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Original Research Article

Markov Chain theoretic approach to modelling industrial safety: some results from Nigeria oil and gas industry

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ABSTRACT

Accident occurrence has remained a daunting challenge despite the huge investments made by the oil and gas industry. This study seeks to unravel the hidden details enwrapped in the safety data which enable the development of a model that would be effective in predicting future occurrence of industrial accidents. The purpose of this study is to spotlight the epidemiological impact of industrial accidents which claim lives, maim personnel and lower productivity through loss of man-hours. The major strategy adopted consists of the examination of a 10-year unified industrial accident recorded from 2007 to 2016 in the oil and gas sector of the Niger Delta of Nigeria. The Markov Chain model was applied to determine how workers habituate among different positions in the company before getting entrapped in any of the absorbing states. The industrial accident records are examined for embedded Markov properties, namely: stochastic regularity, absorbing behavior and the long-run distribution amongst the various states. The statistical computations were carried out with the aid of Matlab (R2017a) software. The historical Health Safety and Environment (HSE) statistical data were found to have an absorbing chain property. Thirteen (13) transition states were defined and named as; fatality, medical treatment, first aid cases, Lost time injury frequency, restricted work cases, first aid case, near miss, lost time injury, environmental incident, fire incident, unsafe acts, unsafe condition and number of attendance of clinic. The result from the study also revealed that staff makes between 17-18 habituations before being trapped in an absorbing state. Remarkably, 99% of workers in the organization had severe medical treatment cases (MTCs) as a result of work-related occupational illness and injury. The implication of the study is that the safety policy outlook of this company should be reorganized to reduce its lost workdays due to minor injury and illness.

Keywords: Absorbing state; HSE records; Industrial accident; Markov Chain; Valued diagraph

1. Introduction

The health, safety and environment within Oil and Gas sector is a growing concern as oil production increases to keep up with demand and technology advances, thereby creating new hazards. Recently, high-profile events of industrial accidents have brought safety and environment concerns to the forefront by drawing the attention of regulators, operating companies and the public to the hazards that loom across the sector. Health and safety issues affect the industrial segment to the extent where the potential risks cannot be ignored. Despite all the efforts in different industries to reduce the number of undesirable accidents, a lot of events always threaten industrial societies. These events often cause huge damages to the environment, facilities, and even in some cases, fatalities, and disabilities for people as well as huge economic loss, therefore it is important to predict these probable accidents and plan to prevent them. Hence, this study seeks to analyze hazards in one of the most important components of National Petroleum Development Company (NPDC), on OML111 Oredo/Oziengbe Fields. In this analysis, critical hazards were identified and classified based on HSE standards. Accidents are very expensive for companies. Human injuries and death, financial losses and security are challenges to NPDC. One of the major responsibilities of each management is increasing productivity through reducing costs. Environmental damages and workplace hazards can influence the organization, directly and indirectly. Therefore, prediction and prevention of harmful accidents are very important for any viable organization. This research plans to offer suggestions to improve existing preventive activities. To conform with the need to protect staff in the working environment, there is need to analyze the safety data obtained which will help to reduce the risk of accidents. This Implementation, will drive an effective evaluation of occupational safety and health management system effectively. It will ensure operations are in-compliance by driving a total culture focused on commitment to safety and process at all times.

Industrial accidents studies have been carried out using several models such as Fourier Fast Transform. See example [1]. Extreme work on the use of Markov model to study industrial accidents has been reported. Typical studies include: [2] who enumerated canon of some typical, sporadic, isolated cases of unending episodes of accidents which resulted from one or a combination of some factors in Nigeria between 1990-2010, and used Markov chain to craft means to stem the epidemiological development. [3] identified hazards, [4] assessed reliability indicators from automatically generated partial Markov chains and [5] used Markov theoretical approach to forecast the severity and exposure levels of workers in the Oil and Gas Sector. [6] reported the effects of severity and relevance while [7-9] opined the attribution analysis, collective beliefs and risk-taking in serious accidents. [10-12] wittingly elucidated on working safe activities, monitoring accidents using software and operating procedures for decommissioning safety assessment respectively. The commonality among these studies is that accident causality is attributed to either work errors or work conditions. Mathematical models are gaining ground in accident prevention research as applied by [13-15] in accident analysis, aviation and construction industry respectively. [16] applied Markov Chain in robot safety, identifying potential risk for industrial robot and the definition of hazard rate at different states for the robot system. Similarly, Zhang [17] applied Markov Chain in construction projects to analyze both short-term and long-term risks. Furthermore, Markov Chain model finds few applications in the oil and gas industry. According to [18] Markov models are powerful statistical tool, which has been successfully applied for component diagnostic, prognostics and maintenance optimization across a range of industries and offer indispensable extrapolations to industrial accident data. This will ultimately serve as a decision support tool to reduce accident occurrence and improve HSE performance. Markov model was used to predict the likelihood of the number of occurrences of accidents in the oil and gas sector in the delta flange of the nation Nigeria under a stochastic environment. Having reviewed extensively the literature relating to the use of Markov in industrial safety, it was discovered that there is little or no work carried out on the epidemiological impact of the industrial accidents which claim lives, maim personnel and lower productivity through loss of man-hours which this study seeks to address. The study will unravel the hidden details enwrapped in the industrial safety data that will help develop an effective model in predicting future occurrence of industrial accidents.

2. Material and Methods

The major strategy adopted consists of the examination of a 10-year unified industrial accident recorded from 2007 to 2016 in the oil and gas sector of the Niger Delta. The industrial accident records are examined for embedded Markov properties, namely, stochastic regularity, absorbing behavior and the long-run distribution amongst the various states. The basic assumptions are explicitly stated in the model developed with the applicable theorems and formulae leading to statistical computations and decision-making processes. The statistical computations and analysis were carried out and simplified with the aid of MATLAB R2017a software. Stability of the transition probability matrix (TPM) was achieved through repeated squaring (iterative process) of the fundamental matrix and its derivatives such as B- matrix (Long-run distribution of subject in various absorbing states) together with the variance and associated standard deviations. Deduction and inference were made from the results, which essentially guided discussion, suggestions and conclusion. A random sampling technique was also employed, as the chosen studied area could be a representative of other similar oil industries within the oil and gas industries. Primary source data, were obtained from HSE records for analysis (See Table 1). The Markov chain model was adopted while sensitivity analysis, in this case, was used to test for model adequacy.

Table 1. HSE Data from NPDC (2007-2016)

S/N	STATES	TOTAL
1	Fatality (FT)	3
2	Medical Treatment Cases (Severe) (MTC_S)	4715
3	Road Traffic Accident (RTA)	30
4	Lost Time Injury Frequency (LTIF)	5
5	Restricted Work Cases (RWC)	168
6	First Aid Case (FAC)	595
7	Near Miss (NM)	8325
8	Lost Time Injury (LTI)	62
9	Environmental Incident (EI)	192
10	Fire Incident (FI)	1
11	Unsafe Acts (UA)	18751
12	Unsafe Condition (UC)	13995
13	No of Attendance of Clinic	76428
	GRAND TOTAL	123,270

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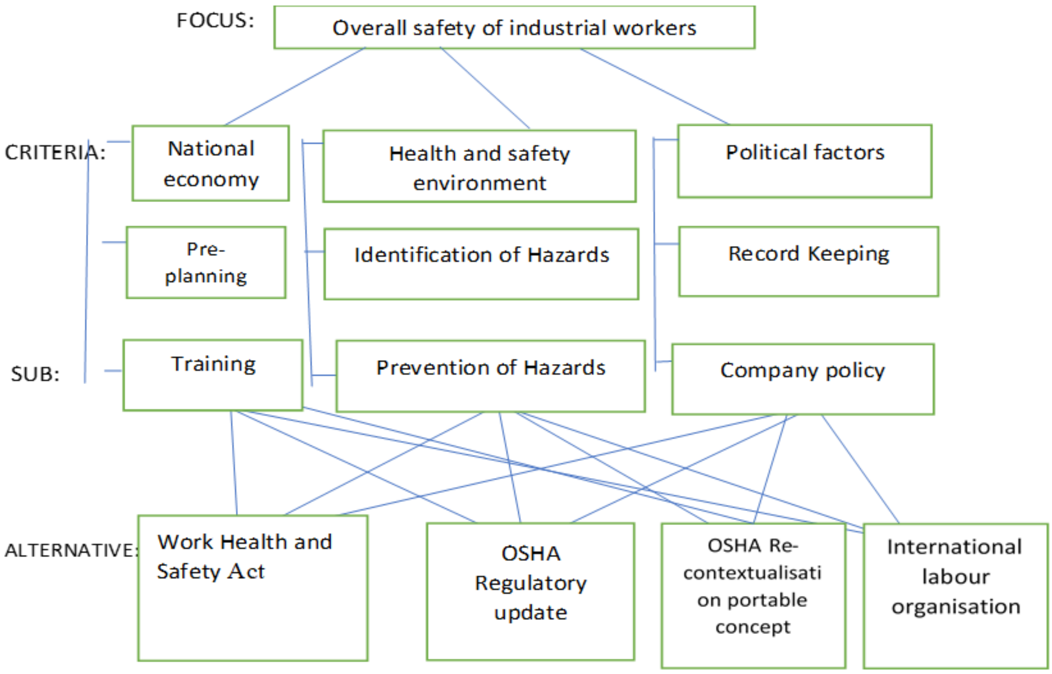

Fig. 1. Hierarchical Model developed for the safety framework selection

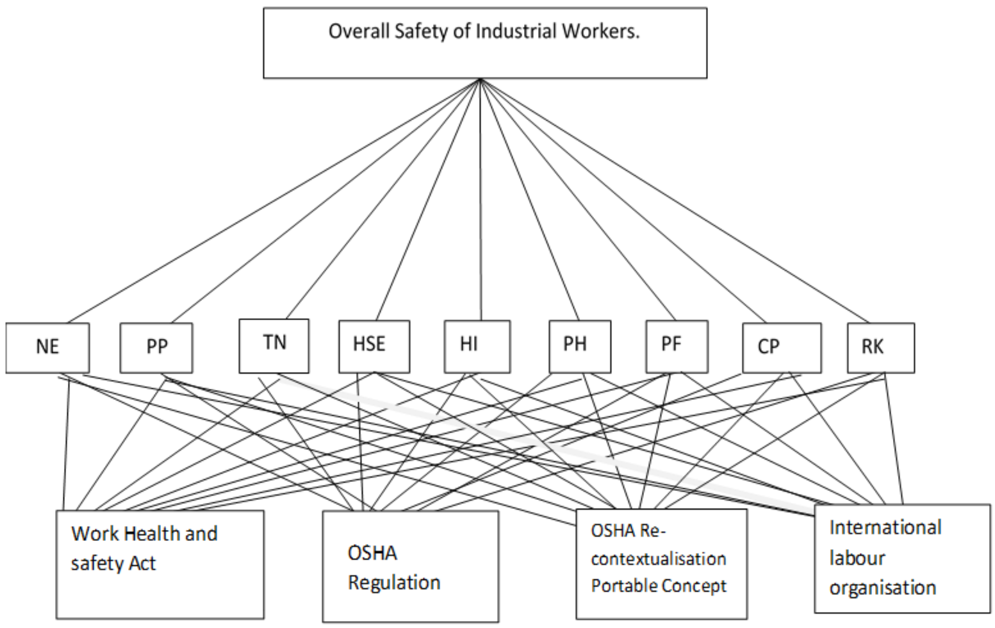

Fig. 2. Performance indicator Model developed for selection of alternatives

Figure 1 show the Hierarchical model developed for the safety framework selection while Figure 2 depict the performance indicator model developed for selection of alternatives.

2.1. Theoretical formulation

A. Markov Chain is an absorbing chain if:

(1) There is at least one absorbing state. A state in a Markov chain is said to be absorbing if the probability of an object's leaving the state is zero, the probability that it stays in the state is 1;

(2) It is possible to go from any state to at least one absorbing state in a finite number of steps.

Theorem

In this consideration, absorbing states are listed first and the standard form is expressed as:

$$T = \begin{array}{c c} & \begin{array}{cc} \text{Abs} & \text{Non abs} \end{array} \\ \begin{array}{c} \text{Abs} \\ \text{Nonabs} \end{array} & \left(\begin{array}{c|c} I & O \\ \hline R & Q \end{array}\right) \end{array} \quad (1)$$

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Fundamental Matrix (N) is developed arbitrarily and we shall state without proof that the transition matrix T,

$$T = \left(\begin{array}{c|c} I & O \\ \hline R & Q \end{array}\right) \qquad (2)$$

$$T^2 = \left(\begin{array}{c|c} I & O \\ \hline (I-Q)^{-1}R & Q^2 \end{array}\right)$$

$$T^n = \left(\begin{array}{l c|c} \text{Tn} = & I & O \\ \hline \text{T} & (I + Q + Q^2 + Q^3 + \cdots + Q^{-n-1})R & Q^2 \end{array}\right)$$

The long-run distribution of T, i.e.

$$T^n = T = \left(\begin{array}{c|c} I & O \\ \hline (I-Q)^{-1}R & Q \end{array}\right) \qquad (3)$$

Equation (3) is vital to the development of the fundamental matrix, $N = (I-Q)^{-1}$, the long-run distribution among the various absorbing states $B = (I-Q)^{-1}R = NR$, variance on the number of steps (2N – I) Ƭ-$Ƭ_{sq}$ and the transient probabilities.

(1) Probability of transition:

The probability of transitioning from i to j in exactly k steps is the j –entry of Q^k. Summing this for all K (0 to ∞) yields the fundamental matrix denoted by N, where

$$N = \sum_{k=0}^{\infty} QK = (I-Q)^{-1} \qquad (4)$$

$$N = (I-Q)^{-1} \qquad (5)$$

Equation 5 specifies the expected or average number of times the object starts in the i^{th} non-absorbing state before being absorbed.

(2) Absorbing probabilities:

Another property is the probability of being absorbed in the absorbing stated j when starting from transient state i which is the (ij)-entry of the matrix.

$$B = NR \qquad (6)$$

$$B = (I - Q)^{-1} R \qquad (7)$$

This specifies the long-run distribution of staff among the various absorbing states.

(3) Expected number of steps or movements:

The expected number of steps before being absorbed when starting in transient state i is the i^{th} entry of the vector.

$$Ƭ = N\,\xi \qquad (8)$$

Where $\xi = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$ is a column vector whose entries are all 1

(4) Variance on number of steps:

$$T_2 = (2N - I)\ \tau = \tau_{sq} \qquad (9)$$

This provides the associated variance on the number of steps before being absorbed.

2.2 Statistical Computation

With reference to the diagraph of the 13-state structure Fig.1, the absorbing state is heuristically determined as follows.

The computation of probabilities for absorbing and non-absorbing state use different approaches. For absorbing state, the heuristic method is adopted. In other words, the reasoning is used. Thus, by heuristic P_{xx}= 1, which is persistence. Others under absorbing state are similarly determined. On the other hand, the determination of probabilities under a non-absorbing state uses Bayesian method.

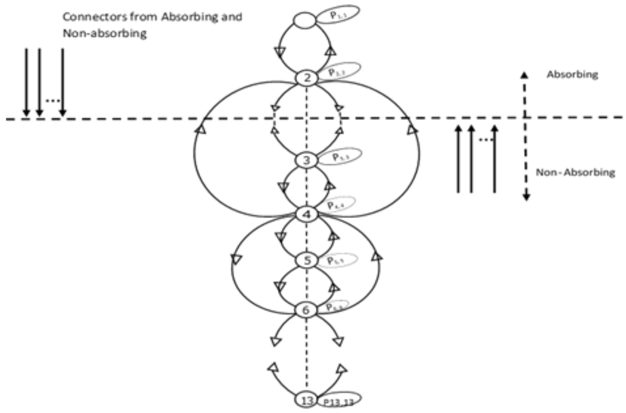

Fig. 3. Diagraph of the absorbing and non-absorbing state

(i) Absorbing state computation

There are two absorbing states which are fatality (FT) and medical treatment case severe (MTCs),

P_{11} =Pr (FT) =1: a staff that is wasted by fatality (death) remains dead (a case of persistence). By a similar heuristic approach, another probability of persistence is that: P_{22}=1

For instance, $P_{1,2}$ represents a subject transiting from fatality (FT) to medical treatment case severe (MTCs), it is a case which is (impossible); which means transiting from a state considered absorbing to another state which is an absorbing or non-absorbing state is implausible.

Then, by a similar heuristic argument; P_{12} = P_{21} = 1, for reasons of unlikelihood.

(ii) Non-absorbing state computation

There are eleven (11) non - absorbing states considered namely, RTA, LTIF, RWC, FAC, NM, LTI, EI, FI, UA, UC, and NAC. Eleven different combinations of the 13 states structure are arranged in Table 2 with the columns indicating different combinations.

Table 2. Eleven different combination of 13 states structure

NON ABSORBING STATE											
11 DiFFERENT COMBINATION OF THE 13 STATE STRUCTURE (NPDC) ARE ARRANGE AS FOLLOWS											
S/NO	V_SET 1	V_SET 2	V_SET 3	V_SET 4	V_SET 5	V_SET 6	V_SET 7	V_SET 8	V_SET 9	V_SET 10	V_SET 11
1	FT=0	FT=3	FT=3	FT=3	FT=3	FT=3	FT=3	FT=3	FT=3	FT=3	FT=3
2	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=4715	MTCs=0	MTCs=4715
3	RTA=30	RTA=30	RTA=30	RTA=0	RTA=30	RTA=30	RTA=30	RTA=30	RTA=30	RTA=30	RTA=30
4	LTIF=5	LTIF=5	LTIF=5	LTIF=5	LTIF=5	LTIF=5	LTIF=5	LTIF=0	LTIF=5	LTIF=5	LTIF=5
5	RWC=168	RWC=168	RWC=0	RWC=168	RWC=168	RWC=168	RWC=168	RWC=168	RWC=168	RWC=168	RWC=168
6	FAC=595	FAC=595	FAC=595	FAC=595	FAC=595	FAC=595	FAC=0	FAC=595	FAC=595	FAC=595	FAC=595
7	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325	NM=8325
8	LTI=62	LTI=62	LTI=62	LTI=62	LTI=0	LTI=62	LTI=62	LTI=62	LTI=62	LTI=62	LTI=62
9	EI=192	EI=192	EI=192	EI=192	EI=192	EI=192	EI=192	EI=192	EI=10	EI=192	EI=192
10	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1	FI=1
11	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751	UA=18751
12	UC=13995	UC=0	UC=13995	UC=13995	UC=13995	UC=0	UC=13995	UC=13995	UC=13995	UC=13995	UC=13995
13	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=76428	NAC=0
TOTAL	123267	104519	123102	123240	123208	109275	122675	123265	123078	118555	46842

(HSE data From NPDC Ozienbge flow station)

It is observed that for each set of 11 different combinations of the 13-state structure, a state is taken off (initialize = 0) to allow for mathematical manageability. This will enable us to determine the 11 sets of probability using Bayesian approach. Column 2, for instance the probability of subjects who commits Unsafe Act (UA) transiting to First Aid Case (FAC), the condition that subject has not had unsafe condition earlier denoted mathematically as **P**{(UA → (FAC)|UC = 0}, similarly, the same column the probability of subject who is exposed to a road traffic accident (RTA) transiting to the commission of the unsafe act (UA) on the account that the subject has not had unsafe condition (UC) earlier, is stated thus P{(RTA→UA|UC= 0)}. Similar determination of probabilities for each of the columns is done following a similar pattern using conditional probability. The Bayesian approach essentially uses a ratio of the subject in any state to the total population of the eleven different combinations in Table 2, to obtain the eleven (11) sets in the computation of the transition probabilities as shown in Table 3 for each probability sets.

Certain assumptions are being made in the use of Bayesian methodology to compute probabilities under non–absorbing regimes. The said assumptions are briefly outlined as follows:

Assumption 1: A staff that is considered by management to have been involved in road traffic cannot at the same time be available to commit fatality (FT= 0), $P_{3,\,1}$.

Assumption 2: A staff who had just suffered lost time injury frequency (LTIF), and is being treated, cannot at the same be exposed as to be prone to unsafe condition (UC =0), $P_{4,\,12}$= 0

Assumption 3: A well-trained staff that has had a restricted work case (RWC) in the industry cannot be available to be involved in another restricted work case at the same time (RWC) =0 (a case of impossibility) and persistence, $P_{5,\,5}$=0.

Assumption 4: A staff whose state is considered as a first aid case (FAC)cannot be said to be involved in a road traffic accident (RTA) =0, $P_{6,\,3}$=0.

Assumption 5: A competent staff who has not been involved in near-miss (NM) cannot be involved in lost time injury (LTI) = 0, $P_{7,\,8}$=0.

Assumption 6: A staff who has been exposed to lost time injury (LTI) cannot be exposed to unsafe conditions (UC) =0, $P_{8,\,12}$= 0.

Assumption 7: A staff who is suffering from an environmental incident (EI) cannot be available to commit a first aid case (FAC) =0, $P_{9,\,6}$

Assumption 8: It is impossible for a staff who has escaped fire incidence (FI) to be at a state considered as lost time injury (LTI) =0, $P_{10,4}$= 0.

Assumption 9: A well trained staff who is involved in an unsafe condition (UC) cannot transit into a state of severe medical treatment case (MTCs) = 0, $P_{12,\,2}$ = 0

Assumption 10: A case of persistence, 9you cannot be involved in medical treatment case and transits (MTCs) = 0, $P_{13,\,13}$ = 0.

Basically, with the eleven (11) non-absorbing state considered previously, an eleven different combinations of the 13-state structure were arranged in Table 4 with the columns indicating different combination.

Table 3. Details of the computation of transition probabilities using Bayesian methodology

Probabilities Set1	Probabilities Set2	Probabilities Set3	Probabilities Set4
P(FT)=(0/123267)=0.0000	P(FT)=(3/104519)=0.0000	P(FT)=(3/123102)=0.0000	P(FT)=(3/123240)=0.0000
P(MTCs)=(4715/123267)=0.0383	P(MTCs)=(4715/104519)=0.0451	P(MTCs)=(4715/123102)=0.0383	P(MTCs)=(4715/123240)=0.0383
P(RTA)=(30/123267)=0.0002	P(RTA)=(30/104519)=0.0003	P(RTA)=(30/123102)=0.0002	P(RTA)=(0/123240)=0.0000
P(LTIF)=(5/123267)=0.0000	P(LTIF)=(5/104519)=0.0000	P(LTIF)=(5/123102)=0.0000	P(LTIF)=(5/123240)=0.0000
P(RWC)=(168/123267)=0.0014	P(RWC)=(168/104519)=0.0016	P(RWC)=(0/123102)=0.0000	P(RWC)=(168/123240)=0.0014
P(FAC)=(595/123267)=0.0048	P(FAC)=(595/104519)=0.0057	P(FAC)=(595/123102)=0.0048	P(FAC)=(595/123240)=0.0048
P(NM)=(8325/123267)=0.0675	P(NM)=(8325/104519)=0.0797	P(NM)=(8325/123102)=0.0676	P(NM)=(8325/123240)=0.0676
P(LTI)=(62/123267)=0.0005	P(LTI)=(62/104519)=0.0006	P(LTI)=(62/123102)=0.0005	P(LTI)=(62/123240)=0.0005
P(EI)=(192/123267)=0.0016	P(EI)=(192/104519)=0.0018	P(EI)=(192/123102)=0.0016	P(EI)=(192/123240)=0.0016
P(FI)=(1/123267)=0.0000	P(FI)=(1/104519)=0.0000	P(FI)=(1/123102)=0.0000	P(FI)=(1/123240)=0.0000
P(US)=(18751/123267)=0.1521	P(US)=(0/104519)=0.0000	P(US)=(18751/123102)=0.1523	P(US)=(18751/123240)=0.1522
P(UC)=(13995/123267)=0.1135	P(UC)=(13995/104519)=0.1339	P(UC)=(13995/123102)=0.1137	P(UC)=(13995/123240)=0.1136
P(NAC)=(76428/123267)=0.6200	P(NAC)=(76428/104519)=0.7312	P(NAC)=(76428/123102)=0.6209	P(NAC)=(76428/123240)=0.6202
Probabilities Set5	**Probabilities Set6**	**Probabilities Set7**	**Probabilities Set8**
P(FT)=(3/123208)=0.0000	P(FT)=(3/109275)=0.0000	P(FT)=(3/122675)=0.0000	P(FT)=(3/123265)=0.0000
P(MTCs)=(4715/123208)=0.0383	P(MTCs)=(4715/109275)=0.0431	P(MTCs)=(4715/122675)=0.0384	P(MTCs)=(4715/123265)=0.0383
P(RTA)=(30/123208)=0.0002	P(RTA)=(30/109275)=0.0003	P(RTA)=(30/122675)=0.0002	P(RTA)=(30/123265)=0.0002
P(LTIF)=(5/123208)=0.0000	P(LTIF)=(5/109275)=0.0000	P(LTIF)=(5/122675)=0.0000	P(LTIF)=(0/123265)=0.0000
P(RWC)=(168/123208)=0.0014	P(RWC)=(168/109275)=0.0015	P(RWC)=(168/122675)=0.0014	P(RWC)=(168/123265)=0.0014
P(FAC)=(595/123208)=0.0048	P(FAC)=(595/109275)=0.0054	P(FAC)=(0/122675)=0.0000	P(FAC)=(595/123265)=0.0048
P(NM)=(8325/123208)=0.0676	P(NM)=(8325/109275)=0.0762	P(NM)=(8325/122675)=0.0679	P(NM)=(8325/123265)=0.0675
P(LTI)=(0/123208)=0.0000	P(LTI)=(62/109275)=0.0006	P(LTI)=(62/122675)=0.0005	P(LTI)=(62/123265)=0.0005
P(EI)=(192/123208)=0.0016	P(EI)=(192/109275)=0.0018	P(EI)=(192/122675)=0.0016	P(EI)=(192/123265)=0.0016
P(FI)=(1/123208)=0.0000	P(FI)=(1/109275)=0.0000	P(FI)=(1/122675)=0.0000	P(FI)=(1/123265)=0.0000
P(US)=(18751/123208)=0.1522	P(US)=(18751/109275)=0.1716	P(US)=(18751/122675)=0.1529	P(US)=(18751/123265)=0.1521
P(UC)=(13995/123208)=0.1136	P(UC)=(0/109275)=0.0000	P(UC)=(13995/122675)=0.1141	P(UC)=(13995/123265)=0.1135
P(NAC)=(76428/123208)=0.6203	P(NAC)=(76428/109275)=0.6994	P(NAC)=(76428/122675)=0.6230	P(NAC)=(76428/123265)=0.6200

Probabilities Set9	Probabilities Set10	Probabilities Set11
P(FT)=(3/123078)=0.0000	P(FT)=(3/118555)=0.0000	P(FT)=(3/46842)=0.0001
P(MTCs)=(4715/123078)=0.0383	P(MTCs)=(0/118555)=0.0000	P(MTCs)=(4715/46842)=0.1007
P(RTA)=(30/123078)=0.0002	P(RTA)=(30/118555)=0.0003	P(RTA)=(30/46842)=0.0006
P(LTIF)=(5/123078)=0.0000	P(LTIF)=(5/118555)=0.0000	P(LTIF)=(5/46842)=0.0001
P(RWC)=(168/123078)=0.0014	P(RWC)=(168/118555)=0.0014	P(RWC)=(168/46842)=0.0036
P(FAC)=(595/123078)=0.0048	P(FAC)=(595/118555)=0.0050	P(FAC)=(595/46842)=0.0127
P(NM)=(8325/123078)=0.0676	P(NM)=(8325/118555)=0.0702	P(NM)=(8325/46842)=0.1777
P(LTI)=(62/123078)=0.0005	P(LTI)=(62/118555)=0.0005	P(LTI)=(62/46842)=0.0013
P(EI)=(0/123078)=0.0000	P(EI)=(192/118555)=0.0016	P(EI)=(192/46842)=0.0041
P(FI)=(1/123078)=0.0000	P(FI)=(1/118555)=0.0000	P(FI)=(1/46842)=0.0000
P(US)=(18751/123078)=0.1524	P(US)=(18751/118555)=0.1582	P(US)=(18751/46842)=0.4003
P(UC)=(13995/123078)=0.1137	P(UC)=(13995/118555)=0.1180	P(UC)=(13995/46842)=0.2988
P(NAC)=(76428/123078)=0.6210	P(NAC)=(76428/118555)=0.6447	P(NAC)=(0/46842)=0.0000

Table 4. Mode of transition table

NPDC Oziengbe Flowstation Transition Matrix Probability Tableau

	FT	MTCs	RTA	LTIF	RWC	FAC	NM	LTI	EI	FI	UA	UC	NAC
FT	1	0	0	0	0	0	0	0	0	0	0	0	0
MTCs	0	1	0	0	0	0	0	0	0	0	0	0	0
RTA	0	0.0383	0.0002	0	0.0014	0.0048	0.0675	0.0005	0.0016	0	0.1521	0.1135	0.62
LTIF	0	0.0451	0.0003	0	0.0016	0.0057	0.0797	0.0006	0.0018	0	0	0.1339	0.7312
RWC	0	0.0383	0.0002	0	0	0.0048	0.0676	0.0005	0.0016	0	0.1523	0.1137	0.6209
FAC	0	0.0383	0	0	0.0014	0.0048	0.0676	0.0005	0.0016	0	0.1522	0.1136	0.6202
NM	0	0.0383	0.0002	0	0.0014	0.0048	0.0676	0	0.0016	0	0.1522	0.1136	0.6203
LTI	0	0.0431	0.0003	0	0.0015	0.0054	0.0762	0.0006	0.0018	0	0.1716	0	0.6994
EI	0	0.0384	0.0002	0	0.0014	0	0.0679	0.0005	0.0016	0	0.1529	0.1141	0.623
FI	0	0.0383	0.0002	0	0.0014	0.0048	0.0675	0.0005	0.0016	0	0.1521	0.1135	0.62
UA	0	0.0383	0.0002	0	0.0014	0.0048	0.0676	0.0005	0	0	0.1524	0.1137	0.621
UC	0	0	0.0003	0	0.0014	0.005	0.0702	0.0005	0.0016	0	0.1582	0.118	0.6447
NAC	0.0001	0.1007	0.0006	0.0001	0.0036	0.0127	0.1777	0.0013	0.0041	0	0.4003	0.2988	0

For example, the probability of a subject who had first aid case transiting to the commission of unsafe act, given that the subject has not had unsafe condition earlier, is denoted thus: P {(FACUA) $\longrightarrow$ |UC=0}. Similar representations apply for all cases under column 1 (V-set 1) of Table 2.

Similar determination of probabilities for each state in column 2 follows the same pattern. Notice in particular that this Bayesian approach uses conditional probability – on the condition of the event whose occurrence is equated to zero in every column.

3. Results and Discussion

The standard form of a Transition matrix;

$$T = \left[\begin{array}{c|c} I & O \\ \hline R & Q \end{array}\right]$$

The computed transition probabilities which are consistent with equation (2) are depicted in the accompanying matrix. The result set out in Table 4 as data matrix has been transposed into a matrix as depicted in equation (9) in conformance with the fundamental transition matrix in canonical form.

T= HTML translation failed

$$T = \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.0383 & 0.0002 & 0 & 0.0014 & 0.0048 & 0.0675 & 0.0005 & 0.0016 & 0 & 0.1521 & 0.1135 & 0.62 \\
0 & 0.0451 & 0.0003 & 0 & 0.0016 & 0.0057 & 0.0797 & 0.0006 & 0.0018 & 0 & 0 & 0.1339 & 0.7312 \\
0 & 0.0383 & 0.0002 & 0 & 0 & 0.0048 & 0.0676 & 0.0005 & 0.0016 & 0 & 0.1523 & 0.1137 & 0.6209 \\
0 & 0.0383 & 0 & 0 & 0.0014 & 0.0048 & 0.0676 & 0.0005 & 0.0016 & 0 & 0.1522 & 0.1136 & 0.6202 \\
0 & 0.0383 & 0.0002 & 0 & 0.0014 & 0.0048 & 0.0676 & 0 & 0.0016 & 0 & 0.1522 & 0.1136 & 0.6203 \\
0 & 0.0431 & 0.0003 & 0 & 0.0015 & 0.0054 & 0.0762 & 0.0006 & 0.0018 & 0 & 0.1716 & 0 & 0.6994 \\
0 & 0.0384 & 0.0002 & 0 & 0.0014 & 0 & 0.0679 & 0.0005 & 0.0016 & 0 & 0.1529 & 0.1141 & 0.623 \\
0 & 0.0383 & 0.0002 & 0 & 0.0014 & 0.0048 & 0.0675 & 0.0005 & 0.0016 & 0 & 0.1521 & 0.1135 & 0.62 \\
0 & 0.0383 & 0.0002 & 0 & 0.0014 & 0.0048 & 0.0676 & 0.0005 & 0 & 0 & 0.1524 & 0.1137 & 0.621 \\
0 & 0 & 0.0003 & 0 & 0.0014 & 0.005 & 0.0702 & 0.0005 & 0.0016 & 0 & 0.1582 & 0.118 & 0.6447 \\
0.0001 & 0.1007 & 0.0006 & 0.0001 & 0.0036 & 0.0127 & 0.1777 & 0.0013 & 0.0041 & 0 & 0.4003 & 0.2988 & 0
\end{pmatrix} \quad (10)$$

Computation of the fundamental matrix, N. (1)

$$N=(I-Q)^{-1} \quad (11)$$

where I is conformable to matrix Q through linear algebra by the definition of I. The null matrix is depicted as O on the upper right quadrant. R and Q are arbitrary matrices belonging to non-absorbing states; I and O are quadrants of absorbing states determined by heuristic method.

$$I-Q = \begin{pmatrix}
0.9998 & 0 & -0.0014 & -0.0048 & -0.0675 & -0.0005 & -0.0016 & 0 & -0.1521 & -0.1135 & -0.62 \\
-0.0003 & 1 & -0.0016 & -0.0057 & -0.0797 & -0.0006 & -0.0018 & 0 & 0 & -0.1339 & -0.7312 \\
-0.0002 & 0 & 1 & -0.0048 & -0.0676 & -0.0005 & -0.0016 & 0 & -0.1523 & -0.1137 & -0.6209 \\
0 & 0 & -0.0014 & 0.9952 & -0.0676 & -0.0005 & -0.0016 & 0 & -0.1522 & -0.1136 & -0.6202 \\
-0.0002 & 0 & -0.0014 & -0.0048 & 0.9324 & 0 & -0.0016 & 0 & -0.1522 & -0.1136 & -0.6203 \\
-0.0003 & 0 & -0.0015 & -0.0054 & -0.0762 & 0.9994 & -0.0018 & 0 & -0.1716 & 0 & -0.6994 \\
-0.0002 & 0 & -0.0014 & 0 & -0.0679 & -0.0005 & 0.9984 & 0 & -0.1529 & -0.1141 & -0.623 \\
-0.0002 & 0 & -0.0014 & -0.0048 & -0.0675 & -0.0005 & -0.0016 & 1 & -0.1521 & -0.1135 & -0.62 \\
-0.0002 & 0 & -0.0014 & -0.0048 & -0.0676 & -0.0005 & 0 & 0 & 0.8476 & -0.1137 & -0.621 \\
-0.0003 & 0 & -0.0014 & -0.005 & -0.0702 & -0.0005 & -0.0016 & 0 & -0.1582 & 0.882 & -0.6447 \\
-0.0006 & -0.0001 & -0.0036 & -0.0127 & -0.1777 & -0.0013 & -0.0041 & 0 & -0.4003 & -0.2988 & 1
\end{pmatrix} \quad (12)$$

$$N = \begin{pmatrix}
1.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5055 & 3.3611 & 6.9786 \\
0.0072 & 1.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0394 & 0.0002 & 4.326 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 1.039 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0069 & 0.0012 & 0.0403 & 1.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 3.0004 & 0.0134 & 0.0391 & 0.0002 & 4.5054 & 3.3611 & 6.9785 \\
0.0071 & 0.0012 & 0.0401 & 0.1421 & 1.9902 & 1.0138 & 0.0389 & 0.0002 & 4.4824 & 3.2158 & 6.9429 \\
0.0072 & 0.0012 & 0.0403 & 0.1379 & 2.0004 & 0.0139 & 1.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 1.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0375 & 0.0002 & 5.5054 & 3.361 & 6.9785 \\
0.0075 & 0.0012 & 0.0419 & 0.1485 & 2.0799 & 0.0144 & 0.0407 & 0.0002 & 4.6846 & 4.4947 & 7.256 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 7.3585
\end{pmatrix}$$

$$N = \begin{pmatrix}
1.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5055 & 3.3611 & 6.9786 \\
0.0072 & 1.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0394 & 0.0002 & 4.326 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 1.039 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0069 & 0.0012 & 0.0403 & 1.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 3.0004 & 0.0134 & 0.0391 & 0.0002 & 4.5054 & 3.3611 & 6.9785 \\
0.0071 & 0.0012 & 0.0401 & 0.1421 & 1.9902 & 1.0138 & 0.0389 & 0.0002 & 4.4824 & 3.2158 & 6.9429 \\
0.0072 & 0.0012 & 0.0403 & 0.1379 & 2.0004 & 0.0139 & 1.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 1.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0375 & 0.0002 & 5.5054 & 3.361 & 6.9785 \\
0.0075 & 0.0012 & 0.0419 & 0.1485 & 2.0799 & 0.0144 & 0.0407 & 0.0002 & 4.6846 & 4.4947 & 7.256 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 7.3585
\end{pmatrix}$$

The matrix N specifies the number of habituations (transition or step movement) that subjects undergo in the transient state before being finally absorbed. Thus, depending on the nature of work condition, the prevailing organization's safety culture, and personal organization, the resident time in the transient state could be short or linger much. For example, $N_{12,6}$ represents the habituation or number of movements (transition) among transient state – unsafe condition before sustaining an injury that will result in first aid treatment. This number is 0.1485, i.e., 14 times in 100 times of movements. This appears reasonably practical. Other entries in the N-matrix are similarly interpreted. The B – matrix s derived from the N – matrix.

$$B = NR = \begin{pmatrix}
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993 \\
0.0007 & 0.9993
\end{pmatrix}$$

The numbering of matrices N and B is consonant with that of Table 1 and as such cross-references among them are facilitated. The B-matrix that follows N is a derivative of N which denotes the long-run transition of subjects in the non-absorbing states before being absorbed. It shows the general trend. Evidently, the row entries in each are the same showing that it actually represents stabilized matrix (trend) and can be interpreted column-wise. State 1, fatality, taken column-wise, shows that 7 subjects in every 10,000 are likely going to have fatality (FT) if the trend of accidents remains. Similarly, column 2 refers, it's likely that in every 10,000 subjects, 9993 could sustain an injury that leads to medical treatment case (severe) (MTC_S) Plausible too:

The accompanying graphic representation in equation (11) maps states the long-run probabilities of occurrence as discernable from the B-matrix depicted.

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$$B = \begin{pmatrix} \text{Fatality} & \rightarrow 0.0007 \\ & \\ \text{Medical Treatment Case} & \rightarrow 0.9993 \end{pmatrix}$$

Variance on number of steps,

Expected number of steps

$$\tau = N\zeta = \begin{pmatrix}
1.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5055 & 3.3611 & 6.9786 \\
0.0072 & 1.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0394 & 0.0002 & 4.326 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 1.039 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0069 & 0.0012 & 0.0403 & 1.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 3.0004 & 0.0134 & 0.0391 & 0.0002 & 4.5054 & 3.3611 & 6.9785 \\
0.0071 & 0.0012 & 0.0401 & 0.1421 & 1.9902 & 1.0138 & 0.0389 & 0.0002 & 4.4824 & 3.2158 & 6.9429 \\
0.0072 & 0.0012 & 0.0403 & 0.1379 & 2.0004 & 0.0139 & 1.0391 & 0.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 1.0002 & 4.5054 & 3.361 & 6.9785 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0375 & 0.0002 & 5.5054 & 3.361 & 6.9785 \\
0.0075 & 0.0012 & 0.0419 & 0.1485 & 2.0799 & 0.0144 & 0.0407 & 0.0002 & 4.6846 & 4.4947 & 7.256 \\
0.0072 & 0.0012 & 0.0403 & 0.1428 & 2.0004 & 0.0139 & 0.0391 & 0.0002 & 4.5054 & 3.361 & 7.3585
\end{pmatrix} \times \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

$$\tau = \begin{pmatrix} 18.0904 \\ 17.9108 \\ 18.0886 \\ 18.0897 \\ 18.0896 \\ 17.8748 \\ 18.0851 \\ 18.0899 \\ 18.0884 \\ 18.7696 \\ 17.47 \end{pmatrix} \quad (13)$$

And we define variance on the expected number of steps subjects habituate before being absorbed as variance,

$$\tau_2 = (2N - I)\tau - \tau_{sq} \quad (14)$$

Equation (13) suggests that subjects habituate on the average about 18 times among non-absorbing states before being finally absorbed into any of the 2 absorbing states numbered in 1-2 in Table 1. The accompanying computations depicted in equations (15-17) demonstrate the determination of the expected number of habituations.

Variance $\tau_2 = (2N - I)\tau - \tau_{sq}$

$$2N - I = \begin{pmatrix}
1.0143 & 0.0024 & 0.0806 & 0.2856 & 4.0009 & 0.0278 & 0.0782 & 0.0005 & 9.011 & 6.7222 & 13.9572 \\
0.0143 & 1.0024 & 0.0806 & 0.2856 & 4.0008 & 0.0278 & 0.0788 & 0.0005 & 8.652 & 6.7221 & 13.9569 \\
0.0143 & 0.0024 & 1.0779 & 0.2856 & 4.0008 & 0.0278 & 0.0782 & 0.0005 & 9.0108 & 6.7221 & 13.9569 \\
0.0139 & 0.0024 & 0.0806 & 1.2856 & 4.0008 & 0.0278 & 0.0782 & 0.0005 & 9.0108 & 6.7221 & 13.9569 \\
0.0143 & 0.0024 & 0.0806 & 0.2856 & 5.0008 & 0.0268 & 0.0782 & 0.0005 & 9.0108 & 6.7222 & 13.9569 \\
0.0143 & 0.0024 & 0.0802 & 0.2841 & 3.9804 & 1.0276 & 0.0778 & 0.0005 & 8.9649 & 6.4317 & 13.8858 \\
0.0144 & 0.0024 & 0.0806 & 0.2759 & 4.0008 & 0.0278 & 1.0782 & 0.0005 & 9.0108 & 6.7221 & 13.9569 \\
0.0143 & 0.0023 & 0.0806 & 0.2856 & 4.0008 & 0.0278 & 0.0782 & 1.0005 & 9.0108 & 6.7221 & 13.9569 \\
0.0143 & 0.0024 & 0.0806 & 0.2856 & 4.0008 & 0.0278 & 0.0751 & 0.0005 & 10.0108 & 6.7221 & 13.9569 \\
0.0149 & 0.0025 & 0.0838 & 0.2969 & 4.1599 & 0.0289 & 0.0813 & 0.0005 & 9.3691 & 7.9894 & 14.512 \\
0.0143 & 0.0024 & 0.0806 & 0.2856 & 4.0008 & 0.0278 & 0.0782 & 0.0005 & 9.0108 & 6.7221 & 13.7169
\end{pmatrix}$$

$$\tau_{sq} = \begin{pmatrix} 327.2617 \\ 320.798 \\ 327.1973 \\ 327.2378 \\ 327.2324 \\ 319.51 \\ 327.0712 \\ 327.2454 \\ 327.1905 \\ 352.2993 \\ 305.1993 \end{pmatrix} \quad (15)$$

$$(2N - I)\tau - \tau_{sq} = \begin{pmatrix} 632.3117 \\ 625.637 \\ 632.2456 \\ 632.2872 \\ 632.2819 \\ 624.145 \\ 632.116 \\ 632.2951 \\ 632.2386 \\ 657.4033 \\ 610.01344 \end{pmatrix} - \begin{pmatrix} 327.262 \\ 320.798 \\ 327.197 \\ 327.238 \\ 327.232 \\ 319.51 \\ 327.071 \\ 327.245 \\ 327.191 \\ 352.299 \\ 305.199 \end{pmatrix}$$

$$\tau_2 = \begin{pmatrix} 305.05 \\ 304.839 \\ 305.0483 \\ 305.0494 \\ 305.0495 \\ 304.6351 \\ 305.0448 \\ 305.0496 \\ 305.0481 \\ 305.104 \\ 304.814 \end{pmatrix} \quad (16)$$

Standard deviation, $\sigma = \sqrt{\tau_2}$

$$\sigma = \begin{pmatrix} 17.4657 \\ 17.4596 \\ 17.4656 \\ 17.4657 \\ 17.4657 \\ 17.4538 \\ 17.4655 \\ 17.4657 \\ 17.4656 \\ 17.4672 \\ 17.4589 \end{pmatrix} \quad (17)$$

The estimated N and B could hover about those mean values by 17. The import is that the values determined could be 17 less or more from the main. This is expected because this analysis is in the realm of stochastic phenomena. Transient probability of visiting transient states. Calculation of variances and standard deviation

Variance on number of visits,

$N_2 = N(2N_{dg} - I) - N_{sq}$

$$N_{dg} = \begin{pmatrix}
1.0072 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1.0012 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1.039 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.1428 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 3.0004 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1.0138 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1.0391 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0002 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 5.5054 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4.4947 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7.3585
\end{pmatrix}$$

$$2N_{dg} = \begin{pmatrix}
2.0143 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2.0024 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 2.0779 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2.2856 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 6.0008 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2.0276 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 2.0782 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.0005 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11.0108 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.9894 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 14.7169
\end{pmatrix}$$

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$$2N_{dg} - I = \begin{pmatrix} 1.0143 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.0024 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.0779 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.2856 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 5.0008 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.0276 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.0782 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0005 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10.0108 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7.9894 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.7169 \end{pmatrix}$$

$$N\left(2N_{dg} - I\right) = \begin{pmatrix} 1.0216 & 0.0012 & 0.0435 & 0.1836 & 10.004 & 0.0143 & 0.0422 & 0.0002 & 45.1036 & 26.8532 & 95.7251 \\ 0.0073 & 1.0036 & 0.0435 & 0.1836 & 10.004 & 0.0143 & 0.0425 & 0.0002 & 43.3065 & 26.8525 & 95.7228 \\ 0.0073 & 0.0012 & 1.1199 & 0.1836 & 10.004 & 0.0143 & 0.0422 & 0.0002 & 45.1025 & 26.8525 & 95.7228 \\ 0.007 & 0.0012 & 0.0435 & 1.4691 & 10.004 & 0.0143 & 0.0422 & 0.0002 & 45.1025 & 26.8525 & 95.7228 \\ 0.0073 & 0.0012 & 0.0435 & 0.1836 & 15.004 & 0.0138 & 0.0422 & 0.0002 & 45.1026 & 26.8531 & 95.723 \\ 0.0072 & 0.0012 & 0.0432 & 0.1826 & 9.9525 & 1.0418 & 0.042 & 0.0002 & 44.8727 & 25.6926 & 95.2352 \\ 0.0073 & 0.0012 & 0.0435 & 0.1773 & 10.004 & 0.0143 & 1.1204 & 0.0002 & 45.1025 & 26.8525 & 95.7228 \\ 0.0073 & 0.0012 & 0.0435 & 0.1836 & 10.004 & 0.0143 & 0.0422 & 1.0007 & 45.1025 & 26.8525 & 95.7228 \\ 0.0073 & 0.0012 & 0.0435 & 0.1836 & 10.004 & 0.0143 & 0.0405 & 0.0002 & 55.1133 & 26.8525 & 95.7228 \\ 0.0076 & 0.0013 & 0.0452 & 0.1909 & 10.401 & 0.0148 & 0.0438 & 0.0002 & 46.8962 & 35.9099 & 99.5297 \\ 0.0073 & 0.0012 & 0.0435 & 0.1836 & 10.004 & 0.0143 & 0.0422 & 0.0002 & 45.1025 & 26.8525 & 100.935 \end{pmatrix}$$

$$N_{sq} = \begin{pmatrix} 1.0144 & 0 & 0.0016 & 0.0204 & 4.0017 & 0.0002 & 0.0015 & 0 & 20.2995 & 11.297 & 48.7012 \\ 0.0001 & 1.0024 & 0.0016 & 0.0204 & 4.0015 & 0.0002 & 0.0016 & 0 & 18.7142 & 11.2965 & 48.6988 \\ 0.0001 & 0 & 1.0794 & 0.0204 & 4.0015 & 0.0002 & 0.0015 & 0 & 20.2985 & 11.2965 & 48.6988 \\ 0 & 0 & 0.0016 & 1.3059 & 4.0015 & 0.0002 & 0.0015 & 0 & 20.2985 & 11.2965 & 48.6988 \\ 0.0001 & 0 & 0.0016 & 0.0204 & 9.0023 & 0.0002 & 0.0015 & 0 & 20.2986 & 11.297 & 48.6991 \\ 0.0001 & 0 & 0.0016 & 0.0202 & 3.9609 & 1.0278 & 0.0015 & 0 & 20.0923 & 10.3416 & 48.204 \\ 0.0001 & 0 & 0.0016 & 0.019 & 4.0015 & 0.0002 & 1.0797 & 0 & 20.2985 & 11.2965 & 48.6988 \\ 0.0001 & 0 & 0.0016 & 0.0204 & 4.0015 & 0.0002 & 0.0015 & 1.0005 & 20.2986 & 11.2965 & 48.6988 \\ 0.0001 & 0 & 0.0016 & 0.0204 & 4.0015 & 0.0002 & 0.0014 & 0 & 30.3093 & 11.2965 & 48.6988 \\ 0.0001 & 0 & 0.0018 & 0.022 & 4.3261 & 0.0002 & 0.0017 & 0 & 21.9452 & 20.2023 & 52.6494 \\ 0.0001 & 0 & 0.0016 & 0.0204 & 4.0015 & 0.0002 & 0.0015 & 0 & 20.2985 & 11.2965 & 54.1468 \end{pmatrix}$$

$$N_2 = \begin{pmatrix} 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.002 & 0.0141 & 0.0406 & 0.0002 & 24.804 & 15.5562 & 47.0239 \\ 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0141 & 0.0409 & 0.0002 & 24.5923 & 15.5561 & 47.0239 \\ 0.0072 & 0.0012 & 0.0405 & 0.1632 & 6.0019 & 0.0141 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.007 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0141 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0136 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.0072 & 0.0012 & 0.0416 & 0.1624 & 5.9916 & 0.014 & 0.0404 & 0.0002 & 24.7805 & 15.351 & 47.0312 \\ 0.0072 & 0.0012 & 0.0418 & 0.1583 & 6.0019 & 0.0141 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0141 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0141 & 0.0391 & 0.0002 & 24.8039 & 15.5561 & 47.0239 \\ 0.0075 & 0.0013 & 0.0434 & 0.1688 & 6.0752 & 0.0146 & 0.0422 & 0.0002 & 24.951 & 15.7076 & 46.8803 \\ 0.0072 & 0.0012 & 0.0418 & 0.1632 & 6.0019 & 0.0141 & 0.0406 & 0.0002 & 24.8039 & 15.5561 & 46.7883 \end{pmatrix}$$

4. Conclusion

This study has been able to successfully unravel the hidden details enwrapped in the 10-year (2007- 2016) unified industrial accident data from the oil and gas sector of the Niger Delta area of Nigeria. A model that was effective in predicting future occurrence of industrial accidents was also developed. The outcome of this study revealed that safety policy outlook of NPDC falls within the moderately acceptable range because the statistical analysis shows near-zero fatality. Also, 99% of the subjects will suffer treatment MTC_S if the trend of accident is sustained. Conclusively, to modify the safety policy of the organization to meet global best practices and reduce its lost workdays as a result of minor injury and illness, it is suggested that the organization's safety policy and practices should be reorganized. This will aid safety administrators to be positioned permanently at various units and department for proper job monitoring in order to inverse industrial accident occurrence. Besides, this research has taken a holistic view of the effects of accident occurrence in the oil and gas industry and predicted the number of habituations the subjects undergo in the transient state before being finally absorbed as 18 times in 100 movements which is reasonably practical.

Authorship contribution statement for Contributor Roles Taxonomy

Dr. Cordelia Ochuole Omoyi and Dr. Samuel Ayodeji Omotehinse have designed the study and collected the data.
Dr. Cordelia Ochuole Omoyi write the article, and critically reviewed by Dr. Samuel Ayodeji Omotehinse.
Dr. Cordelia Ochuole Omoyi coordinate the research activity, planning and execution of the experiment with the help of Dr. Samuel Ayodeji Omotehinse.

Conflict of interest

There is no conflict of interest in connection with this paper, and the material described here is not under publication or consideration for publication elsewhere.

Nomenclature, Symbols, Notations, And Variables

Ab	Absorbing State
DPR	Department of Petroleum Resources
EI	Environmental Incident
FAC	First Aid Case
FI	Fire Incident
FT	Fatality
HSE	Health Safety Environment
LTI	Lost Time Injury
LTIF	Lost Time Injury Frequency
MatLab	Matrix Laboratory
MTC_S	Medical Treatment Cases (Severe)
NAC	No of Attendance of Clinic
NIOSH	National Institute for Occupational Safety and Health
NM	Near Miss
NPDC	Nigeria Petroleum Development Company
OSHA	Occupational Safety and Health Administration
RTA	Road Traffic Accident
RWC	Restricted Work Cases
TPM	Transition Probability Matrix
UA	Unsafe Acts
UC	Unsafe Condition
WHO	World Health Organization
$(n\uparrow)$	Transitions increase
T	Transition Matrix
T^n	Power of Transition Matrix
$\bar{T}$	Stabilized Transition Matrix
I	Identity Matrix
Q	Non-absorbing arbitrary matrix lower left quadrant
Σ	Summation
N	Fundamental matrix
I	Absorbing arbitrary matrix upper left quadrant
O	Absorbing arbitrary matrix upper right quadrant
R	Absorbing arbitrary matrix upper right quadrant
B	Long run transition Matrix
δ	Standard deviation
sq	Square
dg	Diagonal
ξ	Column vector
Ꞡ	Expected number of steps
Pxx	Elements on row i column j

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