Pavement Performance Evaluation and Maintenance Decision-Making in Rwanda

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Abstract. Rwanda is one most developing country of East Africa Countries (EAC), every year has a great development in different areas. Regarding to infrastructure sector there is a great change in terms of housing, traffic (vehicles, trucks), etc., and when every day traffic loads and pavement age both increasing, it will gradually deteriorate and decrease functional and structural performance of a pavement. Deterioration of pavement can be attributed to various factors like age, traffic, environment, material properties, pavements thickness, strength of pavement as well as subgrade properties which affect the mechanical characteristics of a pavement. This research was conducted in order to assess the effect of Truck & Other heavy vehicles (CVPD), California Bearing Ratio (CBR), precipitation, pavement age and thickness factors on deflection and International Roughness Index (IRI) to find out which factors could be used in pavement performance evaluation in Rwanda as predictor variables and to assess the correlation between those variables. The result shows that precipitation and CBR found to be a significant predictor for both deflection and IRI on Rwandan flexible pavement performance and CBR is strongly correlated with precipitation. Therefore, the climate input precipitation was found to be more important factor for predicting different pavement performance in Rwanda, for further studies the temperature and Pavement Condition Index (PCI) need to be collected and analyzed, then the results would be compared to support the greater effectiveness of decision making and program development for Rwanda pavement performance evaluation.

Keywords: Pavement performance model · Deflection · Riding quality · Decision-making · Regression analysis

1 Introduction

Pavement performance is effectiveness or adaptability of road pavement conditions to meet different driving requirements, including functional performance and structural performance. Evaluation of existing flexible pavement condition is a requirement to choose improvement technique that has to be implemented to improve its quality [1]. Pavement management systems are a subset that have been in place for over 30 years, explicitly recognize the importance of maintenance and rehabilitation planning to ensure that the infrastructure assets remain viable [2]. These importance's include items such as ability to document the network condition, ability to predict future conditions given a variable budget, increased creditability among stakeholders [3]. The Pavement

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Design and Management Guide developed by the Transportation Association of Canada [4] as well as the Pavement Management Guide developed by the American Association of State Highway and Transportation Officials (AASHTO) [5], provides useful information on pavement management processes including data requirements, data collection methods, pavement performance prediction, selection of maintenance and rehabilitation treatments, priority analysis, and other pavement management topics. Different types of data are required for managing the road infrastructure, Inventory data describe the physical elements of a road system, condition data describe the condition of elements that can be expected to change over time [6]. The sustainability of data collection is strongly influenced by the frequency of surveys. Data should be collected only as frequently as is required to ensure proper management of the road network. The frequency can vary depending upon the data of interest. The quality of data has to be taken in consideration because if the quality of data is not good, the preservation will not be cost-effective, to quantify the performance extension, quality of data is needed [7]. Pavement evaluations are performed in the field through manual surveys or using specialized equipment. The rate of pavement deterioration, the maintenance treatments appropriate for the pavement condition, the timing of the eventual rehabilitation, the costs incurred, are all part of a single performance period evaluation [8].

2 Pavement Performance Model

The ultimate criterion used for assessing pavement quality is pavement performance, in terms of indicators such as pavement distress, roughness, rutting, anti-skid resistance, structure strength and etc. [9]. In America, For Ontario highways, several Key Performance Index (KPIs) are used for Pavement management decisions, such a as PCI, Distress Manifestation Index (DMI), IRI, Riding Comfort Index (RCI) etc. [10] estimating the prediction models by using Ordinary Least Square (OLS) approach; estimated KPI models they considered all available effecting pavement performance by using 'Seemingly Unrelated Regression (SUR)' method and found that PCI model is highly correlated with DMI and RCI model. However, IRI model is not found highly correlated to other models. For South Carolina state, they developed a performance evaluation models using regression techniques for one of the Mechanistic Empirical Pavement Design Guide (MEPDG) performance indicators: IRI, and three of the South Carolina Department of Transportation (SCDOTS) pavement performance indices: PSI, PDI and PQI. Precipitation was found to be a significant predictor for PSI on both types of pavement Asphalt Concrete (AC) and Jointed Plain Concrete Pavements (JPCP) [11]. For Illinois Department of Transportation has performance models, they used deduct values based on historical performance, route type, pavement type, age, and presence of particular distresses [3]. In India, statistical and Artificial Neural Networking (ANN) modeling was done for performance prediction of low volume roads, it is observed that if pavements are classified on the basis of parameters influencing pavement condition such as pavement age, traffic, CBR of subgrade and pavement thickness then it predicts the pavement condition in a better way. Therefore Maintenance Priority index was developed using three parameters named as deflection, riding quality and traffic to decide the priority [12]. In Sudan, they applied PCI methodology in pavement distress evaluation and maintenance prioritization [13]. In china, based on the “Highway Performance Assessment Standard”, the decision of pavement maintenance plan is determined by the MPI (Maintenance Plan Index), the sub-index of PQI and traffic volume [14]. The performance evaluation of pavement can cover many aspects including assessment of traffic safety on road, evaluation of road surface condition, structural adequacy of pavement and rideability of pavement surface. [15] have developed correlation analysis between pavement distresses and international roughness index by neural network, in that study, the coefficient between pavement distresses and IRI reaches 0.944. It shows that International Roughness Index may totally reflect on pavement distress conditions. Thus, IRI was used as a pavement performance index. [16] has developed pavement roughness and pavement condition model for Saudi highways. The pavement condition rating was calculated based on rutting, raveling, cracking and International Roughness Index They found the R^2 value 83.9% and 95% for Pavement Condition Rating and International Roughness Index by regression model.

3 Decision-Making Framework for Pavement Preservation

A management framework, when looking at roads, can therefore assist in improving the quality of decision-making, and can result in greater effectiveness and efficiency for both customers of the road network and the road administration [17]. In Rwanda, the emphasis is placed on the development of transport infrastructure and services, in terms of construction, rehabilitation and maintenance of the transportation networks [18] but it is a time to think about pavement management systems inventory historical and current conditions of roadway networks in order to predict the future conditions of such networks, and suggest schedules for maintenance, repair, and rehabilitation activities [19]. The Road Maintenance Fund (RMF) is an institution established by the law to ensure collection and funding for the maintenance of road networks in Rwanda. Unfortunately, these achievements are at a modest level in comparison to general maintenance needs throughout the country. This modest level is the consequence of insufficiency of funds [20]. Decision making for pavement maintenance and rehabilitation should be integrated into a yearly management cycle of planning, budgeting, engineering, and implementation activities. There are eight basic steps in the yearly management cycle: review or establishment of levels of service, pavement inventory, identification of needs, prioritization, budgeting, project design, project implementation, and performance monitoring [2].

4 Methodology

The main objectives of this research are to develop a pavement performance evaluation models in Rwanda by using multiple linear regression analysis.

5 Multiple Regression Analysis

Multiple regression analysis is almost the same as simple linear regression. The only difference between simple linear regression and multiple regression is in the number of predictors ("x" variables) used in the regression. The general purpose of multiple regression (the term was first used by Pearson, [21] is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable.

The general linear regression model is given by

$$Y_i = \varepsilon_0 + \varepsilon_1 X_{i1} + \varepsilon_2 X_{i2} + \varepsilon_{p-1} X_{i(p-1)} + \ldots \varepsilon_i, \quad i = 1, 2, \ldots n.$$

for this research:

Xi = Predictors variables (CVPD, precipitation of subgrade, thickness and ages of pavement)

Those factors were chosen according to data available given by Rwanda Transportation Department Agency (RTDA)

Y = Response variables (IRI and deflection)

6 Database

The network selected for the present study is the National Road number one (NR1) in Rwanda from Kigali to Akanyaru (Burundi border). This roadway network has been taken into 16 pavement sections sample with a length of 127.03 km. The NR1 has been designed to be upgraded to surfaced road standards in 1973–77 and the construction works have been executed in 1978–83. The pavement has been rehabilitated in 1998–2000 (Kigali – Muhanga) and in 2004–2005 (Muhanga – Akanyaru).

A geotechnical survey of the existing pavement with sampling and testing has been carried out by Consultants of RTDA and the necessary information has been acquired by destructive and non-destructive testing. The structural types of distress progressively affect the pavement's ability to support traffic loads are found like potholes, longitudinal cracking, fatigue alligator cracking, rutting. The deflection values have been statistically processed following the equivalent surfaces procedure recommended by AASHTO to determine the boundaries of the homogeneous sections. The existing Nyabarongo bridge is in good structural condition but it has been overtopped three times in the recent years (26/04/1998, 04/05/2002 and 19/04/2013) [22]. Referring to the results coming from the geotechnical survey, from the structural point of view, some existing pavement appears in fair structural condition others in good condition as shown in Table 1 with the data of the variables that can affect the road condition available in RTDA database (CVPD, precipitation of subgrade, thickness, age) detected in the year 2016 shown in Table 2.

7 Application and Discussion of Results

The following Table 1 is describing the identification of the selected road with its section. It gives us the information about the location of the road according to the district, the length and AADT.

Table 1.

Region	District	Road name	Starting point	Ending point	Road length (km)	AADT	AADT range
KIGALI CITY	Nyarugenge	RN1	0 + 000	1 + 950	1.95	9739	>5000 < 10000
KIGALI CITY	Nyarugenge	RN1	1 + 950	2 + 500	0.55	9739	>5000 < 10000
KIGALI CITY	Kicukiro	RN1	2 + 500	2 + 700	0.20	15202	>15000 < 20000
SOUTHERN	Kamony	RN1	2 + 700	5 + 000	2.30	15202	>15000 < 20000
SOUTHERN	Kamony	RN1	5 + 000	14 + 225	9.23	9987	>5000 < 10000
SOUTHERN	Kamony	RN1	14 + 225	14 + 225	0.00	9987	>5000 < 10000
SOUTHERN	Kamony	RN1	14 + 225	19 + 600	5.38	4771	>4500 < 5000
SOUTHERN	Kamony	RN1	19 + 600	30 + 400	10.80	4771	>4500 < 5000
SOUTHERN	Muhanga	RN1	30 + 400	41 + 900	11.50	4771	>4500 < 5000
SOUTHERN	Muhanga	RN1	41 + 900	68 + 500	26.60	4771	>4500 < 5000
SOUTHERN	Ruhango	RN1	68 + 500	74 + 500	6.00	1954	>1500 < 2000
SOUTHERN	Nyanza	RN1	74 + 500	90 + 000	15.50	1954	>1500 < 2000
SOUTHERN	Huye	RN1	90 + 000	100 + 200	10.20	1954	>1500 < 2000
SOUTHERN	Huye	RN1	100 + 200	107 + 500	7.30	1954	>1500 < 2000
SOUTHERN	Huye	RN1	107 + 500	125 + 025	17.53	1954	>1500 < 2000
SOUTHERN	Nyaruguru	RN1	125 + 025	127 + 029	2.00	1954	>1500 < 2000

The Table 2 contain the pavement condition data of the selected road as IRI is used by highway professionals throughout the world as a standard to quantify road surface roughness. Pavement roughness is defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle. Roughness is an important pavement characteristic because it does not only affect ride quality but also affects fuel consumption, vehicle delay costs and maintenance costs. Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. surface deflection is an important pavement evaluation method. Deflection is a function of traffic (type and volume), pavement structural section, temperature affecting the pavement structure and moisture affecting the pavement structure. Deflection measurements using back calculation methods to determine pavement structural layer stiffness and the subgrade resilience modulus.

The correlation between IRI and predictor variables are found as low to large, with the Pearson correlation values (r) ranging from 0.01 to 0.582. Precipitation is the strongest related predictor of IRI ($r = 0.582$, $p < 0.01$). The table also shows that some of the predictor variables have strong correlations with each other. For instance, CBR is strongly correlated with precipitation ($r = 0.514$, $p < 0.01$). In contrast, the correlation

Table 2.

Starting point	Ending point	% truck & Other heavy vehicles (CVPD)	IRI m/km	Deflection mm	Pavement thickness cm	CBR	Precipitation	Pavement age
0 + 000	1 + 950	1.42	3	0.6	4.5	28	24	17
1 + 950	2 + 500	1.42	6	0.6	4	24	24	17
2 + 500	2 + 700	21.06	6	0.6	3	24	24	17
2 + 700	5 + 000	21.06	6	0.6	3.4	30	46.5	17
5 + 000	14 + 225	17.9	6	1.1	4.6	52	93.2	17
14 + 225	14 + 225	17.9	6	1.05	5.3	52	56.8	17
14 + 225	19 + 600	7.82	6	0.67	5	30	79.8	17
19 + 600	30 + 400	7.82	6	1.14	4.25	44	98.3	17
30 + 400	41 + 900	7.82	8	1.28	4.3	52	107.3	12
41 + 900	68 + 500	7.82	8	1.88	4.8	52	106	12
68 + 500	74 + 500	13.31	6	1.38	5	44	101.4	12
74 + 500	90 + 000	13.31	8	1.68	3.5	44	105.2	12
90 + 000	100 + 200	13.31	6	0.54	5	28	106	12
100 + 200	107 + 500	13.31	6	1.04	4.7	52	94.5	12
107 + 500	125 + 025	13.31	6	0.89	4	28	101.6	12
125 + 025	127 + 029	13.31	6	0.59	4.9	24	92.6	12

between CVPD with age and CBR are found as low. Lastly, pavement age is highly correlated with IRI but negatively, means that with increasing of pavement age IRI decreases as shown in Table 3.

Table 3.

	IRI	Precipitation	Age	CBR	CVPD	Thickness
IRI	1					
Precipitation	.582	1				
Ages	−.498	−.737	1			
CBR	.473	.514	−.218	1		
CVPD	.168	.061	.010	.095	1	
Thickness	−.127	.384	−.210	.336	−.241	1

Table 4 is The Model Summary offers the multiple r and coefficient of determination (r^2) for the regression model. As can see r^2 = .789 which indicates that 78.9 of the variances in deflection can be explained by our regression model. In other words, the effect of Predictors (CVPD, ages, CBR, thickness, precipitation) are strongly related to deflection.

Table 4.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	.888[a]	.789	.684	.23522

[a]Predictors: (Constant), CVPD, Ages, CBR, Thickness, Precipitation
[b]Dependent Variable: Deflection

By seeing ANOVA Table for verification if the model fit, the model explains a statistically significant proportion of the variance as represented by Table 5.

Table 5.

Model	Sum of squares	df	Mean square	F	Sig.	
1	Regression	2.073	5	.415	7.492	.004[b]
	Residual	.553	10	.055		
	Total	2.626	15			

[a]Dependent Variable: Deflection
[b]Predictors: (Constant), CVPD, Ages, CBR, Thickness, Precipitation

For deflection model developed for AC, CVPD, ages, CBR, thickness, precipitation showed statistically significant effects on deflection ($p < 0.01$)

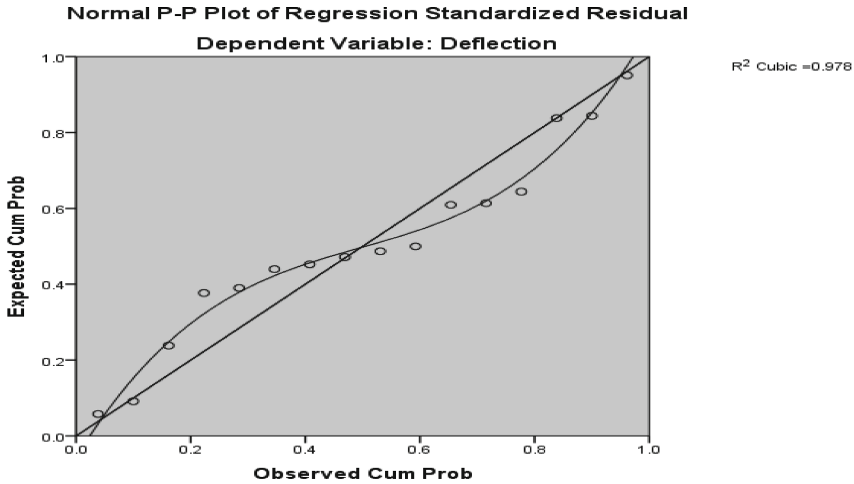
Model coefficients shown by Table 6, gives the constant or intercept term and the regression coefficients (**b**) for each explanatory variable the constant value is (1.359). CBR and precipitation have positive effects on deflection, whereas thickness, age and CVPD has negative effects on deflection for flexible pavement in Rwanda. That means deflection increases with increasing CBR and increasing precipitation. However, deflection decreases with increasing thickness, pavement ages and CVPD. This indicates that for every unit increase in CVPD the model predicts a decrease of −0.014 in deflection, means that this decrease is not significant as showed by significance of 0.213 which is not less than 0.05, the same for ages and thickness of Pavement.

Table 6.

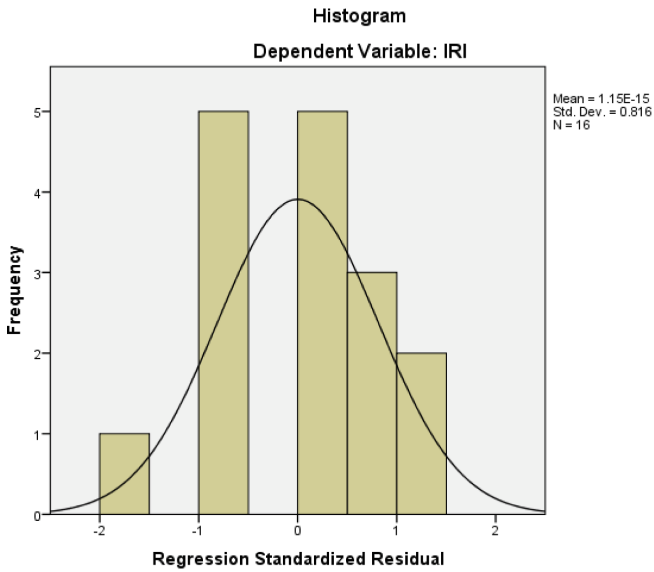
Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	1.359	.772		1.761	.109
	CBR	.028	.006	.785	4.382	.001
	Thickness	−.199	.107	−.314	−1.867	.092
	Precipitation	.002	.003	.151	.573	.579
	Ages	−.038	.036	−.232	−1.031	.327
	CVPD	−.014	.011	−.205	−1.332	.213

[a]Dependent Variable: Deflection

Table 7.



The Table 7 of P-P plot compares the observed cumulative distribution function (CDF) of the standardized residual to the expected CDF of the normal distribution. Note that are testing the normality of the residuals and not predictors.



A Histogram of the residuals suggests that they are close to being normally distributed and there are more residuals close to zero than perhaps would expect.

8 Conclusion

Precipitation and CBR found to be significant predictor for both deflection and IRI on Rwandan flexible pavement ($p < 0.05$). Therefore, the climate input precipitation was found to be more important for predicting different pavement performance in Rwanda, for further studies the temperature need to be collected and the results would be compared. Pavement age and its thickness were found to be highly correlated with IRI but negatively, means that with increasing of pavement age, IRI decreases. The effect of considered predictors for the research (CVPD, ages, CBR, thickness, precipitation) are strongly related to deflection more than to IRI. CBR of soil subgrade have statistically significant effects on Rwandan pavement performance. But there is a need of more different types of data for managing the road infrastructure, inventory data that describe the physical elements of a road system and condition data that describe the condition of elements in Rwandan pavement management database and those kinds of data must be objective, reliable, useful and repeatable. Decision-Making for pavement maintenance and rehabilitation in Rwanda have to be integrated into a yearly management cycle of planning, budgeting, engineering, and implementation activities in order to assist the quality of Decision-Making for Rwandan pavement performance.

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