Factory Accidents Survey and Performance Evaluation in A Nigerian Steel Rolling Mills

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Abstract— **This work developed a statistical approach for steel-mill accident prediction. The hierarchical Poisson distribution analysis method for non fatal occupation injuries within the period of January 2008-December 2013 was used. Also examined are the conditions and nature of the occupational injuries. During the 6 years period understudied, a total of 730 cases of occupational and related injuries were captured. On the average there were 0.507 chance of accident occurrence in the factory (Standard Deviation = 0.29). A dedicated Job Hazard Analysis and a proposed Risk Priority chart was presented for the system. Overall systems behaviours were generated by Monte Carlo simulation in order to estimate relative risk levels on yearly bases (referring to final cumulative distribution). Analysis was done using MiniTab software and it yielded Anderson Darling value of 0.917(P=0.009). A long run, forecasting modelling was carried out to quantitatively predict the expected risk level by using time series analysis(accident includes near miss). The greatest frequency of injuries occurred among contract staff. This was followed by steel making, roll mill, and coke plant. This highest frequency of injuries occurred due to dangerous working method. Safe work behaviour (socio technical procedures) especially for temporary workers is highly recommended to reduce workers related accidents and injuries.**

Index Terms— **Steel mill, accident, injuries, model and safety.**

I. INTRODUCTION

The effort to achieve an accident free working environment should be the responsibility of all staff in a working environment. Many steel companies have found out that it is possible to reduce dramatically, the number of accidents at work place by giving safety the necessary priority. The progress achieved has shown that a safe way of working is offcourse the most efficient work approach . An organized and an acceptable work environment should understand the difference within cases resulting in accident situations. Some are just near miss situation while others may result to loss of life. The difference between an incidence which leads to fatality and one which lead to near-miss is a matter of chance. For every serious injury, there must have been many recorded cases of minor accidents and hundreds of potential acts, Bruno et-al(2008). To eliminate fatalities and serious injuries, it requires the elimination of all incidents and unsafe acts.

Trying to categorize the study on steel mill safety yields two basic types of information. One arm explains the statistical description of accidents and theories covering human factors in the cause of accidents. The other, closely related, is concerned with various methods of accident prevention, from the point of view of safety programs (Celeste and Elaine,2004).With all the available accident models, the rate of accident is still alarming in the rolling-mills. The questions are: is the current knowledge base satisfactory? or is there a need understudying and adapting approaches from other fields of risk research? Is there a need for changes or modification? Is the problem of occupational accident prevention mainly a question of priority, resource application or implementation of techniques? This study will attempt to answer the questions with an understanding of a need of earmarking indicators that abnormally increase accident cases.

What distinguishes occupational accidents from other accidents is that they happen in a working life context and most often, consequences are limited to injuries on the involved worker (Jan and Patrick, 2013). The worker is often the agent even when he is as well a victim.

Accident modelling has a lot to do with different disciplines. It involves: technologists, psychologists, other social scientists etc. It needed a cross-disciplinary approach; combining the skills in human factor technology and organizational behaviour.From the mid-eighties the focus changed from accident modelling to management of men and tools for safety monitoring and safety auditing (Kjellen and Hovden, 1993). They described managements and culture as the third age of safety. The first age was about technical measures, the second about human factors and individual behaviour.

The Idea of Leading versus lagging indicators in prevention of occupational accident in the manufacturing sector, is helpful in improving safety performance and in trying to identify those variables that influence and predict such performance. Again, being able to use predictors of success is obviously far more desirable than identifying causes of failures.

In the context of safety, leading indicators are measures that allow an organization to anticipate and predict specific outcomes such as occupational injuries. By assessing leading indicators, an organization should be able to identify circumstances that are likely to produce a higher probability of occupational injury or that could be a precursor to any degradation in the safety process, thus enabling early intervention and, hopefully, prevention of the undesired outcome (e.g. injury). Lagging indicators are those metrics for events and conditions that already happened, such as occupational injuries. Lagging indicators are useful because an organization can use these to quickly take reactive measures to drive facility performance. Lagging indicators also aid in benchmarking that performance against similar operations. Models studying this area though multidisciplinary but must be social science biased.

Steel mills have long been considered as one of the most hazardous work environments. From the year 2000 most

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recorded hazards of African manufacturing industries come from the production area. In any of its forms, are inherently dangerous and capable of causing disability or death (Eijkemas 2004). It was recorded that in the first eight weeks of 2008, there were seven fatal accidents within the steel industry in the United States, which is more than double the number of fatalities that the industry suffered in all of 2007.
The steel mill is truly a high risk work environments. Safety policies and procedures must always be put in place and fully enforced. At regular assessment, accidents can be reduced, however, to an absolute minimum with appropriate technology and technique. A good forecast will also serve as a warning to the operators of dangers ahead and will consequently advice operators of acceptance to safety protocols.

II. EXPERIMENTAL PROCEDURES

The basic steps of stochastic risk analysis methodology developed for this work are presented and consist of; development of appropriate probabilistic model for the system , collection of steel rolling mill data, quantitative risk assessment, compilation of probability and consequence (severity) evaluation using a Monte Carlo simulation.

2.1 Generalized (Probabilistic) Model for the System (Problem Formulation).

The accident reduction process was formulated using Poisson distribution process. The process presumes that an event that occurs in a time interval depending on the length of the interval and not its spot on the time axis. Poisson distribution is a discrete distribution with infinitely many possible values. It is a particular limiting form of Binomial distribution and is given as (Kreyszig, 1999)

$$P(t) = \frac{\lambda t^n}{n!}.e^{-\lambda t} \qquad (1)$$

Let $[X_1(t), t \geq 0]$ and $[X_2(t), t \geq 0]$ denote unsafe condition and unsafe act respectively.

$$Y_{(t)} = X_{1(t)} + X_{2(t)} \qquad (2)$$

Using equation (1), we have

$$P_{n(t)} = P\{X_{(t)} = n\} = \frac{(\lambda_1 t)^n}{n!}.e^{-\lambda t} \qquad (3)$$

If $X_1(t)$ and $X_2(t)$ are independent, it follows that

$$P\{Y_{(t)} = n\} = P\{X_1(t) + X_2(t) = n\} \qquad (4)$$

$$= \sum_{j=0}^{n} P\{X_1(t) = j\}.P\{X_2(t) = n - j\}$$

$$= \sum_{j=0}^{n} \frac{n!}{j!(n-j)!} \lambda_1^j \lambda_2^{n-j}.\frac{t^n}{n!} e^{-(\lambda_1+\lambda_2)t}$$

$$= \sum_{j=0}^{n} \binom{n}{j} \lambda_1^j \lambda_2^{n-j}.\frac{t^n}{n!} e^{-(\lambda_1+\lambda 2)t}$$

Therefore

$$P\{Y(t) = n\} = (\lambda_1 + \lambda_2)^n.\frac{t^n}{n!} \exp(-(\lambda_1 + \lambda_2 \ )t) \qquad (5)$$

Where

n is the number of incidents
t is the time interval
λ_1 is the existence of the unsafe condition, and
λ_2 is the occurrence of the unsafe act

Since equation (5) represents the probability of at least an accident to occur, therefore for an accident not to occur, we have

$$Q\{Y(t) = n\} = 1 - (\lambda_1 + \lambda_2)^n.\frac{t^n}{n!} \exp(-(\lambda_1 + \lambda_2 \ )t) \qquad (6)$$

2.2 Collection of Steel Mill Accident Data

The steel mill accident data used in this work were collected from a rolling mill in, Southern Nigeria. Out of the three basic functional units of the factory, the technology unit is concerned with the operation of the plant as well as the industrial safety. It employs workers at the rolling mill, furnace, and finishing. The workers are exposed to splinters of metals, welding arc rays, hot molten metal and so on. The technology and production units were recorded as the potential areas for work related hazards.
The workers run a three-shift duty in the production and technology units of the plant while the administrative units run only a morning schedule. The study involved a total of 660 workers divided among the 3 main functional units.
Accident data in the six year period under investigation were collected for analysis. The study includes injuries in case of accidents involving less than one day absence from work. The fatal cases were not taken into consideration.

2.3 Quantitative Risk assessment

This is the quantitative analysis of accident and injury data for measuring safety performance and identifying safety. A problem is usually done through two basic indices, Accident frequency Rate (AFR) and Accident Severity Rate (ASR) : as follows

$$AFR = \frac{\text{total number of accidents x 1000}}{\text{Total number of man-hours works}} \qquad (7)$$

$$ASR = \frac{\text{total number of days-lost x 1000}}{\text{Total number of man-hours worked}} \qquad (8)$$

$$IR = \frac{\text{total number of accidents x 200,000}}{\text{Total number of man-hours worked}} \qquad (9)$$

AFR is an expression relating the number of specific accidents to a number of man-hours worked. The objective of a severity rate is to give some indication of the loss in terms of incapacity resulting from occupational accidents. AFR is calculated by dividing the number of accidents (multiplied by 1000) occurring during the period under consideration by the number of man-hours worked by all persons exposed to the accident or risk during the same period. The severity rate should be calculated by dividing the number of hours of working time to all persons included.
The incidence rate is defined as the number of injuries per 200, 000 employees per hour and the severity measure is the

number of cost workdays per 200,000 employees per hour.The number 200,000 is used to standardize for full-time employees working 40hrs/week and 50 weeks/year.

III. RESULTS AND DISCUSSION.

This study shows that during six years under investigation, a total of 730 accidents were reported. Out of these injuries, 728 were non-fatal and 2 were fatal. The 730 injured workers had a fatality rate of 0.27 per 100 injured workers.

3.1 Record of Injury

The causes of injury in the mill is related to occupational (status of worker) and non-occupational (unsafe act and condition) activities. Analysis of data collected in period understudied are as shown in Figures 1 and 2. This define the percentage of workers of different units of the mill. As shown in Figure 1, it could be seen that 244 cases (33.4%) of injuries which occurred in contractors followed by steel mill 184 cases (25.6%) had the greatest frequency of injuries. Higher frequency of injuries was seen in contractors (casual workers) compared to permanentworker. These findings are in agreement with the few studies available in the literature (Touminen & Saari, (1982)).

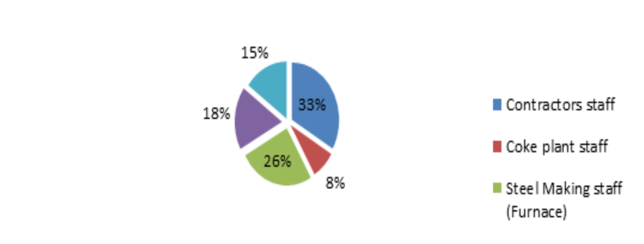

Figure 1; Occupational causes of injury

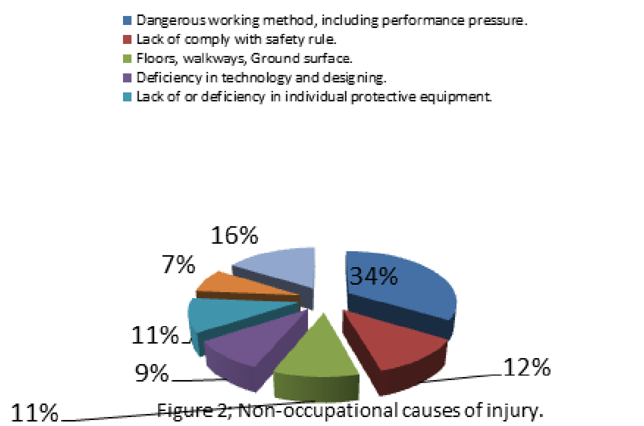

Figure 2; Non-occupational causes of injury.

In the 507 injuries studied, human failure (unsafe act) covers higher part (55.8%), despite the limitation of the sample; these findings seem consistent with those referred in the literature: industrial accidents, unsafe acts are estimated to be the majority, up to 70-80%. (Kosmowski and Kwiesielewicz 2000).

Among unsafe acts, (34.7%) are perceived as to being linked to performance pressure. This factor shows the likelihood of employees violating safety rules by taking short cuts to meet up to work pressure. Lack of or deficiency in individual protective equipment is another unsafe act. This is common with poorly renumerated work environment (Karen, et-al 2000). It was found that workers avoid wearing personal protective equipments due to discomfort, or when it creates interference with work or operations.

3.2 Source of Injury

The distribution of sources of injury captured from 2008 to 2013 is shown in Figure 3.

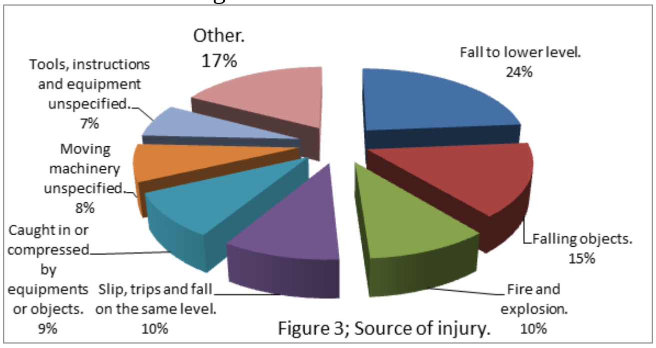

Figure 3; Source of injury.

The greatest contributor to sources of injury is falling to a lower level (24%) followed by falling object (15%). Those most contributor to sources of injury was discovered to be as result of unsafe act which include pouring of lubricant along gang ways, not wearing safety boot, rushing during machine operation and material handling, etc.

3.3 Period and Time of Accident.

The periodic distribution of accidents captured in this study is as shown in Figure 4.

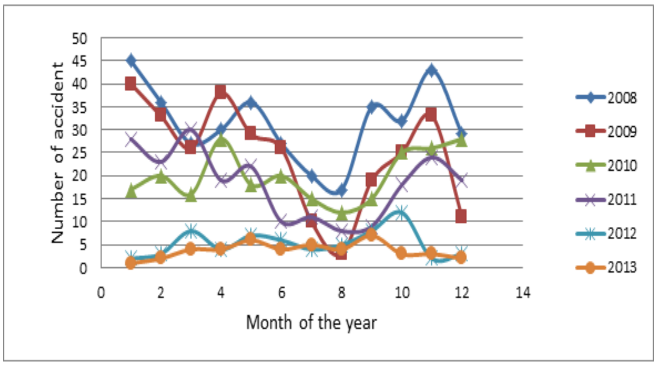

Fig. 4; Six Years Accident Record

As could be seen in Figure 4, the summary of the accidents for the period of two years (2008 and 2009) show that the highest numbers of accidents occur in January and the least in August and their association shows no correlation. In other years, the highest number of accidents occurred in different month, but the least was in August. This is believed to be as result of different work pressure in different period of the year.

3.4 Quantitative Risk Analysis and Accident Forecasting

Planning is central to all activities of an organization and may necessitate obtaining future values of variables needed in the planning .One would wish that there would be no accident (injury) in the future but that is a pipe dream. Therefore there is the need to project into the future to know how the accident conditions will be in the future, as this will place us in a good stead to manage eventaulities. To this end, time series may be used to obtain future estimates of the number of cases of accidents and few other variables. This was carried out using Minitab software.

The Monte Carlo simulation which estimates the impact of accident risk and uncertainty in the poison model is a process which results were used to describe the likelihood, or probability of reaching various results in the model. The results, suggested the various chances of accident averagely for the six years under investigation. The best and worst case scenario were also shown in Figures 5 to 7.

The forecast error is the difference between the actual value and the forecast value for the corresponding period. MAPE, MAD and MSD are related with how close the forecasted values are to the target . The lower the MAPE, MAD, MSD values the better the forecaster. The three error measures were to choose an appropriate trend for the Steel Mill .

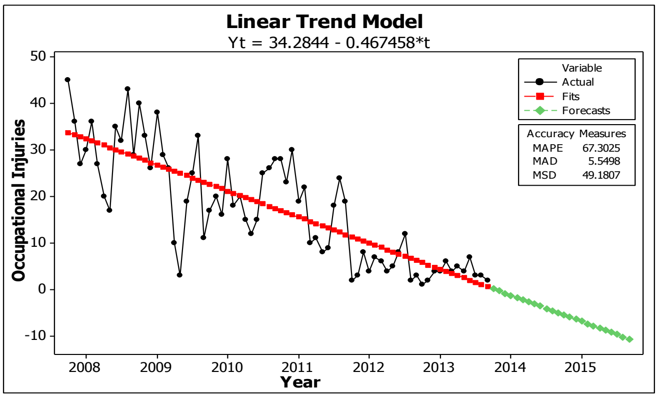

Figure 5: Linear trend Analysis Plot for occupational Injuries of the Steel Mill.

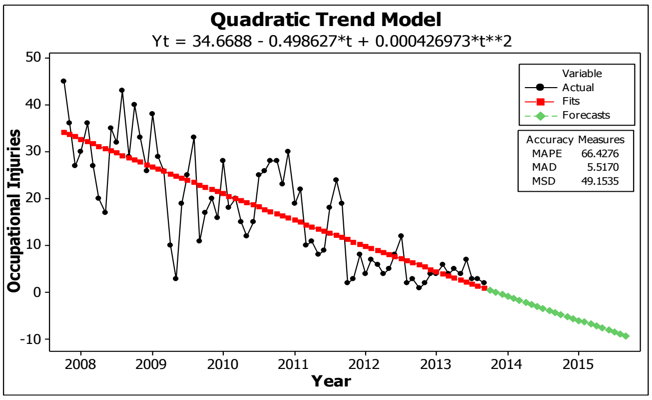

Figure 6; Quadratic trend Analysis Plot for Injuries

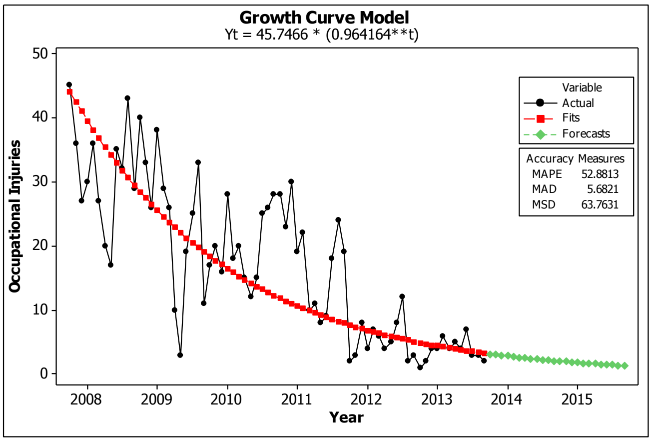

Figure 7; Growth Curve Trend Analysis Plot for Injuries

Examining the forecast values of MAPE, MAD ,MSD of the three models, the respective MAD and MSD values of 5.5170 and 49.1535 of Quadratic model are slightly lower than the corresponding MAD and MSD values of 5.5498 and 49.1807 of linear model and MAD and MSD values of 5.56821 and 63.7631 of growth curve model. But, MAPE value of 52.8813 of growth curve model is lower compared to the corresponding values of 67.3025 and 66.42276 of linear and quadratic model respectively.

Hence, the fact that the values of MAD and MSD of quadratic model is lower compared to other tested models made it the favourable choice as a forecasting model and therefore was selected as an appropriate trend or pattern for the mill.

3.5 Yearly Performance Benchmarking in the Mill

Individual benchmarking after a defined period of time (occupational safety health academy standard)

Working Day; Monday to Friday

Working hour = 8hours/day

Total number of employee = 660.

For 2008; = 59.5

Indicating that for every 100 employees, 59.5 employees have been involved in recordable injury or illness.

Frequency Rate = 297.5

Incident rates of various types are used throughout the industry. The distributions of incident rate and frequency rate for the six years are shown in Figures 8 and 9.

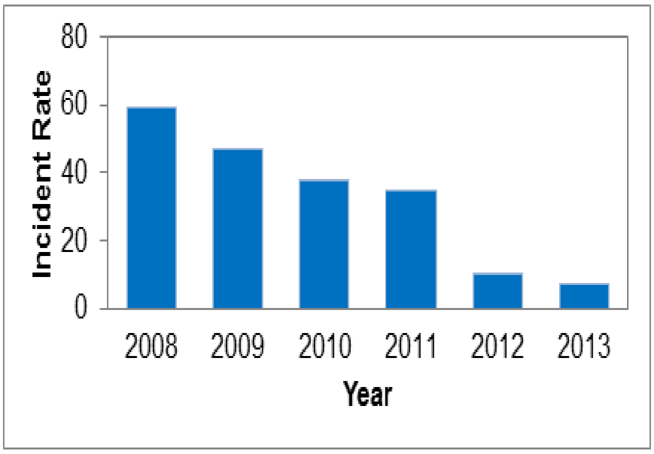

Figure 8; Periodic incident rate

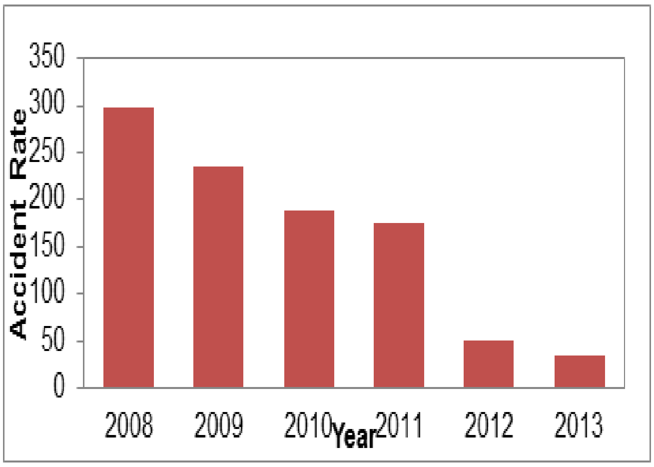

Figure 9; Periodic frequency rate

It could be seen that both trends in Figures 8 and Figure 9 decreased as the years progressed. This is believed to be as a result of acquisition of mastery and experience by the workers and others within the mill.

3.6 Shift Work, Safety and Productivity

The productivity of works over the 24hours was investigated. The real job time and accuracy measures were averaged between 08.00Am and 7.00Pm. At all other time efficiency is likely to be impaired and this is obviously seen during the early hours of the morning as indicated in

In Figure 10, It is recognized that people's performance (efficiency) at performing various tasks was not constant but varies. Tasks were considered to have varied over the course of the normal working day.

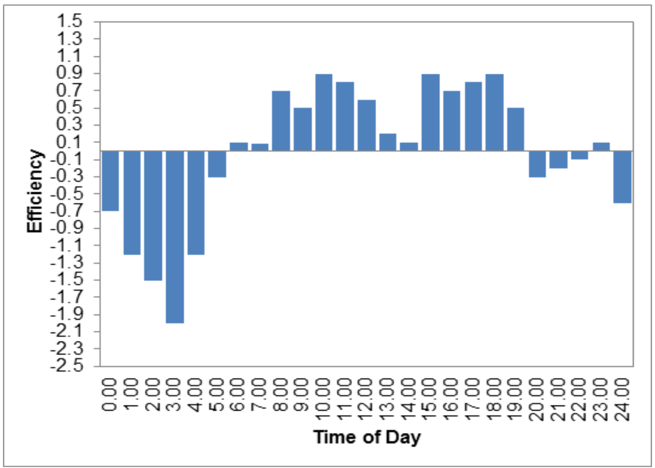

Figure 10; Performance efficiency over the 24 h day

This pattern in Fig 10 may be attributed to either a build-up of mental fatigue over a period of work activeness. Performance proved to be very poor at late hours and nights. Supervision is normally reduced at night and there might be enough active maintenance personnel available to ensure the smooth running of equipment.

3.7 Relative Risk over Hours on Duty

Relative risk of workers was examined for 12hours. There was relatively lower risk in the first hour when compared to any other hour and is highest at the 12th hour as indicated in Figure 11. This must be connected with workers' behaviour under pressure. It could also be noticed that there was relatively lower risk at the 6th hour. This reduction of risk after the 5th hour can be attributed to influence of break rest which was on the 5th hour.

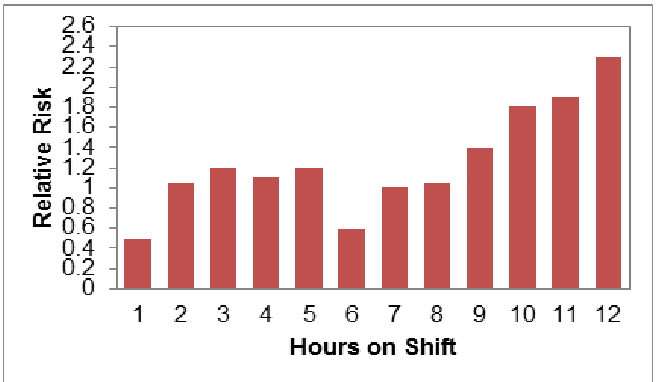

Figure 11; Relative risk over hours on duty.

3.8 Relative Risk across the three Shifts.

Risk across the three shifts existing in the Mill was as well examined. It was noticed that the risk level increased in an approximately linear fashion across the three shifts; morning, afternoon and night as shown in Figure12.

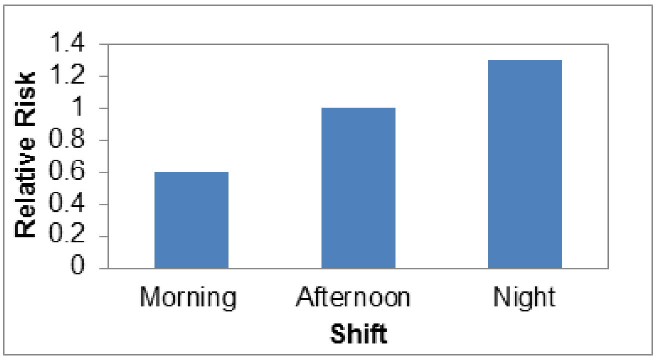

Figure 12; Relative risk across the three shifts.

That was attributed to fatigue which resulted from cumulative effect of other activities carried out in earlier shift under consideration.

IV. CONCLUSION

Accidents are mostly independent and random events; they possess some degree of uncertainly and variability in their occurrences. Therefore, they definitely require stochastic modelling due to these inherent characteristics.

The accident records were evaluated and the main factors affecting the accidents were examined. The maximum number of accidents occurred in the production department. This sector mostly involve contract workers in her operations. Greater than 55% of the cause is as a result of unsafe act by workers in the company.

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