Using Pavement Condition Index to Evaluate the Condition of Flexible and Rigid Pavements

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Abstract: Pavement deterioration is a continuous problem that reduces the service lifetime of the roads if they're not treated before they get worsen. Generally, quality of the materials and construction isn't the sole reason, if so, still they'll be controlled by periodic inspection and maintenance. Pavement condition index is one amongst the effective parameters that is important to be observed for each road and suggested to be updated each year. The objective of this study is to calculate PCI for two roads in Sulaimani city, including both flexible and rigid pavement. The procedure of ASTM D6433 was followed for visual observation of the defects and total station instrument was used for locating the real coordinate of the defects on the roads for any actions to be taken. A 720m long Badinan Road surveyed for rigid pavement and it had been found that due to lack periodic maintenances, transverse joints spalled and widened with some other defects that resulted an overall PCI of 41.1 (Fair). For flexible pavement a 1620m long Hawary Shar road surveyed, although transverse and longitudinal cracking were major defects within the road with some other sorts of defects, but the road performed with a PCI of 95.5 (Excellent). Some maintenance procedures were recommended for both pavement type based on the severity level of the defects.

Keywords: Pavement Condition Index, Pavement Defects, Evaluation of Pavement Condition, Pavement Maintenance

1. Introduction

One of the most widely used index by pavement management systems all over the world is pavement condition index (PCI). By which maintenance and rehabilitation actions can be prioritized, pavement performance at the current time can be predicted, and optimum strategies for the future maintenance and rehabilitation of pavements on the country highways can be developed.

The PCI is a numerical indicator that evaluates the pavement's surface condition. The PCI offers a measure of the current pavement situation based on the distresses observed on the pavement surface, which also shows the structural integrity and operating condition of the road surface. The PCI is not able to give a direct indication of structural capacity of the road nor providing a direct measure of surface roughness or resistance to skid. It offers an objective and rational basis for setting requirements and priorities for maintenance and repair. Continuous PCI measurement is used to determine the rate of deterioration of the pavement, allowing early identification of significant rehabilitation requirements. For validation or enhancement of present pavement design and maintenance processes, the PCI is a powerful indicator which offers feedback on pavement performance (ASTM, D 6433-07).

The surface distress identification has been used by some researchers to rate the condition of pavements, however functional properties of the pavement have been used by some others. Mohammed, Rasha and Zainab (2017) used GIS as a database tool to identify the location of each distresses within the road surface with their corresponding information measured during the surveying process, and keeping data updated, to facilitate decision making of maintenance process. The continuous monitoring of the pavement conditioning index is necessary to establish the rate of pavement deterioration, which permits early identification of major rehabilitation needs.

Karim, Rubasi and Saleh (2017) evaluated the pavement conditions in terms of the surface distresses existing at the time of the field evaluation. The PCI method has been used in this studies as it deals most comprehensively with the topic of pavement distress identification and is based on a sound pavement sampling statistical method.

Faris and Mahir (2012) stated that the maintenance of transportation assets has become the worst challenge for most of the transportation agencies over the world. Tikrit-Tooz Road (in the middle of Iraq) was divided into segments to calculate PCI with the aids of GIS. Based on the results obtained, it was concluded that three kinds of necessities can be compared by the managers; financial, physical, and specifications instructions. Also it was claimed that sometimes Condition Index refers to that assets able to be used for 15 years while specification refers that it can be used for 10 years only and so on.

After thorough searching and investigation within Kurdistan it was seen that still there is no detailed research achieved scientifically to estimate the quality level of the pavements and to estimate the future or remaining service life, as well as lack of inspections and recording the data by the corresponding agencies. For this reason, it was decided to open the gate over the research and study in this field by selecting two roads in Sulaimani city for visual inspection and from there functional evaluation.

Two types of pavements were selected; an asphalt pavement (flexible pavement) and a jointed reinforced concrete pavement (Rigid pavement). ASTM D6433 standard practice for evaluating the surface characteristics of the pavements was followed to evaluate the condition of the roads, and a set of instructions derived to indicate the quality level to indicate proper maintenance and repair strategies.

2. Study Area

To apply the entire procedure provided by ASTM D6433 for both types of pavements (flexible & rigid), two branches of roads were selected from Sulaimani city road network.

The road branch selected for rigid pavement condition studies, is a collector road between the 60-meter Malik Mahmood ring road and the Zargata Intersection. The road is a two way two lane road, with length of 720 m and 9m in width. For PCI determination the road was divided in to 9 segments with the total area of 720 m^2, and the segments further divided into 10 sub segments each with the total area of $72m^2$.

The road branch selected for flexible pavement condition studies, was Hawari Shar road which extends from the Kobane bridge at the 60-meter Malik Mahmood ring road to the Hawari Shar Roundabout. The branch is a two way four lane road, with 1620 m in length and 12.45m in width. For PCI determination the road was divided into 18 sections, each with the total area of $1122.6m^2$ and the sections further divided into 5 subsections, the area of each subsection was 224.52 m^2. The division for both type of pavements was achieved based on the instructions provided by the ASTM standard procedure.

3. Methodology

A. PCI (Pavement Conditioning Index) Determination

The pavement conditioning index is one of the substantial measures that uses the surface distresses for identifying the conditions of different types of pavement of road segments from which maintenance and repair strategies can be organized. Visual survey or visual inspection of the pavement surface is a good indicator of the current situation of the pavement surface.

It is apparent that from the results of the pavement visual surveying:

- Present condition and future predictions can be assumed.
- Urgent maintenance and repair tasks related to different level of the distresses can be estimated.
- It can also be used to evaluate the performance of the materials and techniques used as the solutions.

PCI is a standard procedure that is used by the highway agencies and administrative decision makers in order to visually assess the current pavement condition. The procedure described in American Society for Testing and Materials (ASTM) D6433-09 (2009), was followed for this study. During a PCI survey, visible signs of deterioration are recorded, the final calculated PCI value is a number from zero to 100, with 100 representing a pavement in excellent condition and zero representing the worst (ASTM) D6433.

B. Data Collection

The data required for PCI determination of each road segment was collected by visual observation and total station instrument. The data collected by the total station was used for reproducing the road alignment in AutoCAD software and showing the real location of each distress within the road. The types of the data were distress types, their severity level and measurement of the infected area. Photographs were also taken during the surveying process to help more accurate analysis and decision making.

C. Analyzing the Study Area

The data analysis process was achieved through the following steps:

1. Coordinate data was used for drawing the road alignment and locating the distresses on it.
2. Data collected by visual observation was used for identifying the defects and their severity levels (including their measurement).
3. Deduct values were determined from ASTM D6433 graphs for each segment separately and sections as a group of segments.
4. Corrected deduct values were determined for each section using the standard procedure. If none or only one individual deduct value was greater than 2 then corrected deduct value CDV was determined. If more than one individual deduct value was greater than two, then CDV

was found from the total deduct value by using (q) parameter, which was equal to the number of deduct values greater than 2.

5. PCI was determined from this equation

$$PCI = 100\text{-Max } CDV \qquad [1]$$

4. PCI Calculation

A. Badinan Road (Rigid Pavement)

Is a collector road between the 60-meter Malik Mahmood ring road and the Zargata Intersection. The branch is 720m in length, 9m wide and two way two lane road. It is defined under one branch which is divided into 9 sections each composed of 10 imaginary slabs. The length of each slab is 8 meter.

The procedure explained in ASTM D6433 followed for calculating PCI of the branch. The road was visually inspected to find out any kind of defect produced within the road. Total Station instrument was used for determining the exact location (X,Y,Z) of each defect, so that to draw a map for the road portion including the location of defects, for further actions required to be taken in the future by the corresponding authorities (see Figure 1).

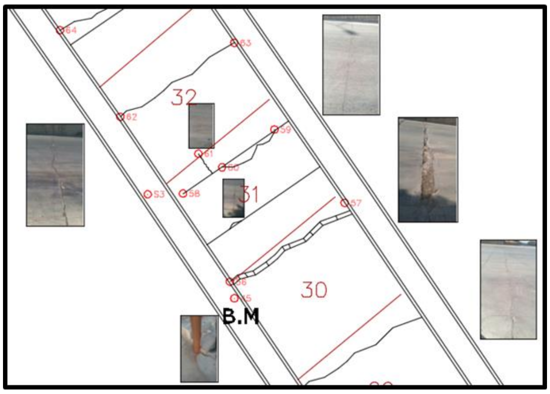

Figure 1: Badinan Road Defect Layout plan

The road layout and location of the defects for the further maintenance and necessary actions were drawn from the coordinate data collected by total station during surveying.

Table 1: PCI Calculation Sample for Badinan Road

NO	DISTRESS TYPES	SEV.LEVEL	NO.SLAB	DENSITY %	DEDUCT VALUE	PCI
1	24	H	1	10	24	62
	39	H	1	10	15	
	39	M	2	20	9	
	29	H	1	10	17	

DV								TOTAL	q	CDV
24	17	15	9					65	4	38
24	17	15	2					58	3	37
24	17	2	2					45	2	36
24	2	2	2					30	1	29

M=	7.98
PCI= 100 - MCDV = 100-38 = 62	

2	39	H	1	10	15	25
	39	M	2	20	9	
	29	L	6	60	22	
	29	M	1	10	6	
	29	H	1	10	17	
	23	H	2	20	51	
	28	H	3	30	37	
	24	H	1	10	23	

51	37	23	22	17	7.50			157.5	6	70
51	37	23	22	17	2			152	5	74
51	37	23	22	2	2			137	4	75
51	37	23	2	2	2			117	3	72
51	37	2	2	2	2			96	2	67
51	2	2	2	2	2			61	1	60

M=	5.50
PCI= 100 - MCDV = 100-75 = 25	

From the above table, it is obviously seen that transverse cracking and spalling of transverse joints are two major defects with the highest density in the rigid pavement under inspection. During the survey and riding through the road several times, it was noticed that lack of maintenance has caused damage to the joint seal and with time the joint has started to spall and widen, that affects riding quality and reduces the traffic in turn.

Table 2: Defects densities within the Badinan road

DEFECTS	SEVERITY LEVEL	DENSITY	SEVERITY LEVEL	DENSITY	SEVERITY LEVEL	DENSITY
	H	%	M	%	L	%
DURABILITY CRACKING	4.5	0.6	0	0.0	0	0.0
SPALLING OF TRANSVERSE JOINTS	85.79	11.9	70.49	9.8	9	1.3
PATCH/PATCH DETERIORATION	20.86	2.9	0.11	0.0	18.78	2.6
MAP CRACKING AND SCALING	4.11	0.6	0	0.0	0	0.0
TRANSVERSE CRACKING	101.75	14.1	36	5.0	46.46	6.5
SCALING	11.76	1.6	6.09	0.8	0	0.0
CORNER BREAK	0	0.0	1	0.1	5	0.7
LONGITUDINAL CRACKING	1.2	0.2	2.82	0.4	0	0.0
UTILITY CUT PATCHING	0	0	0.5	0.1	0	0.0

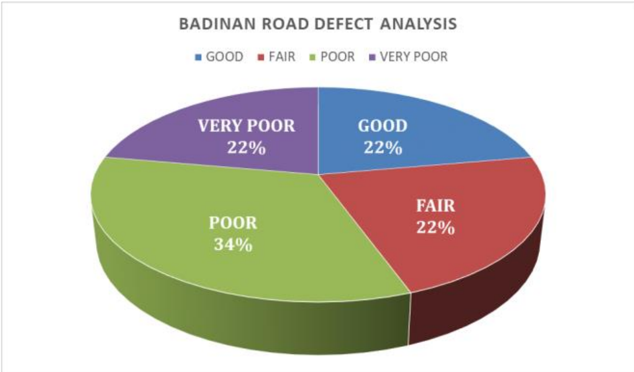

Figure 2: Badinan Road Defect Analysis

From the PCI results analysis, it was found that 22% of the road was in a very poor condition, 34% was in a poor condition, 22% was in a fair condition, 22% was in a good condition and the average road condition was found to be in a fair condition. Since the exact location of the defects are known, a proper action can be taken and the treatment which required can be applied as explained previously.

B. Hawari Shar Road (Flexible Pavement)

Is a flexible pavement that is extended from the Kobane interchange at the 60-meter Malik Mahmood ring road to the Hawari Shar Roundabout. The branch road is a two way four lane road, which is 1620 m in length and 12.45m in width. For PCI determination the road branch was divided into 18 sections, each with the area of 1122.6 m2 and the sections were further divided into 5 sample units each of 224.52 m2 as recommended by ASTM D6433 (Fig.3).

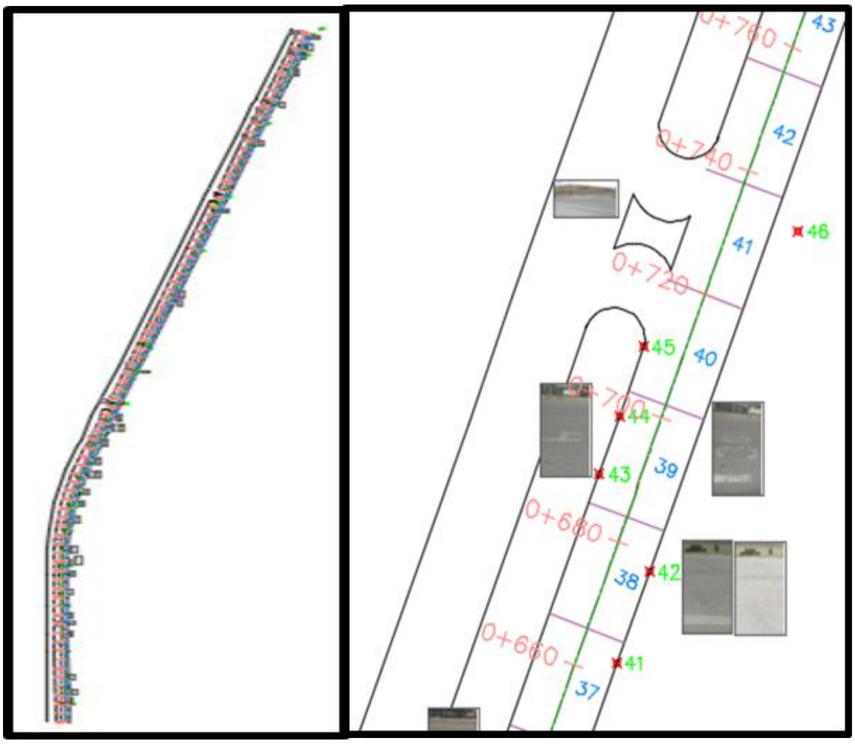

Figure 3: Hawary Shar Road Defect Layout Plan

The complete road branch was taken for calculation and summary of the analyses is shown in Table 3.

Table 3: Density of the defects Hawary Shar Road

DEFECTS	DENSITY/SEVERITY LEVEL		
	H	M	L
1. ALLIGATOR CRACKING	0.00	3.56	0.45
2. BLEEDING	1.34	0.00	0.00
3. BLOCK CRACKING	18.22	21.20	1.71
10. LONGITUDINAL/TRANSVERSE CRACKING	0.00	34.49	1.38
11. PATCHING & UTILITY CUT	0.00	0.98	0.00
13. POTHOLES	0.00	0.03	0.00
19. WEATHERING & RAVELING	6.06	15.17	1.78

From the above table it can be seen that defects with the highest density within the Hawary Shar road are block cracking, Longitudinal/transverse cracking, and weathering & raveling. Although the road performs well with an excellent Condition Index, but still needs some maintenance to preserve the existing condition and maintain it for a longer period.

Table 4: PCI for the Badinan Road

Section	Area	Av.PCI	Rating
1	1122.6	97.7	EXCELLENT
2	1122.6	98.6	EXCELLENT
3	1122.6	100	EXCELLENT
4	1122.6	92.8	EXCELLENT
5	1122.6	90.8	EXCELLENT
6	1122.6	99.4	EXCELLENT
7	1122.6	98.8	EXCELLENT
8	1122.6	95	EXCELLENT
9	1122.6	97.4	EXCELLENT
10	1122.6	100	EXCELLENT
11	1122.6	95.3	EXCELLENT
12	1122.6	96.8	EXCELLENT
13	1122.6	100	EXCELLENT
14	1122.6	92.8	EXCELLENT
15	1122.6	100	EXCELLENT
16	1122.6	92	EXCELLENT
17	1122.6	95.6	EXCELLENT
18	1122.6	88.6	EXCELLENT

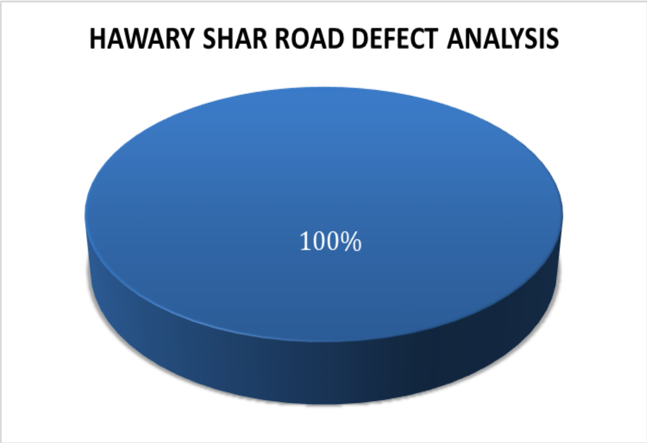

Figure 4: Hawary Shar Road Defect Analysis

5. Suggesting Maintenance Procedure

One of the most important part of pavement evaluation study, is suggesting maintenances for each distress type at different severity levels. Selecting proper maintenance depends on understanding the factors led to the distress in the pavement (David, 2006).

A. Rigid Pavement

The road selected for the study of PCI for rigid pavement was a 720 m in length Urban Collector Street. The following defects and distresses found within the road:

Durability cracking: Is the deterioration that is progressive in concrete due to freezing and thawing action in large sized aggregate.

Causes: The main factors that affect the evolution of “D” cracking, are the existence of humidity due to the base drainage, the happening of freeze-thaw phenomena, the big size aggregate formation (sedimentary rocks such as limestone and dolomite are generally the most prone), the pore size distribution of the coarse aggregate, and the maximum aggregate size.

Suggested treatment: Cutting the defected region to a sufficient depth and removing loose parts from the pavement to ensure adequate bonding between existing concrete and fresh concrete with special properties.

Spalling of transverse joints: Joint spalling and joint deterioration are expressions that refer to cracking, chipping, or wearing of concrete edges at cross sectional or profile joints.

Causes: There are lots of reasons behind joint spalling, some of them include very early wet sawing of cross sectional joints, leakage of incompressible (especially where delamination produced because of insufficient curing), congested amount of reinforcing steel, alkali-aggregate reaction, “D” cracking, weak concrete in the proximity of the joint (e.g., honeycombing, produced due to poor vibrator usge (consolidation)).

Suggested treatment: Cutting off and removing the defected area and refilling with a special concrete, applying bonding agent between old and new concrete.

Patch/patch deterioration: Is a location where the old pavement has been taken out and a filler material is replaced. A service cut is a patch in which original pavement is replaced with to allow the installation or maintenance of underground utilities.

Causes: Weak bonding between old and new concrete or using low strength filler material for the patching purpose or combination of both of them. The reason behind patch deterioration is their level being higher or lower than original road level, which in turn a higher impact wheel load is exerted on them.

Suggested treatment: Grind the patch and re-lay it.

Map cracking and scaling: Is a network of shallow, fine, or hairline cracks extending only through the upper layer of the concrete. The cracks tend to cross at angles of 120°.

Causes: concrete over-finishing is one of the major causes of scaling, which is the slab surface breaks-down to a depth of 6 to 13 mm (1⁄4 to 1⁄2 in.). There are some other possible causes of scaling such as; deicing salts, inadequate construction, freeze-thaw cycles and weak aggregate.

Suggested treatment: The surface require to be scraped and reconstructed with special properties concrete providing adequate agent for bonding between old and new construction, the whole process depend on the severity level and quality of riding.

Cracking (Longitudinal & Transverse): Is the principal structural problem in jointed plain concrete pavements. Heavy wheel loads that is repeatedly applied on the concrete slab causes fatigue, which in turn results cracking of the slab. Since the greatest stress is produced at the outer slab edge due to vehicle wheels, at the midpoint between the cross sectional joints, cross sectional cracking most commonly results at the mid-slab.

Causes: The quantity and quality of applied loads, the depth and stiffness of the concrete slab, the stiffness and consistency provided by the base and foundation, the amount of friction between the base and slab, the amount of load transfer at transverse and longitudinal joints and cracks, the quality of drainage, and climatic influences (daily and seasonal temperature and moisture cycles which influence slab curling, joint and crack opening, and foundation support).

Suggested treatment: Crack sealing or cut-patching is the best treatment types bases on severity level.

Corner break: It is a crack that extends from a distance less than or equal to one-half the slab length on both sides, measured from the corner of the slab and intersects the joints.

Causes: Load repetition combined with loss of support and curling stresses usually cause corner breaks.

Suggested treatment: Depending on severity level, the crack required to be cut-patched with strengthening the foundation.

B. Flexible Pavement

The road branch selected for the PCI determination was an Urban Collector Street with 1620 m in length. The following defects and distresses found within the road:

Alligator cracking: Is a series of interconnecting cracks, caused by fatigue failure of the asphalt concrete surface under repeated traffic loading.

Causes: Factors that have influence over the evolution of alligator cracking can be listed as the number and intensity of the loads applied, the structural design of the pavement, consistency of the asphalt cement, the type and structural integrity of the foundation support, the amount of asphalt within the mixture, the voids and characteristics of the aggregate within the asphalt concrete mix, and the climate of the site (i.e., the seasonal distribution of temperature on the site).

Suggested treatment: Depending on severity level, base recycling or reconstruction, strengthening the pavement or reconstruction, improving the drainage and reconstruct, strengthening the base or reconstruction, replace or treat wearing course.

Bleeding: It is pavement defect that a film of bituminous material accumulates on the pavement surface that creates a shiny, glasslike, reflecting surface that usually becomes quite sticky.

Causes: Existence of excessive amounts of bitumen or tars in the mix, using excess amount of bituminous sealant during maintenance of cracks, or insufficient amount of air voids within the mix, or a combination thereof. It occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface.

Suggested treatment: Applying hot sand to clot up the excess binder to the stone size.

Block cracking: the pavement divides to approximately rectangular blocks due to interconnected cracks.

Causes: Daily temperature fluctuation that results in cycling stress/strain and shrinkage of the asphalt concrete. These cracks are not load-associated.

Suggested treatment: Depending on the cause of cracking, it is suggested to cut and patch or replace the asphaltic surface or sealing the cracks.

Longitudinal/transverse cracking: These types of cracks are not usually load-associated. Longitudinal cracks happen parallel to the road profile. Transverse cracks extend across the pavement at approximately right angles to the road profile or direction of laydown.

Causes: Improper lane jointing during pavement laying. Shrinkage of the pavement surface due to low temperatures or hardening of the asphalt, or daily temperature cycling, or both.

Suggested treatment: Depend on the severity and intensity of the cracks, treatments are applied. When the cracks are not significant, there is no need to do anything, in the case of medium severity, cracks can be filled and in the case of high severity the surface overlay is required.

Patching & utility cut: Is an area of pavement that has been replaced with new material to repair the existing pavement. A patch is considered a defect no matter how well it is performing (a patched area or adjacent area usually does not perform as well as an original pavement section). Generally, some roughness is associated with this distress.

Causes: Repair of the defected area of the existing pavement.

Suggested treatment: There is no specific treatment for this defect, since; it is a repair type itself, but it is possible to remove the patch and reconstruct it.

Potholes: Are small—usually less than 750 mm (30 in.) in diameter—bowl-shaped depressions in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. When holes are created by high-severity alligator cracking, they should be identified as potholes, not as weathering.

Causes: Alligator cracking begins to be severe as water penetrates through them to the underlying layers and pieces of asphalt are thrown away by vehicle wheel movement over the cracks.

Suggested treatment: Based on severity level, it can be patched only or cut patched.

Weathering & raveling: Weathering and raveling are the wearing away of the pavement surface due to a loss of asphalt or tar binder and dislodged aggregate particles. These distresses indicate that, either the asphalt binder has hardened appreciably or that a poor-quality mixture is present. In addition, raveling may be caused by certain types of traffic, for example, tracked vehicles. Softening of the surface and dislodging of the aggregates due to oil spillage also are included under raveling.

Causes: Raveling and weathering happen due to the vanishing of bond among the constituent materials of the asphalt mixture. Sometimes this phenomenon is produced due to the toughening of the asphalt cement, agglomeration of dust on the aggregate surface, Localized areas of asphalt concrete mixture segregation where fine aggregate particles are missing or low in-place mixing density due to insufficient compaction, great range of air void contents are also linked to the rapid aging and increased probability of raveling.

Suggested treatment: Thin bituminous overlay.

6. Conclusions & Recommendations

From the evaluation of PCI for both flexible and rigid pavement of the study areas, following conclusions can be drawn:

PCI gives a good image about the road condition, and this study has to be done annually for the road networks and the data has to be collected in a database format with the aid of GIS and advanced road scanner for continuous monitoring and maintenance decisions which permits early identification of major rehabilitation needs.

From PCI calculation it was found that Hawary Shar road (flexible pavement) doesn't need serious maintenance and repairs while Badinan Road (rigid Pavement) requires maintenances especially transvers joints which they had significant effects on the condition indices of the road sections.

It is recommended to achieve PCI survey with the aid of road scanner or a larger number of trained surveyor for better detection of the defects and their severity levels since the traffic movement cannot be blocked at the sections under inspection which is the major source of errors.

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