Prediction of Pavement Remaining Life and Maintenance Strategy for Asphaltic Concrete Highways by Pavement Condition Index Study.

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Abstract: *This paper presents the results of a pavement condition index (PCI) study for an asphaltic concrete highway. Its aim is to provide a handy method of using the results of such studies to predict the remaining life of the pavement and thereby provide a maintenance strategy for highway authorities in the form of one or a combination of: full reconstruction, surface partial reconstruction, thick overlays, thin overlays, surface treatments and preventive maintenance. The study was conducted on a section of the Lokoja to Abuja highway. This is a major and heavily loaded corridor linking the northern and southern parts of Nigeria. The PCI of 30.6 percent obtained from the study translates as 'poor' on the rating scale of the United States Army Corps of Engineers. This would require a maintenance strategy of surface partial reconstruction. However, when this value of PCI is applied unto an alternative and more stringent scale, a 'very poor' rating will result. This latter rating will translate to a remaining life of zero to five years for the pavement and thereby attract a maintenance strategy of full reconstruction.*

Keywords: *Asphaltic Concrete, Pavement Condition Index, Pavement Maintenance Strategy, Pavement Remaining Life, Alligator Cracking, Rutting, Deduct Value.*

1.0 Introduction:

Pavement Condition Index (PCI) method of rating for asphalt roads originated with the US Army Corps of Engineers and has found widespread acceptance. It is a distress based condition index which identifies specific distresses in the pavement by type, severity and extent. It rates the pavement on a scale of 0 to 100 as shown in Fig. 1. The rating percentage is a composite value representing both structural integrity and serviceability.

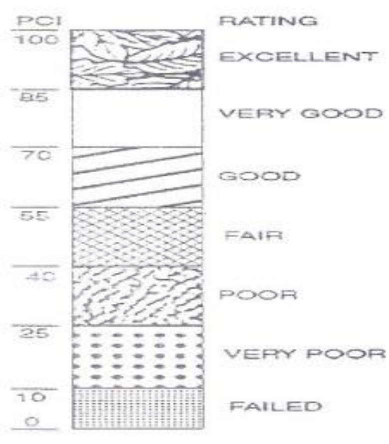


Fig. 1: Pavement Condition Index (PCI) Scale (Fwa, 2006).

2.0 Review of Literature:

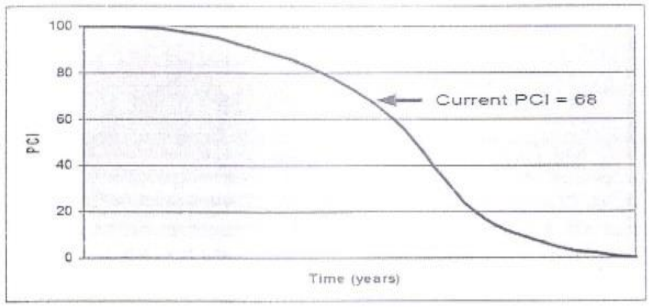


Fig. 2: Generalized Pavement Life Cycle Curve (Nichols Consulting Engineers, 2009).

Fig. 2 shows a generalized pavement life cycle curve (Nichols Consulting Engineers, 2009). Fig. 3 indicates that maintenance strategy could be influenced by the condition of the pavement. For instance, if the PCI is 70% and above, preventive maintenance should be adopted. Otherwise a structural or functional overlay should be the maintenance strategy, depending on whether the distress is structural (affecting any or all of the load supporting structure from the road base to the subgrade) or non-structural (occurring on the surface only).

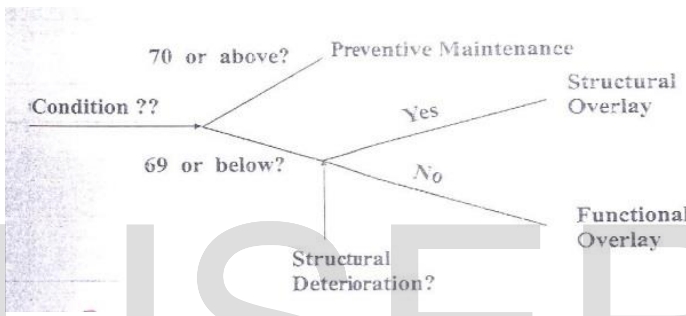


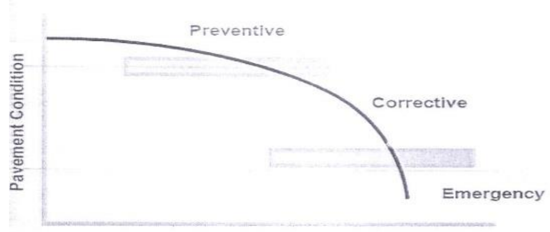
Fig. 3: Decision Trees, Asphaltic Pavement.

Table 1: Decision Matrix for Asphaltic Concrete.

Treatment Type	Surface Type	Condition Level	Structural Deterioration
Preventive Maintenance	Asphalt Concrete	70 – 100	N/A
Functional Overlay	Asphalt Concrete	0 – 69	Not Present
Structural Overlay	Asphalt Concrete	0 – 69	Present

Table 1 is a tabular explanation of the decision trees of Fig. 3

Fig. 4 illustrates the variation of maintenance strategy with the condition and age of the pavement. Preventive maintenance is applied when the PCI is between very good and good while corrective maintenance should be applied when the PCI is poor. Very poor PCI measurements attract emergency rehabilitation.



Time or Traffic

Fig. 4: Categories of Pavement Maintenance, (NCAT, 2008c).

Fig. 5 is a quantitative explanation of Fig. 4, illustrating in more definite terms how the pavement age and/or the PCI score may be used to select a maintenance strategy while Table 2 is a tabular illustration of Fig. 5. It additionally predicts the remaining life of the pavement from its PCI score.

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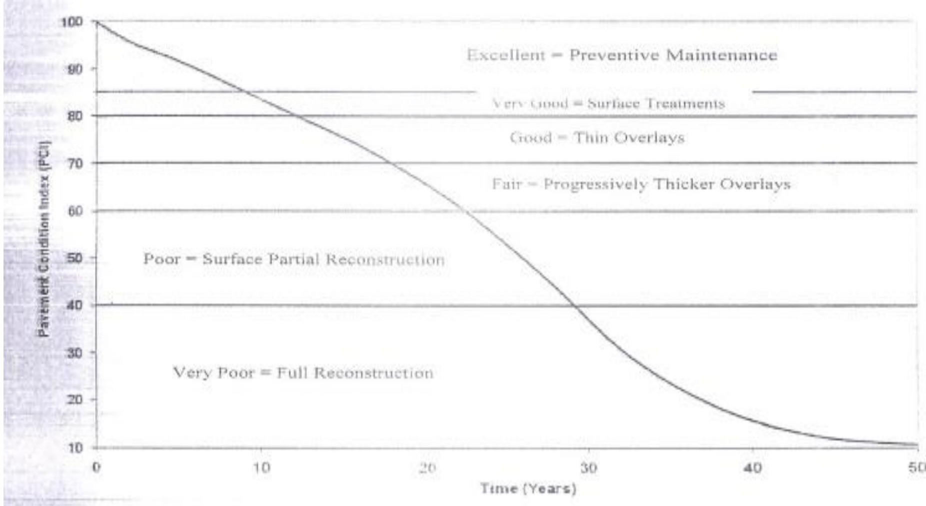

Fig. 5: Understanding the Pavement Condition Index, PCI Score (Michael, 2010).

Table 2: Relative Remaining Life and Maintenance Requirements against PCI.

Pavement Condition Index	Description	Relative Remaining Life	Definition
85 – 100	Excellent	15 to 25 Years	Like new condition – little to no maintenance required.
80 – 85	Very good	12 to 20 Years	Routine maintenance such as patching, crack sealing with surface treatments such as rubber chip seals and micro surfacing.
70 – 80	Good	10 to 15 Years	Seal coating required, thin overlay or possible moderate overlay.
60 – 70	Fair	7 to 12 Years	Thicker overlays required, surface replacement or base reconstruction possible.
40 – 60	Poor	5 to 10 Years	Sections will require very thick overlays, surface replacement, base reconstruction and possible subgrade stabilization.
10 – 40	Very poor	0 to 5 Years	High percentage to full reconstruction.

Source: Michael (2010)

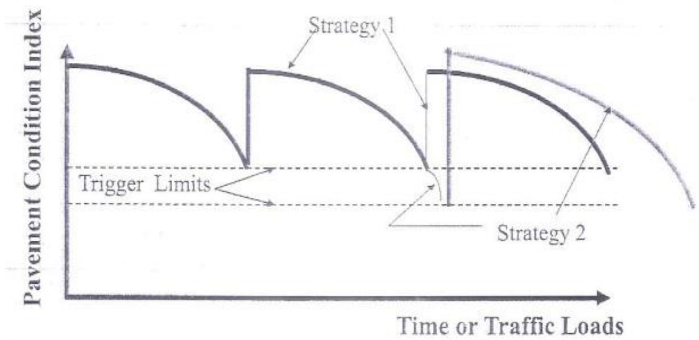

Fig. 6: Illustration of Multiple Treatment Strategies, (NCAT, 2008c).

Fig. 6 illustrates the use of trigger limits in maintenance strategies. Strategy 1 adopts a higher PCI trigger limit compared to strategy 2. A trigger limit is the lowest PCI which the agency will allow a designated road pavement to fall to before maintenance is required. After it has chosen a trigger limit, the agency then performs regular PCI studies to ascertain when this limit is reached. This enables it to intervene timely. Fig. 7 shows how pavement condition (before maintenance intervention) affects maintenance costs. It therefore shows the cost savings of timely intervention.

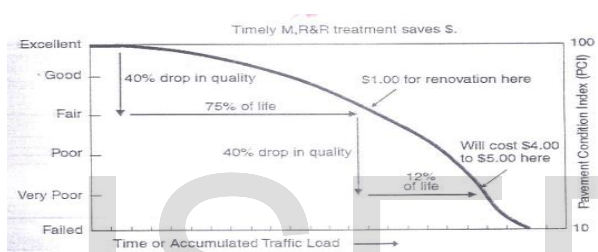

Fig. 7: Pavement Condition Deterioration Effects on Maintenance Costs (Shahin and Walther, 1990).

Distresses in Asphalt Concrete Pavements:

These are shown in Table 3

Table 3: Distresses in Asphalt Concrete Pavements

S/N	Distress Category	Distress Type
1	Cracking	Longitude, Fatigue, Transverse, Reflective, Block, Edge
2	Deformation	Rutting, Corrugation, Shoving, Depression, Overlay bumps
3	Deterioration	Delamination, Potholes, Patching, Ravelling, Stripping, Polished Aggregate, Pumping
4	Mat problems	Segregation, Checking, bleeding

Source: Cook et. al, (2004)

Performance of asphalt concrete can be categorized into two major types of distresses viz: alligator cracking and permanent deformation or rutting (Kim, 2009).

Alligator Cracking or Fatigue Cracking:

It is a series of interconnected cracks in an asphalt layer forming a pattern which resembles an alligator's hide or chicken wire. The cracks indicate fatigue failure of the asphalt layer generally caused by repeated traffic loadings. The cracks allow water to penetrate the layers of the pavement and the sub-grade. This furthers the pavement damage.

Possible causes of alligator cracking include:

- Insufficient pavement structure: insufficient thickness of pavement layer.
- Inadequate base support
- Poor base drainage
- Heavy traffic loads

- Aging of the pavement surface

Fig. 8a: Fatigue Cracking Process in Asphaltic Concrete Pavement (NCAT, 2008c).

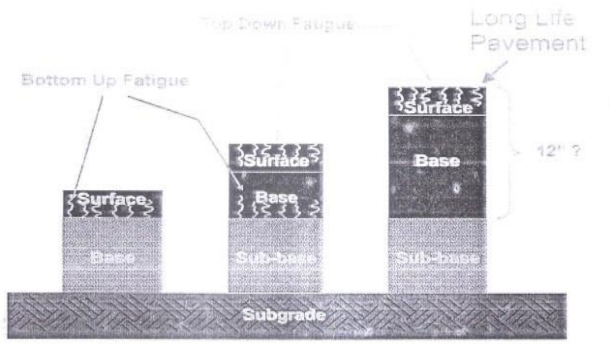

Fig. 8b: Fatigue Cracking Process in Asphaltic Concrete Pavement, (NCAT, 2008c).

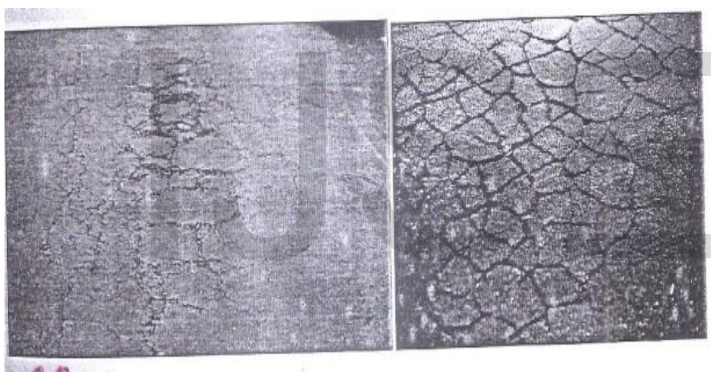

Fig. 9: Alligator or Fatigue Cracking in Asphaltic Concrete Pavement, (NCAT, 2008c).

Rutting or Permanent Deformation:

Rutting in asphaltic concrete pavements is attributable to progressive movement of material under repeated load through consolidation (expulsion of water and air) and plastic flow.

Originally, the AASHO Road Test reported that rutting is primarily caused by the movement of the sub-grade. On the contrary however, studies on rutted pavements by Huber and Heiman (1987), Brown and Cross (1989), Parker and Brown (1990) reported that although rutting could result from the deflection of weak underlying layers, it is almost entirely attributable to permanent deformation in Hot Mix Asphalt layers of existing pavements. This development is at the wake of increased tyre pressures, axle loads and traffic volumes.

Air voids: Rutting tendency is higher for pavements with air voids less than 3%, than those with voids. Brown and Cross (1989) reported that for poorly designed mixes, Hot Mix Asphalt (HMA) pavements laid at about 7 to 8% air voids will be compacted further by traffic down to approximately 4%, after which stability in the rutting regime may be attained.

Visco-elasticity and Creep: According to Pomeroy (1978), HMA possesses both elastic and viscous characteristics and is therefore referred to as visco-elastic. He added that the deflection behavior is time-of-loading as well as temperature dependent. Findley et al. (1976) in their earlier studies of creep and relaxation properties of non-linear visco-elastic materials reported that under constant static or repeated loading, such materials undergo flow or creep which occurs in the form of recoverable and irrecoverable and time dependent and time independent deformation components. They added that HMA and all visco-elastic materials are characterized by instantaneous elasticity, creep, instantaneous and delayed recovery as well as permanent strain. Also, Nair and Chang (1973) had earlier after their studies of creep in HMA isolated three components of deformation in this material as:

(a) Deformation that recovers on load removal.
(b) Gradual recovery deformation.
(c) Permanent deformation.

The temperature at the time of loading and the stress level induced by load determine which of these responses result,

Types of Rutting in Asphaltic Concrete:

Rutting by densification: Huber and Heiman (1987) noted that it is usual that fresh construction leaves the asphalt concrete at an air void content of 7 to 8%, Along with other layers of the pavement viz: the base, sub-base and sub-grade, additional compaction under traffic loading occurs. There will be no problem due to this new deformation if there were uniform compaction of the cross-section. But unfortunately, traffic is channelized along wheel paths and the resulting compaction yields rutting along these paths. For the asphalt concrete, longitudinal compaction rutting continues under traffic loading until the air voids are reduced to approximately 4%. However, compaction rutting of asphalt concrete will continue if densification of the base, sub-base and sub-grade has not stabilized or when there is poor sub-drainage.

Compaction rutting has a sloping soccer shape and width of 750-1000mm. It is illustrated in Figs. 10a and 10b.

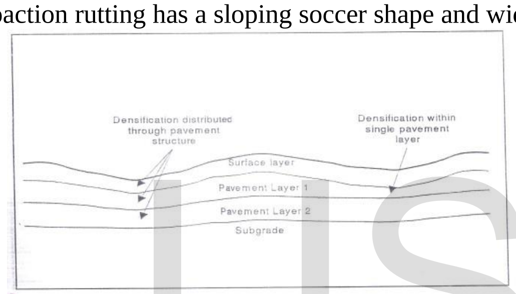

Fig. 10a: Typical Densification Rutting (Asian Dev. Bank/N.D Lea International Ltd., 1995).

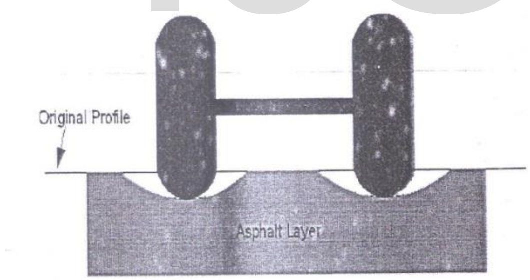

Fig. 10b: Rutting by Densification of the Asphaltic concrete surface layer.

Rutting by shear failure: According to Huber and Heiman (1987), shear failure occurs when asphalt mixtures having very low air void contents of say less than 4% are subjected to traffic loading. Lack of shear resistance in HMA is triggered by low binder stiffness and content, weak aggregate skeleton, moisture damage, temperature and rate and magnitude of traffic loading.

Shear deformation contributes a significantly greater proportion of the total permanent deformation in asphalt concrete mixes than densification, so long as air void contents are less than 8 to 9% at the completion of construction. This is supported by observed rutting of in-service pavements. Shear deformations leading to rutting are limited to the upper portion of HMA layer.
These ruts show as depressions along the loaded wheel paths and as ridges and upheavals on both sides of each wheel path. Figs 11a and 11b illustrate shear failure rutting, while Fig 11c illustrates a general rutting profile in asphaltic concrete.

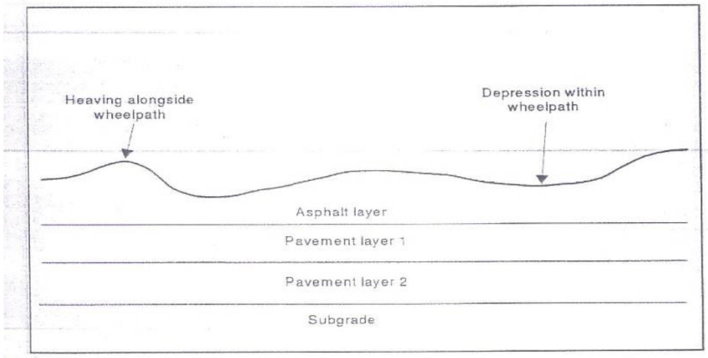

Fig. 11a: Rutting by shear failure (Asian Dev. Bank/N.D Lea International Ltd., 1995).

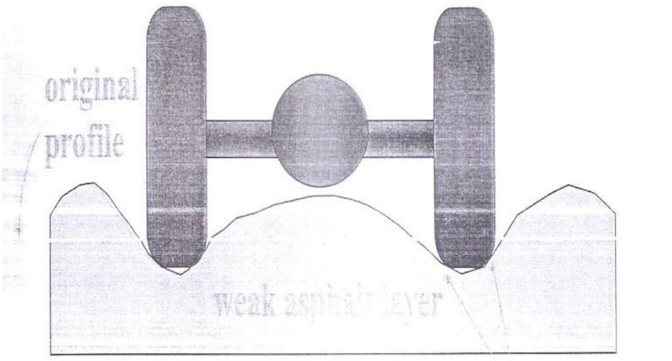

Fig. 11b: Rutting in Asphalt Layer by shear failure.

Fig. 11c: General Rutting Profile in asphaltic concrete.

Severity of Pavement Distress:

The severity of distress in flexible pavements may be categorized into three levels of Low (L), Moderate (M) and High (H) (Nebraska Department of Roads, NDOR, 2002).

Severity of Fatigue Cracking

Low (L): Longitudinal disconnected hairline cracks, not greater than 3mm. They are single or two parallel longitudinal cracks in the wheel path; cracks are not spalled, rutting or pumping not evident. They are also called Alligator ‘A’ Cracking.

Moderate (M): They are longitudinal cracks in the wheel path forming an alligator pattern. Cracks may be lightly spalled and about 3mm-6mm wide. They form an area of interconnected cracks in wheel path forming a complete pattern; rutting or pumping may exist. They are also called Alligator ‘B’ Cracking.

High (H): Pieces appear loose with severely spalled or scaled edges; cracks are 6mm or greater and pumped fines may appear on the surface. They form an area of moderately or severally spalled interconnected cracks outside the wheel path, forming a complete pattern. They are also called ‘C’ Cracking.

Severity of Rutting (Nebraska Department of Roads, 2002)

Low (L): Depressions in the wheel path less than 3mm deep.

Moderate (M): Wheel path depressions 6mm-12mm deep.
High (H): Wheel path depressions greater than 12mm deep.

3.0 Methodology:

3.1 Pavement Condition Index (PCI) Study:

The test highway was divided into 7 sections of approximately two kilometers each and labeled A. B, C etc. as follows:

Km 5+650 to Km 7+650=A, Km 7+650 to Km 9+650 = B, Km 9+650 to Km 11+650 = C
Km 11+650 to Km 13+650=D, Km 13+650 to Km 15+650=E, Km 15+650 to Km 17+650=F
Km 17+650 to Km 19+650 = G.

The sections were labeled A, B, C… to G for ease of referencing. A distressed area was randomly chosen from each section. A 30.48m long section was again sampled out of this chosen area. The details of location, distress type, severity, sample area, extent and density of distress were measured for each sample. The distress types and their respective severity are shown in Table 4. In this Table L, M and H mean Low, Moderate and High levels of severity respectively.

Table 4: Distresses at Varying Locations of the Test Highway Pavement:

Location	Type of Distress	Severity
A	Alligator Cracking	M
B	Rutting	H
	Alligator Cracking	L
C	Rutting	L
	Alligator Cracking	M
D	Rutting	H
	Block Cracking	M
E	Rutting	L
	Patching	M
	Alligator Cracking	H
F	Alligator Cracking	H
	Rutting	H
G	Alligator Cracking	H
	Block Cracking	H

L=Low, M=Medium, H= High

The severity of distress in flexible pavements is categorized into three levels of Low (L), Moderate (M) and High (H) as explained in the Review of Literature.

4.0 Results, Analysis & Discussion:

Table 5: Percentages of Distress and Deduction Values

Location	Type of Distress	Extent of Distress (m2)	Density of Distress (%)	Deduct Value
A	Alligator Cracking	46.45	20	56
B	Rutting	22.13	9.9	61
	Alligator Cracking	15.5	7.0	28
C	Rutting	26.32	11.8	29
	Alligator Cracking	48.08	21.6	57
D	Rutting	29.00	13.0	6.5
	Block Cracking	10.13	4.6	18
	Rutting	20.90	9.4	27
E	Patching	12.80	5.4	20
	Alligator Cracking	23.00	10.3	62
F	Alligator Cracking	61.30	27.6	74
	Rutting	11.10	5.0	50
G	Alligator Cracking	100.20	45.1	82
	Block Cracking	167.20	75.2	73

4.1 Deduct Value (DV) and Corrected Deduct Value (CDV):

A very good pavement will have a hundred percent Pavement Condition Index (PCI) and there will be zero percent deduct values. Thus, the amount to be deducted from hundred percent depends on the distress condition of the road. Deduct values in percentage will therefore tell how bad the distress on the road is. Where there are two or more distresses, for example when rutting, patching and alligator cracking occur simultaneously on the road, then one will have what is called Corrected Deduct Value (CDV). The Total Deduct Value (TDV) will be the addition of the deduct percentages of two or more distresses, which one applies to the graph in Appendix A-3 to obtain the Corrected Deduct Value (CDV). To get only one distress deduct value (DV), one uses Appendix A-1 for cracking and Appendix A-2 for rutting. Thus, one uses different graphs for different distress types. Appendix A-4 is the same graph as Appendix A-3 but was necessary in order to avoid the clumsiness of obtaining the same value of Corrected Deduct Value for two different locations B and C from the same graph.

As an illustration, a chosen location of section A along the road has a length of sample to be 30.48m long and the width of the road is 7.30m.

Thus area of this portion of A, where the distress is held = 7.30 x 30.48 = 222.5m^2

Type of distress = alligator cracking.

Severity of cracking = Moderate (M), length of cracking = 30.8m, width of cracking = 1.52,

Extent or Area of cracking = 30.48 x 1.52 = 46.33m^2
Area in A holding the distress = 222.5m^2 as calculated above.

Density or percentage of cracked area $= \frac{\text{Cracked Area x100}}{\text{Area in A holding the Distress}}$

$$= \frac{46.33 \text{ x } 100}{222.5} = 20.8\%$$

Using 20.8% and the graph of Appendix A-1, the Deduct Value of 56% is obtained. Thus Table 5 was formed. In this way Deduct Values were obtained for all sections of the highway from A to G.

Thus, in order to get all the deduct values (DV) in sections A to G of the highway we note that some sections have more than one type of distress. For all such cases, one has to add all the Deduct Values as stated earlier and then use Appendix A-3 to get the Corrected Deduct Value (CVD). Thus Table 6 was formed, giving Total Deduct Value, number of distress entries (q) with deduct value over 5 points, Corrected Deduct Value (CDV) and the Pavement Condition Index (PCI) which is 100 minus CDV, (100 — CDV).

Table 6: Total Deduct Values (TDV,) q = Number of distress entries with deduct value of over 5 points, Corrected Deduct Values (CDV) and Pavement Conditions Index (PCI)

Location	TDV (%)	q>5	CDV (%)	PCI (%)
A	56	1	56	44
B	89	2	63	37
C	86	2	63	37
D	83	2	60	40
E	109	3	69	31
F	124	2	85	15
G	155	2	90	10

Thus from Table 6, average PCI of Pavement = (44+37+37+40+31+15+10) ÷7 =30.6.

*All Deduct Values and Corrected Deduct Values are read from Expert Pavement Condition Index curves of the United States Army Corps of Engineers (Shahin and Walther, 1990).

Discussion of Results:

From the foregoing analyses of the results of this study, the Corrected Deduct Value (CDV) ranged from 56 percent to 90 percent, giving a Pavement Condition Index (PCI) range of 10 percent to 44 percent. The average PCI of the test highway is 30.6 percent. As shown in Fig. 1, when the PCI is between 25 percent and 40 percent, the pavement is rated poor, going by the United States Corps of Army Engineers' pavement condition rating system (Shahin and Walter, 1990).

However, applying the same PCI value to an alternative scale of Fig. 5 and Table 2 yields a PCI of very poor and a pavement remaining life of 0 – 5 years. The pavement therefore requires a high percentage of full reconstruction (Michael, 2010).

Conclusion:

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The study pavement has a condition index of 30.6 percent. This rates it as poor under a scale used by the United States Army Corps of Engineers. If this value of PCI is applied on a more stringent scale like the one attributable to Michael (2010), then the study pavement will be rated very poor, its remaining life will be 0 – 5 years and a high percentage of reconstruction will be required for its maintenance.

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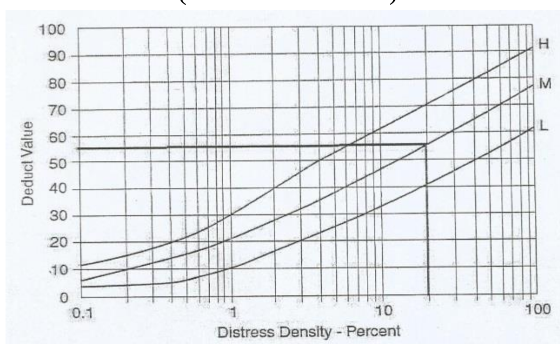
APPENDICES:

APPENDIX A1:

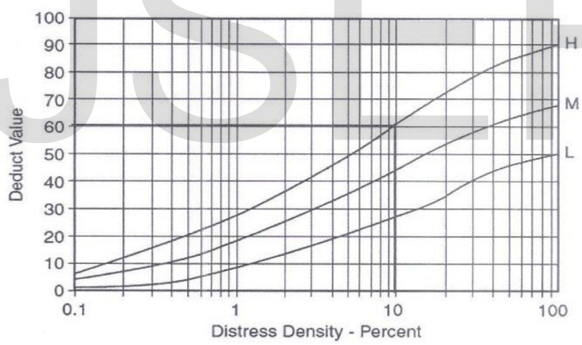
Deduct Value Computation for Alligator Cracks in sample 1, Location A

(Deduct Value = 56)



APPENDIX A-2:

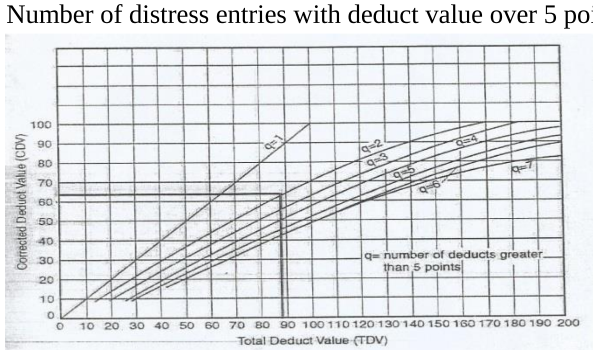
Deduct Value Computation for Rutting in Sample 2, location B (Value 61)



APPENDIX A-3:

Corrected Deduct Value Computation for Sample 2, Location B. (CDV = 63)

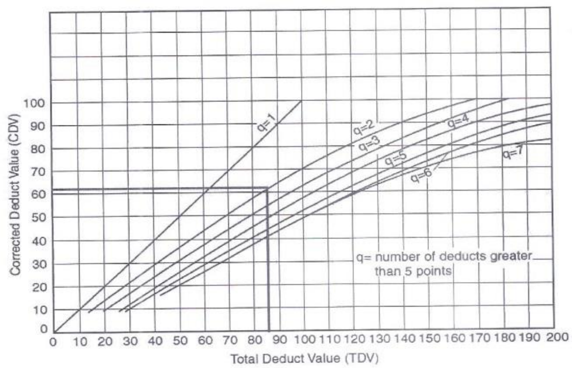
(q = Number of distress entries with deduct value over 5 points).



APPENDIX A-4:

Corrected Deduct Value Computation for Sample 3, Location C. (CDV=63)

(q = Number of distress entries with deduct value over 5 points)..


Corrected Deduct Value (CDV)
Total Deduct Value (TDV)
q=1
q=2
q=3
q=4
q=5
q=6
q=7
q= number of deducts greater than 5 points
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200