PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 27 (4) 829-835 April 2023

Predictive Evaluation of Pavement Deterioration in Ibadan, Oyo State, Nigeria

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ABSTRACT: This work presents a mathematical model for road pavement deterioration condition in Ibadan. The effective deformation model shows the response of the pavement to the axial loads with respect the age, t of the pavement. The correction factor in the model compensates for the other secondary factors that may influence pavement deterioration. Throughout this study, the most common factors influencing pavement distress and the behaviour of distress have been identified and used as input parameters in a predictive mathematical model. The model shows that the pavement will deform along horizontal plane and also deform vertically. The increase in the volume of the failing section implies that there willbe increase in the international roughness index (IRI) of the pavement. Also, the results show that the higher the value of the load on a pavement, the higher the IRI increased becomes.

DOI: **https://dx.doi.org/10.4314/jasem.v27i4.26**

Cite this paper as: ADETOYINBO, A. A; BELLO, A. K; DOMINIC, P. (2023). Predictive Evaluation of Pavement Deterioration in Ibadan, Oyo State, Nigeria. *J. Appl. Sci. Environ. Manage.* 27 (4) 829-835

Dates: Received: 07 February 2023; Revised: 18 March 2023; Accepted: 28 March 2023
Published: 31 March 2023

Keyword: Mathematical Model; Pavement Deterioration; Effective Deformation; flexible Ppavement failure

Pavement maintenance is important for the durability of road not only because the road will be easily accessible for longer time, it will also ease transportation for both vehicles and the users. It will also reduce the cost and time spend in road construction. When development of pavement maintenance management system (PMMS) is provided there will be adequate maintaining process and pavement upgrading for highways Hasan et al., (2020). Pavement maintenance should not be limited to the government alone but should also be of public concern where private individual contribute to the maintenance scheme and thereby creating good atmosphere for the people. Scientific tool was considered for managing the pavements for best possible use of resources available that will benefit the society Bryar, (2013) and Jaselskis, (2009). There should be adequate means of transportation in the land as it play a vital role in economy, it serves as links between businesses or industries and consumers. Inadequate transport system affect the economic development of the country Saad, (2016). The time and cost will reduce through improved road maintenance management system Mohemed, (2010). It was reported that a pavement layer is more superior, if it is to distribute the wheel load stress through a larger area per unit depth of the layer Khannas and Justo (1997). The level of stress and strain within the pavement layers and inadequate design, excessive loading, weathering and climatic condition, and poor quality construction were among the factors responsible for pavement failures Sani, (2001) and Hassan, (2006). Highway pavements are classified into flexible and rigid pavements, flexible pavement failure is due to excessive deformation in sub-grade soil and can be noticed in

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the form of excessive folding, corrugation in the pavement surface and also depressions followed by heaving of pavement surface Ajayi, (1987). Pavement management and preservation (PMP) requires the knowledge of predicted pavement performance for the near future in order to prioritize alternative PMP projects Guangyang *et al.*, (2014). Deterioration of pavement is due to factors such as age, traffic, material properties, pavement thickness, strength of pavement as well as sub-grade properties which affect the mechanical characteristics of a path Ankit *et al.*, (2015). The relationship between pavement condition and the factors that affect deterioration of pavement is determined by pavement deterioration model, the model is use to predicts the future condition of the pavement Ankit *et al.,* (2015). There are different models on road pavement deterioration that have helped to improve road management, construction techniques e.t.c. Several related works on the development of mathematical models that predict the roads pavement failure in Nigeria and even beyond have been done in recent years. An evaluative report of information that is related to this selected area of study are discussed using a pavement performance model which is an equation that relates a number of extrinsic 'time factor' (age, or number of load applications) to a combination of intrinsic factors (structural responses, material properties, drainage, etc.) and performance indicators. Another factor that affect the road performance is road pavement deterioration which is negative condition of the pavement and difficult to predict. Ankit *et al.,* (2015) stated that Artificial Neural Network (ANN) model is developed in MATLAB for best accuracy. These roads are designed for low traffic but actual traffic on these roads are manifold which results in early deterioration. Maintenance priority index (MPI) is also developed on the basis of Maintenance Management Model so that proper and timely maintenance strategy can be applied. The model by Monica, (2003) was used to convert the IRI to slope variance. Using Dayi-Kano Road, Nigeria as a case study, Yusuf *et al.*, (2016) made an Investigation on the structural pavement failures of the road. Some model based on visual survey whose data will lead to increase in prediction error and highly prone to high errors level Owolabi *et al*., (2012). A model was developed for typical flexible roads in Nigeria which can be used to predict deterioration rate of roads over their lifespan Aderinola, (2015). Osogbo-Iwo road in Osun state, Nigeria was investigated to determine failure susceptibility indices Maher et al., (2016). The road was traversed from Osogbo to Iwo in order to establish the failed segments. Physical observations were made on the fifteen (15) major failed sections. Monitoring wells were positioned at fifteen major failed sections to study groundwater movement. Aderinola and Akingbonmire (2016) made use of two models: a distress based deterministic and an age based probabilistic models. They collected existent pavement data in the Long-term Pavement Performance Database (LTPP), part of it was utilized to develop a deterioration trend in pavement condition index (PCI). Adrian and Samer 2000) worked on the model that predict the road pavement deterioration indices using expressway from the Federal University of Technology (FUTA) north gate to NNPC mega station in Akure, Ondo State road network as a case study. Hence, the objective of this work is use mathematical model to predict road pavement deterioration from Monatan to Iyana Offa Oyo State, Nigeria.

MATERIALS AND METHODS

Mathematical model is carefully chosen to be a continuous function model, having considered some basic factors which affect pavement deterioration. Each fragment (or state) of the model can be modeled out separately. Also, a performance indicator such as the pavement's International Roughness Index (IRI) which is the quantitative index of pavement smoothness is considered, it determines the performance of the road pavement Karballaeezadeh *et al.,* (2020).

The Pavement Deformation State: Gupta *et al.,* (2014), Thawat *et al.,* (1987); Abramowitz and Stegun (1965) noted that pavement deterioration process is exponential in nature. By considering a pavement to be an elastic material which can yield to deformation due to some physical factors, let $D_0(x_0, t_0)$ be the initial deformation at time, t_0, initial width, x_0, initial susceptibility index, $\alpha(t_0)$ and at initial deformation parameter, b_0 then the pavement deformation state along its width x may be written as

$$D(x,t) = \frac{D_0(y_0, t_0).b}{\alpha(t) + \exp(xt)'} \qquad (1)$$

Where the deformation parameter, b may be considered as the axial loads from the vehicles or other deformation parameters such as construction age, water intrusion, temperature, rainfall etc.

Deformation Function: Since most of the deformation (especially potholes) increases both vertically and horizontally forming almost U-shapes at last, the deformation function may be quadratic function (i.e.

polynomial of degree two). Therefore, for this model, the deformation function is chosen to be

$$f(x) = \alpha(t) + bx^2 \quad (2)$$

The Pavement Deterioration Model: By considering these conditions, the equation of state, S of the pavement modeled out using MAPLE software reads

$$f^2(x) = \frac{d^2S}{dx^2} + 2f(x)f'x\frac{dS}{dx} + \{2\alpha(t) - 2D_{tot}(x,t)\}S = 0 \quad (3)$$

Where $D_{tot}(x,t)$ total deformation after time, t

RESULTS AND DISCUSSION

By solving for the $D_{tot}(x,t)$, S and α(t) in the differential Equation of equation (3) using MAPLE software, the simplified expressions obtained read

$$D_{tot}(x,t) = \frac{D_0(x_0,t_0).b}{\alpha(t)+\exp(xt)} + \frac{f^2 + xff'}{x} + \frac{f^2}{2x^2}m(m+1) \quad (4)$$

Where f' is the derivative of f with respect to x and m is the number of pavement layers.

$$S = S_0(x)^{(1+\lambda_0)/2} f^{-1-(\lambda_1+\lambda_2)/4} P_m^{(\lambda_2/2,\lambda_2/2)}(\eta) \quad (5)$$

$$\alpha(t) = \frac{1}{2}\left\{-D_0(x_0,t_0) + b[(5(1-\delta)+8+2m(m+1)] + \frac{b}{2}(3+\lambda_1\lambda_2+2\lambda_1+2\lambda_2) + 2bm(2+\lambda_1+\lambda_2) + 4bm^2\right\} \quad (6)$$

Where $\eta = \frac{-2+f}{f} = \frac{-1+b(x)^2}{1+b(x)^2}$, S_0 is some constant, $P_m(\lambda_1;\lambda_2;\eta)$ are Jacobi Polynomials Antonio et al., (2018)

0 ≤ δ ≤ is a free parameter that may be called correction factor, which compensates other factors that may indirectly or secondarily influence the pavement deformation,

$\lambda_1 = \sqrt{1+4[2+m(m+3)+2t(t+1)]}$ and $\lambda_2 = \sqrt{1+\frac{4}{b^2}\{(5b^2+2)+6+m(m+1)\}}$

If α(t) is chosen to be the International Roughness Index (IRI), and the axial load in kilo-Newtons, L(kN) is considered to be the deformation factor $(i.e\ b = L)$ consequently

$$IRL(t) = \frac{1}{2}\left\{-D_0(x_0,t_0) + L[(5(1-\delta)+8+2m(m+1)] + \frac{L}{2}(3+\lambda_1\lambda_2+2\lambda_1+2\lambda_2) + 2mL(2+\lambda_1+\lambda_2) + 4bm^2\right\} \quad (7)$$

and $\alpha_0(t_0)$ in $D_0(x_0,t_0)$ of equation (1) becomes $IRL(t_0)$.

The general table on pavement quality/deterioration in term of its IRI (i.e. Table 1) presents below help in the interpretation of the analytical results, curves and discussions of equation (4) and equation (7) which shall be presented. The total deformation model equation (4) show the response of the pavement to axial loads with respect to age, t of the pavement though the number of the pavement layers also plays a secondary role. The model shows that the pavement will deform both along horizontal plane, (x-axis) and deform vertically. The increase in the volume of the failing section implies that there will be increase in the international roughness index (IRI) of the pavement (Figure 1(a), (b), (c) and (d). It must be noted that the volume of the failing section of the pavement comprises of the volume of the pothole/rut together with the defective region that is already deformed that is why we call equation (4) the effective deformation.

Table 1: Pavement Quality interpretation in term of IRI scale Antonio *et al.,* (2018); Hermawan and Setyawan (2017)

Pavement Quality	IRI
Excellent	0 ≤ IRI ≤ 1
Very Good	1 < IRI ≤ 1:5
Good	1:5 < IRI ≤ 2:0
Fair	2:0 < IRI ≤ 3:0
Poor	3:0 < IRI ≤ 6:0
Very Poor	6:0 < IRI ≤ 20:0
Failed	IRI > 20:0

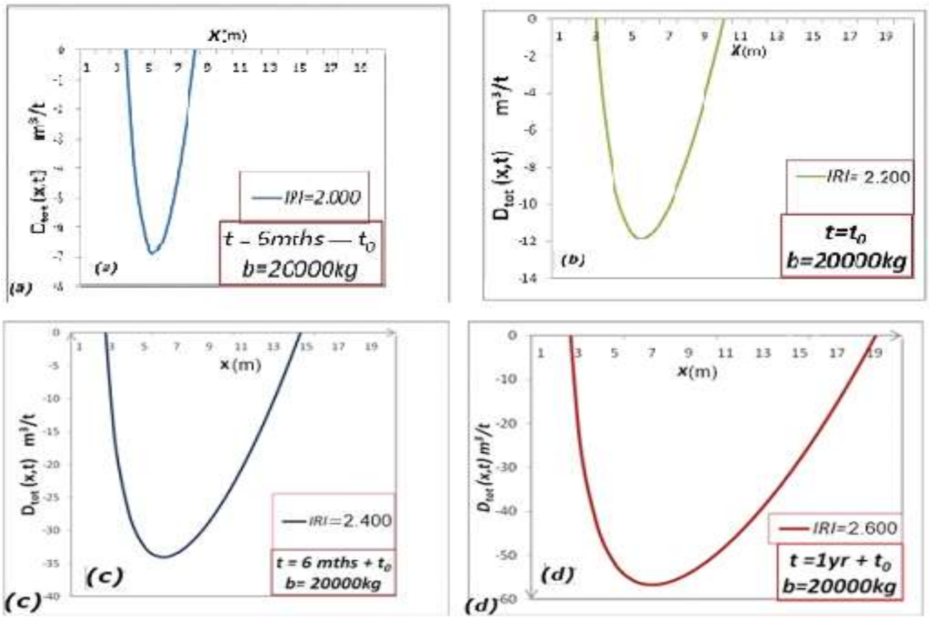

Fig 1: *Predicted total deformation curves of equation (4) for m = 2 showing the failed volume (or accumulated fatigue damage) of the road pavement, at a constant axial load, b=20000 Kg (a) six months earlier before t_0 for IRI=2.000 (b) at t_0 for IRI=2.200 (c) six months after t_0 for IRI=2.400 (d) a year after t_0 for IRI=2.500.*

Equation (4) predicts the volume of the failing section of a pavement due to the stress-strain effect of the axle loading from the heavy truck, if the IRI and the age of the pavement is known. If we really want to extend this model to a real life problem, we must obtain a data on daily, weekly or monthly average load on a particular pavement as that will present a cleared practical picture of the working principle of the model. Notwithstanding, we can save our time from this by comparing the model with other tested existing model: this comparison is presented later in our results.

The analytical description and behaviour of equation (7) that is the model for the performance of pavement with respect to the international roughness index, IRI as a function of age, t of the pavement is presented in fig 2.The IRI model in this work shows that as the road pavement profile deteriorates over its age, the IRI increases with increase in the age of the pavement and the increase in the axle load increases the IRI value, as presented analytically in Figure 2, this trends/curves agree well with some works in the literature reported by Amin, (2015) and Ruiz *et al*., (2019).

An increase in the pavement roughness leads to increase in active defects and this will lead to decrease in service life of the pavement. In order to avoid this situation there should maintenance strategy which shall focus on keeping the roughness, measured with the IRI, below a suitable value.

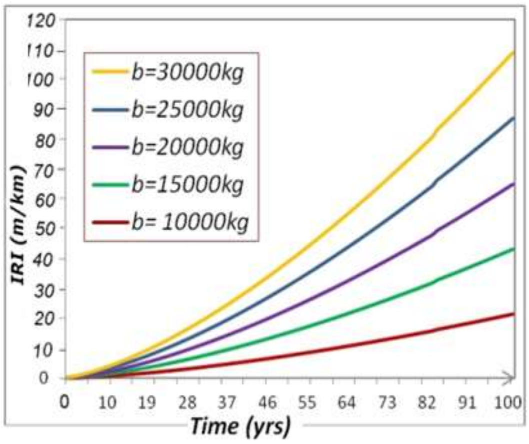

Fig 2: Predicted time progression of the IRI of equation (7) for m = 2 at different constant axle load.

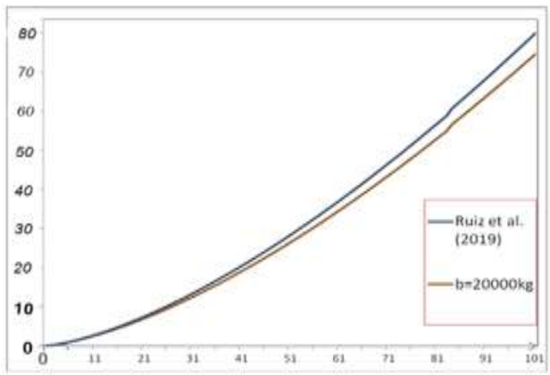

Fig 3: Comparison of the present predicted model at b=20000 Kg for m = 2 with the mathematical predicted model presented by Karballaeezadeh *et al.*, (2020).

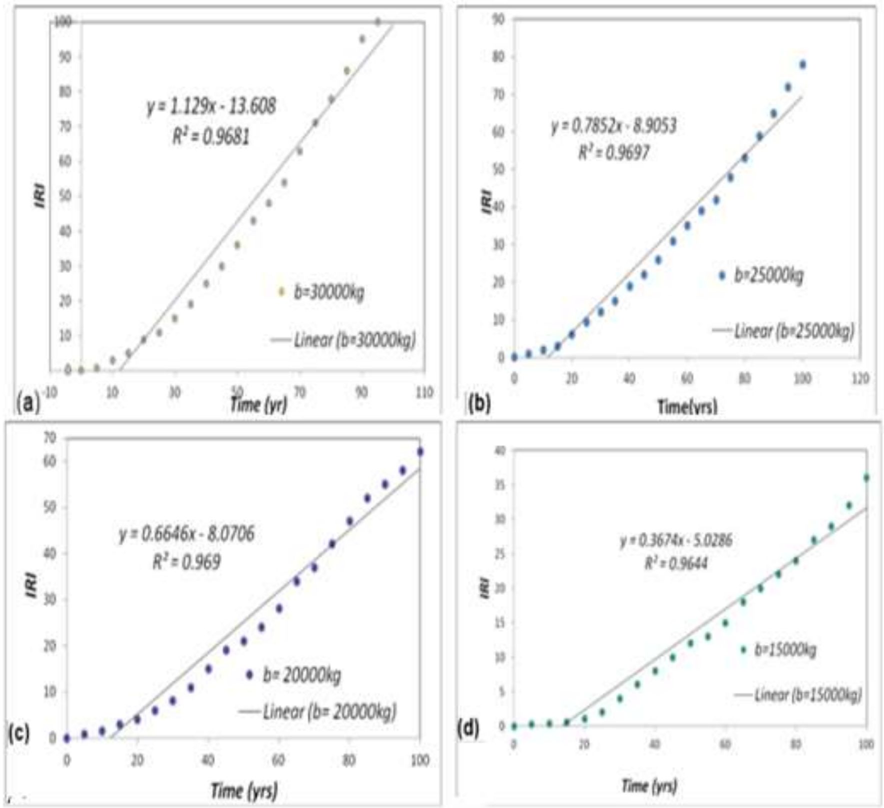

Fig 4: Prediction correlations between time progression and IRI of Eq. (7) at different constant axle load

Figure 2 shows that the higher the value of the load on a pavement, the increase the IRI becomes: the yellow line (i.e. b=30000 Kg) in Figure 2 with the highest axial load presents a rapid increase in the IRI compare with the red line (i.e. b=10000 Kg) with the smallest axial load.

This shows that the rapid road pavement deterioration is primarily due to the heavy loads from the heavy trucks on daily basis. Figure 4 shows show the correlation between the international roughness index, IRI and the age of the pavement. The square of the correlation which determines the fitness of the fit fall between 0.964 and 0.969. $R^2 = 0.9681$; 0.9697; 0.9690 and $R^2 = 0.9644$ values for b = 30000 Kg, 25000 Kg, 20000 Kg and b = 15000 Kg respectively, it shows that the cause of road failure is primarily due to the heavy loads since that is the primary parameter that defines equation (7). Environmental factors such as water, sun, freezing and thawing play secondary roles in the pavement deterioration and the parameter, δ has compensate for these factors. Though there are other factors like the mechanical properties such as the moduli of the pavement which must carefully consider during the course of the pavement's design

Comparison of this model's IRI with IRI models of some literature is achieved through the multiple extrapolation analysis for the corresponding IRI data at a particular time (i.e. year) is obtained and compared with our model. Figure 3 presents the comparison of this present model (i.e. equation 7) with that of Amin, (2015) whose analytical solution written as:

$$IRI_t = 1.04e^{mt}[IRI_0 + 263(1+SNC)^{-5} NE_t] \quad (8)$$

where IRI_t is the roughness index at pavement age, t (m/km), IRI_0 initial roughness, (m/km) is the cumulative *ESALs* at age, t since rehabilitation or reconstruction (years), m is environmental factor and *SNC* is the Structural Number modified Coefficient for sub-grade strength.

There is excellent agreement between our model and the mathematical model presented by Amin, (2015): we begin to experience small deviation for large values of t (i.e t > 30 yrs), though still maintain the same predicting trend.

Conclusion: This developed mathematical model provides a reasonable prediction of pavement condition. The mathematical model presented in this work is capable of estimating several pavement indexes, e.g. Present Serviceability I ndex (PSI), Pavement Condition Index (PCI), Roughness Condition Index (RCI) etc. This developed mathematical model provides a reasonable prediction of pavement condition. Therefore, the model contribute significantly to the successful implementation of road maintenance and rehabilitation programmes thus resulting in the increased performance level of road maintenance.

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