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Application of Markov Chain Models in Evaluating Workers Safety Performance in Power Distribution Company

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Abstract: One of the riskiest industries in Nigeria is the power distribution sector. In addition, there has been less focus on worker, equipment, and work environment safety, thus this research work. A six-year treatment record and a six-year safety kit cost obtained from Benin Distribution Electricity Company was used in this study. Markov chain model was used to evaluate incident records spanning seven (7) years that included medical care, fire incidents, near misses, risky conduct, and fatalities. The Markov chain model analytical tool revealed that before receiving actual medical attention or suffering a fatality, employees had, on average, engaged in seven (7) near-misses, risky acts, unsafe conditions, or fire occurrences. Workers who are involved in near-misses, unsafe acts, unsafe conditions, or fire incidents have a 0.04 probability of dying while working for the company; on the other hand, they have a 0.96 probability of being involved in an incident that requires medical attention.

Keywords: *Power, Markov Chain Models, Safety, Workers, Unsafe Conditions*

INTRODUCTION

Modern society is characterized by a great demand for electrical energy. Most of this energy is needed for lighting, industrial electrical machinery, home appliances, and electric traction (Orhorhoro *et al.*, 2022). Because electrical power is now so essential to daily life, it is best to protect the system from damage in the event of a malfunction and to ensure optimum supply continuity. Because they provide practically all societal sectors with essential services, electrical power networks are considered the center of gravity and strength of economies worldwide, whether in established and emerging nations. It has become increasingly complex and complicated due to technological advancement and population explosion. Unfortunately, this advancement has created vulnerabilities through equipment failures, human errors, weather and other natural causes, physical and cyber-attack. This disturbance if not properly managed can turn local disturbances into a large-scale failure; which may have a disastrous impact on the whole society. As shown in Fig. 1 is electrical accident cases resulting from human failure error in distributing electricity to local populace within Benin Electricity Distribution Company (BEDC).

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Besides, the human, social and economic costs of occupational accidents, injuries and diseases and major industrial disasters have long been cause for concern at all levels from the individual workplace to the national and international (Laurence, 2005; Shrikant, 2018; Geneva, 2018; Victoria, 2019). Measures and policies designed to prevent, control, reduce or eradicate occupational hazards and risks have been established and adopted continuously over the years to keep pace with technological and economic changes (Benjamin, 2008; Blake, 2012; Abdolrasoul *et al.,* 2013). Sophisticated statistical methods are required to analyze such record and bring out meaningful interpretation that will provide decision support for the management of future accident occurrences (Boud *et al.,* 2019; Gülden and Neşen, 2013). This research provides such techniques that can analyze accident records and perceive similarity in dissimilarity and also ascertain if functional relationship exists among the variable recorded. Hardly can qualitative or mere mathematical model achieve this objective.

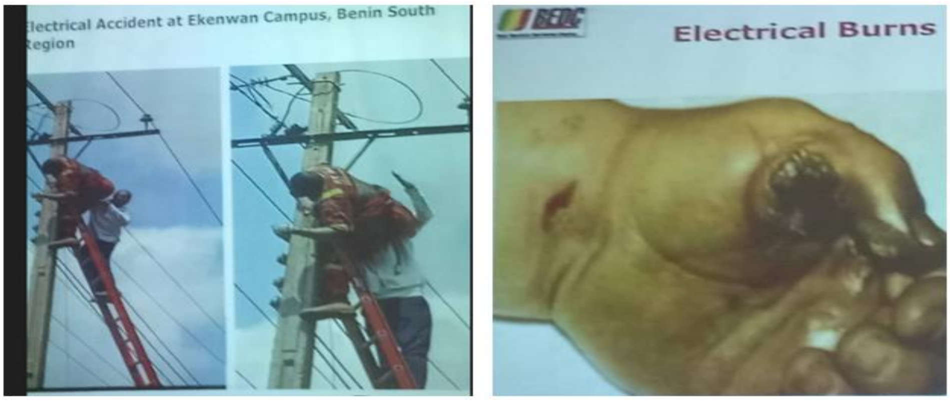

Fig. 1 Electrical accident cases resulting from human failure error (BEDC, Okada District)

Besides, employees expect safe working environment as their fundamental human right. Nevertheless, there are still bad working environments specifically in developing countries. Employees all over the world, face dual occupational hazards, the traditional as well as novel in the complex work settings due to rapid industrialization, technological advancement and globalization, over the last few years. This is resulting into injuries, accidents, illnesses, disabilities and death (Sneddon *et al.,* 2006). Occupational health issues affect individuals, families and communities, as well as the citizens of the world; hence there is a need for occupational health and safety (NIOSH, 1985). Occupational health and safety (OHS), is concerned with the safety, health, and welfare of the workers, family members, employers, customers, and other stakeholders. It studies all factors influencing the health of workers at their workplaces as well as at home, thereby anticipating, recognizing, costing and control of hazards. The standard of occupational health and safety available at any work place is the main determinant of employees' health. The main focus of this research work was to survey a gamut of variable that affect the operation of Okada power station, under Benin Electricity Distribution Company and the inter correlation among the variable or scale items. Additionally, in order to forecast and assess the distribution company's accident rate and create a comprehensive plan that would maximize the safety of Nigerian industrial workers, The strategy calls for using Markov chain analysis to examine the safety performance of distribution companies within Okada Station. In order to determine the degree of safety compliance and guarantee the health and safety of the workforce, Markov chain statistical tools were used to study industrial accidents that occurred at work. Additionally, purposive sampling was used to analyze the safety characteristics of the Nigerian Okada power sector in order to identify and uncover safety flaws and suggest management intervention measures.

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MATERIALS AND METHODS

2.1 Population
The study covered all departments of Okada power station.

2.2 Sample and Sampling Approach
The safety kits and accident report for six (6) years ranging from 2014 to 2019 and employee safety report for seven (7) years ranging from 2014 to 2020 were obtained. The accident report was group into three departments for yearly bases and the safety kits purchased on yearly bases for all departments.

2.3 Method of Data Collection
The success of any research work mainly depends on consistency and importance of the data. In most developing countries like Nigeria, where data are poorly kept, inaccurate collection of data can negatively affect the outcome of the research work and eventually lead to invalid assumptions and misleading conclusions. It is therefore overbearing that data for analysis must be based on evidence, improved scope and method of data collection, as well as consistency in compilation of macroeconomics aggregate. Seven-year (2014 – 2020) data was obtained for safety incidents from Okada power station.

2.4 Method of Data Analysis
The statistical methods employed in the analysis of data was Markov chain modeling and Excel and MATLAB. The mathematical computations required for the research were obtained using Microsoft Excel, and Markov chain modeling were solved using MATLAB. The company's employee safety report was modeled using Markov chain modeling.

2.5 The Application of the Markov Chain Technique
The Markov Chain Modeling was used to model Employee Safety Report, and the procedure adopted consists of:

i. Evaluation of transition probability matrix, T

$$T = \begin{bmatrix} P_{11} & P_{12} & P_{13} \cdots P_{1K} \\ P_{21} & P_{22} & P_{23} \cdots P_{2K} \\ \cdots & \cdots & \cdots\ \cdots\ \cdots \\ P_{K1} & P_{K2} & P_{K3} \cdots P_{KK} \end{bmatrix} \tag{1}$$

$$P_{IJ} = \left\{ \xi_{t_n} = j \,\middle|\, \xi_{t_{n-1}} = i \right\} \tag{2}$$

ii. One-step transition probability of transition from i at t_{n-1} to state j at t_n. Assumed that T is stationary.

$$\Sigma P_{ij} = 1 \ \forall\ i$$

$$\sum P_{ij} \geq 0, \quad \forall\ i \ and\ j$$

iii. Partitioned matrix, i.e. the fundamental matrix was established

iv. Markov theories was used for the interpretation.

2.6 Theoretical Brief

Markov chain can model circumstances if it can be observed as the repeated movement of one or more objects between different classification and states. Let the states been characterized by $X_1, X_2, X_3, \ldots\ldots\ldots X_n$. For each pair (X_i, X_j), let a fixed proportion P_{ij} of object situated at X_i move to X_J during each movement. Thus, the scenario can be signified in a transition probability Matrix as;

$$T = \begin{matrix} & X_1 & X_2 & X_3 & \cdots & X_K \\ X_1 & P_{11} & P_{12} & P_{13} & \cdots & P_{1K} \\ X_2 & P_{21} & P_{22} & P_{23} & \cdots & P_{2K} \\ X_3 & P_{31} & P_{32} & P_{33} & \cdots & P_{3K} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ X_K & P_{K1} & P_{K2} & P_{K3} & \cdots & P_{KK} \end{matrix} \quad (3)$$

$T_{ij} = P_{ij}$ = Probability that an object in state i move, to state j

2.7 Absorbing Markov Chain

If a Markov chain has at least one absorbing state and can likely transition from any given state to an absorbing state (but not all at once), then it is said to be absorbing. is described as having only absorbing and transitory (non-absorbing) states in its state space.

2.8 Canonical Forms

Transition matrices can be used to develop the theory of Absorbing Markov chain in canonical form. In doing so, the row and columns (absorbing states and transient states) are rearranged so that all the absorbing states are treated with first. Their transition probabilities appear together in the top left-hand portion of T, with unities (1s) in the leading diagonal. Then the row and columns for the transition matrix will be;

$$T = \begin{matrix} \\ s\} \\ t\} \end{matrix} \begin{bmatrix} \underbrace{s} & \underbrace{t} \\ I & O \\ R & Q \end{bmatrix} \quad (4)$$

Where: I is an $X \times X$ unit matrix

O is a $s \times t$ matrix of zero elements

R is a $t \times s$ matrix concerned with transit to absorbing states,

Q is a $t \times t$ matrix concerned with transitions from transient states to transient states.

2.9 Matrix and Vectors

Fundamental matrix:

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

$$N_2 = N(2N_{dg} - I) - N_{sq} \quad (5)$$

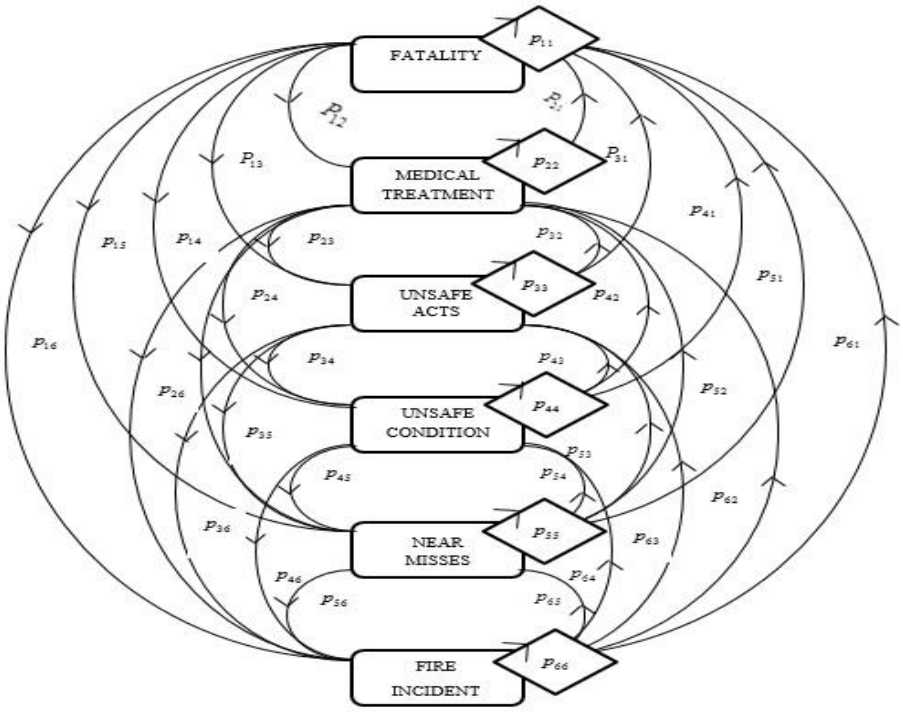

Fig. 2 Digraph of Transition Probability Matrix

RESULTS AND DISCUSSION

Markov chain transiting among states space, X = {X_1, X_2, -----X_6}. From Fig.2, we discover that it is a non-cyclic chain (regular). State 1, 2 are absorbing states while states 3, 4, 5, 6 are non-absorbing states showing that object accustom in step-wise fashion among these states before being trapped in states 1, or 2. Three sets of data emerged from the research that were deemed highly significant. The Markov chain's average and variance among transitory states.

Accordingly:

Mean, $N = (I - Q)^{-1}$

The fundamental matrix, N, is:

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

$$N = A^{-1} = inv(A)$$

Table-1 shows the number of workers in each non-absorbing state as well as the standard deviation of these estimations.

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Table-1 The Value of N

STATES	TO / FROM	NEAR MISSES X_3	UNSAFE ACTS X_4	UNSAFE CONDITION X_5	FIRE INCIDENT X_6	SUM OF ROW
NON-ABSORBING STATES	NEAR MISSES X_3	3.9476	0.7163	1.2917	0.8003	6.756003
	UNSAFE ACTS X_4	3.0666	1.8147	1.1240	1.1881	7.193376
	UNSAFE CONDITION X_5	3.0666	0.6393	2.3656	1.1881	7.259627
	FIRE INCIDENT X_6	3.0835	0.7891	1.3431	2.1947	7.410451

Significant findings include the interpretation of this Table-1 matrix and the value of N. Also, in Table-2, the Value of N_2 provides interesting information about the variance of the estimate of $N = (I - Q)^{-1}$.

Table-2 The value of N_2

STATES	TO / FROM	NEAR MISSES X_3	UNSAFE ACTS X_4	UNSAFE CONDITION X_5	FIRE INCIDENT X_6
NON-ABSORBING STATES	NEAR MISSES X_3	11.6363	1.3703	3.1513	2.0721
	UNSAFE ACTS X_4	11.7411	1.4783	2.9306	2.6154
	UNSAFE CONDITION X_5	11.7411	1.2722	3.2307	2.6154
	FIRE INCIDENT X_6	11.7537	1.4521	3.2076	2.6220

Table-3 The value of σ

STATES	TO FROM	NEAR MISSES X_3	UNSAFE ACTS X_4	UNSAFE CONDITION X_5	FIRE INCIDENT X_6
NON-ABSORBING STATES	NEAR MISSES X_3	3.4112	1.1706	1.7752	1.4395
	UNSAFE ACTS X_4	3.4265	1.2159	1.7119	1.6172
	UNSAFE CONDITION X_5	3.4265	1.1279	1.7974	1.6172
	FIRE INCIDENT X_6	3.4283	1.2050	1.7910	1.6193

The total number of employees that undertook among all the non-absorbing states before being trapped in any of the absorbing state is shown in Table-4 and Table-5. The associated standard variations are shown in Table-6.

Table-4 The value of τ

NEAR MISSES X_3	6.7560
UNSAFE ACTS X_4	7.1934
UNSAFE CONDITION X_5	7.2596
FIRE INCIDENT X_6	7.4105

Table-5 The value of τ_2

NEAR MISSES X_3	4.4721
UNSAFE ACTS X_4	4.5943
UNSAFE CONDITION X_5	4.6117
FIRE INCIDENT X_6	4.6381

Table-6 The Value of σ_τ (Standard Deviation to τ)

NEAR MISSES X3	19.9994
UNSAFE ACTS X_4	21.1075
UNSAFE CONDITION X_5	21.2676
FIRE INCIDENT X_6	21.5116

B = NR = N d_0 as shown in Table-7. The Value of B provides the long-run distribution of employee on the field. Using it, we estimate the probability that employee starting in any of the non-absorbing states can end up in any of the absorbing states. The initial state distribution (d_0) is R is shown in Table-8. τ Matrix represents the movement of employee which is shown in Table-4. The associated variance and standard variation is on Table-5 and Table-6 respectively. It is evident from the entries of τ that employee on the average change position 7 times at each of the transient states before being trapped in any of the absorbing states. Besides, the B Matrix represents the Transition of Employee which is given in Table-7. Recall that the initial state distribution is R Table-8. The initial distribution, when multiple by the fundamental matrix, N given Matrix B which is a probability distribution. The row sums equal one. N is the basic manipulation tool for forecasting expected changes in the initial organization of the safety policies. Employees in the company that is involve in an incident of Near Misses, Unsafe Acts, Unsafe condition and Fire incident has a probability of 0.04 chance of leaving the company through fatality while Employees in the company that is involve in an incident of Near Misses, Unsafe Acts, Unsafe condition and Fire incident as a probability of 0.96 chance to be involved in an incident that will lead to medical treatment.

Table-8 The value of R

STATES	TO FROM	FATALITY X_1	MEDICAL TREATMENT X_2
NON-ABSORBING STATES	NEAR MISSES X_3	0.0074	0.1661
	UNSAFE ACTS X_4	0.0066	0.1160
	UNSAFE CONDITION X_5	0.0063	0.1099
	FIRE INCIDENT X_6	0	0.0968

Table-7 The value B

STATES	TO FROM	FATALITY X_1	MEDICAL TREATMENT X_2	SUM OF ROW
NON-ABSORBING STATES	NEAR MISSES X_3	0.0420	0.9580	1
	UNSAFE ACTS X_4	0.0417	0.9583	1
	UNSAFE CONDITION X_5	0.0417	0.9583	1
	FIRE INCIDENT X_6	0.0364	0.9636	1

B = NR = Nd_o.

The Markov chain model applied in this study has served as both analytical tool and decision support aid that has enabled us to gain insightful perspective of the trend's industrial accidents. It is obvious from the analysis that on the average, employees had committed seven near-misses, unsafe acts, unsafe condition or fire incident before actually undergoing real accident or fatality. Employees in the company that is involve in an incident of Near Misses, Unsafe Acts, Unsafe condition and Fire incident as a probability of 0.04 chance of leaving the company through fatality while Employees in the company that is involve in an incident of Near Misses, Unsafe Acts, Unsafe condition and Fire incident as a probability of 0.96 chance to be involved in an incident that will lead to medical treatment. The implication is that safety programme in the industry is not adequate and effective. One cannot agree more with this result because in Nigeria some companies make empty show of safety programmes. They involve on intricate display of safety publicity that exists only on posters but not in practice.

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Moreso, good safety policies should highlight that performance behaviour is a conscious process, which must be focused towards a desired goal. The awareness should then be used positively to promote safe behaviour in the work place because one is convinced and not forced. Other factors that touch on the design of facilities and management supervision and commitment to safety values enactments could account for the high rate of personnel wastage through medical treatment and fatalities. It would appear that administration is not so rigorous in carrying out hazard operability studies of process designs before adopting them. The law and regulations are there, well stated; yet employee flaunt them without sanction. Despite the huge sum of human material resources, the organization is investing in safety, yet personnel non-compliance is still on the increase. Most Personal Protective Equipment (PPE's) provided and issued to worker are not being put into proper use or not used at all. Also, it was discovered that safety compliance monitoring and intervention were left in the hands of the safety team or safety department alone. These should not be so for effective control-results

CONCLUSION

The study revealed that BEDC accident victims, unlike the road traffic accident victims, familiarize several times before entering the absorbing states. Unfortunately, they learn not to respond to warning signs. Not all they profess to do is done in practice. However, safety tips will protect workers on the job. Regularly highlighting the significance of workplace safety is a good idea. Also, employees shift positions seven (7) times on average during each of the transient states before becoming trapped in any of the absorbing states (fatality or medical treatment). Furthermore, employees who work for a company that experiences near-misses, unsafe acts, unsafe conditions, or fire incidents have a 0.04 chance of leaving the company by way of death, and a 0.96 chance of being involved in an incident that will result in medical treatment.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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