

On the Risk of Urban Road Pavement Failure: A Case Study of Owerri, Imo State

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Abstract

In this research work, we study the risk of road pavement failures in Owerri Imo State. The study deviates from other research work in this area that focused on the nature of road pavement failures without considering the risk involved with respect to human life and others. This was the aspect the study delved into. The researchers used questionnaires to collect primary data from randomly selected respondents on axle load and fatalities within the period under study. The data collected was analyzed using the risk matrix and stochastic processes to determine the long run probability of risk of pavement failures. The risk value was 6.0891, which falls into the rejection region, meaning that a drastic measure is required to reduce the risk imposed on drivers and passengers due to road pavement failures in Owerri. The study also showed that the frequency of pavement failure in Owerri in the long run would lie between the range (26.0, 59.6) with probability 0.2003. Therefore, road pavement failure will account for 20.03% of the total road in Owerri if urgent action is not taken. And for consequence, with probability of 0.2905, the most likely number of fatalities will lie within the range (18.0, 24.0) and will account for 29.05% of the fatality in the long run. These values are reasonably high and unacceptable. Therefore, there is need for drastic risk reduction on road pavement failures in Owerri Imo State. From the study, we made some recommendations to mitigate the imminent risk of road pavement failures in Owerri, Imo State.

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INTRODUCTION

Roads are very important as the socio-political and economic life of any nation is heavily dependent on the road network, especially in developing countries of the world, but good network roads are being threatened by road pavement failures. The beauty of any city is linked to its road network, which is a function of urban planning. Urban planning is a discipline that helps in the sustainable development agenda using space as a major factor for development, and involves wider stakeholders in the process [1, 2]. In this work, we are concerned with the urban city of Owerri, Imo State; its road pavement failures and risk associated with it.

At the center of Urban planning and design are road networks that connect different areas within the city. These roads are constructed and maintained with a huge amount of money. Road network is a

capital project funded mainly by the government and this is often captured in her annual budget. Some related works have been done on pavement failure, their causes, cost, remedies, etc. but none was done to ascertain the risk associated with road pavement failures. Many road pavement deteriorations emanate from cracking as a result of heavy commercial vehicles [3], but Chetan *et al.* did a survey work on pavement failure, where he studied various forms of road failures and their causes [4]. The researchers noted that failures of bituminous pavements are caused by many factors and combinations of factors. The study describes the difficulties caused by pavement failures on the road users and the economic waste on the part of the government on road projects. Pavement failures affect serviceability, safety and quality of the road and need urgent attention to forestall more cost [5].

Owerri is a metropolitan capital of Imo State, it hosts people from diverse places and the city is connected from one area to the other through the road network. The major problem that confronts the inhabitants of the city is the bad road network. The road pavement failure is a concern to the inhabitants of the city. The State government has spent reasonable amounts of money in the repair, rehabilitation, construction and reconstruction of the roads. Since road projects belong to a capital project and huge expenditure is made on it, it is pertinent to study the causes of pavement failures which is rampant in Owerri and the risk associated with it, so as to proffer solutions. So many factors affect roads, especially in Owerri urban area, and all these factors add cost to both government and motorists. In most cases, there is little or no official penalty meted to these road violators that overload the axle of their vehicles. In a well-organized economy, specific charges are made on overloading the axle, but in Nigeria and Imo State in particular, the violators are not sanctioned appropriately, thereby making the State spend more in road construction and rehabilitation than she collects to maintain the roads. The road violators deviate significantly from the standard axle load and overload the axle of their trucks (vehicles) for ECOWAS standard axle load [6]. This overloading of axles destroys the investment the State government is making on the road network in Owerri, Imo State.

Goerlandt and Montewka made us understand that risk has a correlation with investments, and it is defined as the combination of frequencies of occurrence of events and consequences [7]. The frequency is about the rate at which the road pavements deteriorate and the consequences are about the kind of fatalities that result from the road pavement failures. Risk is an event, and correlated with probability. Therefore, risk can be defined as the probability that a given portion of road pavement fails. Since the event is probabilistic, we are concerned with expected risk because our interest is on the long run effect. Hence, expected risk, $E(R)$ is the sum of risk from frequencies and consequences. Our focus in this research is on the risk that emanates from overloading the vehicle Axles: two Axle (2A), three Axle (3A), four Axle (4A), five Axle (5A), and six (6A) and its effects on road pavement failures. This is a concern for urban and regional planning, as road pavement failure constitutes a major cost to the government and impacts the aesthetic nature of the city, which is reflected in its road network. According to Oyekanmi et al. [6], the ECOWAS standard axle load is often exceeded. This overloading of axles damages the investment the state government is making in the road network in Owerri, Imo State. As noted by Goerlandt and Montewka [7], risk has a correlation with investments and is defined as the combination of the frequency of occurrence of events and their consequences. The frequency refers to the rate of occurrence.

LITERATURE REVIEW

Oyekanmi et al. [6] conducted a study on truck overload. On the other hand, in Nigeria, axle-load control and enforcement were poor [8]. They noted that the Nigeria roads are designed to carry a maximum total load of 51.0 t and a maximum load of 11.5 t per axle. And that the maximum design speed of Nigerian Roads is 100 km/h. Their study area was in Lokoja, Abuja road, where a survey on the extent of overloaded trucks was carried out. They observed that there was rampant violation of gross vehicle weight (GVW) amongst different truck drivers of different types. They also carried out a correlation test between the numbers of axles in each truck category and the changes in GVW and found that there was significant correlation between them with a correlation coefficient of 0.855 at 1% level of significance, indicating the contribution of the number of axle to overloading and breakdown on the

Nigerian road. Again, Ochola and Odoki did work on pavement failure due to Axle overload and its associated cost [9]. They were of the opinion that the gains from road transport and its investment have been overtaken by overloading vehicle axles which seriously hamper the pavement life-cycle and create more cost on the economy. On the other hand, KRB noted that the cumulative effect of axle overloading is expressed using the equivalent standard axle (ESA) [8]. It was observed that ESA of an axle is its pavement damaging effect in relation to a standard axle load.

Osadebe and Quadri carried out research on pavement deterioration on the Nigerian highways [10]. They noted that trucks or heavy vehicles are the culprit in this case due to overloading in excess of the legally permitted limits. In a related study, Mohd *et al.* observed that the cracking of pavement was mostly caused by heavy vehicles [11]. But a survey and laboratory worked on the causes of road pavement failure and deterioration in Sudan in order to proffer adequate and proper maintenance technique. The main objective of the work was to identify factors that cause deterioration of recently constructed roads in Khartoum state, Sudan, where they found that low-quality materials was the major cause of pavement failures [12]. The objective of their work was to identify defects in the pavements and suggest the best maintenance strategies to increase the lifetime of road assets. Kurnia *et al.* observed that roads hold a vital role in the transportation system but real road conditions often experience a decrease in performance due to construction failures [13, 14]. The researchers focused on Koti Road in Jayapura and found that some vehicles passing it do not maintain the maximum permissible load. Consequently, there is excessive loading on the pavement which affects the design life of the road. Their study analyzed the percentages of actual overload on each vehicle type, the increase in the cumulative VDF value, and the decrease in the design life on Koti Road, Jayapura. The results from their study showed the actual overload, its effects, and the design life decrease of the roads.

METHODOLOGY

Method of Data Collection

The researchers adopt a survey research method to elicit information from heavy vehicle drivers. This is a different approach adopted by other researchers who station themselves and measure the tons of the load carried by the drivers. This approach is not realistic in many cases where the instrument for this measurement may not be available. In the survey, the researchers ask the truck and heavy vehicle drivers direct questions on the tons they are carrying. This provides more reliable data on current events. In survey research design, the researcher elicits information directly from the respondents, especially in a circumstance where secondary data may not be possible to ascertain. Data obtained with this method is current and can be relied upon compared to secondary data that may have been outdated.

Research Instrument

The researchers used structured questionnaires for data collection. This instrument was used to elicit information directly from the respondents on the axle load on the spot.

Sampling Method

The researchers adopted simple random sampling [15]. Simple random sampling is a probability sampling that gives every unit of the population equal chances of being included in the sample.

Population of Study/Area of Study

The population of study includes all vehicles with two to six axles and all roads in Owerri metropolitan city.

Sampling Size

A total of 350 instruments were distributed to the concerned respondents (drivers) of truck axles ranging from two (2) to six (6) at some specified points on the selected roads. The researchers distributed the instrument to the drivers on five roads drawn for the study. The roads were; (1) Owerri, Aba road (measured at Naze junction); (2) Naze, Obinze junction (measured at Obinze); (3) Owerri, Port-Harcourt road (measured at Control Post); (4) Wetheral road (measured at Wetheral junction); and (5) Okigwe road,

Orji (measured at Orji). From the questionnaires distributed, 324 were completed and returned and that form the sample size for the study. The data collection lasted for 1 month (August, 2024).

Method of Data Analysis

Our interest is to quantify the risk of road pavement failure in Owerri, Imo State, and it should be noted that the Markov chain has been used by researchers in risk management [16]. Again, risk factors can be analyzed using either qualitative or quantitative methods or both [17, 18]. Markov chain is a Markov process where both the state and parameter spaces are discrete. The researchers impose Markov chain model into a 5×5 square risk matrix model to quantify and determine the long run risk of road pavement failures in Owerri. Risk involves consequences such as fatality, major injuries, minor injuries, loss of money on investment, etc., and frequency such as the number of overloaded axles, number of cracks, number of potholes, etc. The researchers analyzed the collected data based on these risk components. We determine the probability transition matrix (PTM) as in Eq. (1).

$$P_{ij} = \left(\frac{n_{ij}}{P_i} \right) = \begin{bmatrix} x_{11} & \dots & x_{1n} \\ \vdots & \dots & \vdots \\ x_{m1} & \dots & x_{nn} \end{bmatrix} \tag{1}$$

The long run probabilities or the limiting transition probability matrix is given in Eqs. (1) and (2) as:

$$(\pi_1 \dots \pi_5)P = (\pi_1 \dots \pi_5) \tag{2}$$

$$P = (\pi_{1*} \dots \pi_{5*}) \tag{3}$$

Table 1 presents the five by five (5×5) risk matrix.

DATA PRESENTATION AND ANALYSIS

Data Presentation for Consequences of pavement failures and Frequencies of axle overload

Data Analysis for Consequences

From Eq. (1) and Table 2, we have the transition probability matrix as:

$$P = \begin{bmatrix} 15 & 23 & 28 & 0 & 42 \\ 25 & 40 & 0 & 0 & 0 \\ 33 & 41 & 0 & 0 & 0 \\ 44 & 21 & 0 & 0 & 0 \\ 29 & 42 & 0 & 0 & 0 \end{bmatrix}$$

$$P_{ij} = \begin{bmatrix} 15 & 23 & 28 & 0 & 42 \\ 25 & 40 & 0 & 0 & 0 \\ 33 & 41 & 0 & 0 & 0 \\ 44 & 21 & 0 & 0 & 0 \\ 29 & 42 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 108 \\ 65 \\ 74 \\ 65 \\ 71 \end{bmatrix}$$

Table 1. A 5×5 qualitative risk matrix with frequency and consequence categories [18].

		Risk index				
		CI				
		1	2	3	4	5
		Consequence in descriptive term				
<i>Fi</i>	<i>Frequency in descriptive term</i>	<i>Insignificant</i>	<i>Minor</i>	<i>Moderate</i>	<i>Major</i>	<i>Catastrophic</i>
1	Rare	2	3 (minor + rare)	4	5	6
2	Unlikely	3	4	5	6	7
3	Possible	4	5	6	7	8
4	Likely	5	6	7	8	9
5	Almost certain	6	7	8	9	10

Table 2. Presents the consequences of pavement failure.

Road	1	2	3	4
	<i>Fatal</i>	<i>Serious</i>	<i>Minor</i>	<i>Insignificant</i>
Owerri/Aba	15	23	42	28
Naze/Obinze	12	21	19	13
Owerri/PH	17	16	22	19
Wetheral	12	14	18	21
Okigwe/Orji	13	23	16	19

Source: Survey August 2024.

$$P_{ij} = \left(\frac{n_{ij}}{P_i} \right) = \begin{bmatrix} 0.1388 & 0.2130 & 0.2593 & 0 & 0.3889 \\ 0.3846 & 0.6154 & 0 & 0 & 0 \\ 0.4460 & 0.5541 & 0 & 0 & 0 \\ 0.6769 & 0.3231 & 0 & 0 & 0 \\ 0.4085 & 0.5916 & 0 & 0 & 0 \end{bmatrix}$$

F

rom Eq. (2), we have:

$$0.1388\pi_1 + 0.2130\pi_2 + 0.2593\pi_3 + 0\pi_4 + 0.3889\pi_5 = \pi_1$$

$$0.3846\pi_1 + 0.6154\pi_2 + 0\pi_3 + 0\pi_4 + 0\pi_5 = \pi_2$$

$$0.446\pi_1 + 0.5541\pi_2 + 0\pi_3 + 0\pi_4 + 0\pi_5 = \pi_3$$

$$0.6769\pi_1 + 0.3231\pi_2 + 0\pi_3 + 0\pi_4 + 0\pi_5 = \pi_4$$

$$0.4085\pi_1 + 0.5916\pi_2 + 0\pi_3 + 0\pi_4 + 0\pi_5 = \pi_5$$

Solving Eq. (2), we have that the stationary transition probability of Eq. (3) as:

$$P = [0.1117 \quad 0.2905 \quad 0.2108 \quad 0.1695 \quad 0.2175]$$

Data Analysis for Frequency

From Eq. (1), we have the transition probability matrix as:

$$P = \begin{bmatrix} 0 & 62 & 94 & 127 & 194 \\ 52 & 0 & 0 & 290 & 183 \\ 119 & 0 & 101 & 0 & 0 \\ 75 & 62 & 0 & 0 & 160 \\ 92 & 68 & 0 & 141 & 0 \end{bmatrix}$$

$$P_{ij} = \begin{bmatrix} 0 & 62 & 94 & 127 & 194 \\ 52 & 0 & 0 & 290 & 183 \\ 119 & 0 & 101 & 0 & 0 \\ 75 & 62 & 0 & 0 & 160 \\ 92 & 68 & 0 & 141 & 0 \end{bmatrix} \begin{bmatrix} 477 \\ 525 \\ 220 \\ 297 \\ 302 \end{bmatrix}$$

$$P_{ij} = \left(\frac{n_{ij}}{P_i} \right) = \begin{bmatrix} 0 & 0.130 & 0.1971 & 0.2663 & 0.4067 \\ 0.0991 & 0 & 0 & 0.5524 & 0.3486 \\ 0.5409 & 0 & 0.4591 & 0 & 0 \\ 0.2525 & 0.2088 & 0 & 0 & 0.5387 \\ 0.3046 & 0.2251 & 0 & 0.4669 & 0 \end{bmatrix}$$

From Eq. (2), we have:

$$0\pi_1 + 0.130\pi_2 + 0.1971\pi_3 + 0.2663\pi_4 + 0.4067\pi_5 = \pi_1$$

$$0.0991\pi_1 + 0\pi_2 + 0\pi_3 + 0.5524\pi_4 + 0.3486\pi_5 = \pi_2$$

$$0.5409\pi_1 + 0\pi_2 + 0.4591\pi_3 + 0\pi_4 + 0\pi_5 = \pi_3$$

$$0.2525\pi_1 + 0.2088\pi_2 + 0\pi_3 + 0\pi_4 + 0.5387\pi_5 = \pi_4$$

$$0.3046\pi_1 + 0.2251\pi_2 + 0\pi_3 + 0.4669\pi_4 + 0\pi_5 = \pi_5$$

Solving the equations, we have that the stationary or the limiting transition probability of Eq. (3) as:

$$P = [0.2003 \quad 0.1999 \quad 0.2003 \quad 0.2000 \quad 0.1995]$$

A long run expected risk is the sum of expected frequency and consequence and calculated:

$$E(C) = \sum_{i=1}^n x_i P_{(c)}$$

x_i	p	$E(c_i)$
1	0.1117	0.1117
2	0.2905	0.581
3	0.2108	0.6324
4	0.1695	0.678
5	0.2175	1.0875
$E(C) =$		3.0906

$$E(F) = \sum_{i=1}^n x_i P_{(f)}$$

x_i	p	$E(f_i)$
1	0.2003	0.2003
2	0.1999	0.3998
3	0.2003	0.6009
4	0.2000	0.8000
5	0.1995	0.9975
$E(F)$		2.9985

$$E(R) = E(C) + E(F) = 6.0891 \tag{4}$$

Interpretation of Results

The result from this study shows that the expected risk falls within the unacceptable region, and therefore, road pavement failures in Owerri Imo State require serious attention (Tables 3–9). The study also shows that the frequency of road pavement failure in Owerri in the long run would lie between the range (26.0, 59.6) with probability 0.2003. Therefore, the number of pavement failures will account for

Table 3. Presents the frequency of axle over load.

Axle/over load	1	2	3	4
	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>
2A	127	194	62	94
3A	52	135	183	155
4A	35	41	43	101
5A	160	62	26	49
6A	47	68	141	45

Source: Survey August 2024

Table 4. Descriptive statistics.

Mean	Std. dev	Max	Min	Range	Class size (C)
19	6.85	42	12	30	30/5=6

Table 5. Classification of Consequences

Consequences (C)	State	Notation	Expression
$12.0 \leq C \leq 18.0$	1	C1	Insignificant
$18.0 \leq C \leq 24.0$	2	C2	Minor
$24.0 \leq C \leq 30.0$	3	C3	Moderate
$30.0 \leq C \leq 36.0$	4	C4	Minor
$36.0 \leq C \leq 48.0$	5	C5	Catastrophe

Table 6. Descriptive statistics.

Mean	Std. dev	Max	Min	Range	Class size (C)
91	54.039	194	26	168	$168/5=33.6$

Table 7. Classification of frequencies.

Consequences (C)	State	Notation	Expression
$26.0 \leq C \leq 59.6$	1	C1	Insignificant
$59.6 \leq C \leq 93.2$	2	C2	Minor
$93.2 \leq C \leq 126.8$	3	C3	Moderate
$126.8 \leq C \leq 160.4$	4	C4	Minor
$160.4 \leq C \leq 194.0$	5	C5	Catastrophe

Table 8. Risk matrix with states probabilities for frequency and consequence categories.

		Consequence (C)				
		State				
		C1	C2	C3	C4	C5
		(12, 18)	(18, 24)	(24, 30)	(30, 36)	(36, 46)
		State probability (Ci)				
Frequency(F)		P (C1)	P (C2)	P (C3)	P (C4)	P (C5)
State	State probability P(F)	0.1117	0.2905	0.2108	0.1695	0.2175
F1 (26.0, 59.6)	P(F1) 0.2003	2	3	4	5	6
F2 (58.6, 93.2)	P(F2) 0.1999	3	4	5	6	7
F3 (93.2, 126.8)	P(F3) 0.2003	4	5	6	7	8
F4 (126.8, 160.4)	P(F4) 0.2000	5	6	7	8	9
F5 (160.4, 194.0)	P(F5) 0.1995	6	7	8	9	10

Table 9. Risk evaluation against risk criteria.

Risk criteria	Pre-determined risk range	Estimated risk E(R)	Evaluation result	Risk reduction measures
Acceptable	2–4	6.0891	0	Recommended
ALARP	4–6			
Unacceptable	6–10			

20.03% of the total road in Owerri in the nearest future. For consequence, with probability of 0.2905, the most likely number of fatalities will lie within the range (18.0, 24.0) and will account for 29.05% of the fatality in the nearest future. This value is reasonably high and unacceptable. Therefore, there is need for drastic risk reduction on road pavement in Owerri, Imo State.

CONCLUSION AND RECOMMENDATION

In this study we carry out a study on the road pavement failures in Owerri, the capital city of Imo State. The study deviates from the previous works that concentrate on the nature of road pavement failures without quantifying the effect of the failures. Although few researchers estimated the financial

cost of road pavement failure, generally, no researcher did work on the risk inherent on the road pavement failures with respect to human life. This was the aspect of research we delved into in this study. We used primary data collection as our method because of the requirement for the currency of the research work. Again, the required data for the work was not documented, hence, the need for the primary source of data collection. We used questionnaires as our instrument for data collection and analyzed the data using the risk matrix and Markov chain analysis. We used the long run probability matrix to estimate the limiting probability of risk of road pavement failures. The risk value falls into the rejection region, this means that a drastic measure is required to reduce the risk imposed on drivers and passengers due to road pavement failures in Owerri. From the study, we recommend the following mitigation measures:

1. Government of Imo State through the relevant Agency should insist on the use of standard materials for road construction in Owerri metropolis; this will save cost and reduce fatality caused by pavement failures.
2. The construction companies must owe it as a duty to put drainage gutters in every road constructed. This will help to extend the life of the road and save a lot of cost for the government and road users.
3. Government of Imo State through the relevant Agency should ensure that the standard axle load is strictly adhered to, as axle overload is the major cause of pavement failures; overloaded vehicles or a vehicle (truck) whose axle was overloaded should not be allowed to ply the roads.

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