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RESEARCH ARTICLE

INVESTIGATION OF THE FACTORS AFFECTING THE DETERIORATION OF LOCAL ROAD INFRASTRUCTURE

*,[1]Abid Ali, [2]Rawid Khan, [3]Safeer Ullah Khattak and [4]Syed Hamza Mustafa

[1]National Institute of Urban Infrastructure and Planning, Peshawar, Pakistan
[2]Department of Civil Engineering, University of Engineering and Technology Peshawar, Pakistan
[3]Department of Civil Engineering, Iqra National University, Peshawar, Pakistan
[4]Department of Civil Engineering, Iqra National University, Peshawar, Pakistan

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ABSTRACT

The investigation of the main factors affecting pavement deterioration is of paramount importance as by effectively addressing the causes, remedial measures can be initiated to control the early pavement deterioration in the local road network. It has been found that the major causes of pavement deterioration are structural factors which are interlinked with excessive traffic and loading. Moreover, the sub soil factors and drainage conditions also affect the pavement condition considerably. The concept of Remaining Service Life is used for prediction of the residual time for which a pavement section will remain serviceable. The trends of the distress types propagation, Pavement Condition Index and Remaining Service Life gives prediction about the future state of pavement deterioration. Now a days most of the highway authorities are using Falling Weight Deflectometer for the evaluation of the structural capacity of the pavement sections which can be further used to devise the rehabilitation strategies and ultimately funding requirements for maintaining roads in optimum condition.

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INTRODUCTION

The road network connects different parts of a country with each other. It is imperative for employment, education, health and livelihood of the residents of a people. It is also important for defence and strategic perspective.The major portion of road infrastructure consists of pavements such as carriageways, parking lots, runways, taxiways, aprons and railway crossings. The pavements require maintenance and a large sum of money is spent annually to meet these needs.As soon as a road is allowed to traffic after construction or maintenance, the process of deterioration starts. It is normally slow and may not be easily noticeable but with the passage of time it accelerates considerably. The relevant highways authorities are spending huge amounts every year to keep the roads in serviceable condition.There is a need to ascertain the main factors affecting deterioration in the local road network so that the effective remedial strategy may be devised in-order to maintain and manage pavement assets of the local road network. The road deterioration is effected by many factors. The main and foremost of which include serviceability, structural capability, functional capacity, safety, environment and traffic loading (Jafari *et al.*, 2016).

The objectives of current study are;

1. To review the different Pavement Deterioration/ Prediction models for assessment of the pavement condition.
2. To ascertain the basic indicators for pavement condition evaluation.
3. To study the major factors affecting pavement deterioration.Proposing the timely maintenance and rehabilitation activities.

Pavement Condition Models

Hudson *et al.* describe the pavement condition model as the mathematical expression that predicts the future state of pavement section. The main factors include surface distress, safety, serviceability and structural adequacy (Hudson *et al.*, 1968). The pavement evaluation should be performed at regular intervals to ascertain the performance assessment of pavement section. In 1962 American Association for State Highways and Transportation Officials (AASHTO) has

***Corresponding author:* Abid Ali,**
National Institute of Urban Infrastructure and Planning, Peshawar, Pakistan.

developed an Index for assessment of Pavement serviceability known as Pavement Serviceability Index (PSI) (Shah *et al*., 2013).

$$PSI = 5.03 - 1.91 \log(1 + SV) - 0.01\sqrt{C + P} - 1.38RD^2$$

Whereas;
SV = the variance in slope of the two wheel tracksC + P = measure of cracking and patching,
RD = measure of rutting depth.
PSI ranges from 5 to 0, where 5 shows a pavement in excellent condition and 0 reveals a pavement which is failed. (Gupta*et al*., 2014)

In 1981 US Army Corps of Engineers has developed Pavement Condition Index (PCI). It has a rating of 100 (excellent) to 0(failed). It has only one explanatory variable known as distress. Mathematically it is expressed as; (Pattinson, 1989)

PCI = C-Σ Σ a (Ti, Sj, Dij) ×, Dij) x F

Where;
C = constant usually taken as 100
Ti, Sj, Dij = Type, Severity, Density of distress
F = adjustment factor in case of multiple distress

The concept of Remaining Service Life is also utilized in this study as Pavement Prediction Model. This will estimate the time period for which the pavement section will further remain serviceable depending upon threshold values of distress types.The equation of Remaining Service Life (RSL) is given as; (Baladi *et al*., 1991)

RSL = Age of pavement in years * (Distress Index – Threshold value)/ (100-Distress Index)

Distress and contributing factors towards deterioration in local roads

There are many distress types; each of them is discussed in detail in the relevant standard ASTM D6433-11. Out of which the most common and recurrent found on the local pavement sections are Alligator cracks, Pot Holes, Rutting, Patching and Raveling. (Shahin and Kohn, 1979) Traffic and loading is an important factor which plays a significant role in the pavement condition deterioration. More traffic count and excessive axle loading will cause earlier structural and functional damage as compared to less traffic and lighter axle loads. (Fernandes *et al*., 2005) The traffic loads are ultimately transmitted to the underlying soil strata. The natural soil conditions, therefore, should be investigated before construction of roads. The clay and silt soils need more attention during design phase.The saturated soils also affect the pavement condition considerably. The high water content may cause early deflections in the top most layers of pavement. The reason behind this is the reduced lateral stability which further reduces the stiffness of the pavement materials. (Dawson and Correia, 1996) The drainage should be adequately provided to the pavement surface and sub surface for the sustainability of road. Cross drainage also plays an important role in the pavement stability. In the absence of effective drainage the pores of pavement surface will be filled with water, resulting into the disintegration of pavement materials, removal of asphalt coating and damage to the structural layers of the road. (Diefenderfer *et al*., 2005) Falling Weight Deflectometer is used by many highway authorities to find the structural capacity of the pavement. It is also efficiently used to estimate the in situ stiffness and layer thicknesses. A load is applied to the surface and subsequent response from the pavement is recorded by means of sensors. (Magnuson *et al*., 1991)

MATERIALS AND METHODS

1. The pavement distress is measured as per the guidelines of the AASHTO standard D-6433-11 "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys".
2. The primary data (i.e. structural and functional factors, sub-soil factors and drainage conditions) is collected from the pavement sections by measurement of distress indices.
3. While secondary data (i.e. traffic count, age of pavement and distress data collected during 2013) is taken from relevant highway authority.
4. The regression and correlation analysis are performed to establish the impact of distress types on the pavement condition.
5. The impact of distress coverage on the Pavement Condition Index will be studied.
6. The Remaining Service Life will be used to determine the critical pavement sections and to estimate the time period for which the pavement will retain serviceability.
7. The inter-relation between distress and Pavement Condition Index, Remaining Service Life of different pavement sections may be used to develop trends of respective indicators.
8. The prediction of future Pavement Condition Index may be inferred from the curve fitting techniques, which may be validated with the Remaining Service Life values.
9. The Falling Weight Deflectometer will be utilized to study the current condition of the pavement sections. Back calculation techniques will also be used to estimate the Structural Number so that proper rehabilitation strategy may be devised.

Pavement sections selected for this study

Three pavement sections were selected for this study namely;

1. Mardan Eastern & Western Bypass (S-1B) length 34 Km
2. Khairabad - Kahi -Nizampur Road (S-6) length 22 Km
3. Umarzai – Harichand – Shergarh Section (S-9) length 33 Km

Each 1 Km length of pavement section has been assigned as a sample unit. Out of total 89 sample units 30, considering 10 sample units from each pavement section were selected on the basis of Simple Random Sampling. Hence the response rate is 33%.

Data collection procedure

The primary data i.e. distress type, density and severity of each distress, drainage condition and sub soil characteristics were collected from sample units. The secondary data such as traffic count and distress indices recorded in 2013 were taken from Pakhtunkhwa Highways Authority. The FWD survey performed by Pakhtunkhwa Highways Authority was also considered as Secondary data. It provided us an insight on the existing condition of the road section and strategy to repair/ rehabilitate it.

RESULTS AND DISCUSSION

The Pavement Condition Index of all the three pavement sections has been calculated as follows;

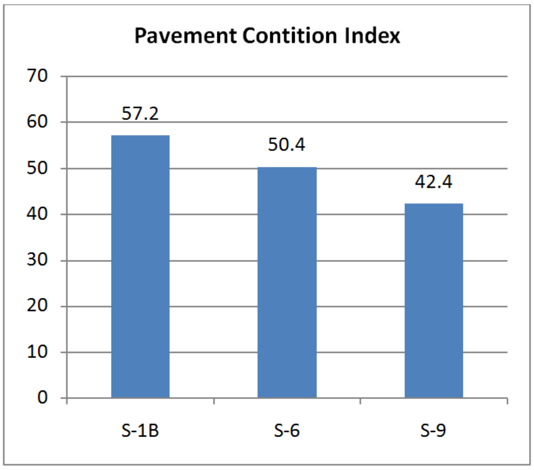


Fig.1. PCI of different pavement sections

The percentage coverage of distress types grouped as structural and functional factors are given as;

Structural Factors

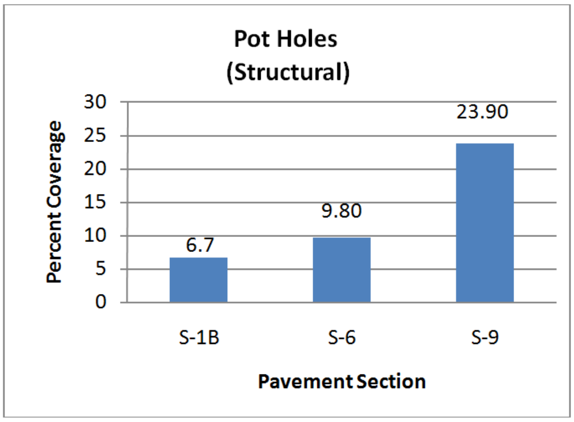


Fig.2. Impact of Pot Holes on PCI

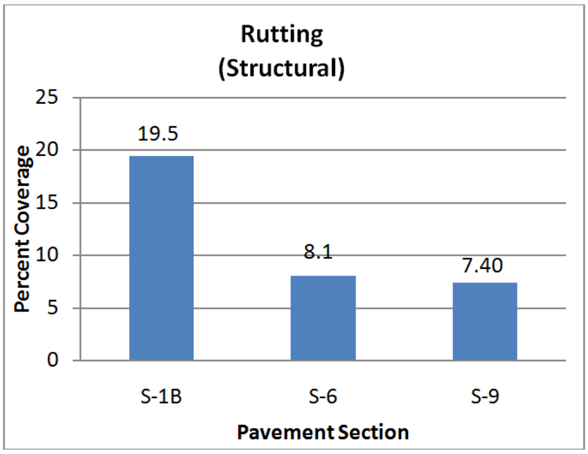


Fig.3. Impact of Rutting on PCI

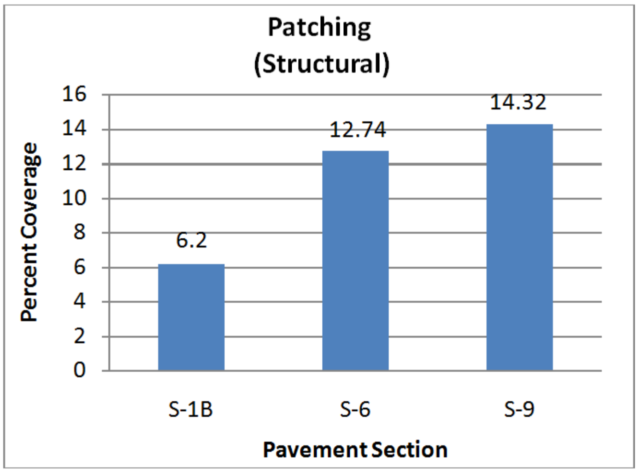


Fig.4. Impact of Patching on PCI

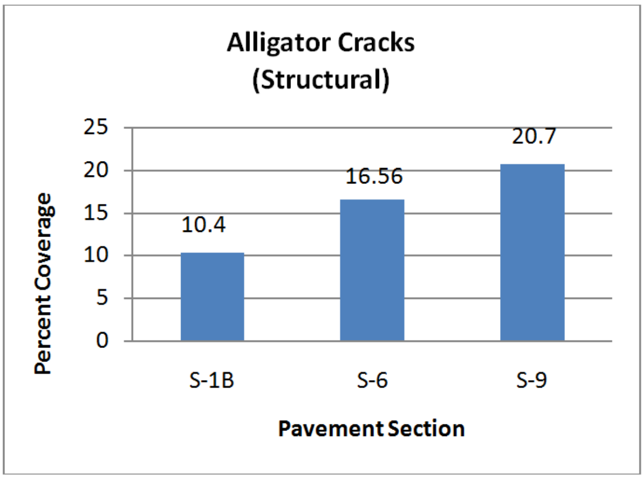


Fig.5. Impact of Alligator Cracks on PCI

These graphs show that the structural factors have significant impact on pavement deterioration.

Functional Factors

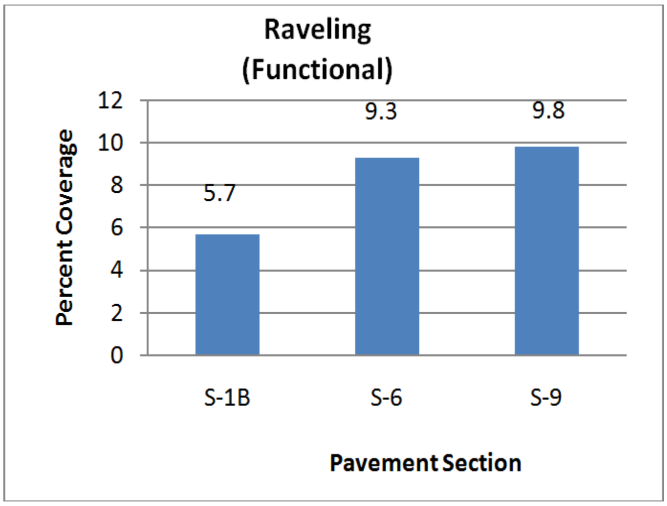


Fig.6. Impact of Raveling on PCI

These graphs show that the functional factors also impact pavement condition considerably.

Sub Soil Factors

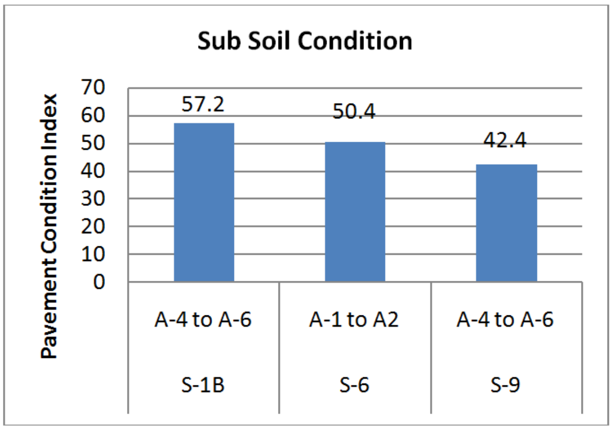


Fig.7. Impact of soil classification on PCI

The results show that S-9 has least index for all the three sections which passes through prime agricultural land.

Drainage Conditions

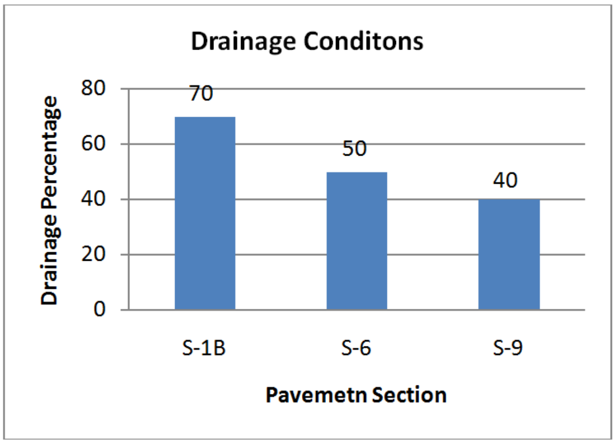


Fig.8. Impact of Drainage Conditions on PCI

This graph shows that the Pavement Sections which have good drainage parameters have reasonably better road conditions and vice versa.

Traffic and Loading

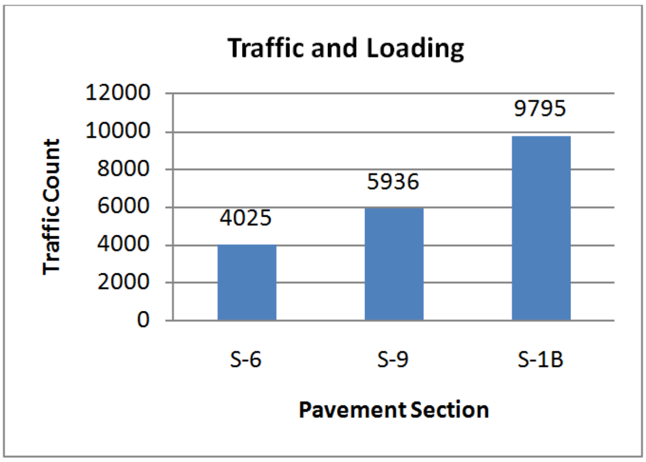
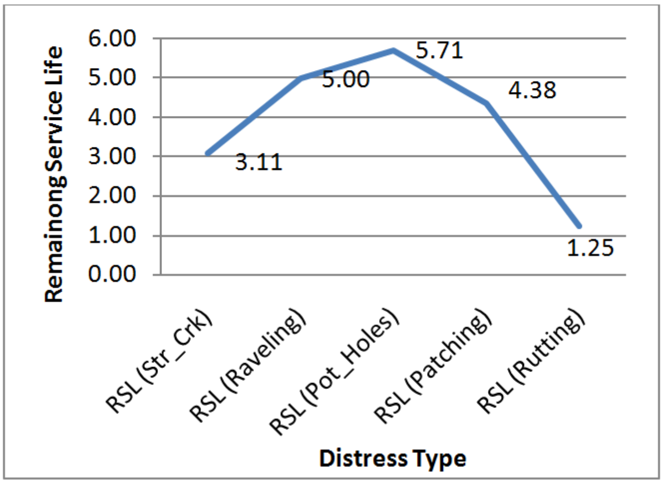


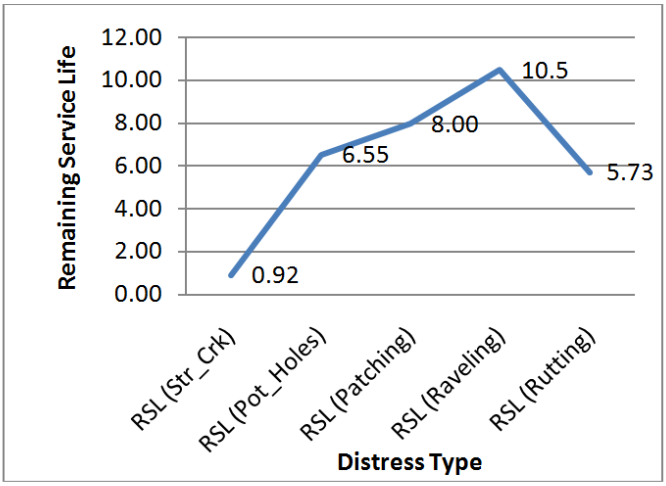
Fig.9. Impact of Traffic & Loading on PCI

This graph shows that the Pavement Condition has an inverse relationship with the traffic count of pavement sections. The axel load has also been increased tremendously in the past few years affecting Pavement Condition adversely.

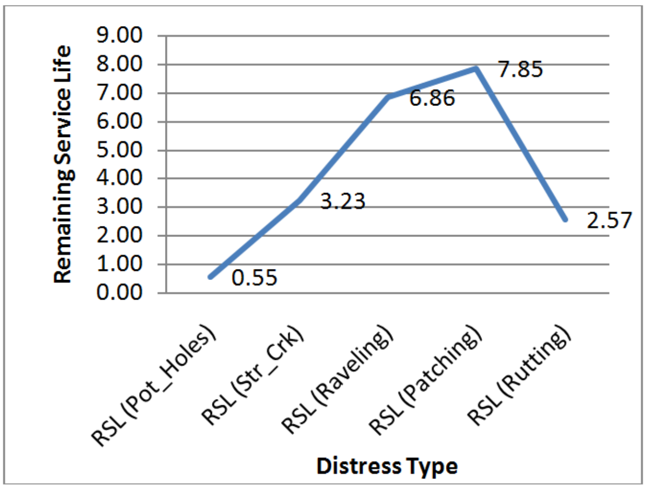
Remaining Service Life for S-1B(Mardan Eastern & Western Bypass)



Remaining Service Life for S-6(Khairabad - Kahi - Nizampur Road)



Remaining Service Life for S-9(Umarzai – Harichand – Shergarh Section)



Remaining Service Life Calculations

The time period for which the pavement section will remain serviceable is calculated according to the threshold values of each distress type. For ease of computation the threshold value of 40 is assumed for the estimation of Remaining Service Life. RSL for S-1 is given as follows. The table shows 5 different values for each road. However, the lowest of them is considered critical for calculation of remaining service life for the pavement section under consideration.

Prediction of Pavement Condition Index

The primary as well as secondary data was used to graph trend between the Pavement Condition Index of all the three pavement sections. The curve fitting technique was used for the PCI curve of S-9 (Umarzai – Harichand – Shergarh Section).The extended trend line for S-6 is meeting the threshold value approximately the same time period as predicted in the Remaining Service Life calculations.Hence it is validated from the PCI trend also.

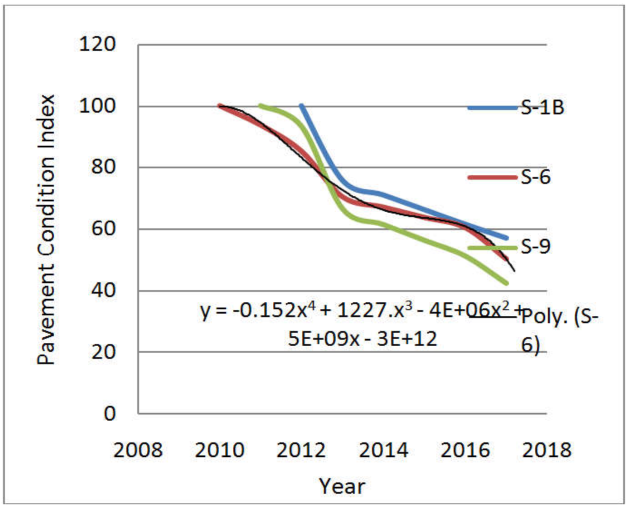


Fig.10. Prediction of Pavement Condition Index for S-6

Use of Falling Weight Deflectometer

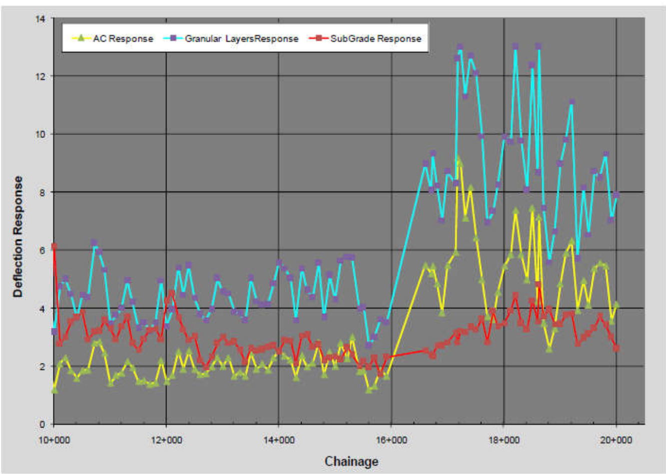


Fig.11. Deflection response of FWD

The Back Calculation of FWD data was performed by AASHTO "Direct Structural Capacity Prediction" method. (Mahoney*et al*., 1989)

$$Mr_{sg} = \frac{(P)(Sr)}{(D_r)(r)}$$

P = plate load (lbs)

Sr = subgrade modulus prediction factor, dependents upon the sugrade Poisson's ratio.

Dr = pavement surface deflection (in.) measured at r distance, from the load, and

r = distance from load to Dr (in.)

Mr_{sg} = subgrade modulus (psi).

Effective Structural Capacity (E_p) is then calculated by the following equation. (Hadidi and Gucunski, 2010)

$$Do = 1.5\, pa\, [1/ (Mr\sqrt{(1+D/a^3\sqrt{(Ep/Mr)}}) + \frac{1-1/(\sqrt{(1+(D/a)^2})}{Ep}$$

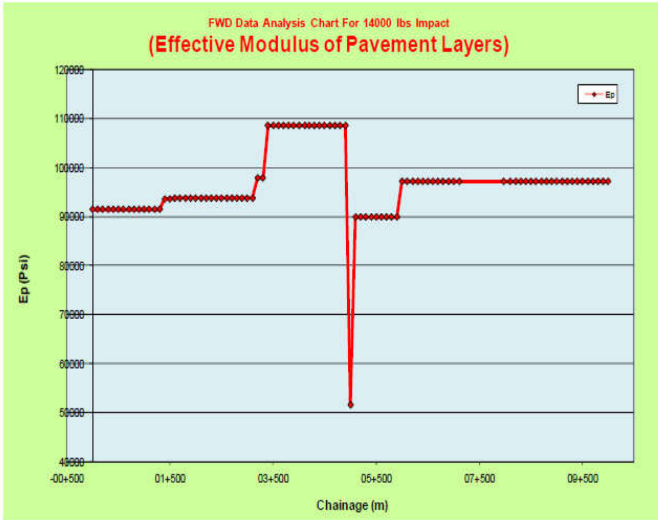


Fig.12. Effective Structural Capacity (E_p)

The Structural Number (SN) is then calculated by using the following equation.

$$SN = 0.0045\, D\, ^3\sqrt{E_p}$$

Where "D" in the above equation is the total thickness of the pavement above the sub grade.

SN_{eff} is afterwards estimated by the following relation. (Asli*et al.*, 2012)

$$SN_{eff} = 0.0045\, D\, ^3\sqrt{E_p}$$

Thick overlay is proposed for rehabilitation of all the three pavement sections. The philosophy behind this is that the stress is considerably reduced below thick overlay and the underlying layers are less prone to superimposed loads. In this case the overlay of asphalt concrete and asphaltic concrete base course will provide the SN_{req} as and when needed.The thickness of overlay is computed by the following equation. (Kitaha and Biligiri, 2016)

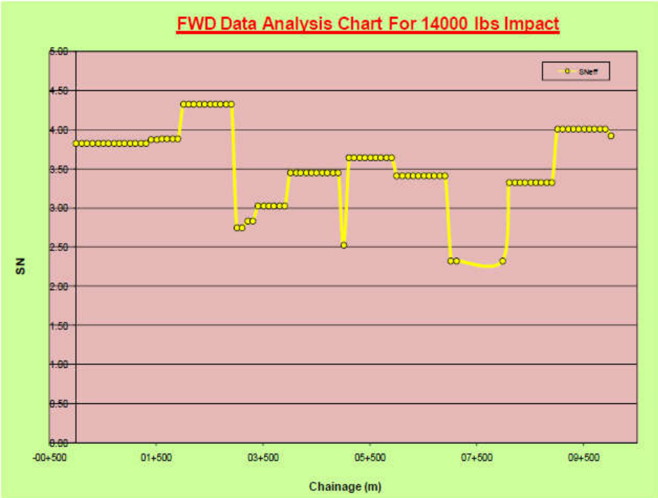


Fig.13. Structural Number (SN)

$$Dol = \frac{SNol}{aol} = \frac{SNf - SN_{eff}}{aol}$$

SNol	=	Required overlay structural number
aol	=	Structural coefficient of AC overlay
Dol	=	Required overlay thickness, inches
SNf	=	Structure number required to accommodate future traffic
SNeff	=	Effective structural number or effective structural capacity of existing pavement

If during construction localized distress is encountered, then deep patching should be considered. In that case all the three structural layers as well as Sub Grade layers should be provided conforming to AASHTO specifications as per design of the pavement section.

Proposed PCI trigger values and respective cost per km

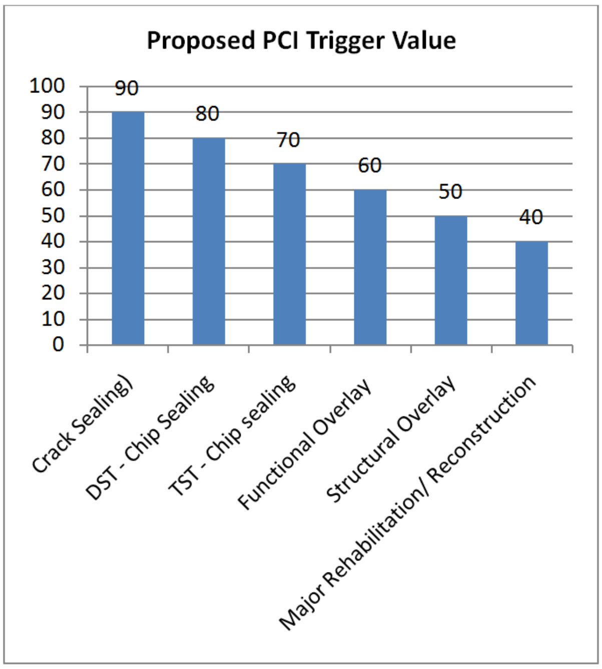


Fig.14. Proposed PCI trigger values

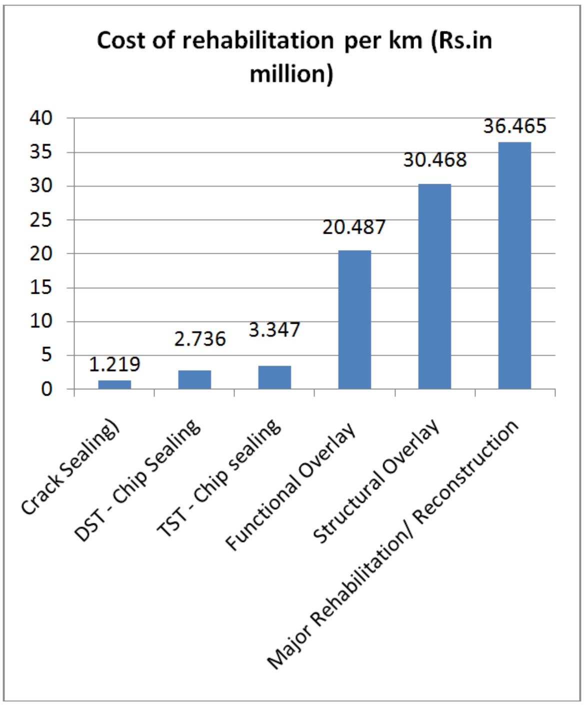


Fig.15. Cost of rehabilitation

The following cost will incur for rehabilitation of flexible pavements per km for a carriageway width of 7.3 m according to the applicable rates currently effective in the Khyber Pakhtunkhwa province.

Conclusions

1. The Pavement Condition Index illustrated the significance of distress types considered in the study.
2. It was demonstrated by the graph charts that the Pavement Condition is affected adversely by the increase in the density and severity of distress types related to structural and functional factors.
3. It was also elaborated that the soil characteristics such as soil classification and plasticity plays an important role in the pavement performance.
4. It was observed that effective drainage from the pavement surface increases life expectancy and vice versa.
5. The traffic and loading patterns were also found to be one of the most contributing factors to the pavement deterioration especially if the load regime is not effectively controlled.
6. Remaining Service Life on the basis of threshold values for distress index was also found to be an effective tool in the estimation of time period for which a pavement section will remain serviceable.
7. It was noted in the Remaining Service Life that out of the three pavement sections, two were prone to failure due to alligator cracks while one was having rutting as the critical value. Thus structural distress were found to be the most recurrent.
8. The time series graph was used to predict the trend of Pavement Condition Index. The secondary data as well as primary data was used.
9. The curve fitting technique gave approximately the same time period as Remaining Service Life for pavement section S-1. Hence it is also verified from Pavement Condition Index.

Recommendations

1. The structural layers of pavements needs further strengthening to cater the additional superimposed loads.
2. The pavement construction should be strictly in compliance with the standards and specifications especially proper compaction should be ensured.
3. The soil characteristics should be carefully investigation and in case of clayey soils filter layer should be introduced to cut off the capillary action to avoid plastic conditions.
4. Proper camber and effective drainage should be provided to immediate disposal of surface runoff.
5. Repair and rehabilitation activities should be timely as and when required to keep the pavement in good serviceable condition.

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