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Condition Survey for Evaluation of Pavement Condition Index of a Highway

Muhammad Saleem Zafar [a], Syed Naveed Raza Shah [a], Muhammad Jaffar Memon [a*], Touqeer Ali Rind [a], Muhammad Afzal Soomro [b]

[a] *Department of Civil Engineering, Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mirs', Sindh, Pakistan.*

[b] *Department of Mathematics and Statistics, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Sindh, Pakistan.*

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Abstract

Pavements are major means of highway infrastructure. Maintenance and rehabilitation of these pavements for the required serviceability is a routine problem faced by highway engineers and organizations. Improvement in road management system results in reduction of time and cost, the pavement condition survey plays a big role in the pavement management. The initial phase in setting up a pavement management system (PMS) is road network identification. A vital element of a PMS is the capacity to assess the present condition of a pavement network and anticipation of future condition. The pavement condition index (PCI) is a numerical index generally utilized for the assessment of the operational condition & structural reliability of pavements. Estimation of the PCI is dependent on the results of a visual inspection in which the type, severity, and quantity of distresses are distinguished. In this research, a pavement distress condition rating strategy was utilized to accomplish the goals of this study. The main targets of this research were to categorize the common types of distress that exist on "Lakhi Larkana National Highway (N-105)", and to estimate the pavement condition index. Using these data, Average PCI for the highway section was calculated. PCI to assess the pavement performance, 10 out of 19 defects were recognized in the pavement, as stated by the PCI method. Results indicated that the common pavement distress types were depressions, polished aggregate, rutting, potholes, block cracking, and alligator cracking.

Keywords: Pavement Management System (PMS); Visual Condition Survey; Corrected Deduct Values (CDV); Pavement Condition Index (PCI).

1. Introduction

The pavement condition and traffic speed are considered as operative and important factors that affect the efficiency of highway systems. The surface rehabilitation of multilane highways should be awarded a high priority by highway establishments, as this represents an important component of the road network [1]. The Traffic speed is a significant factor because it determines safety, time, comfort, convenience, and economics, and is an important indication for predicting pavement condition and surface roughness of roadways. Transportation engineering deals primarily with moving people and goods from one place to another, using waterways, railways, highways and air space. Railways and roads are used for on-land (and underground) transportation by train and vehicles such as cars, busses and trucks. In Pakistan, the largest part of transportation operation is conducted by using highways. The paved length of roads (164,621 km) is more than 14 times the total length of rail tracks (11,881 km) [2].

* Corresponding author: Jaffar.memon@muetkhp.edu.pk

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1.1. Pavement Management

Pavement Management is an efficient technique to investigate and to address pavement condition of the road network. This is a valued gadget, which cautions the road manager regarding acute stage in a life cycle of highway. The significant feature of a PMS is the capacity to conclude the pavement network present condition as well as to predict its future state.

A Pavement Management System (PMS) [3], presented is an international procedure to help decision maker in "finding optimum approach" for pavement maintenance. Road failure is divided into two major parts. The first one is functional failure. In this matter, the road won't perform its intended function without either causing inconvenience to passengers and high impacts to vehicles [4]. The cause of functional failure is distress in pavement surface that these are depressions, cracks, rutting formation and poor riding quality [5]. The second one is structural failure, involves collapsing of pavement layer or breaking of one or two layer of pavement that makes the pavement unable to withstand loads on the surface of the pavement [6].

Pavement management involves, among so many other activities, their maintenance. Management of pavement involves knowledge of its condition and based on it the need and optimal time for maintenance [7]. When such information about a road network is assembled, it becomes much easier to decide the priorities or otherwise for maintenance.

1.2. Pavement Condition Index (PCI)

Pavement Condition Measurement involves Pavement Condition Survey and Calculation of PCI. PCI is a mathematical index, with values ranging from 0 ~ 100, where 0 is denoted for failed pavement and 100 designates faultless (new) condition [8]. Evaluation of PCI is established on the result of visual survey, which recognizes types, quantity and severity of distress. It was established to deliver an index for structural integrity of the pavement and its surface serviceability. The PCI is default condition index for the PAVER system [9].

For the subject research work Lakhi-Larkana National Highway (N-105) shown in Figure 1 is selected due to its national importance as mentioned here:

- This highway is important link between Karachi-Sukkur-Quetta Highway (N-65) and D. I. Khan-Kashmore-Hyderabad, namely Indus Highway (N-55).
- This highway links important cities of Sukkur, Shikarpur, Larkana, and no of towns & villages around it.
- This is utilized by the local formers to move their crops to nearby markets and across the country.

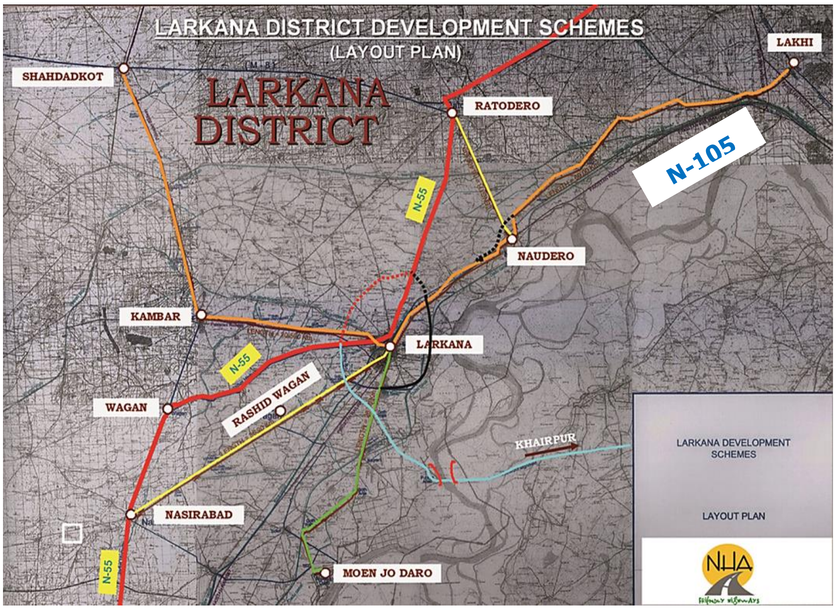


Figure 1. Layout Plan of Lakhi-Larkana National Highway (N-105) [10]

1.3. Problem Statement

Determination of condition of a Pavement is the key element in deciding the nature and extent of the repair that the road should receive, in order to provide the desired service level to the vehicular traffic. In countries such as Pakistan where limited budget allocations are available, a haphazard distribution of maintenance fund may not effectively improve the condition (and of course level of service) of the road and/or road network. Such strategy is expected to tend toward keeping the major road in good shape and neglect those in the lower order of hierarchy. Desired results have not been achieved due to non-use of modern procedures of management and maintenance of road networks/pavement.

Efficient maintenance of a pavement involves setting priorities based upon the importance of a road in a network and its present condition. It has been concluded with experience and research that the management of pavements works on the principle of ***"****Pay now, or pay much more lately."* Nowadays in cost-effective environs, as the pavement network has matured, determination of Maintenance & Rehabilitation (M&R) requirements and its importance is based on systematic approach. Highway networks must now be managed, instead of only maintained.

Plenty researches as shown in Figure 2, which cost of maintenance, that is an extremely poor status, is 4-5 times higher that if the road is supported when in the batter status [11]. Thus, the efficiency of an effective maintenance system will reduce the cost of maintenance.

Pavement Management System (PMS) has been introduced as part of Engineered Management System (EMS). For management of pavement, Pavement Condition rating in the form of "Pavement Condition Index (PCI)" is required [12].

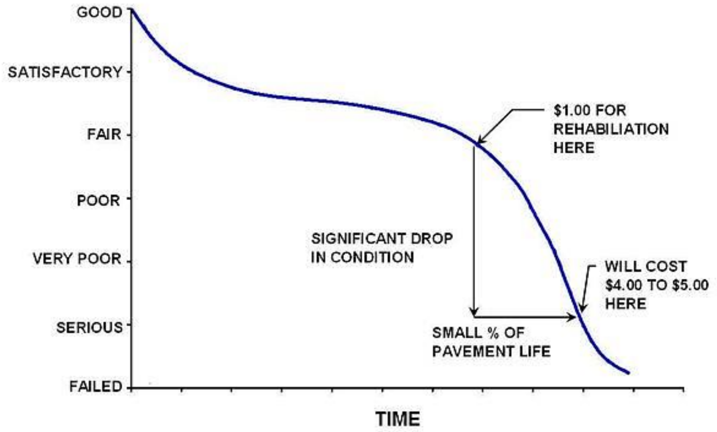


Figure 2. Illustration of a pavement condition life cycle [11]

2. Literature Review

Road pavements, like all other such facilities, need to be maintained. While using roads for transportation, the highway network and its management for an un-interrupted flow of traffic is considered. Management of roads involves, among so many other activities, the maintenance of the pavements. This is extremely vital to monitor the conditions of road pavements along their service life. In this sense, the development of an adequate Pavement Management System (PMS) is a very key tool for road agencies [13 & 14]. For determining the need and optimal time of maintenance of a pavement many method are in use. Some of the classical approaches are listed below;

- Even in developed countries, it would be considered sufficient to provide 2-inches asphalt concrete overlay over an old pavement, provided funds are available.
- "Just to spray the pavements black at the end of the year", would be considered sufficient in another environment [15].
- In Pakistan, National Highway Authority (NHA) has introduced Pavement Maintenance Management System (PMMS) using Maintenance Intervention Level (MIL) inspection procedure.
- In United States of America, Utah State Department of Traffic (UDOT) uses International Roughness Index (IRI) to establish present pavement condition for their Pavement Management System [16].
- Washington State, Department of Traffic (WSDOT) in the USA, uses Falling Weight Deflecto Meter (FWDM), which is the most sophisticated NDT equipment, for their Pavement Management System. With the help of FWDM, bearing capacity, estimated expected life of a pavement are determined. Based on this information overlay requirement over a desired design life is calculated.
- Pavement Management System (PMS) has been introduced by United States Army for Management of Roads and Airfields as part of Engineered Management System (EMS). PMS uses Pavement Condition Index (PCI) as basis.
- In some circumstances, maintenance of a road is driven in a democratic way.

- The South Dakota Department of Transportation (SDDOT) used master models to create PCI-predictive models by considering the ideas of experienced engineers who knew about the deterioration patterns of different types of pavements [17]. In their exertion, a scaling system was applied to build up the deduct values related with the severity and the extent associated with each of the defined distress types in the initial step. Then professional engineers were assigned to evaluate the pavement age on the basis of various distresses severity and extent.
- Deterioration is a result of complex distress as pavement cracking through fatigue under repeated loadings and environmental cycles [18].
- Chandra [19] investigated relationship between the pavement roughness, road capacity, and speed on a two lane highway by establishing a simple linear relationship between the free flow speed and roadway roughness. It was found that the roadway roughness negatively correlates with the free-flow speed, and that roughness is an important variable in this relationship.
- Premature failures like rutting and Fatigue have very high impact on pavement performance [20].

3. Research Methodology

For any pavement maintenance and/or management activity, the knowledge of its condition is the basic requirement. Therefore, there is a need for a standardized method for assessing the condition of the pavement. After the condition of a pavement has been determined, only then a decision as to the need for maintenance can be made. The process of measurement or evaluation of Pavement Condition Index is graphically shown in Figure 3.

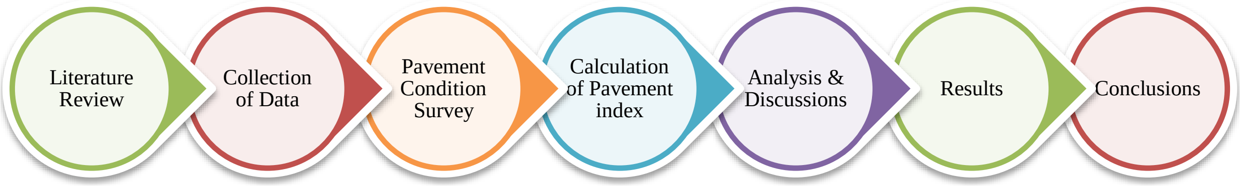


Figure 3. The Flowchart for Evaluation of PCI

3.1. Pavement Condition Survey

Prior to evaluation of PCI (Pavement Condition Index) a set of procedures has to be followed. Now, for accomplishing the subject task, i.e., the actual evaluation of PCI, the following three steps are involved:

- Pavement Network Definition
- Pavement Condition Measurement or Survey; and
- Determination of PCI.

In this research pavement network for ***Lakhi Larkana National Highway (N-105), Section KM 7 to KM 15*** has been defined and condition survey has been conducted on it.

3.1.1. Pavement Network Definition

- *Network Definition*

The network comprises of N-65 (Karachi-Sukkur-Quetta National Highway), N-105 (Lakhi Larkana National Highway), and N-55 (D. I. Khan-Kashmor-Hyderabad National Highway).This highway links important cities of Sukkur, Shikarpur, Larkana, and no of towns & villages around it. N-105 Highway takes off toward West to Larkana City from Lakhi Village, 22 km from Sukkur City on N-65.

- *Branch & Section*

A readily recognizable part of a network that has a distinct function is termed as a Branch. The easy way to classify the branches comprising the pavement network is to use the current name ID system used on the maintaining agency's maps.

Since a branch is generally a large unit of the pavement network, it does not always have regular characteristics all over its entire area or length. For this reason, branches are divided into smaller modules called sections for managerial purposes. A section is the smallest management unit when considering the application and selection of M & R treatments. Each branch consists of at least one section, but may consist of more, if pavement characteristics vary throughout the branch.

- *Sample Units in the Section KM 7-15 (LLNH)*

Before it is possible to start physical condition survey of a road section, it has to be segmented into smaller units called sample units. The size and number of sample unit has been determined as follows;

Standard area for sample unit of an Asphalt Road		= 2,500 ± 1,000 Square Ft ± 40 %
Length of Road KM 7-15	(7.80 km)	= 25,590 Ft
Width of Road	(7.30 m)	= 24 Ft
Total Road surface area	24×25,590	= 614,160 Square Ft
No of Sample Units considering target sample area of 2,500 Square Ft	614,160 / 2,500	245.66 = 246 Nos.
Sample Unit area	614,160 / 246	= 2,496.59 Square Ft
Initial Length of Sample Unit	2,496.59 / 24	= 104.02 Ft
Selected length of sample unit		= 100 Ft
Selected area of sample unit	24×100	= 2,400 Square Ft
(2,400 Square Ft is within 4 % of the recommended sample unit area against the limit of 40 %)		
No of sample units	25,590 / 100	= 256 Nos

- *Sample Units to be Inspected*

The inspection of each sample unit in a pavement section may require significant effort, especially if the section is large. To constrain the amount of resources required for an inspection, a sampling plan was developed so that a rationally precise PCI could be assessed by inspecting only a limited number of the sample units in the pavement section. The mandatory degree of sampling depends on the usage of the pavement, whether the survey is conducted at the network or project level.

For the purpose of this research, project level inspection has been considered and the number of sample units to be inspected is also worked out accordingly.

Length of Road	= 25,590 Ft		
Total no of sample units in the pavement section, N	= 256 Nos		
PCI Standard Deviation for Standard AC road, s	= 10		
PCI range	= 25		
No of sample units to be surveyed (Figure 3)	= 15		(a)
No of sample units to be inspected for Network Level sampling when N is over 40	= 10% = 10%×256 n= 25.6 =26		(b)
No of sample units to be surveyed as per the equation	$n = [N.\ s^2] / [(e^2/4)\ (N - 1) + s^2]$		(Eq.-1)
Where			
e = Allowable error in the estimation of the section PCI		= 5	(c)
s = Standard Deviation of the PCI between sample units in the section		= 13	(c)
$n = [256\times13^2] / [(5^2/4)\ (256 - 1) + 13^2]$		= 24.54 n= 25	(c)
Selected no of sample units to be surveyed,	n= 26		(option b)

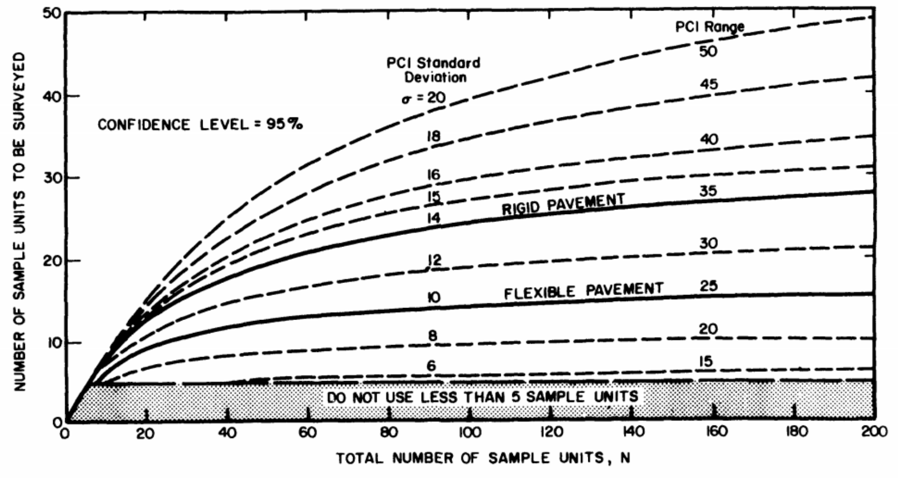


Figure 4. Selection of the min: no. of sample units [12]

- *Sampling Interval*

To introduce a systematic approach in to the random sampling process, a sampling interval should be determined. That's why such type of random sampling is termed as systematic random sampling.

$$\textit{Sampling Interval,} \quad I = \mathrm{N/n} = 256/26 = 9.85$$

$\text{Sampling Interval} = 10$

$\text{Random Start (arbitrarily)} = 6$

The basic parameters for sampling / condition survey as calculated / selected above are summarized in Table 1 below. The selected sample units for condition survey, based on these criteria, are tabulated in Table 2.

Table 1. Basic parameters

Systematic Random	Sampling Parameters
Sample units to be surveyed	26
Sampling Interval	10
Random Start	6

- *Identification of Sampling Units to be Surveyed*

After the above exercise, it needs to be determined as to which of the sample units in terms of their identification numbers have to be surveyed to fulfil the requirements of the systematic random sampling. The following table explicitly indicates the detail of sample unit, considering the determined criteria for systematic random sampling approach.

3.1.2. Pavement Condition Survey of Section KM 7-15 (N-105)

Since our subject road section is an Asphalt Concrete (AC) pavement, the pavement condition rating procedure for asphalt, tar-surfaced, and asphalt over concrete pavements laid out in PCI distress Manual was used.

- *Some Examples of Completed Data Sheets*

For the purpose of demonstration two data sheets selected on random basis are explained here. These are data sheets with serial number 3 and 16, corresponding to sample unit numbers 26 and 156, respectively.

Table 2. Selected sample units for condition survey

SR. No.	Sample Unit			SR. No	Sample Unit		
	Number	Station			Number	Station	
		Start	End			Start	End
1	6	600	700	14	136	13,600	13,700
2	16	1,600	1,700	15	146	14,600	14,700
3	26	2,600	2,700	16	156	15,600	15,700
4	36	3,600	3,700	17	166	16,600	16,700
5	46	4,600	4,700	18	176	17,600	17,700
6	56	5,600	5,700	19	186	18,600	18,700
7	66	6,600	6,700	20	196	19,600	19,700

8	76	7,600	7,700	21	206	20,600	20,700
9	86	8,600	8,700	22	216	21,600	21,700
10	96	9,600	9,700	23	226	22,600	22,700
11	106	10,600	10,700	24	236	23,600	23,700
12	116	11,600	11,700	25	246	24,600	24,700
13	126	12,600	12,700	26	256	25,500	25,590

Serial No. 01

Conditional Survey Data Sheet For Sample Unit Of
Lakhi Larkana National Highway (N-105)

BRANCH: LLNH SECTION: KM: 7 to 15 SAMPLE UNIT: 26
SURVEYED BY: MSZ DATE: 26 Dec 18 SAMPLE AREA: 2400 SFt

1 Alligator Cracking	6 Depressions	11 Patching & Util. Cut	16 Shoving
2 Bleeding	7 Edge Cracking	12 Polished Aggregate	17 Slippage Cracking
3 Block Cracking	8 Joint Reflection Cracking	13 Potholes	18 Swell
4 Bump and Sags	9 Lane Shoulder Drop Off	14 Railroad Crossing	19 Weathering/Ravelling
5 Corrugations	10 Long. & Trans. Cracking	15 Rutting	

DISTRESS SEVERITY	QUANTITY								TOTAL	DENSITY %	DEDUCT VALUE
1 L	72	100							171.5	7.15	30
1 M	664								664	27.67	60
15 L	45.5	664							709.5	29.56	40
15 M	48								48	2.00	25

L = Low M = Medium H = High LLNH = Lakhi Larkana National Highway MSZ = Mohammad Saleem Zafar

Figure 5. Asphalt Surfaced Pavement sample unit condition survey sheet

Serial No. 02

Conditional Survey Data Sheet For Sample Unit Of
Lakhi Larkana National Highway (N-105)

BRANCH: LLNH SECTION: KM: 7 to 15 SAMPLE UNIT: 156
SURVEYED BY: MSZ DATE: 07 Jan 19 SAMPLE AREA: 2400 SFt

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

DISTRESS SEVERITY	QUANTITY							TOTAL	DENSITY %	DEDUCT VALUE
2 L	2	3						5	0.21	0
19 L	7							7	0.29	0.7

L = Low M = Medium H = High LLNH = Lakhi Larkana National Highway MSZ = Muhammad Saleem Zafar

Figure 6. Data recorded on condition survey data Sheet. Photo shows light bleeding

3.1.3. Calculation of Pavement Condition Index

Now, when, the condition Survey has been completed for each selected sample unit, the results are used to estimate the PCI. The PCI calculation is established on the deduct values — weighing factors from 0 to 100 that specify the impact, each distress has on pavement condition.

- *Calculation of a Sample Unit PCI*

During the process of pavement condition survey of LLNH section KM 7-15, the distress quantity and intensity of each distress type observed were measured in accordance with the distress definitions and procedures for asphalt surfaced roads.

The calculation steps for asphalt surfaced pavements are shortened in Figure 5. Following is an explanation of each step.

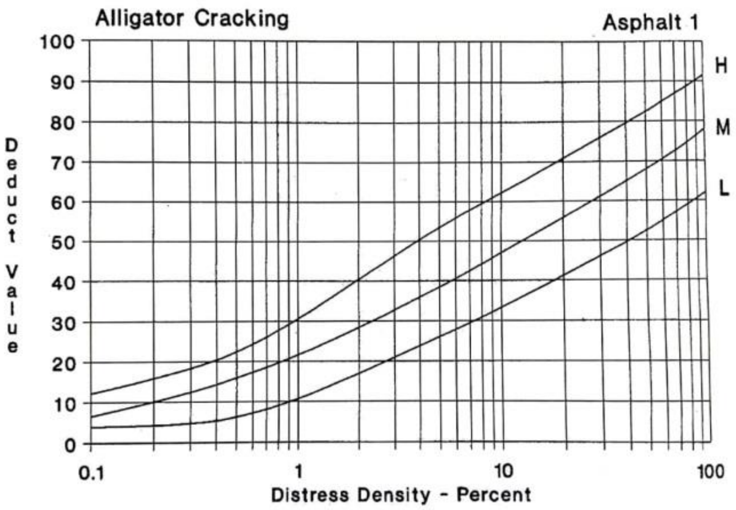
Step 1: ***Determine deduct value***

1(a). The totals for all distress type at each severity level are added and recorded under "Total" on the survey form. Quantities of distress have been measured in square feet (SFt), linear feet (LFt), or number of occurrences, depending on the distress type.

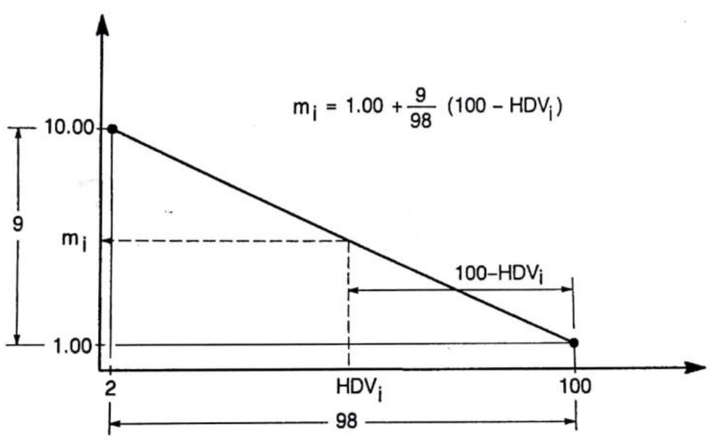
1(b). The quantity of all distress type at each severity level was divided by the total area of the sample unit and multiplied by 100 to get the percentage of density per sample unit for every distress type and severity.

1(c). The deduct value for every distress type and severity level combination was measured from the distress deduct value curve given in PCI Distress Manual. Figure 6 shows an example of a deduct curve for distress l, "Alligator Cracking", for AC pavements.

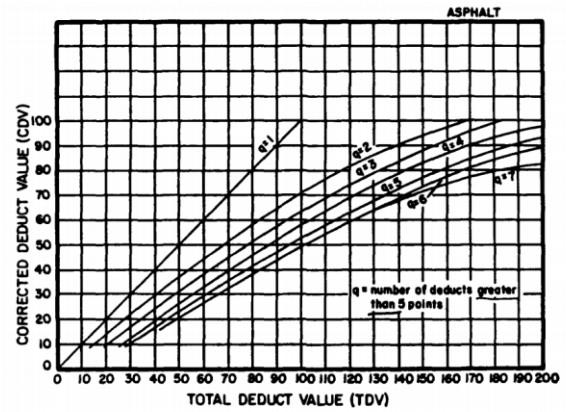
Step 1: Determine Deduct Values



Step 2: Determine Max Allowable No of Deducts (m)



Step 3: Determine Max Corrected Deduct Value



Corrected deduct value curves for asphalt-surfaced pavements

Step 4: Calculation of PCI

PCI = 100 - Max. CDV

Figure 7. Steps for PCI calculation of a sample unit

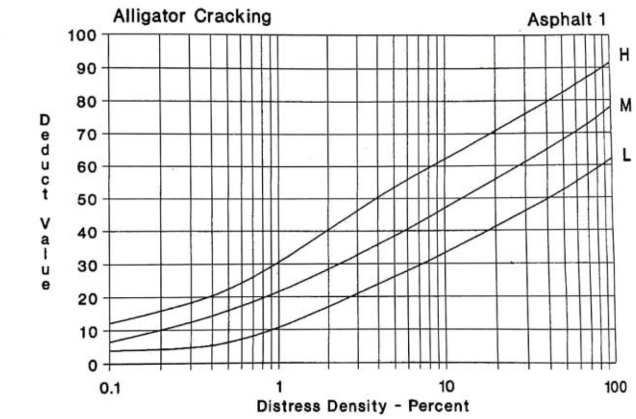


Figure 8. AC pavement deduct curve for the alligator cracking distress

Step 2: Decide the maximum allowable no of deducts (m)

2(a). In case only one individual deduct value (or none) was > 2, the total deduct value was used in place of the maximum CDV in Step 4; otherwise, Steps 2(b) and 2(c) were followed.

2(b). The individual deduct values were listed in descending order.

2(c). The allowable number of deducts, *m* (Figure 7) was determined using the following formula for AC roads:

$m_i = 1 + (9/98)(100 - HDV_i)$

Where; m_i = allowable number of deducts, including fractions, for sample unit *i;* HDV*i* = highest individual deduct value for sample unit *i.*

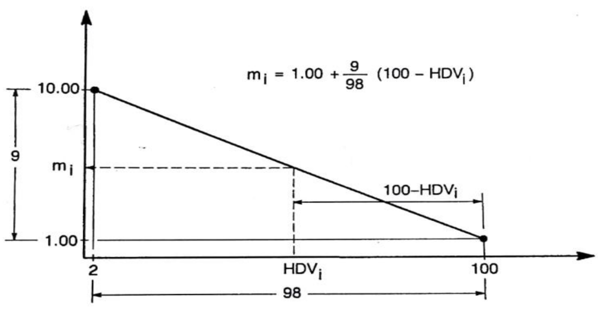


Figure 9. Calculation of max allowable deducts (m) for pavements

2(d). The no of individual deduct values is restricted to *m*, including the fractional part. If less than *m* deduct values are available, then all of the deduct values are used.

Step 3: Determine the maximum corrected deduct value (CDV)

The max CDV is determined iteratively as follows:

3(a). The number of deducts with a value > 2 for AC surfaced roads was determined.

3(b). Total deduct value by adding all the individual deduct values was calculated.

3(c). The Corrected Deduct Value (CDV) was determined by looking up the pertinent correction curve in PCI Distress Manual. Figure 8 shows the correction curve for AC Roads and Parking Lots.

3(d). For AC surfaced roads, the smallest individual deduct value that is > 2 is reduced to 2.0. Repeat Steps 3(a) through 3(c) till *q* is equal to 1. See Figure 9 for demonstration of this process.

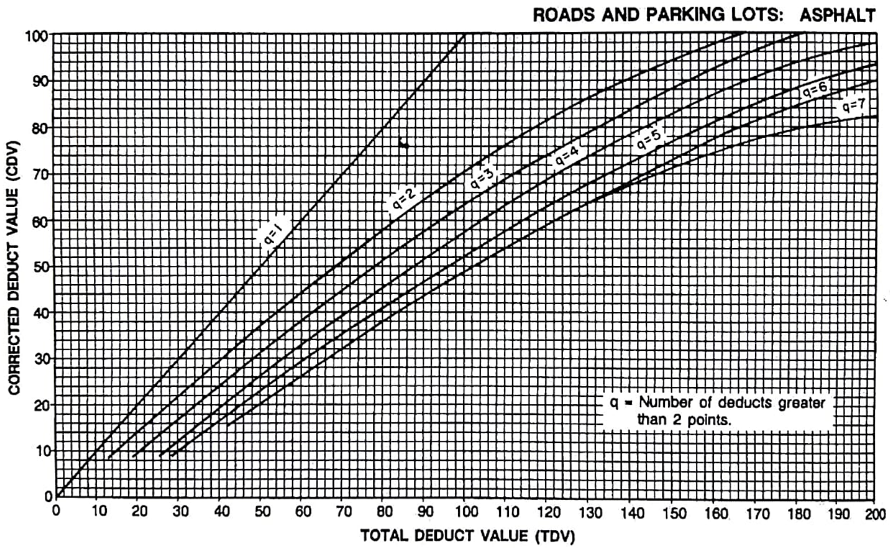


Figure 10. Corrected Deduct Value (CDV) graph for AC roads and Parking Lots [22]

CDV (Corrected Deduct Values) Sheet

Serial No: **AUS-1(27)**

Branch: **LLNH (N-105)** Section: **KM: 7 TO 15** Sample Unit #: **70**

S/No	Deduct Values								Total	q	CDV
1	64	37.5	26	19	~~5~~					5	
2	64	37.5	26	19					146.5	4	81.5
3	64	37.5	26	2					129.5	3	78
4	64	37.5	2	2					105.5	2	74
5	64	2	2	2					70	1	70
6											
7											
8											

m = 4.31 ***Discard q=5 value*** CDV = 81.5

PCI = 100 – CDV = 100 - 81.5 = **18.5**

Figure 11. CDV sheet for calculation of PCI

3(e). The max CDV is the largest of the CDVs determined. In the example of Figure 9, the maximum CDV is 81.5.

Step 4: Calculation of PCI

Figure 5 summarizes the PCI calculation procedure for a sample unit of AC pavement. As shown in Figure 9, once maximum CDV has been established, calculation of PCI is very simple.

$$PCI = 100 - Maximum\ CDV$$

$So, PCI = 100 – 81.5 = 18.5$

- *Calculation of the PCI for Section KM 7-15*

The individual PCIs of all the twenty six random sample units are summarized in Table 3. The total and average has also been calculated. The PCI for *LLNH* section KM 7-15 is the average PCI for *26* sample units calculated by this procedure and comes out to be 57.45. And two additional sample units are also inspected; a weighted average must be used. The weighted average is calculated by using the equation as below:

$$PCI_s = ((N - A)PCIr + A\ PCIa)/N \quad (2)$$

Where; PCI_s = PCI of pavement section, PCI_r= avg PCI of random (or representative) samples, PCIa= avg PCI of additional samples, N= total no of samples in the section, A= no of additional samples surveyed.

Table 3. Sample units PCI

Calculation of PCI of Random Sample Units					
Sr. No	**Sample Unit #**	**Sample Unit PCI**	**Sr. No**	**Sample Unit #**	**Sample Unit PCI**
1	6	44	14	136	32
2	16	36	15	146	8
3	26	15	16	156	99.3
4	36	34	17	166	98
5	46	32.5	18	176	95
6	56	44	19	186	69
7	66	28	20	196	53
8	76	40	21	206	58
9	86	24.5	22	216	63.5
10	96	36	23	226	90
11	106	97	24	236	81
12	116	48	25	246	100
13	126	85	26	256	83
Sub Total		564	Sub Total		930
Total = 1,493.80					
Average (PCI) = 57.45					

The impact of the individual PCIs of the additional survey units can be determined only by taking a weighted average. For this, the average of PCIs of the additional sample units needs to be determined as given in Table *4*. To evaluate the PCI of pavement section (PCI_S), the equation (Equation 2) for weighted average is used.

Ave PCI of random (or representative) samples (PCI_r) = 57.45

Ave PCI of additional samples (PCI_a) = 9.25

Total no. of samples in the section (N) = 256

No of additional samples inspected (A) = 2

PCI of pavement section (PCI_S) = $((N - A)PCIr + A\ PCIa)/N = [(256 – 2) \times 57.45 + 2 \times 9.25] / 256$

PCI_S = 57.10

This PCI value determined above (57.1) is the representative present pavement condition PCI of LLNH Section KM 7-15 and can be rated as marginally *Good* (over 55 to 70).

Table 4. PCI of additional samples

Serial No	**Sample Unit #**	**Sample Unit PCI**
27	70	18.5
28	74	0
Total		**18.5**
Average PCI_a = 9.25		

3.2. Total Extrapolated Distress Quantities for Pavement Section

After detailed working on extrapolation of pavement distress quantities for each distress type and severity, further processing is required to obtain total distress quantity for various distress types and severity and to estimate the total affected area of the pavement section under study. Following table presents the summary of above processing to help estimate the desired quantities.

Table 5. Summary of distresses

Summary Of Distress Quantities For LLNH Pavement Section					
Distress Type	**Distress Description**	**Units**	**Distress Severity**		
			L	**M**	**H**
1	Alligator Cracking	SFT	26,167	66,823	13,337
2	Bleeding	SFT	49		
3	Block Cracking	SFT	5,254	7,519	
4	Bumps and Sags	LF			
5	Corrugations	SFT			
6	Depressions	SFT		395	
7	Edge Cracking	LF			
8	Joint Reflection Cracks	LF			
9	Lane Shoulder Drop Off	LF			
10	Long. & Trans. Cracking	LF		420	
11	Patching &Utill. Cut Patching	SFT	525	1,172	376
12	Polished Aggregate	SFT	9,590		
13	Potholes	CNT	20	10	49
14	Railroad Crossing	SFT			
15	Rutting	SFT	16,489	469	
16	Shoving	SFT			
17	Slippage Cracking	SFT			
18	Swell	SFT			
19	Weathering & Raveling	SFT	1,123		
Total			**59,217.00**	**76,808.00**	**13,762.00**
Grand Total			149,787.00		
Density of Extrapolated Distress area = 149,787 / 614,160 × 100			24.39 %		

3.3. Pavement Condition Index (PCI) and Distress Area Quantities Evaluated for Pavement Section

Detailed calculations for evaluation of PCI for pavement section, based on the data collected during condition survey of the pavement, are summarized below;

Overall PCI of LLNH Pavement Section = 57.10

Rating = Good

Position of Typical PCI Curve = Critical Range

Calculation of extrapolated distress area quantities is closely related and very important indicator of distress. The estimates for maintenance work are also based on the extrapolated distress area. Therefore, distress quantities in the *Low, Medium, High* severity levels for subject LLNH pavement section have been calculated in Table 6. A summary of the results follows;

Low severity distress area in pavement section = 59,217 SFt

Medium severity distress area in pavement section = 76,808 SFt

High severity distress area in pavement section = 13,762 SFt

Total distress area in pavement section = 149,787 SFt

Density of Extrapolated distress area = 24.39 %

4. Analysis and Discussion

Now there is a need to analyze and briefly discuss the success or otherwise of the various components involved and pros and cons of the whole exercise, and to sum up the findings / accomplishments. Some analysis and discussion on each step involved in the process follows.

4.1. Pavement Condition Survey of LLNH (KM 7-15)

The pavement condition survey of the LLNH (N-105) section KM 7-15 for the purpose of this research work was conducted and observed distress types, distress severities and quantities of the sample units, selected on the basis of systematic random sampling technique, in accordance the PCI Distress Measurement procedure. In addition to randomly sampled units, two additional sample units were also surveyed.

4.2. Evaluation of Pavement Condition Index (PCI)

Pavement Condition Index (PCI) of the pavement section was calculated from the data collected during the Pavement Condition Survey conducted earlier. PCI of the individual sample units was calculated on Corrected Deduct Value (CDV) calculation sheets. The combined PCI for the entire selected section was calculated by determining the average of the random sample unit PCIs and the effect of additional sample unit PCIs was taken into account by the way of weighted average.

In accordance with Table 6, the qualitative Rating of the subject pavement section falls between the limit of Good (56-70). Therefore, the condition of the selected pavement section may be qualitatively rated as *GOOD.*

Table 6. Pavement condition rating [12]

Condition Rating	PCI	Remarks
Failed	0-10	Totally Unserviceable
Very Poor	11-25	
Poor	26-40	
Fair	41-55	Critical Range (55-70)
Good	56-70	
Very Good	71-85	
Excellent	86-100	Newly Constructed

4.3. Extrapolation of Distress Areas for the Pavement Section

During the pavement condition survey of 26 systematically random selected sample units, it has been found that 15,231 SFt of pavement area manifests against 62,400 SFt of sample area, showing a sampled distress density of 24.41 %. It was also found that a pavement area 1,051 SFt had been distressed in the 2 additional sample units with total area of 4,800 SFt, resulting in distress density of 21.90 %. The affected area recorded during condition survey of random & additional sample units, on the basis of distress severity is summarized.

Table 7. Summary of extrapolated distress quantities

Summary Of Extrapolated Distress Quantities for LLNH Pavement Section						
Distress Type	Distress Description	Units	Distress Severity			
			L	M	H	Total
1	Alligator Cracking	SFT	26,167	66,823	13,337	106,327
2	Bleeding	SFT	49			49
3	Block Cracking	SFT	5,254	7,519		12,773
4	Bumps and Sags	LF				
5	Corrugations	SFT				
6	Depressions	SFT		395		395
7	Edge Cracking	LF				
8	Joint Reflection Cracks	LF				
9	Lane Shoulder Drop Off	LF				
10	Long. & Trans. Cracking	LF		420		420
11	Patching & Utill. Cut Patching	SFT	525	1,172	376	2,073
12	Polished Aggregate	SFT	9,590			9,590
13	Potholes	CNT	20	10	49	79
14	Railroad Crossing	SFT				
15	Rutting	SFT	16,489	469		16,958

16	Shoving	SFT				
17	Slippage Cracking	SFT				
18	Swell	SFT				
19	Weathering & Raveling	SFT	1,123			1,123
	Total (24.39 %)		59,217	76,808	13,762	149,787
	Composition of Distress Severity		**39.53 %**	**51.28 %**	**9.19 %**	**100 %**

It seems appropriate to consider that the development of distresses initiates with low severity and are promoted to medium and high severity with the passage of time. However, further low severity distresses continue to add up depending upon pavement design, quality of construction, loading and M&R practices.

An analysis of distress compositions in terms of Low, Medium, and High severity distresses shows that the highest occurrence is of Medium- severity (51.28%) followed by Low-severity (39.53%), with High-severity being the least (9.19%).

Low severity distress area in pavement section = 59,217 SFt

Medium severity distress area in pavement section = 76,808 SFt

High severity distress area in pavement section = 13,762 SFt

Total distress area in pavement section = 149,787 SFt

Density of Extrapolated distress area = 24.39 %

Table 8. Pavement section distress types in order of distress density

Total Area of the Section = 614,160 SFT					
Distress Type	**Distress Description**	**Units**	**Distress Area**	**Distress Density %**	**Causes of Distress**
1	Alligator Cracking	SFT	106,327	17.31	Load
15	Rutting	SFT	16,958	2.76	Load / Material
3	Block Cracking	SFT	12,773	2.08	Durability (shrinkage of AC & daily temp cycling)
12	Polished Aggregate	SFT	9,590	1.56	Materials (aggregates of low hardness)
11	Patching & Utill. Cut Patching	SFT	2,073	0.34	All
19	Weathering & Raveling	SFT	1,123	0.18	Durability (poor quality mixture)/ Material(asphalt binder has hardened appreciably)
10	Long. & Trans. Cracks	LF	420	0.07	Climate/Durability (poorly constructed paving lane joint)
6	Depressions	SFT	395	0.06	Load (settlement of the found. soil or improper const.)
13	Potholes	CNT	79	0.01	Load(abrasion of small pieces of pavement surface by traffic)
2	Bleeding	SFT	49	0.008	Materials/Durability(excessive bitumen or low air void contents in AC)
	Total		**149,787**	**24.39**	

4.3.1. Composition of Distress Types in Pavement Section

From Table 8, it is clear that 10 distress types out of 19, have been encountered over the subject road. Distress area quantities are listed in descending order and also indicate respective percentages.

4.3.2. Highest Occurring Distress Types

A glance at Table 8 reveals that the four highest occurring / most damaging distress types in order of distress density are:

- Alligator Cracking (17.31%)
- Rutting (2.76%)
- Block cracking (2.08%)
- Polished Aggregate (1.56%)

The remaining negligible distresses have climate, load, or other-related causes.

4.3.3. Comparison between Observed and Extrapolated Distress Quantities

The distress area of the subject pavement recorded during survey of sample units and distress quantities extrapolated for the section are tabulated below for the purpose of comparison and analysis (Table 9).

Random Sample Units: Observed Density of distress area = 24.41 %
(I5,231/62,400 x 100)

Additional Sample Units: Observed Density of distress area = 21.90 %
(1,051/4,800 x /00)

Overall Extrapolated Density of distress area = 24.39 %
(149,787/614,160 x 100)

Table 9. Comparison between observed and extrapolated distress quantities for pavement section

Description	Distress Severity			
	L	M	H	Total
Observed/Surveyed Distress Quantities	6,052.3(39.74%)	7,808 (51.26%)	1,370.5(9.00%)	15,231
Extrapolated Distress Quantities	59,217(39.54%)	76,808(51.28%)	13,762(9.19%)	149,787

The slight difference between the distress area density for surveyed sample units and extrapolated distress area density for the pavement section is due to inclusion of the impact of additional sample units in the latter by the way of weighted average. This also attaches importance to the use of weighted average approach when additional sample units are involved in the surveyed sample units.

4.4. Impact of Additional Sample Units on Section PCI and Extrapolated Distress Quantities

Average PCI for Random Sample Units = 57.45

Average PCI for Additional Sample Units = 9.25

Overall PCI for LLNH Section = 57.10

Very low PCI value (9.25) of additional sample units has lowered the section PCI to 57.10 from the average value of 57.45for random sample units. To put it differently, the additional sample units have resulted in a slightly more deteriorated (-0.609 %) pavement condition.

Distress Density for Random Sample Units = 24.41 %

Distress Density for Additional Sample Units = 21.90 %

Overall Extrapolated Distress Density for Section = 24.39 %

The lower distress density of additional sample units has slightly lowered (-0.082 %) the value of the Extrapolated Distress Density to 24.39 from distress density of random sample units (24.41%). In other words, it has slightly increased the unaffected pavement area.

4.5. Achievements

Work on the State-of-the-Art Technique for evaluation of PCI for an Asphalt Pavement has been done. The accomplished during the research work, are listed below;

1. Compilation of PCI Distress Manual, and Condition Survey of LLNH Pavement Section have been conducted in a satisfactory manner.
2. PCI of LLNH Pavement Section has been evaluated as per the prescribed procedure.
3. Extrapolated Distress Quantities for LLNH Pavement Section have been calculated.
4. Comparison for impact of Additional sample units on section PCI and Extrapolated Distress Quantities was highlighted.

5. Results

The outcome of the subject research work has been satisfactory in that the desired objectives have been completely accomplished. The condition survey of LLNH Section KM 7-15 has been satisfactorily conducted and calculation of PCI and Extrapolated Distress Quantities has been completed. The results of the Condition Survey and consequent evaluation of its PCI are as below;

5.1. PCI of LLNH Pavement Section

PCI of LLNH pavement section = 57.45

PCI Rating of LLNH pavement section = *GOOD*

5.2. Extrapolated Distress Area of LLNH Pavement Section

Low severity distress area in pavement section = 59,217 SFt

Medium severity distress area in pavement section = 76,808 SFt

High severity distress area in pavement section = 13,762 SFt

Total distress area in pavement section = 149,787 SFt

Density of Extrapolated distress area = 24.39 %

Distress Area Composition by Type:

Alligator Cracking = 17.31%

Rutting = 2.76 %

Block Cracking = 2.08%

Polished Aggregates = 1.56%

Others = 0.68 %

6. Conclusions

Based on the results the following points are concluded:

- Major Cause of Distress is Heavy Traffic Axle load and water logged area.
- The PCI of LLNH Pavement Section is on the lower limit of Critical PCI range, warranting immediate Repairs.
- Similarly, from the data collected in the work suggested above analysis as to the composition of various distresses and relation of total distress area to PCI of a pavement may be established for being able to determine these parameters on reciprocal basis.
- The carriageways may be designed to take heavier loads by providing thicker base course as suggested in Road Note 29 for slow lane of a multilane/separated carriageway.
- Occurrence of the condition of the pavement under consideration in Critical PCI Range warrants for its timely rehabilitation.
- Based on the experiences learnt from the activities performed during the accomplishment of the task, it is recommended that condition survey on a newly constructed road/pavement should be carried out by a student and its PCI be determined. The same pavement should be surveyed every year by another student and reported. After every 5 years a student should be assigned the task of combining the 5 surveys and developing a characteristic/family PCI curve for the pavement so as to compare it with typical PCI curves and to be able to predict for future condition PCI.

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8. Conflict of Interest

The authors declare no conflict of interest.

9. References

[1] Al-Suleiman, Turki I., Mohammed Taleb Obaidat, Ghassan T. Abdul-Jabbar, and Taisir S. Khedaywi. "Field Inspection and Laboratory Testing of Highway Pavement Rutting." Canadian Journal of Civil Engineering 27, no. 6 (2000): 1109–1119. doi:10.1139/cjce-27-6-1109.

[2] Wikipedia.org (2019) Pakistan Railways - https://en.wikipedia.org/wiki/Pakistan_Railways [Retrieved on April 09, 2019].

[3] He, Zhaoxiang, Xiao Qin, Hao Wang, and Chad Comes. "Implementing Practical Pavement Management Systems for Small Communities: A South Dakota Case Study." Public Works Management & Policy 22, no. 4 (July 26, 2017): 378–391. doi:10.1177/1087724x17721714.

[4] Sarsam, S. I. "Pavement Maintenance Management System: A Review". Trends in Transport Engineering and Applications, Vol. 3 No. 2, (2016): 19-30.

[5] Zumrawi, M. M. E., "Survey and Evaluation of flexible Pavement Failures," International Journal of Science and Research, Vol. 4, No. 1, (2015): 1602-1607.

[6] Smith. R. E., Darter. M. I. And Herrin. S. M., "Highway Pavement Distress Identification Manual", Federal Highway Administration, United States.

[7] Karim, F.M.A., Rubasi, K.A.H. and Saleh, A.A. "The road pavement condition index (PCI) evaluation and maintenance: a case study of Yemen." Organization, Technology and Management in Construction: an International Journal, vol. 8, no. 1, (2016): 1446 – 1455. doi: 10.1515/otmcj-2016-0008.

[8] Hafizyar, R. and Mosaberpanah, M. A. "Evaluation of Flexible Pavement Distress and Cost Analysis of Pavement Maintenance: A Case Study in Kabul Afghanistan" International journal of Science and engineering research, vol. 09, no. 08, (2018): 1909 – 1919.

[9] Babashamsi, Peyman, Nur Izzi Md Yusoff, Halil Ceylan, Nor Ghani Md Nor, and Hashem Salarzadeh Jenatabadi. "Evaluation of Pavement Life Cycle Cost Analysis: Review and Analysis." International Journal of Pavement Research and Technology 9, no. 4 (July 2016): 241–254. doi:10.1016/j.ijprt.2016.08.004.

[10] National Highway Authority of Pakistan (2019) NHA road network & maps of projects part i - http://nha.gov.pk/wp-content/uploads/2016/04/NHA-Road-Network-Maps-of-Projects-02.01.2012-Part-01.pdf. [Retrieved on April 09, 2019]

[11] ASTM D6433 - 11, "Practice for Roads and Parking Lots Pavement Condition Index Surveys" (2011). doi:10.1520/d6433-11.

[12] Shahin, M. Y., & Walther, J. A. "Pavement maintenance management for roads and streets using the PAVER system" (No. CERL-TR-M-90/05). Construction Engineering Research Lab (Army) Champaign IL (1990).

[13] Zoccali, Pablo, Giuseppe Loprencipe, and Andrea Galoni. "Sampietrini Stone Pavements: Distress Analysis Using Pavement Condition Index Method." Applied Sciences 7, no. 7 (June 29, 2017): 669. doi:10.3390/app7070669.

[14] Bonin, G, S Polizzotti, G Loprencipe, N Folino, C Rossi, and B Teltayev. "Development of a Road Asset Management System in Kazakhstan." Transport Infrastructure and Systems (March 8, 2017): 537–546. doi:10.1201/9781315281896-71.

[15] Loprencipe, Giuseppe, Antonio Pantuso, and Paola Di Mascio. "Sustainable Pavement Management System in Urban Areas Considering the Vehicle Operating Costs." Sustainability 9, no. 3 (March 19, 2017): 453. doi:10.3390/su9030453.

[16] Loprencipe, Giuseppe, and Pablo Zoccali. "Use of Generated Artificial Road Profiles in Road Roughness Evaluation." Journal of Modern Transportation 25, no. 1 (February 11, 2017): 24–33. doi:10.1007/s40534-017-0122-1.

[17] Yang, Jidong, Jian Lu, Manjriker Gunaratne, and Bruce Dietrich. "Modeling Crack Deterioration of Flexible Pavements: Comparison of Recurrent Markov Chains and Artificial Neural Networks." Transportation Research Record: Journal of the Transportation Research Board 1974 (January 2006): 18–25. doi:10.3141/1974-05.

[18] Moynihan, Gary, Hao Zhou, and Qingbin Cui. "Stochastic Modeling for Pavement Warranty Cost Estimation." Journal of Construction Engineering and Management 135, no. 5 (May 2009): 352–359. doi:10.1061/(asce)co.1943-7862.0000005.

[19] Chandra, S. "Effect of Road Roughness on Capacity of Two-Lane Roads", Journal of Transportation Engineering, vol. 130, no. 3, (2004): 360–364. doi: 10.1061/(ASCE)0733-947X(2004)130:3(360).

[20] Rind, T.A. Memon, N.A. and Qureshi. A.S. "Analysis And Design Of Flexible Pavement Using Empirical-Mechanistic Based Software KENPAVE" Proceeding Of 1st International Conference On Sustainable Development In Civil Engineering. (2019): 120 – 125.

[21] Thagesen, Bent, ed. Highway and traffic engineering in developing countries. CRC Press, 2003.

[22] Shahin, M. Y. "Pavement Management for Airports, Roads, and Parking Lots" (1994). doi:10.1007/978-1-4757-2287-1.