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Road Pavement Failure Susceptibility Assessment of Osogbo-Iwo Road, Nigeria

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ABSTRACT

Failure susceptibility indices of Osogbo-Iwo road were assessed in this study. Data for the study were obtained through condition survey of the roads and traffic volume counts while monitoring wells were installed at 15 failed and 1 stable segments along the road to measure ground water levels for 22 months. Soil samples were also collected from the road segments for geotechnical study and the laboratory tests. The failure susceptibility index (value) of the road was evaluated using TDCRAMIS point count rating system (modified TDRAMS) and a predictive model calibrated using the curve estimation tool of SPSS (TDCRAMIS model). Pavement susceptibility indices obtained using the TDCRAMIS rating system include 144, 169, 230, 218, 207, 221, 184, 210, 201, 153, 236, 197, 212, 206, 232, 92 for the 16 road segments considered respectively. Results obtained using the predictive TDCRAMIS model were highly correlated with those obtained using the TDCRAMIS rating system. A high correlation (R) value of 0.905, Mean Biased Error value of 0.875 and Root Mean Square Error value of 16.5 served to validate the accuracy of the predictive model. The results confirm that the TDCRAMIS rating system could be used to prioritize road maintenance activities because the road condition could sufficiently be predicted by TDCRAMIS rating system and the TDCRAMIS model with a high level of accuracy.

Key words: Pavement failure, Failure Index, Susceptibility, TDCRAMIS, Road maintenance

INTRODUCTION

A road pavement is said to have failed due to impairment of its serviceability capacity. This decrease in serviceability of the pavement can be attributed to several distresses on the various pavement layers. [1] stated that pavement failure may be considered as structural, functional, or materials failure, or a combination of the three. Structural failure refers to a condition where the pavement is no longer able to absorb and transmit the wheel loading through the road structure without causing further deterioration while Functional failure indicates the loss of any function of the pavement such as skid resistance, structural capacity, and serviceability or passenger comfort [2].

Results acquired from detailed investigations into pavement failures are highly valuable and useful resource which could be assistive in minimizing the susceptibility of road pavements to failure and costs associated with pavement failures in the future. Some studies carried out have identified several factors associated with the failure of road pavements. These factors include: excess fines and very low liquid limit values combined with a very low CBR value and substandard paving properties [3]; inadequate design and maintenance of drainage system and shoulder cross fall, along with inadequate pavement thickness[4]; inadequate pavement or aged surfacing, high shoulders or ponding water on pavement and clogged side ditches. excessive stress [5]; inadequate quality control and insufficient equipment for maintenance purposes [6]; insufficient strength properties of bituminous mixes, movement of heavy duty vehicles, bad drainage condition, natural disaster and lack of properly and timely maintenance [6]

Therefore, it is important to carry out adequate studies which will result in development simplified methods for inspection and evaluation of pavement failures thereby forestall the contributions of these factors in road pavement failure. [7] stated that it is important to find out a method to minimize the maintenance cost under a limited budget. [8] engaged finite element analysis to evaluate stress distribution and failure mechanism on bituminous pavement; [9] posited the superiority of Fuzzy regression method to traditional methods in assessing pavement performance; [10] developed a combined Overall Pavement Condition Index (OPCI) for assessing pavement condition and performance while [11] presented an efficient approach for reliability-based mechanistic-empirical pavement design considering fatigue and rutting failures which much less computational effort to determine probability of failure. In view of the foregoing and in an attempt to improve on existing methods of pavement failure susceptibility assessment, this study attempts to apply the TDCRAMIS point count rating system and a statistical predictive model (TDCRAMIS model) in assessing failure susceptibility of Osogbo-Iwo road. It is expected that the results of the study will aid timely and cost-effective construction and maintenance activities thereby minimizing the failure susceptibility of major highways in Nigeria.

The Study Area: Osogbo-Iwo Road

The Osogbo-Iwo road is located within latitudes 7º 37' 36.24"N and 7º 47' 22.08"N and longitudes 4º 09' 22.20"E and 4º 30' 23.58"E. The road connects Osogbo to Iwo and the adjoining towns and villages. The road is about 45 km long. The area around the road has an annual rainfall of about 1250mm and lies mainly in the deciduous forest area which spreads towards the grass land belt of Ikirun North of Osogbo. The area includes a regional topographic depression in form of a flood plain or wetland that exists between Origo/Osuntedo and Asamu/Telemu towns at a general contour elevation of about 274m (900ft) above the sea level, and it is drained by the Osun River and its tributaries. The road is part of Ibadan-Iwo-Osogbo road. Its problems started with its design in 1977 when the design consultant was changed. The problems continued with old Oyo State until 1992 when Osun State was created, and the state inherited the road and its problems. All efforts made to fix the incessant failure of the road, has been to no avail. It is therefore, in realization of this fact that a predictive mathematical model is being developed to pre-empt the incidence of incessant pavement failure of the road by using the model to detect the sections of the road in urgent need of rehabilitation.

METHODOLOGY

The reconnaissance and condition survey of Osogbo-Iwo road was conducted. The road was meticulously traversed from one end to the other to establish the failed segments along the highway. Based on the field reconnaissance survey, MW16(Ch.43+210) was found to be unquestionably stable. The physical observations made on the other fifteen major failed locations showed that all other segments manifested signs of failure either in shear and/or massive forms. Figure 1 shows Osogbo-Iwo road, the map of Osun state showing the location of the road and map of Nigeria showing the location of Osun state respectively. Further measurements, observations and analysis were carried out on these fifteen (15) major failed segments and one (1) stable segment as enumerated below.

Pavement condition survey was done manually by a team of experienced pavement raters on the considered road segments. Parameters such as existing asphalt pavement thickness, type of distress/severity, the condition of cambering were physically scored during the pavement condition survey. Traffic count of Osogbo-Iwo road was conducted for seven consecutive days so as to determine the magnitude of traffic load to which the highway is subjected. With the collected traffic data, the equivalent standard axle load on the various segments of the road were computed.

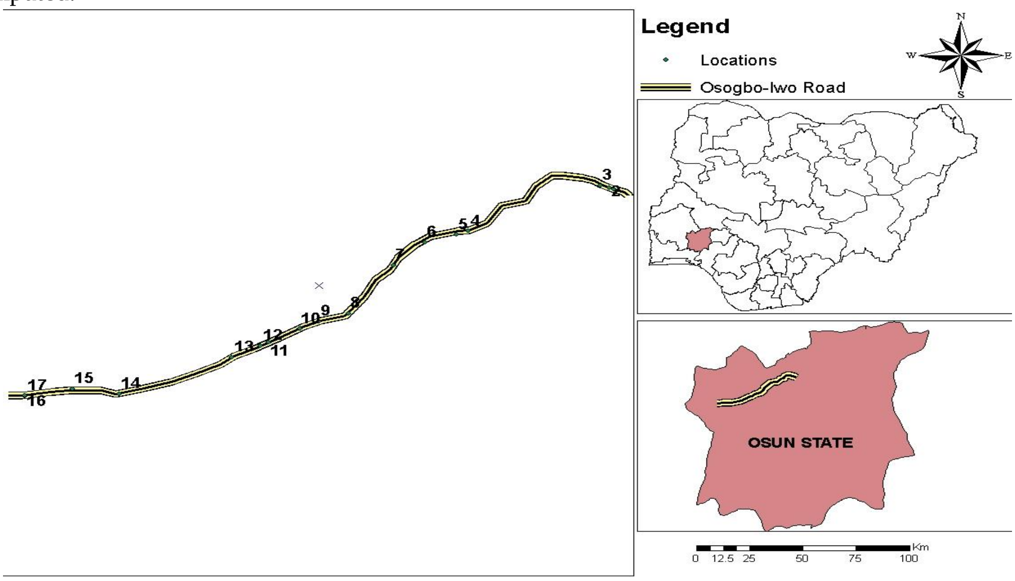

Fig. 1 Osogbo-Iwo road, Map of Osun State and Map of Nigeria

The initial Equivalent Single Axle Load $(\text{ESAL})_0$ is given by:

$$(\text{ESAL})_0 = \frac{\text{TESA}(\%\text{Truck})}{100}\frac{(\text{ADT})}{2} \qquad (1)$$

Where

$(\text{ESAL})_0$ is initial Equivalent Single Axle Load on the day the road is opened to traffic.

ADT is Average Daily Traffic.

ESAL is Equivalent Single Axle Load

TESA is Total Equivalent Single Axle

Monitoring wells were installed at the considered road segments to determine prevalent groundwater levels using the water level meter. All the monitoring-wells were placed in the various locations based on our reconnaissance survey as shown in Figure 2. Soil samples were also collected from bore holes drilled at the various road segments. All the samples retrieved during drilling were visually identified on site at the time of sampling and subsequent geotechnical tests were carried out in the laboratory to determine various geotechnical properties of the soil samples, chief amongst which were California Bearing Ratio (CBR), Maximum Dry Density (MDD) and Group Index (GI). The modified AASHO (modified Proctor) compaction test procedure with compaction energy of 2710.5 KJ/m^3 which is about five times that of the standard test was used for both the compaction (to determine MDD) and CBR tests. Further measurements were also carried out at the fifteen (15) major failed segments and one (1) stable segment to determine existing properties of the highway such as, conditions/properties of existing drains and road cambering (cross-section) condition.

With the parameters obtained from the observations, measurements and analysis above, an evaluation of the road pavement failure susceptibility was carried out using the TDCRAMIS index. The TDCRAMIS index is a modification of a point count system model called TDRAMS which is used in the assessment of pavement failure susceptibility. TDCRAMIS index employed a numerical ranking system that assigned relative weights to the obtained parameters for the fifteen failed segments and one stable segment.

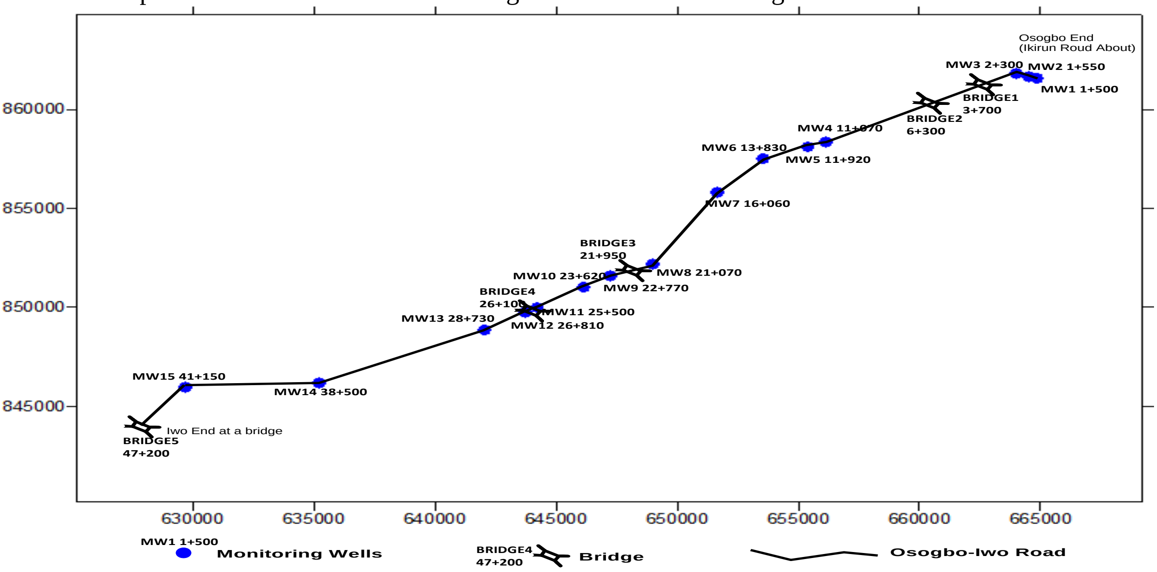

Fig. 2 The Site Plan For Osogbo-Iwo Road Showing The Monitoring Wells.

Hence, the parameters considered in the TDCRAMIS index model are Traffic load [T], Depth to water table [D], Cross-sectional area of drain[C], Soaked CBR[R], Cambering[A], Maximum dry density [MDD], Index (group index) of soil[I] and Asphalt thickness[S] which form the acronym TDCRAMIS. Each of the parameter was given range, which was sub-divided into discrete hierarchical intervals. The intervals were assigned rating reflecting the relative degree of failure susceptibility, and the rating points multiplied by weights summed to give the degree of susceptibility of such segment. The typical rating ranges between 1 and 18 and weight from 1 to 8. TDCRAMIS failure susceptibility evaluation model is mathematically expressed in Equation 2;

$$T.TDCRAMIS.I = T_r T_w + D_r D_w + C_r C_w + R_r R_w + A_r A_w + M_r M_w + I_r I_w + S_r S_w \qquad (2)$$

$$\text{Therefore:} \quad T.TDCRAMIS.I = \sum_{i=1}^{8} \text{Rating}_\text{i} \times \text{Weight}_\text{i} \qquad (2.1)$$

Where

T.TDCRAMIS.I is Total TDCRAMIS Index (total failure susceptibility value)

T_r is Rating assigned to Traffic load

D_r is Rating assigned to Depth to water

T_W is Weight assigned to Traffic Load

D_w is Weight assigned to Depth to water table

C_r is Rating assigned to cross-sectional area of drains

C_w is Weight assigned to cross- sectional area of drains

R_r is Rating assigned to CBR

R_w is Weight assigned to CBR

A_r is Rating assigned to Cross-section slope

A_w is Weight assigned to Cross-section slope

M_r is Rating assigned to MDD

M_w is Weight assigned to MDD

I_r is Rating assigned to Index (Group Index)

I_w is Weight assigned to Index (Group Index)

S_r is Rating assigned to Asphalt thickness

S_w is Weight assigned to Asphalt thickness

Table 1 shows the TDCRAMIS rating system. It shows the rating and weights assigned by the rating system for a range and mean values of pavement condition parameters. With this table rating and weight values corresponding to a specific parameter are obtained.

Table -1 TDCRAMIS Rating System and Weights [13]

Parameter	Range	Mean	Rating	Weight
[T] Traffic Load (KN)	0-25 25-50 50-75 75-100 100-125 125-150 150-175 175-200 200+	12.5 37.5 62.5 87.5 112.5 137.5 165.5 187.5	1 2 5 8 10 12 14 16 18	8
[D] Depth to water table (m)	0 - 0.4 0.4 - 0.8 0.8 - 1.2 1.2 - 1.8 1.8 - 2.2 2.2- 2.6 2.6 – 3.00+	0.2 0.6 1.0 1.5 2.0 2.4 2.8	10 8 6 4 3 2 1	7
[C] Cross-sectional Area of Drain(m^2)	0-0.05 0.05-0.10 0.10-0.15 0.15-0.20 0.20-0.25 0.25-0.30 0.30-0.35 0.35+	0..025 0.075 0.125 0.175 0.225 0.275 0.325	10 8 6 5 4 3 2 1	6
[R] Sub-grade CBR Soaked (%)	0-10 10-20 20-30 30-40 40-50 50+	5 15 25 35 45	9 7 5 4 2 1	5
[A] Cambering (%)	0-0.75 0.75-1.50 1.50-2.25 2.25-3.00 3.00-3.75 3.75+	0.375 1.125 1.875 2.625 3.375	8 7 5 3 2 1	4
[M] MDD (kg/m^3)	0-400 400-800 800-1200 1200-1600 1600-2100 2100+	200 600 1000 1400 1850	10 8 5 4 2 1	3

[I] Index(Group)	0-2 2-4 4-6 6-8 8-10 10-12 12-14 14+	1 3 5 7 9 11 13	1 2 4 6 7 8 9 10	2
[S] Asphalt Thickness (m)	0-0.01 0.01-0.02 0.02-0.03 0.03-0.04 0.04-0.05 0.05+	0.005 0.015 0.025 0.035 0.045	7 6 5 4 2 1	1

Predictive Modelling

A statistical model was calibrated using Curve Estimation regression tool of Statistical Package for Social Sciences (SPSS 19.0). The rating of each of the parameters was made the dependent variable while the mean of the range of the parameters was made the independent variable. Both linear, quadratic and cubic estimations of the ratings were carried out using the curve estimation regression tool and for each parameter the estimate with best output was chosen and used to compute new set of rating values. The ratings obtained from the statistical model equations were multiplied by their assigned weights, added and simplified to give the statistical model predicted pavement susceptibility index. The accuracy of the SPSS model was validated using the co-efficient of correlation, Mean Bias Error (MBE), Root Mean Square Error (RMSE) between TDCRAMIS rating system (modified TDRAMS) and TDCRAMIS (SPSS 19.0 model) results for Osogbo-Iwo road.

RESULTS

Field and Laboratory Results

Results obtained from field observation and laboratory tests for each of the parameters of the TDCRAMIS rating system are as shown in Table 2. The results show that for traffic loading (T) in terms of Equivalent standard axles load (ESAL) at the 16 locations ranges between 81KN – 111KN with the lowest loading of 81KN occurring at the one stable segment of the road selected for this investigation. Depth water-table (D) measurements revealed that eleven (11) monitoring wells constituting into 69% of the monitoring- wells had ground water levels within 1.0m of the pavement structure. Assessment of the cross-sectional area (C) of the existing drains showed that most of the segments had adequate cross-sectional drain area with only two out of the 16 observed segments having inadequate drain area. This implies that drain cross-sectional area inadequacy contributes minimally to failure of the road. The CBR (R) test results revealed that the parameter ranged from 9-69. The peak value of 69 occurred at the 13^{th} road segment while the least value was at the 11^{th} segment. However, Maximum dry density (M) results showed that its peak value was 2120kg/m^3 at the 8^{th} road segment while the lowest MDD value of 1710kg/m3 was recorded at the 14^{th} segment.

Table -2 Field And Laboratory Results Of TDCRAMIS Parameters For Osogbo-Iwo Road

MWs	**T**	**D**	**C**	**R**	**A**	**M**	**I**	**S**
1	97	1.43	0.32	20	2.4	1750	1	0.04
2	97	1.34	0.32	19	2.1	2050	1	0.05
3	97	-0.26	0.32	11	0	2000	1	0.06
4	97	0.13	0.48	22	0	2040	6	0.05
5	97	0.90	0.23	23	0	2080	0	0.05
6	97	-0.01	0.23	18	2.9	1750	1	0.04
7	97	-0.16	0.21	45	4.8	2080	1	0.03
8	111	-0.29	0.11	54	3	2120	4	0.05
9	111	1.35	0.13	16	3	2020	1	0.05
10	111	1.02	0.36	49	3.5	1960	3	0.05
11	111	0.05	0.30	9	3.3	2000	8	0.05
12	111	-0.05	0.45	34	2.6	1910	0	0.06
13	111	0.0	0.15	69	3	1800	0	0.03
14	111	0.02	0.33	39	2.8	1710	3	0.05
15	111	0.71	0.11	14	2.9	1970	2	0.04
16	81	3	0.35	50	3.8	2100	0	0.05

The results of measured cross-section slopes (A) revealed their inadequacies in all the failed segments along the road because they fell below the Highway Manual specifications. Generally, 3% of the average slope passed the required specification while 97% did not. Group index (I) values obtained from laboratory analysis of samples from different segments of the road considered ranged between 0 and 8 while results of asphalt thickness (S) measurement at the failed and stable segments along the road revealed the road had 33% of the segments fulfilling the required asphalt thickness of 50mm.

Ratings and Weights

With the field and laboratory data obtained, the TDCRAMIS ratings and weight system in Table 1 was used to determine the respective parameter ratings and weights. Table 3a and 3b shows the respective parameter ratings and weights for all segments of the road considered in this investigation. For example, MW1 with the following data: T=97kN, D= 1.43m, C= 0.32m^2, R= 20%, A= 2.4%, M= 1750kg/m^3, I= 1 and S= 0.04m. The ratings are: 8, 4,2,6, 3, 2, 1 and 2 respectively while the weights are 8, 7, 6, 5, 4, 3, 2 and 1 respectively.

Table -3a Ratings And Weights For TDCRAMIS Parameters

Parameters	Rating												Weight
	MW1	**MW2**	**MW3**	**MW4**	**MW5**	**MW6**	**MW7**	**MW8**	**MW9**	**MW10**	**MW11**	**MW12**	
T	8	8	8	8	8	8	8	10	10	10	10	10	8
D	4	4	10	10	6	10	10	10	4	6	10	10	7
C	2	2	2	1	4	4	4	6	6	1	1	1	6
R	6	7	7	5	5	7	2	1	7	2	9	4	5
A	3	5	8	8	8	3	1	2	3	2	2	3	4
M	2	2	2	2	2	2	2	1	2	2	2	2	3
I	1	1	4	6	6	4	1	3	1	2	7	1	2
S	2	2	3	3	2	2	5	2	2	2	2	1	1

Table -3b Ratings and Weights For TDCRAMIS Parameters (Cont'd)

Parameters	Rating				Weight
	MW13	**MW14**	**MW15**	**MW16**	
T	10	10	10	8	8
D	10	10	8	1	7
C	6	2	6	1	6
R	1	4	7	1	5
A	2	3	3	1	4
M	2	2	2	1	3
I	1	2	2	1	2
S	5	2	3	1	1

Using equation 1, the total TDCRAMIS index is 144 which is the total failure susceptibility value for MW1 failed segment. Mathematically the failure susceptibility value for MW1 is computed thus:

$$T.TDCRAMIS.I = 8\times8+ 7\times4 + 6\times2 + 5\times6 + 4\times3 + 3\times2 + 2\times1+1\times2 = 144$$

Failure susceptibility values for the other road segments are obtained in the same manner as MW1. These values are shown in Table 4a and 4b.

Table -4aIndex Values For TDCRAMIS Parameters And Susceptibility Values For MW1-MW12

Parameters	Segments											
	MW1	**MW2**	**MW3**	**MW4**	**MW5**	**MW6**	**MW7**	**MW8**	**MW9**	**MW10**	**MW11**	**MW12**
T	64	64	64	64	64	64	64	80	80	80	80	80
D	28	28	70	70	42	70	70	70	28	42	70	70
C	12	12	12	6	24	24	24	36	36	6	6	6
R	30	35	35	25	25	35	10	5	35	10	45	20
A	12	20	32	32	32	12	4	8	12	8	8	12
M	6	6	6	6	6	6	6	3	6	6	6	6
I	2	2	8	12	12	8	2	6	2	4	14	2
S	2	2	3	3	2	2	5	2	2	2	2	1
∑	**144**	**169**	**230**	**218**	**207**	**221**	**184**	**210**	**201**	**153**	**236**	**197**

Table -4b Index Values For TDCRAMIS Parameters And Susceptibility Values For MW13-MW16

Parameters	Segments			
	MW13	MW14	MW15	MW16
T	80	80	80	64
D	70	70	56	7
C	36	12	36	6
R	5	20	35	5
A	8	12	12	4
M	6	6	6	3
I	2	4	4	2
S	5	2	3	1
∑	**212**	**206**	**232**	**92**

Predictive Model Results

The SPSS model yielded a new equation for estimating the rating of each of the parameters. This is shown in Equation 3. To obtain the new ratings, the mean of the range of the parameters from Table 1 are substituted into Equation 3. The ratings obtained from the statistical model equation were multiplied by their assigned weights, added and simplified to give the statistical model predicted pavement failure susceptibility index.

$$T.TDCRAMIS.I= 249.008+(0.808T-0.0005T^2)T_W-(40.201D+5.509D^2)D_W-(353.454C+985.716C^2-1333.332C^3)C_W-(0.850R)R_W+(5.112A-8.888A^2+1.580A^3)A_W-(0.010M)M_W+(2.964I-0.063I^2)I_W-(176.448S+4821.429S^2-83333.333S^3)S_W \text{------------------------------} (3)$$

Equation 3 resulted in new set of pavement failure susceptibility values as predicted by the SPSS model. These new failure susceptibility index predicted by the SPSS model are shown in Table 5.

From Table 5, it is seen that the Predictive SPSS TDCRAMIS Model predicted susceptibility values which had a correlation of about 0.905 with those of the calculated TDCRAMIS rating system. The implication of this is that these two indices calculated by two different methods - TDCRAMIS rating system (Modified TDRAMS) and TDCRAMIS (SPSS 19.0) could represent each other since a co-efficient of correlation of 0.8000 is good enough and it is 0.905 here thereby validating the accuracy of the model. The Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) of the statistical model are 0.875 and 16.5. A MBE of value 0 and a RMSE of value 0 describe a perfectly predictive situation. MBE and RMSE values above 0 signify over- predictive situation and their values below 0 signify under-predictive situation. Based on this, the Predictive SPSS TDCRAMIS model over-predicts failure susceptibility indices for Osogbo-Iwo road. Figure 3a shows the correlation of the predicted and calculated values on a scatter while Figure 3b shows how closeness between these values as can been seen from the trend on the chart.

Table -5 Predictive Model Results

MWs	TDCRAMIS Index (Modified TDRAMS)	TDCRAMIS Index (SPSS 19.0)	Correlation Coefficient (R)	Mean Biased Error (MBE)	Root Mean Square Error (RMSE)	% Error (MBE)	% Error (RMSE)
1	144	176	0.905	0.875	16.5	0.028	0.53
2	169	168					
3	230	240					
4	218	197					
5	207	198					
6	221	225					
7	184	221					
8	210	230					
9	201	196					
10	153	152					
11	236	239					
12	197	175					
13	212	195					
14	206	205					
15	232	226					
16	92	83					

Note (R) = Co-efficient of Correlation (MBE) = Mean Bias Error (RMSE) = Root Mean Square Error.

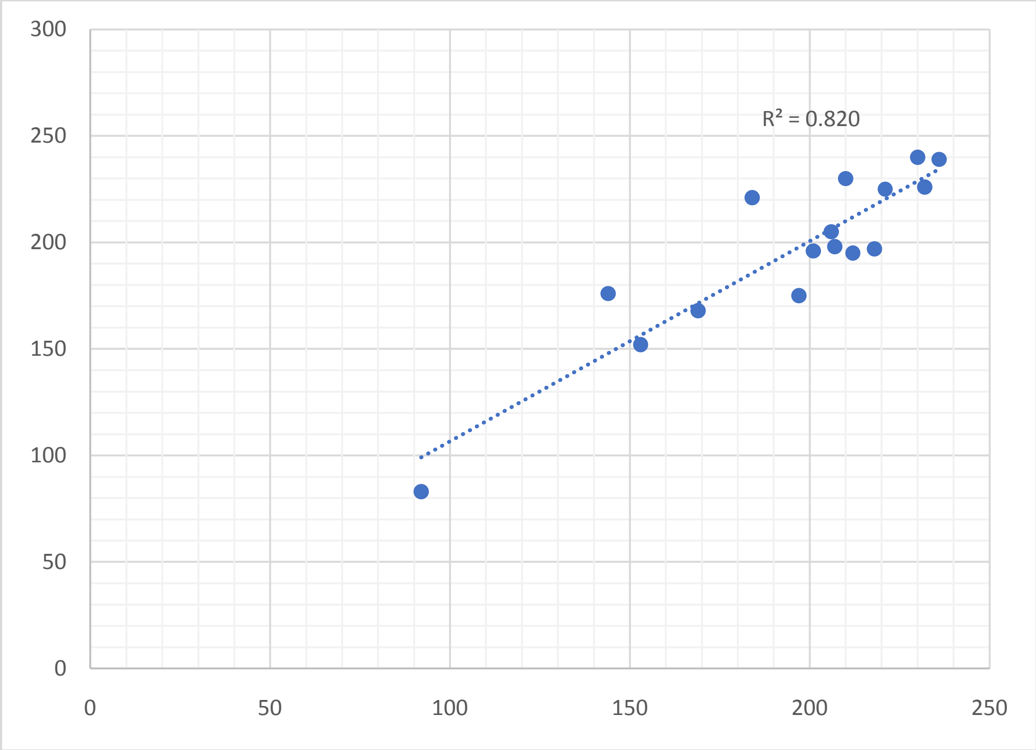

Fig. 3a Scatter Plot

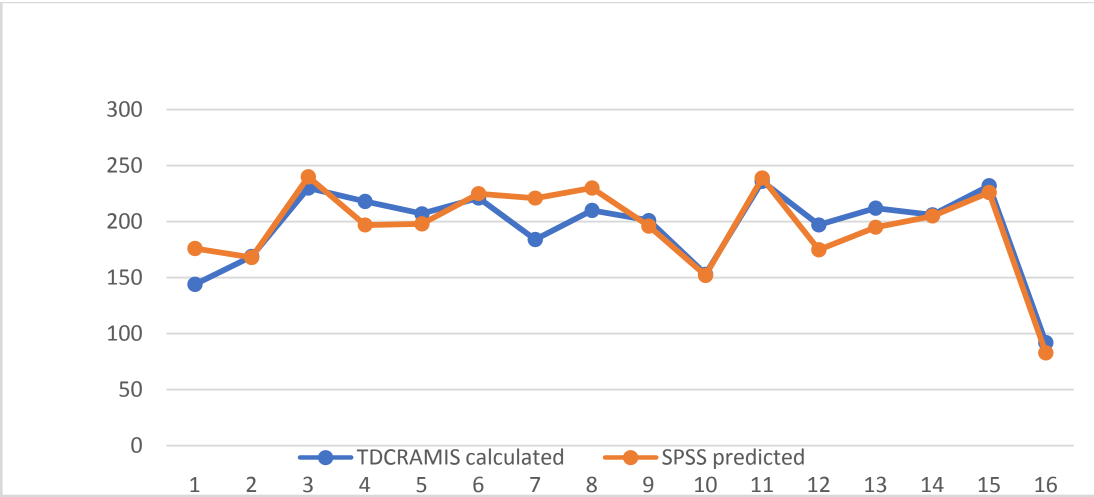

Fig. 3b TDCRAMIS/SPSS predicted values Trend

CONCLUSION

Models for prediction of failure susceptibility of different segments of Osogbo-Iwo road were developed in this study. Data for the study were obtained from road condition survey of Osogbo Iwo road Data on drainage conditions, asphalt thickness, water table depth, cross slope, traffic load, geotechnical characteristics such as CBR, MDD and G.I were collected during a 22-month period from 15 failed segments and 1 stable segment of the road. The acquired data were analysed using the TDCRAMIS rating system which is a point count rating system for determination of pavement failure susceptibility.

Pavement susceptibility indices obtained using the TDCRAMIS rating system include 144, 169, 230, 218, 207, 221, 184, 210, 201, 153, 236, 197, 212, 206, 232, 92 for the 16 road segments considered respectively. The data were further analysed using the curve estimation tool of SPSS to calibrate a predictive model for estimating failure susceptibility of the road. Comparison of the results obtained showed that the predictive model calibrated using SPSS could predict failure susceptibility values with a correlation as high as 0.905 thereby validating the SPSS predictive model. Mean Biased Error value of 0.875 and Root Mean Square Error value of 16.5 also served to validate the accuracy of the predictive model. The results confirm that the TDCRAMIS rating system could be used to prioritize road maintenance activities because the road condition could sufficiently be predicted by TDCRAMIS rating system and the SPSS calibrated model with a high level of accuracy.

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