On Stochastic Estimation of the Risk of Maritime Accident

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Abstract: In this paper, we investigated the occurrence of accidents involving marine vessels/boats along the coasts and inland waters of Northern and Southern Nigeria to determine if the risk was within the tolerable limit. We collected secondary data on maritime accidents from reports of the Accident Investigation Bureau of the government's Departments and Parastatals in Nigeria, covering the period from 2019 to 2023. We superimpose the risk matrix Markov chain model to determine the long-run risk of maritime accident occurrence. From the result of our analysis, we observed that the number of accidents will be between (50.6, 96.2) with 20.45% of the entire cases of accidents within the period under study, followed by (96.2, 141.8) with 20.36%, etc. As for consequence, fatality will be between

(62.4, 119.8) with 20.52% of the entire fatality within the period under study, followed by (117.2, 234.6) fatality with 20.48%, etc. And the estimated risk value is (5.6327). This value is high and close to the unacceptable region, but tolerable. We, constructed confidence interval for true risk value and found that at 10% level of significance, the risk value lies between [5.329, 5.931]; at 5% level of significance, it lies between [5.273, 5.987] and at 1% level of significance, the risk value lies between [5.160, 6.100]. We recommend close monitoring and strict adherence to safety standards set by NIMASA, NIWA, and other safety protocols of the International Maritime Organization (IMO) to reduce risk in the maritime industry.

Key-Words: - Maritime accident, Maritime Transportation, Risk, Markov chain analysis, Risk matrix.

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1 Introduction

Maritime transportation is very crucial to national and regional economic growth. It is the most cost-effective means of transportation and facilitates international seaborne trade among nations worldwide when compared to other modes of transportation, such as road, rail, and air. As noted by [1], shipping is four times as important as rail transport and four hundred times as air in terms of volume of freight moved between origin and destination. These characteristic underscores the importance of marine transportation to the economic growth of nations. However, the major challenge is the risk of an accident. Marine accidents have negatively impacted national security and hampered international trade. Accidents involving passenger and fishing vessels constitute the major types of marine accidents recorded in Nigeria’s inland and coastal waters. [2] enumerated various causes of the mishap and suggested a mitigation approach to estimating the risk of marine accidents based on frequency and consequences. Accident risk prediction and analysis can help policy administrators in decision-making.

Due to the frequent occurrence of accidents involving marine vessels and the need to mitigate them, Formal Safety Assessment (FSA) was devised by the International Maritime Organization (IMO) as a structured and systematic methodology to enhance marine safety using risk analysis and cost-benefit assessment [3]. Risk in maritime transport is better analysed quantitatively using the risk matrix. The risk matrix is rarely used by management or decision-makers to make vital decisions on the tolerability of risk. The matrix [4] is a two-dimensional model to aid decision-making. Marine transportation is crucial for foreign trade and the growth of the economy, but the catastrophe arising from the marine vessel accident has posed a very serious threat to life, property, and the environment. Since risk is synonymous with probability, researchers adopted a Markov Chain-based method to determine the stationary probabilities. The rising demand for maritime transportation has led to high accident risk in that sector [5]. For effective analysis, risk matrices are employed as a tool for risk management. The risk matrix employs quantitative measures to ensure a consistent method of determining risk, and its management is aimed at reducing the risks to a level deemed tolerable by society [6]. The risk matrix presents the risk problem in a form that permits proper analysis to be carried out on it, allowing ranges within which the risk could be adjudged tolerable or intolerable. Therefore, risk can be defined as the probability that a particular adverse event occurs at a given time.

The importance of maritime transportation cannot be overstressed, as maritime transportation facilitates more than two-thirds of the world's trade, even though currently the world seaborne trade is experiencing an extended decline, attributed in part to composite risks besetting marine transportation [7]. But [8] observed that researchers have recently been focusing more on the risk analysis of marine accidents involving vessels. They noted that risk correlates with probability, with emphasis that few researchers delved into uncertainty. In this paper, the parameters that we considered under Frequency (fatality) are: vessel-to-vessel collisions (involving service vessels with fishing boats leading to fatalities, injuries, and loss of cargo), vessel groundings due to shallow draughts, passenger boat capsizing due to overloading, engine, and machinery failures. Others include vessel grounding/foundering due to environmental factors- heavy storms, tidal variations, and turbulent waves. Under consequences, we classify fatality into very serious, Serious, less serious, and Minor incidents. Our interest is in risk quantification using a Markov chain, a subset of Stochastic processes. This paper is organized into five sections, namely: Section one was devoted to the introduction of the research area. Section two treated the literature review of related works done in the area. Section three dealt with materials and methods, while section four treated data presentation and analysis. Section five was devoted to discussions and recommendations.

2 Literature Review

Risk has a positive correlation with investments in seaport projects [8] because it helps investors in making decisions. Still on the vital role played by the marine transportation to world trade and economic growth, [9] observed that maritime transport provides opportunity for such operations but pointed out that port systems are more prone to risk and recommended that decision makers should select the measures to identify the Risk Control Options (RCOs) that keep risks as low as reasonably practicable (ALARP). In reality, data on marine transport accident risks may be difficult to obtain or too scanty to be useful in analysis. In this case, [10] simulated accident model for assessing accident risk in marine transportation due to a lack of adequate data. Their method was based on Markov modelling and Markov Chain Monte Carlo (MCMC) simulation. However, due to the high risk involved, [11] observed that the risk assessment studies on maritime transport safety usually consider the state of the system as two ultimate states, where one is the normal state and the other is the complete failure state. They adopted a Markov Chain-based methodology to determine the variations in the state system to determine when a low-probability incident transforms into a high-risk event.

Incessant occurrence of accidents in the maritime industry has been discouraging, irrespective of stringent safety measures put in place by the oil and gas companies in that sector [12, 13]. The researchers sought to unravel the negative impact of industrial accidents that have claimed lives and properties in the maritime industry. Considering a ten years data set on industrial accident in the oil and gas sector of the Niger Delta region of Nigeria, they applied Markov Chain model to determine the transition of workers from one state to the other before getting entrapped in any of the absorbing states. The result of their study showed that staff transition between 17-18 habituations before being trapped in an absorbing state. They suggested that there should be some level of mitigation to reduce risk due to minor injury and illness.

On the other hand, the Markov chain model has been useful in risk management; in the work of [14, 15], the Markov chain method was adopted to forecast the severity of risks workers were exposed to in the oil and gas industry. They used the method to determine the average length of time it would take before a worker is exposed to less severity and the possibility of transitioning to a state where the risk is high. The transition probability matrix was classified into four states, where fifty randomly selected Warri Refining and Petrochemical Company (WRPC) workers were classified. They noted that maritime transport has been acknowledged for its contribution to international trade, but the major setback it has is its susceptibility to certain risk factors. In maritime safety research, risk is assessed based on the formal safety assessment (FSA), which provides guidelines to improve the safety of lives, assets, and the environment. The risk factors are analysed using both qualitative and quantitative methods [16]. These researchers applied a risk matrix to screen the identified undesirable events. The result from their work revealed that man overboard (MOB) event is a major risk factor in marine seismic survey operation; lack of training, unsafe work practice, slippery deck as a result of rain, snow or water splash, sea state affecting human judgement, and poor communication were the major risk contributors to the MOB event, which could be reduced by applying FSA methodology for safer marine operations. The focus of this paper is to quantify the risk factor and determine the tolerance limit of the marine vessel accident to data available at the Accident Investigation Bureau, National Inland Waters Authority, Nigerian Maritime Administration and Safety Agency, and Marine Police Division of NPA covering five years.

3 Materials and Methods

A Markov chain is a subset of a stochastic process $\left\{X(\mathrm{t}), t > 0\right\}$, which is a family of random variables indexed by time, where the random variable $t \in T$ is the indexing parameter. A stochastic process is represented by the state and parameter spaces, where the state space is the collection of all possible values of a random variable, and the parameters are the set of integers ranging from 0 to ∞. The parameter space is the collection of all possible values of the indexing parameter. The indexing parameter is the set of numbers from $1\ to\ \infty$. We classify the infinite number of stochastic processes by using the nature of the state and parameter spaces: i. Process with discrete parameter and state space; ii. Process with discrete parameter but continuous state; iii. Process with continuous parameter space and discrete state space and iv. Process with continuous state and parameter spaces. Any stochastic process can be classified according to the four categories listed above.

Let $X_{0}, X_1, \ldots, X_n$ be the state in a Markov process. In other words, the system must occupy one of the r states. Let $A_k(j)$ be the event that X_j is occupied at the kth transition; that is, on the kth trial x_j occurred. For integers j and X_i, we define the Markov trial if the following is satisfied:

$$P[X_r = j|X_{r-1} = j-1, \ldots, X_1 = 1] = P[X_r = j\,|X_{r-1} = j-1] \quad (1)$$

That is, the probability of any outcome depends only on the outcome of the preceding event. For i and j, the homogeneous one-step transition probability is defined as:

$$P_{ij} = P[X_r = j|X_{r-1} = i] \quad (2)$$

Thus, a Markov chain is a Markovian process in which the state and parameter spaces are discrete. Our concern in this paper is to estimate maritime accident risks using the stochastic method and risk matrix. We define risk in this context as the frequency of occurrence of events and their respective consequences. We embed a Markov chain model into the n x n risk matrix. The essence is to introduce certainty and quantitatively determine the risk for accuracy, better prediction of future accidents, suggest mitigation measures, and eliminate subjective results that could be damaging to the economy. Since risk involves consequences such as death, loss of property and goods, injuries, etc., and frequency of the occurrence, we analyse any given set of data based on these components of risk, though the two components have similar analyses but different interpretations. We determine the procedure for consequences and frequency as follows:

For Consequences:

Step 1: Determine the following from the sample data

Maximum = m

Minimum = k

Range = m – k = w

Number of State S

Class size (Z) $= \frac{w}{s}$

Step 2: Classification of the sample into States

For Consequences (Ci)

Intervals	State	Notation	Expression
K1 ≤ K1+Z1	1	C1	Insignificant
K1 +Z1 ≤ K1+Z2	2	C2	Minor
K1 +Z2 ≤ K1+Z3	3	C3	Moderate
K1 +Z3 ≤ K1+Z4	4	C4	Major
K1 +Z4 ≤ K1+Z5	5	C5	Catastrophe

Step 3:

From Step 2, classify the data according to the risk matrix with five states

Year	C1	C2	C3	C4	C5	Total
20X1	X11	X12	X13	X14	X15	X1.
20X2	X21	X22	X23	X24	X25	X2.
20X3	X31	X32	X33	X34	X35	X3.
20X4	X41	X42	X43	X44	X45	X4.
20X5	X51	X52	X53	X54	X55	X5.
Total	X.1	X.2	X.3	X.4	X.5	X..

From Step 3, establish the transition probability matrix t.p.m given as:

$$P_{ij} = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{m1} & \cdots & P_{nn} \end{bmatrix} \quad (3)$$

The above matrix is the transition probability matrix P of moving from state i to state j with step one. We estimate the t.p.m as follows:

$$P_{ij} = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \cdots & \vdots \\ P_{m1} & \cdots & P_{nn} \end{bmatrix} \begin{bmatrix} P_{1.} \\ \vdots \\ P_{n.} \end{bmatrix} \quad (4)$$

$$P_{ij} = \left(\frac{n_{ij}}{P_{i.}}\right) = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{nn} \end{bmatrix} \quad (5)$$

But our interest is on the limiting probabilities, where the respective probability of consequences converges at their respective point. To achieve this, we apply Chapman-Kolmogorov equation given in equation (6) and derive the limiting probabilities that are used to make forecast on the risk.

$$P_{ij}^{n} = \sum_{k=0}^{r} P_{ik}^{(n-c)} P_{kj}^{c}; \quad (6)$$

where c, r, are row and column of the stochastic matrix

We determine the limiting probability as follows:

Using a one-state transition probability matrix with one step;

$$P = \begin{bmatrix} 1-a & a \\ b & 1-b \end{bmatrix} \quad (7)$$

Let $i = 1; j = 0; r = 1$, c = 1, we have

$$P_{10}^{(n)} = \sum_{k=0}^{r} P_{1k}^{(n-1)} P_{k0} \quad (8)$$

$$P_{10}^{(n)} = P_{10}^{(n-1)} P_{00} + P_{11}^{(n-1)} P_{10}$$

$$P_{10}^{(n)} = P_{10}^{(n-1)}(1-a) + P_{11}^{(n-1)} b$$

$$P_{10}^{(n)} = (1-a)P_{10}^{(n-1)} + b(1 - P_{10}^{(n-1)})$$

$$P_{10}^{(n)} = b + P_{10}^{(n-1)}[1-a-b]$$

For n =1,

$$P_{10}^{(1)} = b$$

$$P_{10}^{(2)} = b + P_{10}^{1}[1-a-b]$$

$$= b + b[1-a-b]$$

$$P_{10}^{(3)} = b + P_{10}^{2}[1-a-b]$$

$$= b + (b + b(1-a-b))[1-a-b]$$

$$= b + b(1-a-b) + b[1-a-b]^2$$

$$P_{10}^{(n)} = b + b(1-a-b) + b(1-a-b)^2 + \ldots + b(1-a-b)^{n-1} \quad (9)$$

Summing the series, we have

$$P_{10}^{(n)} = \frac{b}{a+b} - \frac{b(1-a-b)^n}{a+b} \quad (10)$$

Similarly

$$P_{11}^{(n)} = 1 - P_{10}^{(n)} \quad (11)$$

$$P_{11}^{(n)} = \frac{a}{a+b} + \frac{b(1-a-b)^n}{a+b} \quad (12)$$

We also carry out the same operation for $P_{01}^{(n)}$ and obtain

$$P_{01}^{(n)} = \frac{a}{a+b} - \frac{a(1-a-b)^n}{a+b} \quad (13)$$

where $0 \le a, b \le 1$ *and* $|1-a-b| < 1$ (14)

Hence, the nth transition probability matrix is

$$P_{ij}^{(n)} = \begin{bmatrix} \frac{b}{a+b} + \frac{a(1-a-b)^n}{a+b} & \frac{a}{a+b} - \frac{a(1-a-b)^n}{a+b} \\ \frac{b}{a+b} - \frac{b(1-a-b)^n}{a+b} & \frac{a}{a+b} + \frac{b(1-a-b)^n}{a+b} \end{bmatrix} \quad (15)$$

Taking the limit of equation (15) as n tend to infinity, we obtained the stationary or the limiting transition probability matrix

$$\lim_{\to 0} P_{ij}^{(n)} = P = \begin{bmatrix} \frac{b}{a+b} & \frac{a}{a+b} \\ \frac{b}{a+b} & \frac{a}{a+b} \end{bmatrix} \quad (16)$$

Calculating the limiting transition probability from equation (16), we have

$$(\pi_1 \quad \pi_2 \quad \pi_3)P = (\pi_1 \quad \pi_2 \quad \pi_3) \quad (17)$$

$$P = (\pi_{1*} \quad \pi_{2*} \quad \pi_{3*}) \quad (18)$$

We classify the risk value as presented in Table 1. In this Table, a risk value of 2 is classified as insignificant; 3 is minor; 4 is moderate; 5 is major and 6 is classified as catastrophic. See Appendix 1.

4 Data Presentation and Analysis

4.1.1 Data Presentation for Consequences

Table 4.1 presents the data on consequences of marine accidents. The data covers five years period starting from 2019 – 2023. See Appendix 2.

4.1.2. Data Presentation for Frequency

Table 4.2 presents the data on frequency of marine accidents. The data covers five years period starting from 2019 – 2023. See Appendix 3.

4.2.1. Data Analysis for consequences

Descriptive statistics

Max	Min	Range	Class Size (C)
253	5	248	248/5 = 57.4

Consequence (C)	State	Notation	Expression
5.0 ≤ C1 ≤ 62.4	1	C1	Insignificant
62.4 ≤ C ≤ 119.8	2	C2	Minor
119.8 ≤ C ≤ 177.2	3	C3	Moderate
177.2 ≤ C ≤ 234.6	4	C4	Minor
234.6 ≤ C ≤ 292	5	C5	Catastrophe

From equation (3) and Table 1, see Appendix 2, we have the transition probability matrix as;

$$P = \begin{bmatrix} 157 & 411 & 149 & 0 & 238 \\ 109 & 284 & 126 & 183 & 253 \\ 251 & 310 & 176 & 188 & 0 \\ 107 & 447 & 169 & 182 & 0 \\ 245 & 225 & 164 & 186 & 0 \end{bmatrix}$$

From equation (4)

Frequencies (F)	State	Notation	Expression
5.0 ≤ C1 ≤ 50.6	1	C1	Insignificant
50.6 ≤ C ≤ 96.2	2	C2	Minor
96.2 ≤ C ≤ 141.8	3	C3	Moderate
141.8 ≤ C ≤ 187.4	4	C4	Minor
187.4 ≤ C ≤ 233	5	C5	Catastrophe

$$P_{ij} = \begin{bmatrix} 157 & 411 & 149 & 0 & 238 \\ 109 & 284 & 126 & 183 & 253 \\ 251 & 310 & 176 & 188 & 0 \\ 107 & 447 & 169 & 182 & 0 \\ 245 & 158 & 164 & 186 & 0 \end{bmatrix} \begin{bmatrix} 955 \\ 955 \\ 925 \\ 905 \\ 753 \end{bmatrix}$$

From equation (5), we have

$$P_{ij} = \left(\frac{n_{ij}}{P_{i.}}\right) =$$

$$\begin{bmatrix} 0.1644 & 0.4304 & 0.1560 & 0 & 0.2492 \\ 0.1141 & 0.2974 & 0.1319 & 0.1916 & 0.2492 \\ 0.2714 & 0.3351 & 0.1903 & 0.2032 & 0 \\ 0.1182 & 0.4939 & 0.1867 & 0.2011 & 0 \\ 0.3254 & 0.2098 & 0.2178 & 0.2470 & 0 \end{bmatrix}$$

Applying equations (17), we have

$$0.1644\pi_1 + 0.4304\pi_2 + 0.1560\pi_3 + 0\pi_4 + 0.2492\pi_5 = \pi_1$$

$$0.1141\pi_1 + 0.2974\pi_2 + 0.1319\pi_3 + 0.1916\pi_4 + 0.2492\pi_5 = \pi_2$$

$$0.2714\pi_1 + 0.3351\pi_2 + 0.1903\pi_3 + 0.2032\pi_4 + 0\pi_5 = \pi_3$$

$$01182\pi_1 + 0.4939\pi_2 + 0.1867\pi_3 + 0.2011\pi_4 + 0\pi_5 = \pi_4$$

$$0.3254\pi_1 + 0.2098\pi_2 + 0.2178\pi_3 + 0.2470\pi_4 + 0\pi_5 = \pi_5$$

Solving the resulting equation (17), we have that the stationary transition probability of equations (18) is

$$P = [0.2007 \quad 0.2052 \quad 0.1892 \quad 0.2048 \quad 0.2001] \qquad (19)$$

4.2.2. Data Analysis for Frequency

Descriptive statistics

Max	Min	Range	Class (C)
233	5	228	228/5 = 45.6

From equation (3) and Table 2, see Appendix 3, we have the transition probability matrix as;

$$P = \begin{bmatrix} 182 & 120 & 228 & 0 & 203 \\ 110 & 217 & 102 & 159 & 233 \\ 91 & 411 & 271 & 0 & 0 \\ 101 & 212 & 206 & 302 & 0 \\ 148 & 119 & 343 & 153 & 0 \end{bmatrix}$$

From equation (4), we have

$$P_{ij} = \begin{bmatrix} 182 & 120 & 228 & 0 & 203 \\ 110 & 217 & 102 & 159 & 233 \\ 91 & 411 & 271 & 0 & 0 \\ 101 & 212 & 206 & 302 & 0 \\ 148 & 119 & 343 & 153 & 0 \end{bmatrix} \begin{bmatrix} 733 \\ 821 \\ 773 \\ 821 \\ 763 \end{bmatrix}$$

From equation (5), we have

$$P_{ij} = \left(\frac{n_{ij}}{P_{i.}}\right) =$$

$$\begin{bmatrix} 0.2483 & 0.1637 & 0.3111 & 0 & 0.2769 \\ 0.1340 & 0.2643 & 0.1242 & 0.1937 & 0.2838 \\ 0.1177 & 0.5317 & 0.3506 & 0 & 0 \\ 0.1230 & 0.2582 & 0.2509 & 0.3678 & 0 \\ 0.1940 & 0.1560 & 0.4495 & 0.2005 & 0 \end{bmatrix}$$

From equations (17), we have

$$0.2483\pi_1 + 0.1637\pi_2 + 0.3111\pi_3 + 0\pi_4 + 0.2769\pi_5 = \pi_1$$

$$0.1340\pi_1 + 0.2643\pi_2 + 0.1244\pi_3 + 0.1937\pi_4 + 0.2838\pi_5 = \pi_2$$

$$0.1177\pi_1 + 0.5317\pi_2 + 0.3506\pi_3 + 0\pi_4 + 0\pi_5 = \pi_3$$

$$0.1230\pi_1 + 0.2582\pi_2 + 0.2509\pi_3 + 0.3678\pi_4 + 0\pi_5 = \pi_4$$

$$0.1940\pi_1 + 0.1560\pi_2 + 0.4495\pi_3 + 0.2005\pi_4 + 0\pi_5 = \pi_5$$

Solving equation (17), we have that the stationary or the limiting transition probability

of equations (18) is

$$P = [0.1988 \quad 0.2045 \quad 0.2036 \quad 0.2030 \quad 0.1901] \quad (20)$$

We present the limiting probabilities of consequences and frequencies in Table 4.3. See Appendix 4. And a long run expected risk, [E(R)], is determined by getting the sum of expected frequency and consequence as follows:

$E(C) = \sum_{i=1}^{n} x_i P_{kc}$; where n = 5

x_i	p	$p(x_i)$
1	0.1644	0.1644
2	0.4364	0.8608
3	0.156	0.468
4	0.0000	0.0000
5	0.2492	1.246
	$\sum_{i=1}^{5} p(x_i)$	2.7392

$E(F) = \sum_{i=1}^{n} x_i P_{kf}$; n = 5

x_i	p	$p(x_i)$
1	0.2483	0.2483
2	0.1637	0.3274
3	0.3111	0.9333
4	0.0000	0.0000
5	0.2769	1.3845
	$\sum_{i=1}^{5} p(x_i)$	2.8935

$$E(R) = E(C) + E(F) = 5.6327 \quad (21)$$

See Appendix 5 for the expected risk presentation.

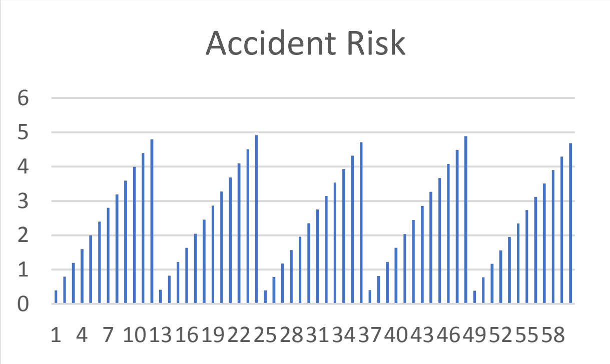

Fig. 1. Accident risk values for 60 months

Table 5 Confidence interval for true risk value of maritime accidents

Parameters	0.1 (90%)	0.05 (95%)	0.01 (99%)
Za/2	1.65	1.96	2.58
Mean	5.63		
Std.dev.	1.412		
N	60		
E(R)	5.6327		
Cl	[5.329, 5.931]	[5.273, 5.987]	[5.160, 6.100]

4.3. Interpretation of Results

From the result of our analysis, we observed that the most frequent maritime accident in the long run would be between the ranges (50.6, 96.2) with the probability of 0.2045, followed by the range of (96.2, 141.8), with the probability of 0.2036. Therefore, the number of maritime accidents will be between 96.2 and 141.8, with 20.45% of the entire cases of accidents that happened within the period under study, followed by 20.36%, etc. As for consequence, with the probability of 0.2052, the most likely number of fatalities will be between (62.4, 119.8), followed by the probability of 0.2048, the expected fatalities will be between (117.2, 234.6). Therefore, the fatality will be between (62.4, 119.8) with 20.52% of the entire fatality within the period under study, followed by (117.2, 234.6) fatality with 20.48%, etc. Hence, the estimated risk is 5.6327. This value is high and close to the unacceptable region; therefore, decision makers should select the measures to identify the Risk Control Options (RCOs) that keep risks as low as reasonably practicable (ALARP).

From the plot in Figure 1, we observed that the frequency and fatality in each year were within acceptable regions except in their respective months of November and December. This could be attributed to safety seminars mounted by NIMASA and the Inland Waterway Authority for risk reduction in maritime transportation. Also, from Table 5, we observed that the confidence interval for true risk value of maritime accidents at 10% level of significance or 90% confidence interval lies between [5.329, 5.931]; at 5% level of significance or 95% confidence interval, the risk value lies between [5.273, 5.987] and finally, at 1% level of significance or 99% confidence interval, the risk value lies between [5.160, 6.100].

5. Conclusion and Recommendation

In this paper, we investigated the occurrence of marine vessel/boat accidents and fatalities in the years 2019 to 2023. The purpose was to determine if the risk was within control or a tolerable limit. We collected secondary data on marine accidents from records of the Accident Investigation Bureau, NIMASA, NIWA, and the Marine Police. We applied Markov chain analysis to quantitatively determine the risk of maritime accidents using the risk matrix. From the analysis, we concluded that the risk value falls outside the acceptable range but within the tolerable limit. Therefore, decision makers should apply some measures and identify the Risk Control Options (RCOs) that keep risks as low as reasonably practicable (ALARP). Therefore, we recommend that urgent intervention is needed to restore confidence and reduce the risk of maritime accidents. There should be close monitoring on the strict adherence to the IMO convention on prevention of collision at Sea and other protocols on safety standards to drastically reduce risk in this industry.

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Appendix 1:

Table A. A 5×5 qualitative risk matrix with frequency and consequence categories.

Risk Index						
		CI				
		1	2	3	4	5
		Consequences in descriptive terms				
Fi	Frequency in descriptive terms	Insignificant	Minor	Moderate	Major	Catastrophic
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

Source: Adapted from [17]

Appendix 2:

Table 1. Monthly Fatalities (of person casualties or consequences) (2019-2023)

	Months											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2019	238	112	149	68	81	52	35	14	25	31	69	81
2020	253	183	126	65	64	37	32	5	16	19	83	72
2021	188	176	90	75	66	56	30	12	53	41	79	59
2022	182	169	85	69	98	68	21	12	26	63	48	64
2023	186	164	59	71	87	35	37	13	17	29	67	55

Source: Accident Investigation Bureau, Inland Waterway Authority, Nigeria Maritime Administration and Safety Agency, Marine Police Unit, NPA.

Appendix 3:

Table 2. Monthly Frequencies (of person casualties) (2019-2023)

	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
2019	203	99	129	51	69	41	30	14	12	36	17	32
2020	233	159	102	53	51	33	35	5	18	54	59	19
2021	136	135	68	55	58	44	29	11	7	63	93	74
2022	150	152	75	48	82	55	20	8	10	15	104	102
2023	135	153	49	57	62	30	37	9	11	12	98	110

Source: Accident Investigation Bureau, Inland Waterway Authority, Nigeria Maritime Administration and Safety Agency, Marine Police Unit, NPA

Appendix 4:

Table 3: Probabilistic risk matrix with state probabilities for frequency and consequences

		Consequence (C)				
		State				
		C1	C2	C3	C4	C5
		(5.0, 62.4)	(62.4, 119.8)	(119.8, 117.2)	(117.2, 234.6)	(234.6, 292)
		State probability (Ci)				
Frequency(F) State	State probability P(Fi)	P (C1) 0.2007	P (C2) 0.2052	P (C3) 0.1892	P (C4) 0.2048	P (C5) 0.2001
F1 (5.0, 50.6)	P(F1) 0.1988	2	3	4	5	6
F2 (50.6,96.2)	P(F2) 0.2045	3	4	5	6	7
F3 (96.2,141.8)	P(F3) 0.2036	4	5	6	7	8
F4 (141.8,187.4)	P(F4) 0.2030	5	6	7	8	9
F5 (187.4, 233)	P(F5) 0.1901	6	7	8	9	10

Source: Author's Elaboration

Appendix 5:

Table 4 Risk evaluation against risk criteria

<table>
<tr><th>Risk criteria</th><th>Pre-determined risk range</th><th>Estimated risk E(R)</th><th>Evaluation Result</th><th>Risk reduction measures</th></tr>
<tr><td>Acceptable</td><td>2 – 4</td><td rowspan="3">5.6327</td><td rowspan="3">0</td><td rowspan="3">Recommended with cost-benefit analysis</td></tr>
<tr><td>ALARP</td><td>4 – 6</td></tr>
<tr><td>Unacceptable</td><td>6 – 10</td></tr>
</table>