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Performance Modeling the Geometric Characteristic of Curved Sections in the Two-Way Two-Lane Rural Roads on the Pavement Distress

Ehsan SOLATIYAN

Young Researchers Club, Zanjan Branch, Islamic Azad University, Zanjan, IRAN

***Corresponding Author**

e-mail: Ehsan.solatian@yahoo.com

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Abstract

In the two-lane two-way rural roads of rural, the curved sections deteriorate further than the straight section. In this research, we investigate a significant relationship between the distress position and geometric characteristics of roads. For this purpose, many samples of the distress measurement of three roads in three different regions are obtained. The results show that in the mountainous region, there is strong relationship between Pavement Condition Index (PCI) and geometric characteristics.

Keywords: Pavement Condition Index, two-lane two-way rural roads, geometric characteristic, pavement distress

INTRODUCTION

Asphalt Pavements often deteriorate much earlier than their nominal life, and also in some times using repeated pavement cannot gain favorite results and makes high costs over the time. A predictive forward pavement performance modeling capability can provide the road infrastructure manager with a powerful tool for undertaking his functions. The application of realistic and sensitive pavement performance models allows the forward projection of current condition under a range of user defined scenarios of future loading and maintenance. However, for a predictive modeling approach to be effective, the models need to conform to a set of generic factors of reasonableness to promote the acceptability of the modeled outcomes [1].

There are many effective factors in deterioration of asphalt pavements. Researchers have investigated effects of some parameters such as traffic loads, loading, asphalt concrete design, temperature, moisture, heat stress, poor drainage of pavement, quality and properties of materials, but the effect of geometric designs has been in less attention.

In the most two-lane two-way rural roads, distresses often can be more seen in the curve sections. Since a significant portion of the main rural roads are two-lane, and also since these roads often have a high traffic, it should be dedicated a high quality of pavement to perform at optimal level in long-term. However, existing distress in the pavement, especially inside of curves can increase the potential risk of accidents.

Many factors that cause pavement distress such as climate change, changes in temperature, quality of construction, type and quality of materials and traffic act the same way in curve and straight section of roads. But it feels that there is a relationship between the position of the pavement distress and geometric characteristics in the two-lane rural roads.

Before we present the proposed method we review the context of pavement distress models [2].

Pavement distress models form a small but essential part of the over-all pavement management systems (PMS) and processes.

Figure 1 illustrates the typical 'building blocks' of a PMS data management, forecasting capabilities and the decision logic and optimization.

Data management involves all items related to understanding the extent and status of the road network. Typically the following information would be crucial to the asset engineer [3-6]:

1. The full extent of the network including length and total area of all pavements layers and surfaces;
2. Quantities of various material types for both the pavements and surfaces;
3. The condition and status of each individual section length of the network;
4. Current and future demand for the network in terms of traffic loading.

Most advanced PMSs are capable of performing to varying degrees, sophisticated analysis and optimization routines. Some apply decision logic on the data to determine when to treat a road length based on a set of intervention criteria. Others will include an optimization process that determines the best possible maintenance programme for each road, depending on the budget and the life cycle cost aspects of a particular road section.

For any forecasting of future maintenance, funding requirements and future condition, pavement distress models are essential. These pavement condition models are therefore the 'heartbeat' of any system that is capable of predicting the future network status and budget requirements. In addition, other models such as road user cost and level of service outcomes

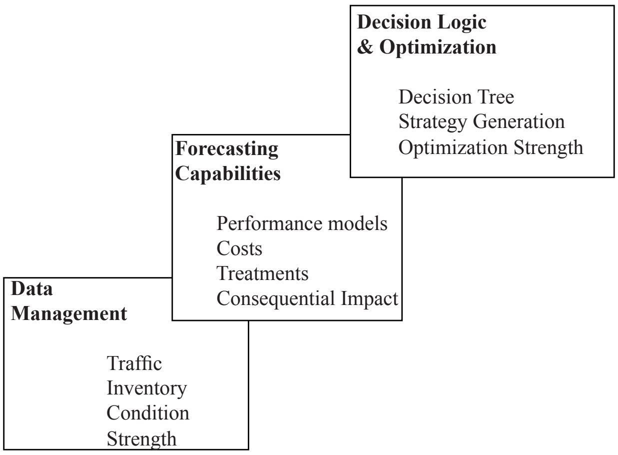

Figure 1. Building Blocks' of a Pavement Management System

are dependent of the pavement models for their predictions. As illustrated in Figure 1, there are a number of predictions made within the PMS, with the pavement prediction models being only one component of the forecasting process. Yet all other predictions such as cost, treatments and impacts of treatments are reliant on the pavement deterioration models. Therefore, these models are a small yet vital component of modern PMSs. The rest of this paper is organized as follows. Material and methods section introduces the overall proposed experiment and describes the Objectives of the Research, Sampling position selection and its characteristics and Data gathering. Result and discussion section applies the proposed experiment and describes Data analysis. Finally, Conclusion section provides the concluding remarks along with suggestions for future work.

MATERIAL AND METHODS

In this section we explain the Objectives of the Research, Sampling position selection and its characteristics and Data gathering.

Objectives Of The Research

In this study, all effective factors on pavement deterioration such as traffic and loading, changes in temperature and climate, quality of materials and performance is considered constant, but geometric design is considered as operating variable. For this purpose, three sections (including straight and curved) in three different topography regions are selected and each section is divided into a number of sample units. In each sample, different pavement distresses (various cracks, bleeding, pothole, etc) and geometric characteristics (including line width, shoulder width, curve radius, longitudinal slope (Grade) and cross slope) is taken based on an observational approach. For measuring the parameters, we use appropriate equipments. According to the collected data, Pavement Condition Index (PCI) is considered and measured as deterioration index.

In the analysis, a statistical test to determine statistically significant differences between the two populations of obtained PCI for inside and outside of curve is considered. If there is a significance level of confidence in the difference between the two populations, to model relationship between variables, the correlation coefficient is calculated between geometrical design and Pavement Condition Index.

Sampling Position Selection And Its Characteristics

According to the lack of documented information about geometrical design and maintenance of pavement in the two-lane rural roads that are constructed many years ago, we have to collect data in the shape of a field study. The collected geometric information, includes lane width, shoulder width, longitudinal slope (grade), cross slope and radius of the curve and the deterioration information includes the type of cracking (longitudinal, transverse, alligator, and edge cracks), bleeding, lane/shoulder-drop off, potholes, and rutting. Accordingly, in order to investigate the behavior of the geometric characteristics in different amounts on the curve pavement distress, three position in three regions with different topography are selected based on three criteria, including accessibility to the road, being the main road and being familiar with the layer Pavement and geometric features of road that are as fallowing.

- Old road Zanjan-Miyane - located in the central plains region
- Road of Zanjan - Bijar located in the rolling region.
- Road of Zanjan - Gylvan located in the mountainous region.

After choosing roads, for each road, three sections (including the curve and straightly) with the following conditions must be selected:

- The selected item should not have access to other roads.
- The number of lines must be the same.
- In the same time and by a same contractor have been made.
- The asphalt mix design, asphalt, base and sub base thicknesses should be the same in the length of section.
- Pavement life must be the same from the last time of coating.

Each sample is divided into five sample units that three unites are placed inside of curve and one unit is before curve and one unit is after curve to have an appropriate distribution of the distress data. In order to facilitate sampling and due to differences in traffic the lanes, each unit is divided into two parts. According these deviations each sample is divided into eight sections. With regard to the right-handed or left-handed curves of road, numbering of samples was done so that inside of curves have the odd number and outside of arcs have the even number. In this research, the minimum area size, about 140 square meter units for each sample was taken. Table 1 shows dimensions of units in different regions of the sample topography and figure 2 and 3 show selected units for each region.

Table 1. Dimension of samples units in different topography

Topography of region			Samples units
Mountain	Rolling	Plain	
25 × 5.7	22 × 6.6	20 × 7	Dimension

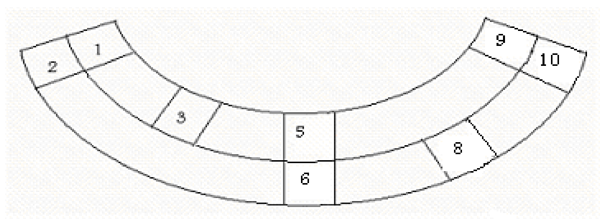

Fig.2. Sample units in plain and first and third pieces of mountain region

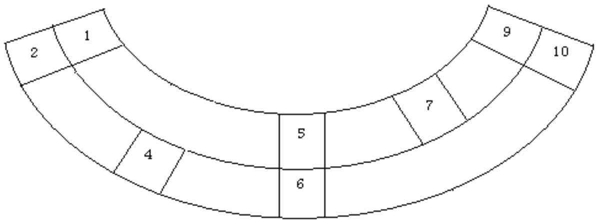

Fig.3. Sample units in rolling and second pieces of mountain region

Data Gathering

In this study, the geometrical information including radius of the curve, roadway cross slope, longitudinal slope(grade), road width and shoulder width and also information about distress including distress level, length, width and depth of cracks (all of cracks including longitudinal cracking, transverse cracking, edge cracking, alligator cracking) and area of distress (such as rutting, bleeding, pothole, depression, alligator cracking) and the depth of distress (lane/shoulder-drop off potholes, rutting, depression) in 72 samples of the three regions located in three different topographic were gathered. Geometric characteristics such as radius, cross slope and longitudinal slope is gathered by using a total station camera (model Nicon DTM522) and with sampling some of points with a specific distance from both side's edge and axis were determined. Also, using a metal meter, area of distress, and using the bevel, straightedge and millimeter ruler other information is gathered. For distress sampling, we use distress identification manual [7].

RESULTS AND DISCUSSION

In this section we analyze data and results and also discuss about them.

Data Analysis

At first based on gathered information, pavement condition index for each sample is determined. For this purpose relevant decreasing coefficient for each distress is calculated. This coefficient is a weighting coefficient that indicates amount of influence on the pavement condition from each combination of type and severity of deterioration and also concentration of it. After determining decreasing coefficient for each distress, we sort them descending. Maximum numbers of decreasing coefficient (m) for roads with asphalt surface is characterized by the following equation.

$$m_i = 1 + \left(\frac{9}{98}\right)(100 - HDV_i) \quad (1)$$

In which m_i is allowed numbers of decreasing coefficient with considering decimal for each sample *i*, HDV_i is biggest partial decreasing coefficient for each sample *i*.

Next, we calculate the maximum value for modified decreasing coefficient. Thus with having numbers of decreasing coefficient larger than 2 $(q \geq 2)$ and total decreasing coefficient (CDV) (that is obtained with summing partial decreasing coefficients), the amount of CDV is determined by relevant correction curve. Then, the smallest partial decreasing coefficient which is larger than 2 reduced to 2 and this process is repeated until q=1 [8]. Results of calculation of PCI for samples are illustrated in figure 4 to 6.

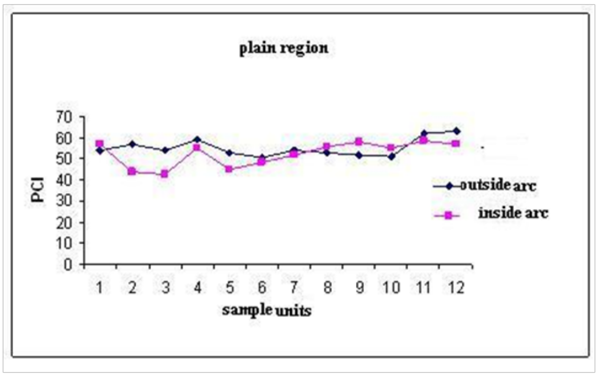

Fig.4. Diagram for PCI changing in outside and inside curve of plain region

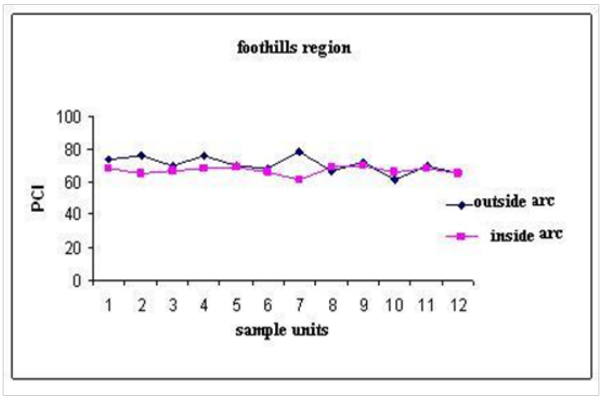

Fig.5. Diagram for PCI changing in outside and inside curve of rolling region

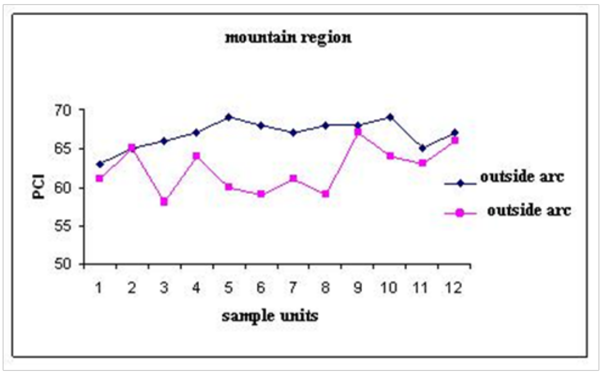

Fig.6. Diagram for PCI changing in outside and inside curve of mountain region

Then we implement the independent t test on population of PCI that gathered from inside and outside the curve on different topography to determine whether there is a significant difference between these two populations or not. The results of this test in each area are presented in Table 2.

Results of the test in Table 2 indicate that in plain area, t test that is based on independency of PCI population of inside and outside of curve cannot be rejected in 95% confidence level. But the test indicates a significant difference between PCIs of rolling and mountain areas.

Table 2. Results of t test in regions

Difference of averages	Confidence level	T test	Topography of region
-3.16	0.139	-1.53	**plain region**
-3.81	0.028	-2.53	**rolling region**
-5.32	0.004	-5.04	**mountain region**

Independency Of PCI And Geometrical Characteristics In Rolling Region

In order to indicate correlation between geometrical variables with pavement condition index (PCI), correlation matrix is obtained for rolling and mountain areas separately.

Results show that in rolling and mountain areas, PCI indexes have a strong correlation in 95% confidence level with radius and cross slope variables. Also we implement a linear regression between geometric information as independent variables and PCI as dependent variables. Results of rolling modeling are presented in Table 3 and 4.

The determination coefficient of Table 3 shows that in the rolling region, linear regression of the geometric characteristics on PCI explains alone about 41% of the total variation. The correlation coefficient between the observed dependent variable and its predicted value is 0.64 by the regression model.

Significant value for fisher test in Table 4 indicates the null hypothesis (no significant linear regression) can be rejected at the 95% confidence level. Linear regression of geometric characteristics on the pavement damage index (PCI) is significant and the relationship is consistent with Equation 2.

$$PCI = 1.93\ W - 4.38\ C + 2.15\ E\text{-}005R - 2.27\ Grade + 79.86$$
$$R^2 = 00.409$$
$$Grade + 79.86 \quad (2)$$

In which W is sum of shoulder and lane width in terms of meter, C cross slope in percent, R radius of the curve according to meters, and G is the longitudinal slope (grade) in percentage.

Equation 2 indicate that by considering each independent variable as operating variable while other independent variable are constant, with increasing one unit in width road, PCI increases 1.93, with increasing one unit in width slope,PCI decreases 4.38, with increasing one unit in radius, PCI increases 2.15E-0.005 unit and finally with increasing one unit in longitudinal slope, PCI decreases 2.27.

According to Equation 2 radius and width of road haven't a significant influence on PCI. Figure 7 and 8 indicates sensitivity analysis of PCI on cross slope and longitudinal slope in the rolling region.

Independency Of PCI And Geometrical Characteristics In Mountainous Region

Tables 5 and 6 show the results of modeling the mountainous region. The determination coefficient of Table 5 shows that in the mountainous region, linear regression of the geometric characteristics on PCI explains alone about 67% of the total variation. The PCI with linear correlation 0.82 is dependent to

Table3. Results of regression of geometrical properties on PCI of rolling region

Standard deviation, coefficient of multiple determination	Modified coefficient of multiple determination	Coefficient of multiple determination	Multiple correlation coefficient	model
2.65068	0.284	0.409	0.639	

Table4. ANOVA table for linear regression of geometrical properties on PCI of rolling region

Significance level	Fisher statistic	Mean of Square	Degrees of freedom	Total squares		model
0.033(a)	3.286	23.086	4	92.343	regression	
		7.026	19	133.496	residual	

Table5. Results of regression of geometrical properties on PCI in mountain region

Standard deviation, coefficient of multiple determination	Modified coefficient of multiple determination	Coefficient of multiple determination	Multiple correlation coefficient	model
2.09989	0.602	0.671	0.819	

Table6. ANOVA table for linear regression of geometrical properties on PCI in mountain region

Significance level	Fisher statistic	Mean of Square	Degrees of freedom	Total squares		model
0.000(a)	9.686	42.711	4	170.884	regression	
		4.41	19	83.781	residual	

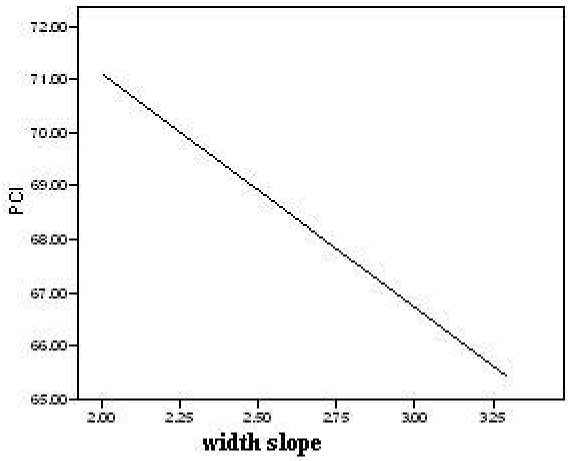

Fig.7. PCI sensitivity analysis of width slope in the rolling

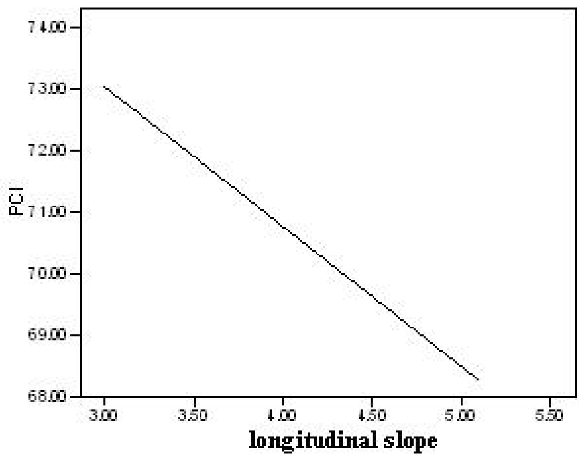

Fig.8. PCI sensitivity analysis of longitudinal slope in the rolling

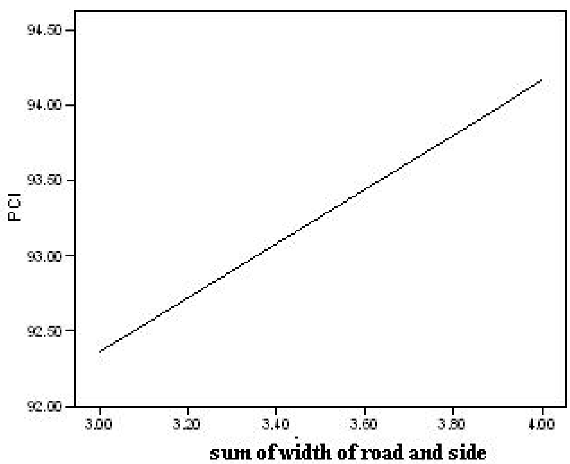

Fig.9. PCI sensitivity analysis of sum of road width and side in the mountain

the set of geometric characteristics. Significant value for fisher test in Table 6 indicates there is a linear regression between the geometric characteristics and pavement condition index (PCI) in the mountainous region and the relationship is consistent with Equation 3.

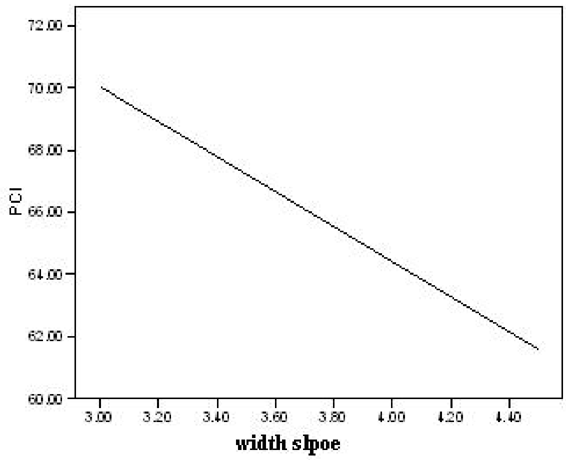

Fig.10. PCI sensitivity analysis of width slope in the mountain

$$PCI = 1.81\ W - 5.6\ C + 0.0002\ R - 0.09\ G + 86.9 \qquad R^2 = 0.67 \qquad (3)$$

In which W is sum of lane and shoulder width in terms of meter, C cross slope in percent, R radius of the curve according to meters, and G is the longitudinal slope in percentage.

Equation 3 indicate, by considering each of independent variable as operating variable while other independent variable are constant, with increasing one unit in lane and shoulder width amount, PCI increase 1.81, with increasing one unit in cross slope, PCI decrease 5.63, with increasing one unit in radius, PCI increase 0,0002 unit and finally with increasing one unit in longitudinal slope, PCI decrease 0.92 unit.

According to Equation 2 radius and longitudinal slope of road haven't a significant influence on PCI. Figure 9 and 10 indicates sensitivity analysis of PCI on cross slope and width of road in the mountain region.

CONCLUSION

This article examines the effectiveness of the geometric characteristics on the pavement distress in the curved sections of the two-way two-lane rural roads. For this purpose, all effective factors on pavement distress such as traffic and loading, changes in temperature and climate, quality of materials and performance is considered constant, but geometric design is considered as operating variable. Therefore, geometric characteristics and pavement distress information is gathered in 72 sample unit from three roads in three regions with different topography. According to data analysis, we recognize that topography of region has a significant influence on pavement distress. Results of research indicate that there isn't a significant difference between PCIs of inside and outside of curve in plain area but this deference is significant in rolling and mountain areas. Also in both of the rolling and mountainous regions was fitted an appropriate linear regression model for the variation of geometric elements on PCI. By comparing obtained relationships in rolling and mountain areas between geometric elements as independent variables and PCI as dependent variable, we can conclude this relationship is stronger than in mountain area. Also cross slope in both of the rolling and mountainous areas has the greatest negative effect on pavement condition index.

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