Alternative Method for Estimating the Maintenance Cost of Roads in Anambra State, Nigeria

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Authors’ contributions

¹This work was carried out in collaboration among all authors. Author GOE managed the literature searches. Author JOE wrote the introduction. Authors NUO and COA designed the study and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study proposed an alternative method for the estimation of maintenance cost of roads in Anambra State, Nigeria. The proposed method referred to as the permuted quadratic model (PQM) involves permuting of the dependent variable of the quadratic model.

Place and Duration of Study: The data used in this study was secondary data sourced from the records department of consolidated construction company asphalt plant Anambra state, Nigeria from 2004 to 2019.

Methodology: The linear regression model and the permuted quadratic model were used to analyze the data for the study.

Results: The result found that 74.0% correlation exists between the observed maintenance cost of roads and the predicted maintenance cost of roads using the linear model while the predicted maintenance cost of roads using the permuted quadratic model has 75.8% correlation with the...
observed maintenance cost of roads. This result indicates that the proposed permuted quadratic model performed better than the linear model for the estimation of the maintenance cost of roads in Anambra State.

**Conclusion:** The study recommends the proposed model for the estimation of maintenance cost of roads in Anambra State until future studies prove otherwise.

**Keywords:** Linear model; maintenance cost; permutation; quadratic model; roads.

### 1. INTRODUCTION

The provision of good roads between the urban and the rural communities has the potential to reduce the poverty rate thereby harnessing important social benefits and development. Road networks form important links between production centres and markets. Also, because of the multiple functions of providing access to labour, social, health and educational services, the road network is vital in the fight against poverty by opening up more areas and promoting economic and social development.

The problem of poor road maintenance is widespread around the world, particularly in developing countries like Nigeria. New roads cost money to build, but without properly maintaining the roads, they deteriorate very quickly. If nothing is done, roads with a lifespan of decades may need replacing or major repairs in as little as a few years. However, a backlog of outstanding maintenance has led to an irreversible deterioration in the road network.

In Nigeria, investment on building new roads is believed to be of political benefit. This does not provide the same opportunity to policymakers to showcase maintenance as an achievable project. Road condition in most parts of Nigeria does not only require urgent attention rather they are in critical conditions. Decision-makers need to understand the cost of road maintenance and the cost of road non-maintenance. The money saved in the maintenance budget when the roads are not maintained is ultimately paid for by users and society. This can be called an invisible tax, and the total cost to the economy is enormous. However, the need to advocate the importance of road maintenance must not be overemphasized. Also, reliable data on road maintenance is required to help policymakers plan and make effective decisions. It has been observed that all the methods used in the literature to estimate the cost of road maintenance are largely parametric and most authors failed to indicate that the data used for the analysis meet the required assumption of normality, independence and constant variance. An alternative to the parametric approach, which does not rely on strict assumptions, is the permutation method. The present study, therefore, tries to propose an alternative method for estimating the maintenance costs of roads in the state of Anambra.

### 2. LITERATURE REVIEW

The study by [1] employed the multiple regression approach for the estimation of maintenance cost of roads in Nigeria. The study considered the impact of factors such as the length of the road in kilometres, type of road defects, the width of the road, terrain and year of awarding the maintenance contract on maintenance cost of roads. The result of the study found a coefficient of determination value of 70.0%, which indicates that the model is adequate for the estimation of the maintenance cost of roads within the observed period.

The study by [2] employed the Markov-based model for the minimization of both the maintenance cost of roads and user cost subject to several constraints including the average annual budget limit and the performance requirement. They modelled the road deterioration process as a discrete-time Markov process in which the states of the road performance were defined in relation to the road roughness and the state transition probabilities were estimated taking into account the effects of deterioration and maintenance measures. The findings of the study showed that the optimal road maintenance plan obtained from the model was practical to implement and is cost-effective when compared to the periodical road maintenance plan. The authors concluded that with more frequent maintenance, the maintenance costs for the life cycle increase and the user costs for the life cycle decrease.

The study by [3] examined the maintenance cost of roads in Anambra State using the times series approach. The study used the simple linear model for determining the trend of the road maintenance cost for the period 2004-2013. The study found that the maintenance cost of roads
has an increasing trend over time. Forecast from
the study revealed that the maintenance cost of
roads in Anambra State was estimated to be
about N237, 226,028 in the year 2018.

The study by [4] examined freight transportation
prices to account for external costs, including
maintenance costs on roads and bridges, delays
due to traffic congestion, injuries, fatalities, and
property damage from accidents and harmful
effects of Exhaust missions in the United States.
The results suggest that measures such as an
increase in the existing tax on diesel fuel, the
introduction of a tax on the transport of shipping
containers, or an increase in the existing tax on
truck tires are expected to results to a shift of 3.6
per cent-tonne-miles from trucking.

The study by [5] proposed a mathematical model
for estimating the emergency costs of a road
maintenance contract. The model was used to
predict the emergency costs for each of the road
maintenance activities included in the contract
using an artificial neural network model based on
the historical change orders (CO) data. The
authors argued that designing an efficient model
will help in providing reliable estimates of the
contingency cost of the project and this will, in
turn, be useful in the efficient management
during the construction or maintenance phase of
the project.

According to [6], roads remain the dominant
mode of passenger and freight transport in Africa
and the need for a better road network is growing
rapidly. As argued by most of the literature
reviewed in the present study, African countries
are not doing enough to ensure the sustainability
of road infrastructure, as it has been widely
reported that roads are affected by premature
deterioration to varying degrees. Most African
countries have adopted institutional reforms,
such as the creation of road funds and road
agencies, and have made significant progress in
road maintenance. However, in all of them, many
challenges remain to be addressed to ensure
adequate maintenance. Poorly maintained roads
limit mobility, significantly increase vehicle
operating costs, increase accident rates and the
associated costs for people and property, and
exacerbate isolation, poverty, poor health and
illiteracy in rural communities.

The study by [7] compared the variation between
the road agency costs and the road user's costs
from maintenance and rehabilitation treatment on
the selected road network in Iran. The study
dwelled more on the usefulness of road user's
costs in long-term economic analysis and
planning of future maintenance and rehabilitation
activities. The findings of the study revealed that
the road user's cost was higher than road agency
costs on each route of the selected roads
network. Also, traffic composition was identified
as one of the major factors that contributed
significantly to the road user's cost.

According to [8], both the construction and the
use of roads have several environmental impacts
which call for the evaluation of the sources of
their exposure to take correct mitigation
measures. Life cycle analysis (LCA) is a useful
way of providing verifiable, accurate and non-
misleading information for decision-makers. The
study focused on the effects of the construction,
and maintenance phases, the lighting, and the
use of the vehicles on the built road. The results
of using the SimaPro model showed that almost
half of the impacts occurred during the
construction phase rather than the use phase.
The authors, therefore, concluded that the
introduction of greener road design practices, the
use of low impact methods in the manufacture of
materials, and the use of secondary raw
materials could have the greatest potential for
reducing environmental impact.

Speaking on the importance of maintenance, [9]
stated that maintenance management has
become increasingly important in the
development of highways and government
investments, but lack of funding is still a problem.
The authors noted that if the administrative
department checks the cost, the existing
valuation method cannot be applied to the
current national state and the calculation process
is too complicated. To improve this situation,
their study examined the various factors that
affect maintenance costs and determines the
quantitative relationship between the six most
important influencing factors such as traffic
volume, time, location, number of lanes, overlaps
and major refurbishments. Also, the authors
proposed a regression analysis model for
estimating maintenance costs that can be
automatically updated according to market
conditions. Their study used data from 18 typical
highways in Guangdong Province, China. The
result of their study found that their model can be
used as a guide for cost planning and capital
allocation in sustainable maintenance and that it
has achieved good results in its application, so it
is worth promoting in other areas.

The study by [10] considered a comparative
review of cost models and cost factors published
in several studies on freight transport. The authors tried to determine and categorize cost factors from various perspectives in the reviewed studies, including cost factors (operating costs, time value and external costs), study area (Europe, USA, North America and Asia) and cost models (process costing (ABC), statistical models, Surveys, data mining, geographic information system (GIS), meta-analysis and mathematical models). The road freight transport cost model and the methods for estimating road freight transport costs and data collection were proposed by the authors. They argued that the proposed models are used to identify gaps between cost types or inconsistencies in cost factors and consist of an overall structure and multiple substructures.

3. METHODS AND MATERIALS

3.1 Method of Data Collection

The data used in this study is secondary data sourced from the records department of Consolidated Construction Company Asphalt Plant Anambra State, Nigeria.

3.2 Method of Data Analysis

Suppose we consider the model

\[ Y = X \beta + \epsilon \]  

(1)

Where, \( Y \) is a \( n \times 1 \) random vector called the response or dependent variable, \( X \) is an \( n \times (k+1) \) matrix of scalars \( \epsilon \) is a \( n \times 1 \) random vector called the random error with mean 0 and variance \( \sigma^2 \).

To estimate the regression parameters \( \beta \) properly using the method of least-squares estimation, the assumption that \( n > k \) must hold. Here \( n \) is the number of observations while \( k \) is the number of regression coefficients. The unbiased estimate of the regression coefficients is defined as

\[ b = (X'X)^{-1}X'Y \]  

(2)

The present study considers a situation where the response variable \( Y \) is permuted large number of times to generate a distribution of permuted regression coefficients. In this case, equation (2) can be redefined as

\[ b^* = (X'X)^{-1}X'Y^* \]  

(3)

In equation (3) \( Y \) is replaced by the permuted response variable \( Y^* \) and this is expected to produce a permuted regression estimate \( b^* \).

\[ b^* = mean \left[ \begin{array}{c} b_{01}^* + b_{02}^* + \cdots + b_{0p}^* \\ b_{11}^* + b_{12}^* + \cdots + b_{1p}^* \\ \vdots \\ b_{k1}^* + b_{k2}^* + \cdots + b_{kp}^* \end{array} \right] \]  

(4)

Where \( p \) is the number of permutations

A permutation test calculates the probability of obtaining a value that is equal to an observed value of a test statistic under a particular null hypothesis. This can be achieved by recalculating the test statistic after randomly shuffling the data. Permutation test has gained the attention of the natural and behavioural sciences since the advent of a generally accessible high-speed computer. Permutation methods have proven to be very useful because of their flexibility, freedom of distribution, and intuitive formulation, which makes it easy to convey the general principles of such test procedures to users [11].

3.3 Model Specification

The permuted quadratic model where the dependent variable is being permuted was proposed in this study. The model is specified from equation (1) as given

\[ y^* = \beta_0 + \beta_1 t + \beta_2 t^2 + \epsilon \]  

(5)

Where, \( y^* \) is the permuted dependent variable, \( t \) is the time which is annually and represents the dependent variable, \( \beta_0, \ldots, \beta_2 \) are model coefficients to be estimated, and \( \epsilon \) is the random error.

The general procedure for running the permuted quadratic model analysis is as follows:

1. Permute the dependent variable \( y \) at random to obtain \( y^* \)
2. Compute the estimate of the permuted regression model using equation (5) and the permuted dependent variable obtained in step (1) above
3. Repeat step 1 and 2, 1000 times to obtain the distribution of the permuted regression coefficients.
4. Compute the mean of the permuted coefficients using equation (4)
3.4 Data Presentation

Table 1. The distribution of annual maintenance cost of roads (MCR) in Anambra state in billions of Naira

| Year | MCR   | t code |
|------|-------|--------|
| 2004 | 57.846| 1      |
| 2005 | 61.211| 2      |
| 2006 | 83.061| 3      |
| 2007 | 152.24| 4      |
| 2008 | 201.949| 5     |
| 2009 | 130.67| 6      |
| 2010 | 182.753| 7     |
| 2011 | 97.13 | 8      |
| 2012 | 141.779| 9     |
| 2013 | 191.932| 10    |
| 2014 | 179.088| 11    |
| 2015 | 170.255| 12    |
| 2016 | 155.544| 13    |
| 2017 | 170.645| 14    |
| 2018 | 200.14| 15     |
| 2019 | 231.11| 16     |

Source: Consolidated Construction Company (CCC) Asphalt Plant Anambra State, Nigeria

4. DATA ANALYSIS AND RESULTS

In this section, the result of the permuted quadratic model and the linear model will be presented. The linear model was used to examine the performance of the proposed permuted quadratic model.

4.1 Test of Normality of MCR

The test of normality of the variable was conducted using the Anderson-Darling test for normality. The null hypothesis that the variable is normally distributed was evaluated at 5% significance level. The null hypothesis was accepted in each if and only if the p-value of the test statistic is greater than the significant level, otherwise reject the null hypotheses. The need for the test for normality is to enable the appropriate fitting of the simple linear model which will be used to validate the result obtained from the proposed model.

The result obtained in Table 2 indicates that variable MCR is normally distributed since a p-value of 0.265 which was found to be greater than the α-value of 0.05 was obtained. Hence, the variable is approximately normally distributed and meets the assumption of normality required to perform the regression analysis.

4.2 Result of the Linear Model (LM) and the Permuted Quadratic Model for Estimating MCR

The result of the linear regression model was expressed as

\[ y = 81.83 + 8.07 \times t \]  \hspace{1cm} (6)

While the permuted quadratic model was expressed as

\[ y = 64.23 + 17.21\times t - 0.55\times t^2 \]  \hspace{1cm} (7)

The result presented in Table 3 shows the actual MCR, predicted MCR using the LM and PQM. This result was further expressed in Fig. 1 and this result indicates that there is little variation between the actual MCR and the predicted MCR using the LM and the PQM. In other to validate the aforementioned claim, a correlation analysis was performed between the actual and the predicted MCR of the models. The result presented in Table 4 showed that 74.0% degree of linear relationship exists between the actual MCR and the predicted MCR using the LM while 75.8% correlation was found between the actual MCR and the predicted MCR using the PQM. Also, Table 5 in the Appendix shows the 1000 permuted coefficients used to obtain equation (7).
Fig. 1. Graph showing the actual MCR and the predicted MCR using the LM and the PQM

Table 2. Summary of test for normality for MCR

| Variable | Anderson-Darling Test Statistic value | P-value | Remark          |
|----------|--------------------------------------|---------|-----------------|
| MCR      | 0.433                                 | 0.265   | Normally Distributed |

Table 3. MCR and the predicted MCR using the LM and the PQM

| Year | MCR  | LM   | PQM   |
|------|------|------|-------|
| 2004 | 57.846 | 89.9 | 80.89 |
| 2005 | 61.211 | 97.97| 96.45 |
| 2006 | 83.061 | 106.04| 110.91 |
| 2007 | 152.24 | 114.11| 124.27 |
| 2008 | 201.949 | 122.18| 136.53 |
| 2009 | 130.67 | 130.25| 147.69 |
| 2010 | 182.753 | 138.32| 157.75 |
| 2011 | 97.13 | 146.39| 166.71 |
| 2012 | 141.779 | 154.46| 174.57 |
| 2013 | 191.932 | 162.53| 181.33 |
| 2014 | 179.088 | 170.6 | 186.99 |
| 2015 | 170.255 | 178.67| 191.55 |
| 2016 | 155.544 | 186.74| 195.01 |
| 2017 | 170.645 | 194.81| 197.37 |
| 2018 | 200.14 | 202.88| 198.63 |
| 2019 | 231.11 | 210.95| 198.79 |

Table 4. Result of correlation analysis between the observed MCR, the predicted MCR for the linear model and the permuted quadratic model

| Model               | MCR   | P-value |
|---------------------|-------|---------|
| Linear Model        | 74.0% | 0.001*  |
| Permutated Quadratic model | 75.8% | 0.001*  |

Note: Asterisks (*) denote statistical significance at a 5% level
5. CONCLUSION
This study proposed an alternative method for the estimation of maintenance cost of roads in Anambra State, Nigeria. The proposed method referred to as the permuted quadratic model (PQM) involves permuting of the dependent variable of the quadratic model. The linear model was fitted to assess the performance of the proposed model. The performance of the proposed for the estimation of the maintenance cost of roads was better than the linear model since the predicted maintenance cost of roads using proposed model recorded a higher correlation coefficient than the linear model. Hence, the present study recommends the proposed model for the estimation of maintenance cost of roads in Anambra State until future studies prove otherwise.

DISCLAIMER
The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS
Authors have declared that no competing interests exist.

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APPENDIX
Table 5. Summary result of permuted quadratic (PQM) regression coefficient for the estimation of MCR

| p   | b0        | b1        | b2        |
|-----|-----------|-----------|-----------|
| 1   | 59.0166   | 15.6779   | -0.4473   |
| 2   | 159.325   | 0.7802    | -0.16574  |
| 3   | 141.066   | 3.3852    | -0.20727  |
| p  | b0     | b1     | b2     |
|----|--------|--------|--------|
| 4  | 160.622| -10.0179 | 0.80203 |
| 5  | 175.226| -0.8012  | -0.19203 |
| 6  | 129.001| 2.7146  | -0.01727 |
| 7  | 185.474| -3.8641  | -0.0231 |
| 8  | 99.654 | 13.0205 | -0.6403 |
| 9  | 210.881| -19.317 | 1.10988 |
| 10 | 167.348| 4.49    | -0.5888 |
| 11 | 88.07  | 19.7322 | -1.1265 |
| 12 | 175.999| -7.0318 | 0.36611 |
| 13 | 187.769| -8.0464 | 0.33247 |
| 14 | 158.312| -3.8619 | 0.2671 |
| 15 | 171.809| 4.4873  | 0.21466 |
| 16 | 152.201| -4.0933 | 0.3535 |
| 17 | 161.316| -4.4846 | 0.29159 |
| 18 | 172.117| -7.2657 | 0.42889 |
| 19 | 191.927| -14.6316| 0.88665 |
| 996| 190.929| -8.8767 | 0.37415 |
| 997| 107.471| 15.6943 | -0.96698 |
| 998| 146.263| -2.0561 | 0.23181 |
| 999| 91.676 | 14.5434 | -0.69342 |
| 1000| -9097.4| 1915.79 | -64.93 |

Mean 64.23001 17.20993 -0.5460

**Fig. 2. Probability plot of the MCR**

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