medium-severity longitudinal and transverse cracks.

The survey and distress identification procedures were carried out as per the references mentioned for the 15 samples. Figure 3 shows the condition survey data sheet for Sample No. 278, which shows that the sample has PCI = 67 and a rating of 'Good'.

Figure 3 also tells us that the distresses in the sample are high-severity edge cracks (Distress 7) and medium-severity potholes (Distress 13) only.

Each distress type has a separate figure to find the deduct value for that distress. Figure 4 shows the flexible pavement's deduct values for Distress 7, while Figure 5 shows the flexible pavement's deduct values for Distress 13. The TDV for each sample unit is determined by adding all the deduct values for each distress condition observed.

The CDV is determined using Figure 6. The PCI of the sample unit inspected is calculated as follows PCI = 100 – CDV. The PCI of the entire section is the average of the PCI values of all sample units inspected.

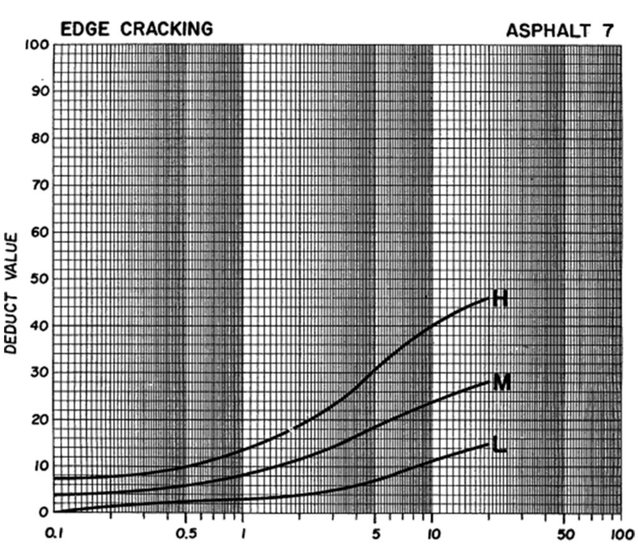


Fig. 4: Flexible pavement deduct values, Distress 7, edge cracking.

Table 2 shows the summary of the PCI values of the 15 samples and the overall PCI and rating of the Al-Fiush Road sections.

The PCI of Al-Fiush Road is 80.3, with rating being 'Very good'.

Because the PCI range (maximum PCI – minimum PCI) is 100 – 62 = 38, which is greater than the initial assumed PCI range for asphalt pavement (i. e. 25), it would be necessary to go back to Figure 2, start at 355 on the N scale again, proceed vertically to the curve for PCI range = 34 and read 38 on the n scale. In this case, it would be necessary to survey an additional 16 samples (31 – 15 = 16).

While selecting additional sample units, the surveyor should select unusual sample units such as very 'poor' or 'excellent' sample units or non-typical distresses as additional sample units. An additional unit implies that the

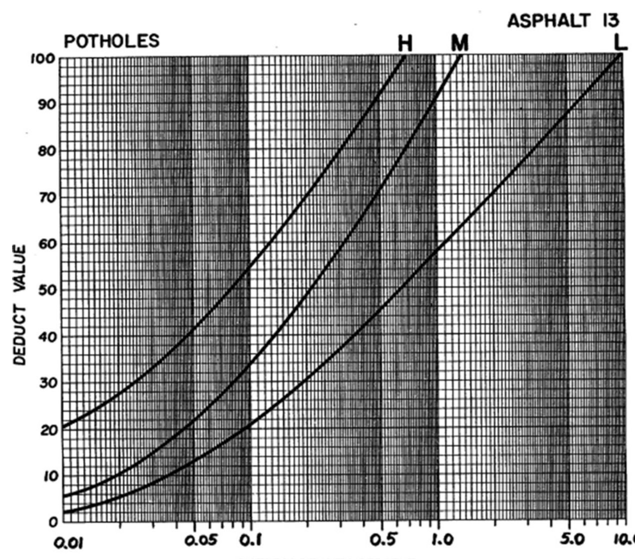


Fig. 5: Flexible pavement deduct values, Distress 13, potholes.

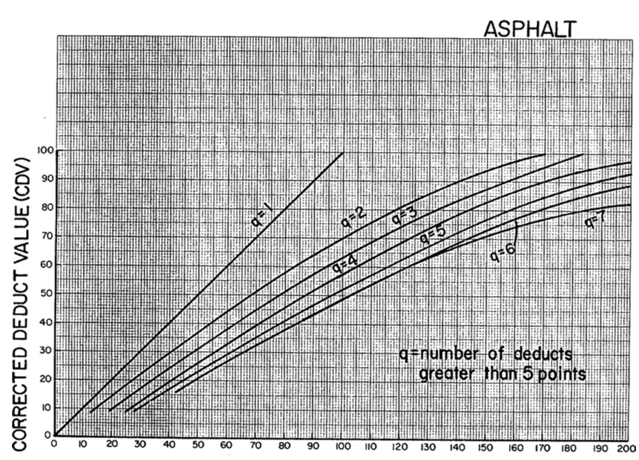


Fig. 6: Corrected deduct values for flexible pavements.

Tab. 2: PCI values of Al-Fiush Road sections

No.	Sample No.	Sample unit area, m² (ft²)	PCI	Rating
1	2	213.5 (2,300)	80	Very good
2	25	213.5 (2,300)	100	Excellent
3	48	213.5 (2,300)	91	Excellent
4	71	213.5 (2,300)	78	Very good
5	94	213.5 (2,300)	90	Excellent
6	117	213.5 (2,300)	88	Excellent
7	140	213.5 (2,300)	73	Very good
8	163	213.5 (2,300)	81	Very good
9	186	213.5 (2,300)	78	Very good
10	209	213.5 (2,300)	70	Very good
11	232	213.5 (2,300)	65	Good
12	255	213.5 (2,300)	62	Good
13	278	213.5 (2,300)	67	Good
14	301	213.5 (2,300)	92	Excellent
15	324	213.5 (2,300)	90	Excellent
Average PCI of sections			80.3	Very good

sample was not selected at random and/or contained distress(es) that were not representative of the section.

The additional sample units selected were samples 1, 17, 30, 84, 87, 96, 105, 128, 158, 173, 199, 214, 217, 220, 230 and 237, respectively. These samples were inspected and the PCI values of these samples were determined as shown in Table 3 below.

The calculation of the PCI value when additional sample units are included is done using Equation 1 shown earlier.

$PCI_f = \frac{(355-16)}{355} \times 80.3 + \frac{16}{355} \times 59.5 = 79.4$, and the rating is ‘Very good’.

6 Suggested maintenance procedure for sections of Al-Fiush Road

Because the PCI value of the Al-Fiush Road section is 79.4, with rating of ‘Very good’, which has a PCI value greater than the limiting value, assumed as PCI = 70 as per *Technical Manual TM 5-822-5* (1992), continuation of the existing maintenance policy is recommended. The information in Table 4 (PAVER 1982) is used as a guide to select the appropriate maintenance method. This table presents the feasible maintenance methods for each distress type at a given severity level. However, because a few samples of the section have a poor rating, these may need special attention.

Figure 7 shows high-severity edge cracks for Sample No. 278 in Al-Fiush Road.

Tab. 3: PCI of additional samples for sections of Al-Fiush Road

Sample No.	PCI	Sample No.	PCI	Sample No.	PCI
1	27	105	81	217	26
17	82	128	81	220	51
30	46	158	32	230	60
84	73	173	87	237	67
87	88	199	17	Average PCI	59.5

Figure 8 shows medium-severity potholes for Sample No. 278 in Al-Fiush Road.

A check should be made to determine whether an existing pavement section of Al-Fiush Road is strong enough to support moving traffic loads. It is necessary to find the pavement’s load-carrying capacity. Methods for determining the load-carrying capacity are given in *Technical Manual TM5-822-2* (1987) and *Technical Manual TM 5-822-5* (1992) for roads and pavements.

7 Determination of load-carrying capacity of the existing pavements of Al-Fiush Road sections

7.1 Structural composition of the pavement

The pavement of Al-Fiush Road section has structural composition shown in Table 5.

7.2 Traffic composition of vehicles moving on the pavements

Traffic on the road sections consists of a combination of passenger cars, light-delivery trucks, two-axle trucks and trucks with three or more axles, as shown in Table 6, along with the corresponding passenger car equivalent units (PCUs) for flat terrain:

As shown in Table 6, the critical PCU values are in the north direction, and this value is taken for the analysis.

Determination of the class of roads was done in this study as per *Technical Manual TM5-822-2* (1987), and the effective design hourly volume (DHV) was taken as 15% of the average daily traffic, which is 0.15 × 13,626 = 2,044 PCUs.

Table 7 (*Technical Manual TM5-822-2* 1987) shows the road class according to the effective DHV. Because the

Tab. 4: Asphalt concrete pavement distress types and M-and-R alternatives

Distress Type / M-and-R Method	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Pothole Filling	Apply Heat & Roll Sand	Apply Surface Seal Emulsion	Apply Rejuvenation	Apply Aggregate Seal Coat	Notes
1 Alligator Cracking			M, H	M, H				L	L		
2 Bleeding	L						L, M, H				
3 Block Cracking	L	L, M, H							L	L, M	
4 Bumps & Sags	L		M, H	M, H	M, H						
5 Corrugation	L		M, H	M, H							
6 Depression	L		M, H	M, H	M, H						
7 Edge Cracking	L	L, M	M, H	M, H							If predominant, apply shoulder seal, e.g., aggregate seal coat
8 Joint Reflective Cracking	L	L, M, H	H								
9 Lane/Shoulder Drop Off	L										If predominant, level off shoulder and apply aggregate seal coat
10 Longitudinal Transverse Cracking	L	L, M, H	H					L	L	L, M	
11 Patching & Utility Cut	L	M	H*	H*							*Replace patch
12 Polished Aggregate	A									A	
13 Potholes			L	L, M, H		L, M, H					
14 Railroad Crossing	L				L, M, H						
15 Rutting	L		L, M, H	M, H	L, M, H						
16 Shoving	L		M, H								
17 Slippage Cracking	L	L	M, H								
18 Swell	L			M, H							
19 Weathering & Raveling	L		H					L, M	L	M, H	

Note: L = low severity; M = medium severity; H = high severity; A = has only one severity level.

Fig. 7: High-severity edge cracking in Sample No. 278, Al-Fiush Road.

Fig. 8: Medium-severity potholes in Sample No. 278, Al-Fiush Road.

DHV in the road sections in this study was 2,044 PCUs, which is >900 PCUs; thus, the classification assigned for the road in this study is Class A Road.

As per *Technical Manual TM5-822-2* (1987), if the percentage of trucks on a road is >25%, then this road is considered as belonging to Category IVA.

Tab. 5: Structural composition of Al-Fiush Road pavement

No.	Layer	Thickness, cm (in)	CBR
1	Subgrade		10
2	Sub-base	30 (11.8)	20
3	Base	20 (7.9)	50
4	Surface	7 (2.75)	
Total thickness		57(22.45)	

Tab. 6: Traffic in passenger car equivalent units (PCUs) on sections of Al-Fiush Road

No.	Vehicle type	PCU	Southbound		Northbound	
			Vehicles	PCU	Vehicles	PCU
1	Passenger car	1	4,684	4,684	3,782	3,782
2	Two-axle trucks	2	2,679	5,358	3,436	6,872
3	Trucks with ≥3 axles	2	1,135	2,270	1,486	2,972
Total PCU				12,312		13,626

Tab. 7: Road classification based on DHV

Effective DHV (equivalent passenger cars per hour)		
Class	Road	Street
A	≥900	≥1,200
B	720–899	1,000–1,199
C	450–719	750–999
D	150–449	250–749
E	10–149	25–249
F	<10	<25

For Traffic category IVA and Road class A, the pavement design index is six, as shown in Table 8 (*Technical Manual TM5-822-2* 1987).

For pavement design index 6, based on the information in Figure 9 (PAVER 1982), the pavement thickness required over a CBR of ten is 12 in (38.1 cm); over a CBR of 20, the required thickness is 9.0 in (23 cm). The overall thickness of the existing pavement is 22.45 in (57 cm). Therefore, this pavement section is structurally strong enough for the load it carries. Therefore, continuation of the existing maintenance policy is recommended. The information in Table 4 (PAVER 1982) is used as a guide to select the appropriate maintenance method.

7.3 Surface roughness of Al-Fiush Road

The surface roughness was determined by riding at 60 km/h speed over the pavement sections of Al-Fiush Road, and it was found that the roughness is moderate.

Tab. 8: Pavement design index

Traffic category	Pavement design index for road or street classification					
	A	B	C	D	E	F
I	2	2	2	1	1	1
II	3	2	2	2	2	1
III	4	4	4	3	3	2
IV	5	5	5	4	4	3
IVA	6	6	6	5	5	4

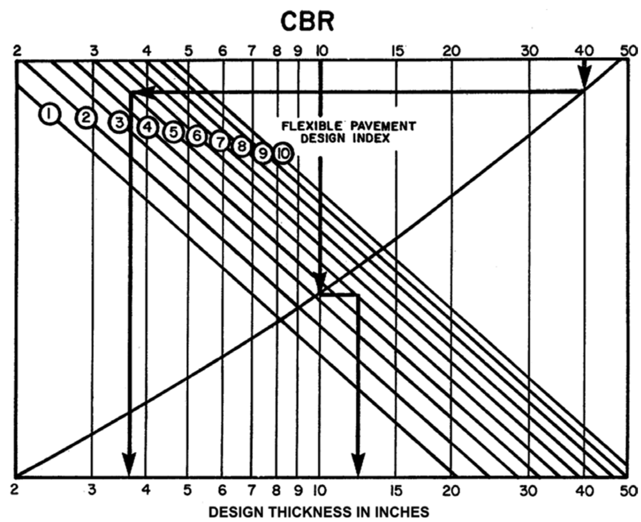


Fig. 9: Thickness design requirements for flexible pavements.

8 Conclusion

In this study, an attempt was made to evaluate a major heavy-traffic highway road corridor connecting Aden city (the commercial capital of Yemen) to the northern region of the country, namely, sections of the Al-Fiush Road, by the visual inspection method..

An appropriate sample size was selected for visual inspection and rating. It has been found that the Al-Fiush Road section rating is 'very good', with PCI = 79.4, with a few samples rated as 'poor'.

A check was made to determine whether an existing pavement section of Al-Fiush Road is strong enough to support moving traffic loads, as it is necessary to find the pavement's load-carrying capacity. The analysis reveals that the pavement sections are structurally strong to carry the imposed traffic.

Based on the determined rating, the suggested maintenance for the pavement sections is continuation of the existing maintenance policy. The information in Table 4 obtained from *Pavement Maintenance Management* (1982) is used as a guide to select the appropriate maintenance method. The tables present feasible maintenance methods for each distress type at a given severity level.

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