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Predictive Model for Road Pavement Deterioration Indices

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Abstract: Nigeria has a matured flexible pavement road network owned by the public sector called the Federal Road. The 72km road networks from Ilesha – Akure are providing excellent service to road users for interstate movement. Due to movement of vehicles on the road, bitumen pavements tend to crack at some point of their lives under the combined action of traffic and the environment. These cracks are defects in the pavement surfacing which weaken the pavement and allow water to penetrate and cause potholes on the pavement. The results of a study conducted to facilitate the development of road pavement performance models that are appropriate for Nigeria and other similar developing countries, which could predict the rate of deterioration over their lifespan, have been presented. Comprehensive investigations were carried out on the expressway from the Federal University of Technology (FUTA) North Gate to NNPC Mega Station in Akure, Ondo State – apparently one of the busiest section along the road. The data collected are on traffic characteristics, Structural Number (pavement thickness), potholes and other distress types. Using these data and with the help of stepwise regression analysis, models were developed to predict the road pavement deterioration within the area of study and that could be useful for evaluating the failure susceptibility of the road. The calibrated model has 98.8% and 98.7% as R2 and adjusted R2 respectively. The model also has 8.8% (as average) difference between the predicted and actual rate of deterioration. The model can therefore, be used for planning maintenance programs of flexible pavement roads.

Keywords: Deterioration; Models; Pavement; Potholes; Structural number; Traffic.

1. Introduction

Pavement deterioration process is complex and involves not only structural fatigue but also involves many functional distresses of pavement resulting from the interaction between traffic, climate, material and time. Deterioration is used to represent the change in pavement performance overtime. The ability of the road to satisfy the demands of traffic and environment over its design life is referred to as performance. Due to the great complexity of the road deterioration process, performance models are the best approximate predictors of expected conditions. There are many parameters that need to be acquired to successfully predict the rate of pavement deterioration. Among them are average daily traffic (ADT), percentage of trucks, drainage, pavement thickness, pavement strength in term of structural number (SN) or California Bearing Ratio (CBR) value and mix design parameters. The objective of this study is to establish simple practicable pavement performance model for network level of the Nigerian Federal Roads where rutting is the focus of the measurement. The model shall incorporate relevant variables such as pavement condition, pavement strength, traffic loading and pavement age. Statistical analysis by means of multiple linear regressions were conducted to test and examine the data as well as to develop the model.

Prediction of deterioration is a mathematical description of the expected values that a pavement attribute will take during a specified analysis period. An attribute is a property of a pavement section or class of pavements that provides a significant measure of the behavior, performance, adequacy, cost, or value of the pavement. In other words, it is a mathematical description that can be used to predict future pavement deterioration based on the present pavement condition, deterioration factors, and the effect of maintenance.

Deterioration or prediction models express the future state of a pavement as a function of explanatory variables or factors that include pavement structure, age, traffic loads, and environmental condition. Modeling each distress individually will help in estimating the pavement condition and the level of maintenance in the future because these models predict the distress density much better than other overall pavement condition indices. Also, prediction models permit increased understanding of pavement behaviour so that steps can be taken to reduce the development of distress or extend the service life of the pavement. Curved models are often fitted through past measures of condition to show past performance. Prediction models are generally used to forecast changes in condition over some future time period. Prediction models are some of the most important components of a pavement management system (PMS). Successful PMS are largely depending on these models. Better prediction models make a better

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pavement management system, which lead to considerable cost savings. Some authors differentiate between performance and prediction models based on specific definitions developed for selected measures of condition. In this study, it was preferable to use the term prediction models to describe predicted condition because the aim of the study was to use historical data to predict the future.

2. Objectives

The aim of this research is to develop a model for the prediction of road pavement deterioration within the area of study (from FUTA north gate to NNPC Road in Akure) and other roads with similar conditions.

The specific objectives are to:

i. identify and quantify the trend of the predominant pavement condition failures on the road,

ii. determine the statistical relationship between the quantified failure, the structural number of pavement and the traffic condition expressed as Average Daily Traffic (ADT), and

iii. develop a model that will predict the deterioration rate of the road pavement

3. Factors Affecting Potholes on Road Pavement

A variety of factors such as traffic loading, specific standards of service and design, drainage, climate change, risk factors, temperature, rainfall, and other atmospheric influences contribute to pavement deterioration, and in particular to pavement cracking, over the years.

Croney and Croney (1998) stated that deterioration of pavement arises from deformation under traffic loading generally associated with cracking and such deformation is often associated with heavy commercial vehicles. The increased loading will then cause failures such as cracks and depression on the pavement. According to the American Association of State Highway and Transportation Officials AASHTO (1986), Road Test, heavily loaded trucks can do more than 10,000 times the damage done by a normal passenger car. Sargious (1975) highlighted the fact that one of the most important factors affecting pavement performance is climate. Both the pavement and the underlying supporting layers are exposed to strong climatic influences. Climate change here refers to any change in climate over time. Information extracted from global climate models suggests that the average temperatures and annual precipitation will increase over the next several decades with potential implications for pavement performance and design. Climates factors considered also include rainfall and annual variations in temperature. A review of pavement management practices, and engineering models and approaches used to monitor, assess and predict flexible pavement performance revealed that climate, and thus potential climates changes is an important consideration in the pavement deterioration processes. Rainfall has a significant influence on the stability and strength of the supporting pavement medium because it affects the moisture content of the sub-grade and sub-base. The effect of rain on road pavements can be destructive and detrimental as most pavements are designed based on a certain period of rainfall data. In addition, rainfall is well established as a factor affecting the elevation of the water table, the intensity of erosion and infiltration. Long periods of rainfall of low intensity can be more adverse than short periods of high intensity because the amount of moisture absorbed by the soil is greater under the former conditions.

Sargious (1975) further emphasized that water and poor drainage are the critical factors that cause road pavement failures. Once water has entered a road pavement, the damage initially is caused by hydraulic pressure. Vehicles passing over the road pavement impart considerable sudden pressure on the water, this pressure forces the water further into the road fabric and breaks it up. This process can be very rapid once it begins. When vehicles pass the weak spot, the pavement will start to crack and soon the crack generate several cracks. Water will then enter the surface voids, cracks and failure areas. This can weaken the structural capacity of the pavement causing existing cracks to widen. Eventually, the water will descend to the sub-grade below the road pavement, weakening and hence lowering the CBR value of the sub-grade on which the road pavement design was based. Inadequate sub-grade drainage will increase the severity and acceleration of the failure.

Climate changes in temperature and rainfall patterns can interact together where higher temperatures increase cracking, which compounds the effects of increased rainfall. Climate change can have direct and indirect impacts on road infrastructure. The direct impacts predominantly are due to the effects of rainfall and temperature. Rainfall can alter moisture balances and influence pavement deterioration while the temperature changes can affect the aging of bitumen resulting in an increase in embrittlement of the surface chip seals. Embrittlement of the bitumen causes the surface to crack, with a consequent loss of waterproofing of the surface seal. The indirect impacts of climate change on roads are due to the location of the area and human activity altering the demand for roads. A road pavement begins to deteriorate as soon as they are opened to the traffic and the designs life is normally subjected to period of 10 years. Normally, a new paved road deteriorates very slowly in the first ten or fifteen years of their life and they deteriorate faster if maintenances are not taken into consideration. Bituminous surfacing tends to crack at some stage of life under the combined actions of traffic and the environment through one or more different mechanisms. Pavement failure may be considered to be either a structural, functional, or materials failure, or a combination of these types. Structural failure is the loss of load carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the fabric of the road without causing further deterioration. Materials failure occurs due to the disintegration or loss of material characteristics of any of the component materials.

Pavement failure can either be deformation failures or surface texture failures. Deformation failures include corrugations, depressions, and potholes, rutting and shoving. These failures may be due to either traffic (load associated) or environmental (non-load associated) influences. It may also reflect serious underlying structural or material problems that may lead to cracking.

The pavement crack is a defect in the bitumen surfacing which weakens the pavement and allows water to penetrate and cause further weakening. Cracking is characterized by two distinct phases. The initiation of cracking is defined as the appearance of the crack at the surface. Once initiated, cracking usually increases in its extent, severity and intensity, leading eventually to disintegration of the bitumen surface. Subsequently, cracking extends progressively over the surface and individual cracks widen. The early detection and repair of defects such as cracks in pavements is one of the most important elements in road maintenance works. Cracks and other surface breaks which in their early stages are almost unnoticeable, may develop and further deteriorate into serious defects if not attended to promptly.

4. Research Methodology

This study was conducted to predict the road pavement deterioration rate with particular reference data from in-situ model like the data gotten from the measuring of the potholes on road pavement and later calibrated with the use of odd numbers and even numbers for the validation.

The adopted methodology is as followed:

- **i.** Identification of the proposed area of study and selection of potholes and the locations along Ilesha-Akure Express road (FUTA north gate to NNPC area in Akure);
- **ii.** Conduction of traffic census within the proposed area of study;
- **iii.** Review of the behaviour, performance and deterioration of flexible pavement subjected to traffic loading and number of potholes to be investigated;
- **iv.** Collection of data by taking the measurement of deterioration characters on the flexible pavement;
- **v.** Running the data in linear regression analysis of Statistical Package for Social Sciences (SPSS);
- **vi.** Calibrating the model using even number data for the pavement deterioration; and
- **vii.** Validating the model using the odd number data to confirm its functionality.

5. Results and Discussion

5.1. Data Collection and Model Calibration

Tables 1a and 1b are the outcome of the regression analysis performed on the data. Table 1a shows the model summary for the Linear Regression while Table 1b shows the model coefficients. From Table 1a, it is seen that the R^2 and the adjusted R^2 of the model are 98.8% and 98.7% respectively indicating that the rate of deterioration (D_R) is sufficiently explained by the parameters investigated even when associated errors were considered (adjusted R^2). From Table 1b, the mathematical expression of the model could be written thus:

$$\mathbf{D_R = 0.002 - 2.650/10^{10}\,(T_C) + 1.397/10^{6}\,(S_N)} \ldots\ldots\ldots\ldots \quad \mathbf{(1a)}$$

Where **D_R** = Rate of deterioration (as the dependent variable);
T_C = Traffic count (as independent variable) - number of vehicles per hour
S_N = Structural number (as independent variable); and
0.002 = a constant.

Figure 1 shows the expected cumulative probability of the data against the observed cumulative probability in a normal p-p graph for the linear regression plot.

Table 2 shows the number of days measurements were taken, the result of traffic count and potholes deterioration data from FUTA Northgate to NNPC Mega station in Akure. The Table shows the volume of traffic per hour, the structural number of pavement and the potholes deterioration rate within the section of road studied. The deterioration rate is expressed as volumes (in mm^3). Similarly, for locations 2 to 10, parameters were also run with linear regression (using SPSS.17.0), the statistical analysis and the interpretation of other similar Tables and Figures led to the formation of the model equation as given thus:

Table-1(a). Model Summary for the Linear Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	0.994[a]	0.988	0.987	0.000000246	0.988	719.186	2

Table-1(b). Model Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.
	Constant	0.002	0.000		2067.852	0.000
	Traffic Load	-2.650 E-10	0.000	-0.121	-4.454	0.000
	Structural Number	1.397 E-6	0.000	1.019	37.516	0.000

Fig-1. Normal p-p graph for the linear regression

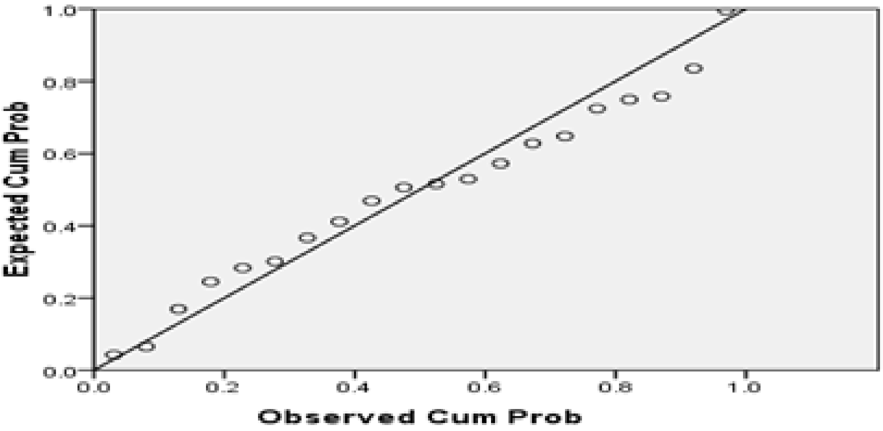

Table-2. Result of Traffic Census and Potholes Data between FUTA North Gate and NNPC Mega Station in Akure, Ondo State.

Day	Traffic Count(T_C) (Veh/hr)	Structural Number(S_N)	Potholes Deterioration Data (mm^3) D_R Length	Width	Depth	Volume
1	3987	27.00	0.349	0.434	0.0147	0.002230
2	4365	27.20	0.349	0.434	0.0147	0.002230
3	5744	27.40	0.349	0.434	0.0147	0.002230
4	4773	27.70	0.349	0.434	0.0147	0.002231
5	4802	28.00	0.350	0.435	0.0147	0.002231
6	5528	28.28	0.350	0.435	0.0147	0.002231
7	5254	28.56	0.350	0.435	0.0147	0.002232
8	5804	28.78	0.351	0.435	0.0147	0.002232
9	5354	29.00	0.351	0.435	0.0147	0.002232
10	5047	29.25	0.351	0.435	0.0147	0.002233
11	5741	29.50	0.351	0.435	0.0147	0.002233
12	5824	29.75	0.352	0.436	0.0148	0.002234
13	6907	30.30	0.352	0.436	0.0148	0.002234
14	6824	30.35	0.352	0.436	0.0148	0.002234
15	7742	30.75	0.352	0.436	0.0148	0.002234
16	5454	30.85	0.353	0.437	0.0149	0.002235
17	5967	31.00	0.353	0.437	0.0149	0.002235
18	4027	31.40	0.354	0.438	0.0149	0.002236
19	6088	31.80	0.354	0.438	0.0149	0.002236
20	4070	32.00	0.356	0.439	0.0149	0.002237

Source: Field Data

$$\mathbf{D_R = 0.002 - 2.650/10^{10} (T_C) + 1.397/10^{6} (S_N)} \text{…………………………} \mathbf{(1b)}$$

$R^2 = 98.8\%$, p-value = 0.0001, F = 719.186, R^2 (adjusted) = 98.7%

6. Validation of the Model

Table 3 shows the result of validating the predictive mathematical model using the field data of FUTA-North gate to NNPC Mega station. The Table shows the values for each respective selected Chainage point. Equation I (b) was used in the validation as shown in the Table. The Table shows the actual deterioration data in terms of length, width, depth and volumes of the potholes, the predicted deterioration using the model, the difference between the actual and the predicted deterioration and the percentage difference within the area studied. From the Table, it is seen that the lowest and the highest percentage difference are 8.53 and 9.10 respectively, all within the tolerable limit.

Table-3. Results of Validating the Model from FUTA North Gate to NNPC Mega Station, Akure

Day	Actual Deterioration Data (mm^3)				Predicted Deterioration (mm^3)	Difference	Difference (%)
	Length	Width	Depth	Volume			
1	0.349	0.434	0.0147	0.002226	0.002036	0.000190	8.53
2	0.329	0.434	0.0147	0.002231	0.002037	0.000194	8.69
3	0.329	0.434	0.0147	0.002231	0.002038	0.000193	8.65
4	0.329	0.434	0.0147	0.002231	0.002038	0.000193	8.65
5	0.350	0.435	0.0147	0.002238	0.002039	0.000199	8.89
6	0.350	0.435	0.0147	0.002238	0.002040	0.000198	8.84
7	0.350	0.435	0.0147	0.002244	0.002040	0.000204	9.09
8	0.351	0.435	0.0147	0.002244	0.002041	0.000203	9.04
9	0.351	0.435	0.0147	0.002244	0.002043	0.000201	8.90
10	0.351	0.436	0.0147	0.002249	0.002044	0.000205	9.10

7. Comparing the In-Situ and Predicted Road Pavement Deterioration

Table 4 shows the difference between the actual and the predicted deterioration. The Table shows the in-situ deterioration, the predicted deterioration, the difference and the percentage difference of ten (10) of the points along the road used for the validation of the model. This Table revealed that all the results (100%) has a percentage difference less than 10%. The lowest and the highest percentage difference are 8.53 and 9.10 respectively. Therefore, it could be said that the predictive model is reliable and could be used to predict the deterioration of a road pavement of any section of the road where any of the parameters used here has been investigated.

Table-4. Comparison of the Results of Actual Deterioration and Predicted Deterioration

Chainage	Days	Insitu Deterioration	Model Deterioration	Difference	% Difference
CH 1 + 000	1	0.002220	0.002036	**0.000190**	**8.53**
	2	0.002231	0.002037	**0.000194**	**8.69**
	3	0.002231	0.002038	**0.000193**	**8.65**
	4	0.002231	0.002038	**0.000193**	**8.65**
	5	0.002238	0.002039	**0.000199**	**8.89**
	6	0.002238	0.002040	**0.000198**	**8.84**
	7	0.002244	0.002040	**0.000204**	**9.09**
	8	0.002244	0.002041	**0.000203**	**9.04**
	9	0.002244	0.002043	**0.000201**	**8.90**
	10	0.002249	0.002044	**0.000205**	**9.10**

8. Conclusion

Akure – Ilesha road in the South Western Nigeria was investigated to find out the contribution of traffic load, structural number elements in road pavement failure. Extensive reconnaissance of the roads showed twenty (20) failed portions of the road riddled with potholes between FUTA North gate and NNPC Mega station in Akure. The rate of deterioration of these potholes were measured in mm^3 within twenty (20) days in the morning, afternoon and evening and the average recorded. Other parameters investigated were traffic census (veh/hr) and the structural number of the pavement materials within the studied section. A predictive mathematical model was developed making the rate of deterioration (D_R), the dependent variable , the traffic count(T_C) and the Structural Number(S_N),the independent variables. Linear regression analysis of SPSS was used for the model.

The results revealed the following:

1. The traffic on the road is heavy showing the road is always very busy.
2. The rate of deterioration of the road as measured in mm^3 is slow but steady.
3. The maximum variation in the structural number of the section is about 18% (32-27)
4. The developed model has R^2 and the R^2(adjusted) as 98.8 and 98.7% respectively with a significance of 0.000
5. The validated model showed a percentage difference less than 10 between the actual and predicted deterioration.
6. The predictive model works within the tolerable allowance to confirm that it can replicate the in-situ situation of the area investigated.

Therefore, it is strongly believed that the model will significantly contribute to the successful implementation of road maintenance and rehabilitation programs thus resulting in the increased performance level of road, cost saving to the maintenance authority and increase the level of comfort and safety of the road users.

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