International Journal of Mechanical Engineering and Applications
2016; 4(3): 103-108
http://www.sciencepublishinggroup.com/j/ijmea
doi: 10.11648/j.ijmea.20160403.11
ISSN: 2330-023X (Print); ISSN: 2330-0248 (Online)

Application of Markov Theoretical Model in Predicting Risk Severity and Exposure Levels of Workers in the Oil and Gas Sector

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To cite this article:

Okwu Modestus Okechukwu, Thaddeus Nwaoha, Ombor Garrick. Application of Markov Theoretical Model in Predicting Risk Severity and Exposure Levels of Workers in the Oil and Gas Sector. *International Journal of Mechanical Engineering and Applications.* Vol. 4, No. 3, 2016, pp. 103-108. doi: 10.11648/j.ijmea.20160403.11

Received: May 9, 2016; **Accepted**: May 21, 2016; **Published**: June 6, 2016

Abstract: In this research, Markov theoretical approach (MTA) was used to forecast the severity of risk workers were exposed to in the oil and gas industry and to determine the average period of time it would take workers to get exposed to menace of less severity and the possibility of transiting to a state where risk is high. The perils were classified into four states which include: catastrophic, critical, marginal and negligible. A solution procedure for addressing industrial hazards was developed from Markov. Fifty (50) workers in Warri Refining and Petrochemical Company (WRPC) were randomly selected for the purpose of questionnaire administration. Analysis of the data was carried out using QM software. The results showed that 56.66% of workers in marginal state would likely move to catastrophic state, while 43.34% of workers in marginal state would probably transit to critical state. Also 41.32% of workers in negligible state would move to a catastrophic state, while 58.68% of workers in negligible state would likely move to critical state within an average period of 2 to 3 years. It is therefore recommended that provision of personal protective equipment and appropriate healthcare facilities be made, risk assessment of all workers be continuously carried out; workers must be properly trained on regular basis and the enforcement and strengthening of existing legislation effectively carried out to dispel these hazards.

Keywords: Markov Chain, Catastrophic State, Critical State, Negligible State, Marginal State

1. Introduction

The human and economic costs of accidents, injuries and major industrial disasters have long been a cause for concern at workplace. Job hazard analysis (JHA) is a technique that focuses on job tasks as a way to identify hazards before they occur. It focuses on the relationship between the worker, the task, the tools, and the environment [1]. JHA is employed in the oil and gas sector, manufactory industries, construction companies, bottling companies etc. The importance of JHA is often overlooked and people tend to associate hazard analysis with multi-national companies and huge factories in the urban areas while less attention is given to JHA in smaller organizations. These view hindered the development of job hazard analysis in developing countries. In most industrial settings, workers are being subjected to array of hazards on a daily basis. There are different categories of workplace hazards such as chemical hazards, mechanical hazards, electrical hazards, industrial hazards etc. [2] [3] discussed the huge oil spill and explosion in 2010, at Gulf of Mexico as the largest incidental marine oil spill in the history of the petroleum industry, where eleven people were killed and several others injured. [4] in his research on workplace hazard came to a conclusion that there are over two million deaths that are attributed to workplace hazards and injuries annually, while 4% of gross domestic product (GDP) is lost due to these hazards and injuries. JHA on the safety of workers is concerned with the control of workplace risk, protection and promotion of working populations and the humanization of work [4]. Also JHA has its positive effect on productivity, quality work and increase in workers morale and work satisfaction [4]. Measures and strategies designed to prevent, control, reduce or eliminate industrial hazards and risks have been developed and applied continuously over the years. Yet, despites these efforts, industrial hazards and risks are still frequent and their cost in terms of human suffering and economic burden continues to be significant. Poor performance in hazard analysis can take a heavy financial toll on any business, not to mention the human cost of work related illness, injuries and fatality. This is the primary aim of effective Job hazard analysis. The implementation of such a system can help greatly in business especially in dealing with legal imperative and industrial relation and improvement in financial performance. Therefore, the aim of this study is to adopt Markov-theoretical approach (MTA) in predicting severity of risk that workers are exposed to in the oil and gas sector. Such approach will facilitate addressing industrial hazards, investigating the average period it would take workers exposed to risk of less severity to transit to state of higher risk, and developing solution procedure to address the industrial hazards.

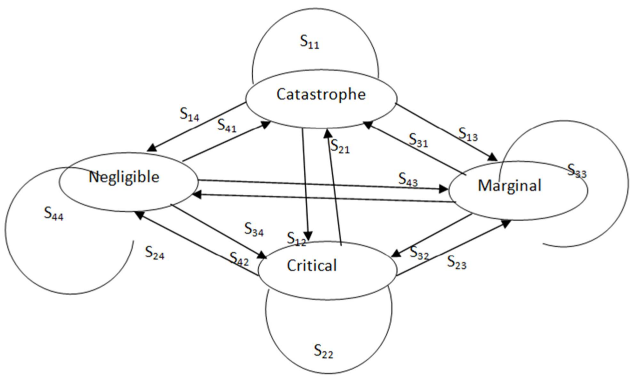

Fig. 1. *The transition diagram (value diagraph).*

2. Review of Literature

[5] researched on Occupational Health and Safety in the oil and gas industry by investigating the various hazard workers are exposed to, the effect of these hazards to the health of the workers, the effectiveness of the existing means of mitigating these hazards and the adequacy of the legislation that impacts on the provision of occupational health and safety in the oil and gas industry. Statistical package for Social Sciences (SPSS) software was used for the analysis. [6] studied hazards control measurement by evaluating the effective use of personal protective equipment, good housekeeping, adequate maintenance, good maintenance of machinery, emergency procedures to follow when there is accident in confined space. Confined space include but are not limited to storage tanks, compartments of ships, process vessels, pits, silos, vats, reaction vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines [7]. [8] carried out a hazard identification and risk analysis in iron ore and coal mining operations. The study revealed that the number of high risks hazards in the coal mining operations was more than the one of the iron ore mining operations. [9] used Hazard and Operability Method (HAZOP) method to identify the potential hazards and operability problems of decommissioning operations and concluded that the decommissioning of a nuclear research reactor must be accomplished according to its structural conditions and radiological characteristics. [10] conducted risk assessment of threat to process plants. The researcher revealed the sources of threats, types of threat in his work. [11] applied the probabilistic safety assessment in chemical industry. The method was applied to a pressurized spherical tank for ammonia storage in order to estimate reliable risk of its casual rupture with different magnitude of the tank damage. [12] studied basic reasons for pipeline failure and its probable consequences taking individual and societal risk into consideration and proposed methodology of risk assessment for hazards associated with hazardous substance transport in long pipelines.

The relevance of Markov chain in risk assessment exercise has been revealed by many researchers. [13] looked at management of job-oriented accidents in Nigeria oil-industry using Markov model. A 10-year historical accident data were characterized and found to have absorbing chain properties. Four open-and-shot transition states namely: fatality, accident, near-miss and unsafe act were identified. The results suggested that on the average, 59% of staff is wasted through fatality or severe accidents. [14] Ramin examined the application of semi-Markov models to the phenomenon of earthquakes in Tehran province. In his research, the province of Tehran was divided into six regions and grouped the earthquakes using their magnitude into three classes. Semi-Markov model was used to predict the likelihood of the time and place of occurrence of earthquakes in the province under stochastic environment. [15] researched on credit card fraud detection using hidden Markov model. It was found that hidden Markov model helps to obtain high fraud coverage combined with a low false alarm rate. The usefulness of Markov model was also proved in [16]. The researchers did some computation using Mean Time to Failure (MTTF) values with the help of Markov models. It shows what Markov models can be utilized to achieve valid and important information for safety instrumented systems.

2.1. Transition Probability Matrix

The transition probability matrix (T) is a square matrix which shows the probability of the movement of object from one state (S) to another. This can be illustrated further with the notation that the transition matrix given by P and its elements by P_{ij}, denotes the probability of going to state j next when currently in state *i*. When the state space has m states (is finite), P is a square m×m matrix. This can be seen in eq.1.

$$T = \begin{matrix} & S_1 & S_2 & S_3 & \cdots & S_k \\ S_1 & P_{11} & P_{12} & P_{13} & \cdots & P_{14} \\ S_2 & P_{21} & P_{22} & P_{23} & \cdots & P_{24} \\ S_3 & P_{31} & P_{32} & P_{33} & \cdots & P_{34} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ S_k & P_{k1} & P_{k2} & P_{k3} & \cdots & P_{k4} \end{matrix} \quad (1)$$

2.2. Absorbing State of Markov Chain

Absorbing Markov chain in the mathematical theory of probability is a Markov chain in which every state can attain an absorbing state [14]. An absorbing state is an interesting state that, once entered, cannot be left. By definition, state *i* is absorbing when P_{ij} =1 (and hence P_{ij} = 0 for all j ≠ i). Markov chain is absorbing if and only if the following two conditions are satisfied:

(i) It is possible to go from any state to at least one absorbing state in a finite number of steps. In an absorbing Markov chain, a state that is not absorbing is a transient state.

(ii) There is at least one absorbing state.

The transition matrix of an absorbing Markov chain can be written in canonical form as below:

$$\begin{pmatrix} I & 0 \\ A & B \end{pmatrix} \quad (2)$$

Where A is the rectangular sub matrix, given transition probabilities from non-absorbing to absorbing states, B is the square sub Matrix given these probabilities from non-absorbing to non-absorbing states, I is an identity matrix, and 0 is a rectangular matrix of zeros.

2.3. Fundamental Matrix of an Absorbing Markov Model

The fundamental matrix of an absorbing Markov chain is given by the form:

$$N = (I_n - B)^{-1} \quad (3)$$

Where I_n is an n×n identity matrix corresponding in size of matrix B. The fundamental matrix gives the expected number of visits to each state before absorption take place. Finally the product matrix NA gives the probability of a system originally in a non-absorbing state, end up in an absorbing state.

Properties of an Absorbing State

The properties are:

(i) Regardless the initial state, in a finite number of steps, the chain will enter an absorbing state and then remain in that state.

(ii) The power of a transition matrix gets closer and closer to some particular matrix.

(iii) Long term trend depends on the initial state. Let T be the transition matrix for an absorbing Markov chain. Rearrange the rows and columns of matrix T so that the absorbing state comes first. Matrix T will have the form.

$$T = \begin{pmatrix} I_m & 0 \\ A & B \end{pmatrix} \quad (4)$$

Where I_m is an identity matrix, with m equal to the number of absorbing states, 0 is a matrix of all zeros, for the fundamental matrix. Where I_n has the same size with B. The element in row *i*, column *j* of the fundamental matrix gives the number of visits to state *j* that expected to come before absorption, given that the current state is the state *i*.

3. Methodology

Warri Refining and Petrochemical Company (WRPC) was used as a case study. WRPC is located in Delta State. It is a subsidiary of the Nigerian National Petroleum Corporation (NNPC), an oil company involved in refining crude into fuel, kerosene and other by-products. The study area is located around latitude 5031‟N and 6011‟N and between longitude 5044‟E and 5047‟E. Five (5) out of fifteen (15) of sub-systems in WRPC were selected based on the fact that they pose more risk to the health of workers in the system. The selected five are Fluid catalytic cracking unit (FCC), Crude distillation unit (CDU), Vacuum distillation unit (VDU), Polypropylene Plant (PPP) and Carbon black plant (CBP).

3.1. Mode of Data Collection

Data was obtained from management of WRPC who were assured of confidentiality of information collected. Primary and secondary source of data collection was adopted in this research. Primary source of data collection includes getting information from past record book of the company, journals, textbooks, unpublished and published research work etc. Secondary source of data collection involve the use of questionnaire to obtained data from staff of WRPC.

3.2. Method of Data Analysis

Markov chain was used for analyzing the data from questionnaire. Response was recorded in frequency table. To effectively use Markov model, the basic steps are to:

(i) characterize the data as an absorbing Markov chain

(ii) classify the data into different states or subsets.

(iii) view the repeated movement of one or more object or workers among various classifications or state.

(iv) develop transition matrix to illustrate these movement

(v) develop fundamental matrix from the transition matrix

(vi) obtain an F matrix; and

(vii) obtain the product of FB matrix.

3.3. Markov Application Procedure

Call up Markov on QM command window to activate Markov model with the states. In this research, the severity of the risk is investigated in four different states or classification. These states are (1) catastrophic (S_1), (2) critical (S_2), (3) marginal (S_3), and (4) negligible (S_4). State specifically implies the severity of the risk objects or workers are exposed to over a period of time. The data obtained from the questionnaires was analyzed using Markov chain considering the movement of workers from one or more states (Si), where = 1, 2, 3… k. Movement of workers from the various states can be clearly seen in the Transition matrix T.

Table 1. *Classification of Risk Severity.*

Categories	State	Equipment	Personnel	Environment
i	Catastrophic	System loss	Death	Severe damage
ii	Critical	Major system damage	Severe injury or severe occupational illness	Major damage
iii	Marginal	Minor system damage	Minor injury or minor occupational illness	Minor damage
iv	Negligible	less than minor system damage	Less than minor injury or minor occupational illness	Negligible damage

A transition probability matrix was developed from the data obtained. Where the entry $[T_{ij}] = p_{ij}$ shows the likelihood or probability that the workers in state $s_i$is moving to state $s_j$during each step process. It is clear that each p_{ij} must satisfy 0≤ p_{ij}≤1. It follows that the entries in each row of T sum to 1. The transition is shown in Eq. 1.

The fundamental matrix for an absorbing Markov chain as shown in Eq. 3 tells us the expected number of visit to each state before the absorption occurred. Finally the product of the FA matrix shows the movement of object from moving from the non absorbing state to an absorbing state.

4. Result and Analysis

Warri Refining and Petrol chemical company (WRPC) was used as a case study. WPRC has fifteen (15) plants, five (5) out of fifteen (15) plants were selected based on the fact that they pose high level of risk to the health of workers in the system. The selected five include: Fluid catalytic cracking unit (FCC), Crude distillation unit (CDU), Vacuum distillation unit (VDU), Polypropylene Plant (PPP) and Carbon black plant. The research identifies industrial hazards and delineates the awareness of hazards in the refinery. In addition, it includes the risk assessment of hazards to the workers, predict the severity of the risk on the health of the workers within a period and possible control measures to prevent and mitigate the impact of the hazards on the health and well-being of workers.

Using Markov chain as a tool for analysis gives the expected result at the end of the analysis. Also from the information obtained from the company, hazards are categorized into the following: physical**,** chemical, mechanical/Ergonomic and biological hazard.

The severities of hazards are classified into: catastrophic (Ca), critical (Cr), marginal (Ma) and Negligible (Ne).

Table 2 shows the summary of the severity of risk associated with workers at Warri Refining and Petrol Chemical Company. The information was obtained with the aid of a questionnaire. Table 3 represents the state space.

Table 2. *Risk Severity Data.*

Severity / Hazards	Catastrophic (Ca)	Critical (Cr)	Marginal (Ma)	Negligible (Ne)
Physical	8	7	19	16
Chemical	10	10	15	15
Mechanical	10	5	19	16
Biological	6	4	17	23

Table 3. *State space.*

State	No
Catastrophic (S1)	34
Critical (S2)	26
Marginal (S3)	70
Negligible (S4)	70
Total	200

This shows the present state of workers at WRPC. After all statistical computations were made.

$$T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0.2615 & 0.2 & 0.5385 & 0 \\ 0 & 0.1566 & 0.4217 & 0.4217 \end{pmatrix}$$

Table 4. *Data inputted into QM Software.*

	Initial	S1	S2	S3	S4
S1	0	1	0	0	0
S2	0	0	1	0	0
S3	0	0.2615	0.2	0.5385	0
S4	0	0	0.1566	0.4217	0.4217

Table 4 shows data input into Markov platform called up from QM simulation software for analysis. This is the Transition probability matrix (T).

Table 5 shows that there are two absorbing states which are the catastrophic and critical states (S1 and S2) and two transient/non absorbing states which are marginal and negligible states (S3 and S4).

Table 5. *Static Analysis.*

JOB HAZARD ANALYSIS USING MARKOV THEORETICAL MODEL		
State	**Type**	**Class Number**
S1	Absorbing	1
S2	Absorbing	2
S3	Transcient	
S4	Transcient	

Table 6. *Job Hazard Analysis Using MTA Approach.*

JOB HAZARD ANALYSIS USING MARKOV THEORETICAL APPROACH STEADY STATE TRABSITION MATRIX				
Markov Matrix	S1	S2	S3	S4
S1	1	0	0	0
S2	0	1	1	1
S3	0.5666	0.4334	0.5385	0
S4	0.4132	0.5868	0.4217	0.4217
B matrix	S3	S4		
S3	0.5385	0.4		
S4	0.4217	0.4217		
F matrix	S3	S4		
S3	2.1666	0		
S4	1.5801	1.7292		
FA matrix	S1	S2		
S3	0.5666	0.4334		
S4	0.4132	0.5666		

Table 6 shows three set of significant result, B matrix shows a non absorbing matrix moving to a non-absorbing state. F matrix is the fundament matrix gives the expected number of visit to each state before getting to absorption. From first rows of F matrix shows that workers currently in marginal state (S_3) are expected to spend 2.2 + 0 = 2.2years (i.e. an average of 2 years and 2months) in the various states non absorbing state before getting to absorption (i.e. catastrophic and critical state). Also in the second row it is expected that workers currently in negligible state are expected to spend 1.6 + 1.7 = 3.3years (i.e. an average of 3.3years) in the various state before getting to absorption. Finally the multiplication of the F matrix with the A matrix gives the product FA. The product matrix FA gives the probability that the system originally in non-absorbing state, will end up in an absorbing states. The matrix above shows that 56.66% of workers which was in marginal states will transit to a catastrophic state. Also 43.34% of workers in marginal state will transit to a critical state. It is also found that 41.32% of workers in negligible state will be moving to a catastrophic state and 58.68% of workers in negligible will move to critical state.

Table 7. *Markov Analysis Result from QM.*

JOB HAZARD ANALYSIS USING MARKOV THEORETICAL APPROACH STEADY STATE TRABSITION MATRIX				
	S1	S2	S3	S4
S1	1	0	0	0
S2	0	1	1	1
S3	0.5666	0.4334	0	0
S4	0.4132	0.5868	0	0
Ending number	0	0	0	0
Steady state probability	1	1	0	0

Table 7 shows the result of the analysis, the matrix result explains the fact that after series of transition, the non-absorbing Markov chain will eventually reach an absorbing Markov state. This can be seen in state (S_{31} and S_{32}) in row 3 and state (S_{41} and S_{42}) in row 4.

A total of 50 respondents participated in the study. Also Markov chain was used as a forecasting tool in this study, which greatly helps ineffective planning for existing hazard analysis practices in the oil and gas sector. For various reasons, ranging from lack of proper work procedures, obsolescence of tools/equipment, lack of permit to work, non-usage of personnel protective equipment, lack of proper HSE practice etc, 56.66% of workers in marginal state would likely move to a catastrophic state, while 43.34% of workers in marginal state would likely move to critical state. Also 41.32% of workers which were in negligible state would likely move to catastrophic state, while 58.68% of workers in negligible state would likely moved to critical state as shown in Markov analysis result in table 7. These figures are significant and helped to show high rate of catastrophic and critical severity of risk in the oil and gas sector which would enable management of these companies plan better for their workers in order to curtail risk in the system.

5. Conclusion

With Markov theoretical approach, the risk workers were exposed to over a period of time has been clearly revealed. The result showed that workers would spend several years in a non-absorbing state before moving to an absorbing state. It is evident from the results of the study that 41.45% of workers would likely transit from negligible state to catastrophic state; also 56.66% of workers would likely transit from marginal state to a catastrophic state, while 58.68% of workers in Negligible state would likely transit to Critical state, 43.34% of workers would possibly transit from Marginal state to critical within an average period of 2-3 years as shown in the Markov solution table. It is concluded that management of most oil and gas industry should use this result as basis to plan better in order to minimize risk that affect workers in the industry.

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