International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Modelling Approach to Risk Management and Safety in Industries

OGIDI Mayowa Ayodele [a], ABIOYE Adekunle Oluyede [a], OJO Olumayowa Ayotunde [b], OGINNI Olarewaju Thomas [c]*

[a] *Civil Engineering Department, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria*
[a] *Electrrical/Electronic Engineering Department, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria*
[a] *Mechanical Engineering Department, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria*

A B S T R A C T

Manufacturing sectors are vital to the development of a nation, but sadly, they are assessed as the third-most dangerous sector internationally. As a result, risk and safety management are essential in this sector, and there is a need to find measures to minimize them in the industry. This research developed a mathematical model for risk and safety management in industry. Accident records with relevant other data sets from three manufacturing companies for a period of ten years (2010–2020) were collected and evaluated. The systems dynamics approach (SDA) was applied to create the mathematical model for safety and risk management in the research region using Vensim software. The findings were examined, and a t-test for validation was undertaken, which showed that the expected and quantitative values were not substantially different. Accident-caused (AC) and accident-prevented (AP) models were also established. These were evaluated with real-life data and performed successfully. The proposed model is a useful tool in manufacturing industries as it accurately anticipates the condition of danger and safety controls in production industries, consequently making it very useful for safety management.

Keywords: Accident, Manufacturing Industry, Mathematical model, Production, Simulation

1. INTRODUCTION

The largest portion of each nation's annual budget is allocated to the industrial sector, which renders production the most influential industry in any country. Certain manufacturing facilities contribute significantly to the industrialization of Nigeria, offering the country's economy an essential quantum leap (OHSA, 2019). Advanced and novel technologies are being integrated into industrial processes in response to their dynamic nature, even if they are not operated by skilled workers. Damage to both the equipment and the alleged human may result from injuries caused by improper handling. Security awareness should perpetually permeate the management mindset of every manufacturing species, according to Brain (2015). The occurrence of accidents within an organization has the potential to negatively impact not only the security and productivity of the workforce but also the administration of the economy and business (Ezinwa, 2019; Udeze, 2015).

In manufacturing industries, accidents represent intrinsic difficulties that necessitate a concerted effort to mitigate their detrimental impact (Adebiyi, et. al., 2017). The management of Nigerian manufacturing industries should address the implementation of measures to reduce, if not eliminate entirely, the occurrence of injuries and accidents in these sectors, given that such incidents impede organizations from accomplishing their objectives and priorities (Islam, 2012; Ahlang, 2019). According to Brain (2015), empirical evidence suggests that individual defects are caused by three out of every five injuries within the manufacturing sector. Instances incur direct or indirect costs for the organization due to the potential for harm, injury, or death (Khakzad, 2020). This paper focused on the effects of hazard and security mitigation in manufacturing industries and addressed shortages of models for hazard and security mitigation in industrialization.

2. METHODOLOGY

2.1 Data acquisition

Accident records with relevant other data sets were collected through a survey of the organization and contacts with the department heads from the safety and operational departments in three Nigerian manufacturing facilities (A, B, and C) for a period of ten years (2010–2020). Accident occurrences during the working period were collected at both the safety department and clinic of the companies.

2.2 Data analysis of accident causal

A questionnaire was designed and administered to the management and workers of the four manufacturing companies to identify the causes of accidents in the companies and their corresponding effects on individual workers and the organization.

Formulation of the model

The approach consists of a system of correlated differential equations based on the Forrester theory of synthesis. The model consists of two factors that are dynamic, which are: caused accidents and prevented accidents. The number of accidents caused depends on the rate of accidents avoided and the probability of their occurrence. The number of accidents prevented depends on the safety goals of each company, the likelihood of activities prevented, and the preventative time lag.

The system accounts for a share of the budgeting factor, the planned cost, the proportion of the present accident preventive plan, and the performance of preventive activities. The system is developed to forecast future developments and complicated interactions between the components of the project. The model forecasts successful safety quality and hazard behavior for the cost of injuries prevented. The system dynamics technique was applied and simulated to construct the model using Vensim software (Version 7.2 PLE) to devise a risk and safety system quality measure.

2.3 System boundary

The model provides assistance and functions as a smart decision tool for risk and safety activity creation and control in the manufacturing sector. The following assumptions were made before the development of the models:

Consistency is ensured in the operating conditions;

a. Known integral control system for manufacturing safety program;
b. Establishment policy stability:
c. Standard values are based on costs;
d. Government policy stability;
e. The resources consumed are proportional to the budget laid out, and
f. Non-negative initial values for accident caused and accident prevented
g. Specification of set of quantities
h. The quantities, measurements, and descriptions used in the simulation were determined by the safety program elements.

2.4 Specification of causal diagram

The diagram provides explanations for the operations of a manufacturing system with two feedback loops. A cost plan is composed and revised. It is carried out through safety-related learning activities: awareness-raising, computer control, encouragement of workers, and the usage of protection equipment. Hazards are avoided in line with a defined target, based on the effectiveness of each of the procedures. The likelihood of accidents affects the rate of accident causation, which eventually decreases to attain the target. The quantities calculated and the proportions suggested are described. The causal loop diagram is generated by applying this approach and depending on experience and the options of the experts.

2.5 Development of model equations

The amounts of accidents prevented (At) were defined in terms of the budgeting factor, implemented budget proportion, safety program activities effectiveness, training, accident investigation, use of personal protective devices, safety incentives and personnel awareness, workforce, accidents proneness factor, and safety program action-result time lag as contained in equation 1.

$$A_t = D_p \zeta L \sum_{k=1}^{M} r_k \varphi_k \left[1 - l^{-l^{-k(wx-A_t)}} \left({}^{t}/_{s}\right)\right] + A_0 l^{-l^{-k(wx-A_t)}} \left({}^{t}/_{s}\right) \quad (1)$$

3. RESULTS AND DISCUSSION

The analysis of the questionnaires and comments from direct interviews with management experts and workers revealed that human factors, safety failures, and the general working environment all contributed to the accident casualties. Training and raising awareness. Monitoring, investigation of accidents, incentives, and usage of personnel protection equipment were the modes of accident prevention actions employed by these companies.

Company A recorded a total number of annual accidents ranging from 13 to 31 (2020 recorded 13 accidents while 31 accidents were recorded in 2016) and an average accident record of 26; Company B ranges from 26 to 45 accidents (2020 recorded 26 accidents while 2015 recorded 35 occurrences), and the mean number of accidents recorded is 36; and Company C ranged from 16 to 29 accidents (16 in 2020 and 29 in 2014) with an average accident record of 23. A sinusoidal trend follows the accident.

The model was evaluated in all three industries participating in this study to predict accidents. The following diagrams demonstrate the comparison of the actual accidents in each production company and the anticipated simulation accident in each company. Figures 1, 2, and 3 provide the results of the average projected accident and the actual observed accidents in this company. The outcome confirms the correctness and precision of the model.

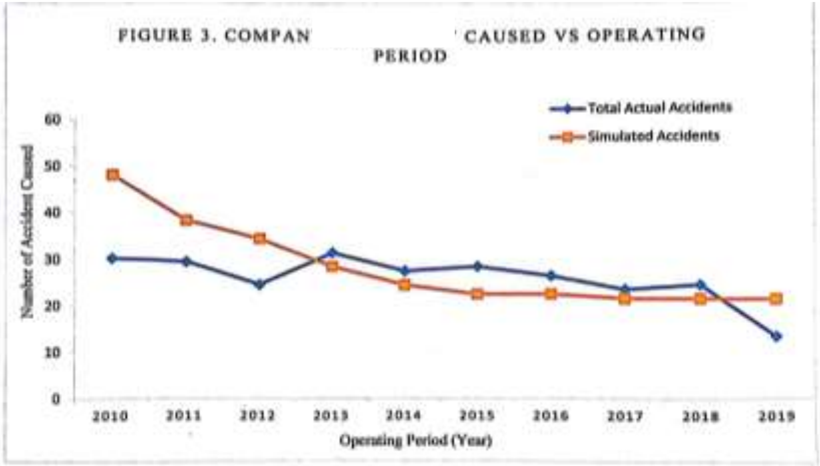

Figure 1: Comparison of actual accident and simulated accident of company A

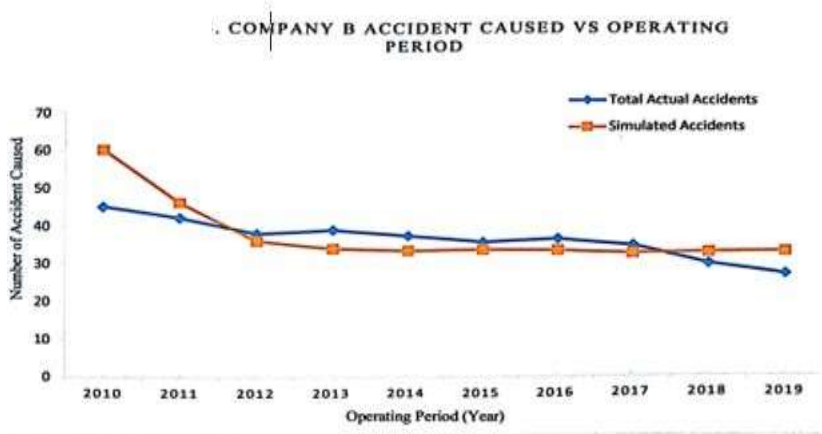

Figure 2: Comparison of actual accident and simulated accident of company B

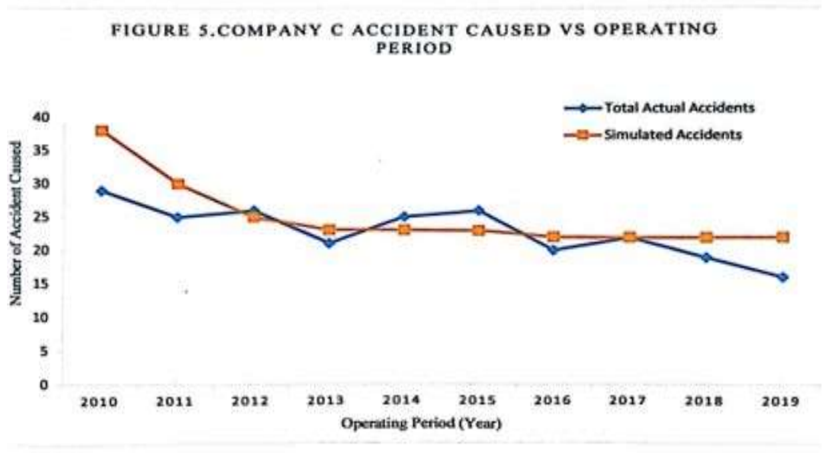

Figure 3: Comparison of actual accident and simulated accident of company C

4. THE MODEL

4.1 The Simulation Results

Simulation results for Company A:

The findings of the simulation for actual, simulated, and prevented safety accident records of company A are shown in Tables 1 and 2. The results in Tables 1 and 2 show a decrease in the number of accidents caused. In 2010 and 2016, the number of accidents decreased significantly, from 48 to 22. In 2017, it was reduced to 21 and remained stable until 2019. Between 2010 and 2012, the number of actual accidents grew without any beneficial impact or effect on the model. Furthermore, the predicted average number of accidents was 27.

The T-tests used to assess predicted values and empirical values are not significantly different. The rate of accidents caused and the number of avoided accidents by empirical evaluation are 26 and 29, respectively. However, the projected average values for the number of accidents caused and accidents prevented are 27 and 23, respectively. The t-test findings demonstrate that the expected and real values are at 5 percent, showing no significant difference. Since, the t values for accident number determined from 0.63 to 0.08 are less than the crucial value of 2.13.

Table 1: Actual and simulated safety accidents records of Company A

Year	Actual Accidents	Simulated Accidents
2010	30	48
2011	29	36
2012	24	30
2013	31	26
2014	27	24
2015	28	22
2016	26	22
2017	23	21
2018	24	21
2019	13	21
Mean	26	27

Table 2: Actual and simulated prevented accidents of Company A

Year	Prevented accidents calculated	Prevented accidents predicted
2010	20	3
2011	26	12
2012	31	19
2013	24	23
2014	28	26
2015	27	28
2016	29	29
2017	32	29
2018	31	29
2019	42	29
Mean	29	23

The findings of the simulation for actual, simulated, and prevented safety accident records of company B are shown in Tables 3 and 4. The simulation's findings reveal an incremental decrease in the number of injuries caused. From 60 to 33 between 2013 and 2019, the number of accidents caused has fallen drastically. It subsequently decreased to 32 in 2020 and remained constant until 2022. Nevertheless, the overall number of accidents predicted was

37. At a transitory stage, the number of predictable accidents began in 2013 with 10 anticipated accidents, exponentially rose to 38 in 2017 and stabilized until 2022. The mean projected accident number was estimated at 33.

T-test run to assess the anticipated values, and the empirical values obtained differ considerably. The number of caused accidents and the number of avoided accidents are 36 and 34, respectively. However, the projected average values for the number of accidents caused and accidents prevented are 37 and 33, respectively. The t-test findings reveal that the expected and real values are not significantly impacted at 5%. As the values of t values estimated for accident numbers of accidents caused and prevented accidents, 0.77 and 0.80 are less than the crucial values of 2.13.

Table 3: Actual and simulated safety accidents records Company B

Year	**Prevented accidents calculated**	**Prevented accidents predicted**
2010	45	60
2011	42	46
2012	38	36
2013	39	34
2014	37	33
2015	35	33
2016	36	33
2017	34	32
2018	29	32
2019	26	32
Mean	36	37

Table 4: Actual and simulated prevented accidents of Company B

Year	**Prevented accidents calculated**	**Prevented accidents predicted**
2010	25	10
2011	28	24
2012	32	32
2013	31	36
2014	33	38
2015	35	38
2016	34	38
2017	36	38
2018	41	38
2019	44	38
Mean	34	33

The findings of the simulation for actual, simulated, and averted safety accident records of Company C are shown in Tables 5 and 6. The results show that the number of accidents caused has decreased exponentially. There were exponential decreases in the number of accidents caused between 38 and 23 in 2010 and 2016, but declined to 22 in 2017 and stabilized until 2019. The average number of caused accidents was 25. During transition, the numbers of expected accidents started in 2010 with 2 and exponentially ascended to 10 in 2013, accompanied by an asymptotic rise in 2017 to 18 and stabilized around 2019. The mean number of avoided accidents was reported at 15.

T-test performed to assess whether the anticipated values and experimental values were significantly different. The average number of accidents caused and prevented is 23 and 17, respectively. However, the average expected values for the number of accidents caused and prevented are 25 and 15, respectively. The t-test findings demonstrate that the expected values and the true values are not substantially different at a rate of 5%. Therefore, the values of t-values of 0.32 to 0.38 are less than the required values of 2.11 for the number of caused accidents and accidents prevented.

Table 5: Actual and simulated safety accidents records of Company C

Year	**Total Actual Accidents**	**Simulated Accidents**
2010	29	38
2011	25	30
2012	26	25
2013	21	23
2014	25	23
2015	26	23
2016	20	22
2017	22	22
2018	19	22
2019	16	22
Mean	23	25

Table 6: Actual and simulated prevented accidents of Company C

Year	**Prevented accidents calculated**	**Prevented accidents predicted**
2010	11	2
2011	15	10
2012	14	15
2013	19	17
2014	15	18
2015	14	18
2016	20	18
2017	18	18
2018	21	18
2019	24	18
Mean	17	15

The analysis of the findings for companies A, B, and C demonstrated that the expected and empirical values are not significantly different, and that the model can effectively forecast the risk and safety actions in manufacturing companies.

5. CONCLUSION

The manufacturing industry is one of the most significant sectors responsible for every country's economic growth, but its activity is full of accident-prone risks, so its management towards safety and risk is critical. A careful analysis of the safety and risk actions in this industry will minimize accidents and increase production. The mathematical model constructed using systems dynamics and Vensim PLE 7.2 software was profitable and economical. The methodology was effectively deployed in three different manufacturing industries in Nigeria with an organized program on risk and safety utilizing historical accident causative data for the safety program periods. The model demonstrated the dynamic interrelationships among the number of occurrences of accidents, the number of prevented accidents, the rate of accidents, and the rate of prevention in risk and safety management in manufacturing industries. Controls risk and safety operations efficiently in manufacturing industries and aids the decision-making of the planner for manufacturing safety programs.

References

Ahlang, S.O. (2015) "Fallacies of Risk". Journal of Risk Research, Vol. 7, No.3, pp. 353- 360.

Brain G. (2015) "Safety at Work" Information Booklet on II.S.E (Warri SDC Corporate Reprographic Center).

Ezinwa A.O (2019) "A study of reported accident experiences and safety management practices in Nigeria Factories" Niger Med Journal: 32, 56-60.

Islam, M. A., (2012). Risk Management in Small and Medium-Sized Manufacturing Organizations in New Zealand, PhD Thesis, Department of Mechanical Engineering. The University of Auckland, New Zealand.

Khakzad, N. (2020), "Revolutionizing safety and security in the chemical and process industry", applying the CHESS concept. - Journal of Integrated Security Science. 1 (1) 2- 15.

Occupational Health and Safety Act (OHSA), RSO 2016. c. 14.

Udeze J.O (2015) "Human Resources" Management in Nigeria, Enugu Joe Best Books. 43. Wilson, R. (2016) "A Process Framework for Risk Communication" Journal of Science, Technology & human Values, Vol. 12, No. 3/4. Summer- Autumn pp 131-137.

Adebiyi, K.A., Charles-Owaba O.E., and M.A. Waheed. 2017. "Safety Performance Evaluation Models - A Review". Disaster Prevention and Management, an International Journal. 16 (2):178-187