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DETERMINANTS OF ACCIDENT IN THE MINES: A RETROSPECTIVE STATISTICAL ANALYSIS OF MINING ACCIDENTS IN GHANA

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Abstract:
The mining industry continues to be an important sector of the Ghanaian economy, contributing to the foreign exchange, employment and socioeconomic development after the colonial period. The current trend of mining operations requires greater skills and technical knowledge because they involve sophisticated machines, dangerous chemicals and explosive mechanisms, underground operations etc. Accidents in the mines just like any occupational accident may lead to deaths, injuries, disabilities and financial losses. One of the ways of improving occupational knowledge and skills is to acquire some level of understanding of accident causation mechanism. An analytical technique which will form the basis for accident and injury epidemiological studies is therefore necessary to ensure operational safety improvement. A retrospective statistical analysis of accidents in eight gold mining companies was undertaken through measures of association, hypothesis testing, trend analysis and predictive measurements. The results of the study indicate that 20% of accident cases resulted in deaths, 30% were serious and 50% minor accidents. Underground mining increases the risk fatal accident by 1.46, morning shift increases the risk of fatal accident by 4.81 and being a contract miner increases the risk of fatal accident by 1.05. The part of body injured can predict the degree of injury by reducing the error of prediction by 40.2%. Since proportion of accident fatalities increases with increasing age of miners, it is recommended that miners with higher age should not be task with high risk jobs. It is recommended again that, miners should be given improved protective clothes to guide against occurrences of fatal incidents. Especially, clothes to cover the head and upper part of the body since they top the fatality chart and the fact that fatality is strongly associated with body part.

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1. Introduction

The World Health Organization (WHO) defines Occupational health which serves as a benchmark for ensuring the wellbeing and safety of workers as a multidisciplinary activity aimed at:

> "*The protection and promotion of the health of workers by preventing and controlling occupational diseases and accidents and by eliminating occupational factors and conditions hazardous to health and safety at work; The development and promotion of healthy and safe work, work environment and work organization; The enhancement of the physical, mental and social wellbeing of workers and support for the development and maintenance of their working capacity, as well as professional and social development at work; Enabling workers to conduct socially and economically productive lives and to contribute positively to sustainable development*." [1]

Whilst policy makers and legislators continuously invest in ensuring that laws and policies are structured and enforced to attain high tax revenues, more mining investors and increase in mineral commodities etc., there are few strict occupational safety and health policies (Factories, Offices and Shops Act 1970, Act 328, PNDC Law 187 and the Radiation Protection Instrument, 1993 (L.I 1559) etc.) in Ghana enforcing the very basics of the definition proposed by [1].

The current trend of mining operations requires greater skills and technical knowledge since they involve sophisticated machines, dangerous chemicals and explosive mechanisms, underground operations etc. An accident may occur when for example, the supportive structure for underground work collapses, a conveyor belt failure, firedamp explosion and many more uncertainties. Such occurrences usually lead to production loss, damages, man – hour loss, treatment cost, societal burden in the case of permanent disability and psychological problems. Since accident frequency rate or injury frequency rate cannot be said to have been completely minimized, we cannot rely only on existing knowledge and skills in ensuring work safety and wellbeing.

Even though mining is classified as one of the high – risk industries worldwide in terms of the number of accidents, permanent incapacities and deaths [2] there appears to be little statistical research into mining accidents in Ghana. One of the ways of improving occupational knowledge and skills is to acquire some level of understanding of accident causation mechanism. Just as many researchers have sought to do, we intend to deepen the accident causation knowledge in the Ghanaian mining industry to reduce the over reliance on classical health and safety legislations and policies in ensuring health and safety standards at the work place.

1.1 Accidents and Health Issues in the Mines

A healthy workforce is vital for sustainable social and economic development on global, national, and local levels [1].

After the review of the Occupational Health and Safety (OHS) Legislation in Australia in 2012, it was identified that there is the need for a conceptual framework which will serve as a basis for professional certification. The framework was structured in the context that:

> *"…work impacts on the safety and health of humans who work in organizations; organizations are influenced by the socio – political context; organizations may be considered as a system which may contain hazards which must be under control to minimize risk; this can be achieved by understanding model causations for safety and health which will result in improvement in the safety and health of people at work; the OHS professional applies professional practices to influence the organization to bring about this improvement."* [3]

The framework suggests that the mines can improve and understand the safety and health of workers through a deepened knowledge of accident causation models. These models reveal what factors increase risk of accidents of miners on duty.

When an individual mine worker slips and falls, electrocuted, or injures any part of the body leading to hospitalization or some hours lost, the total work output is affected thereby affecting the gross mine productions. Given the great contributions that mining industries provide in areas of employment, trade and the Gross Domestic Product (GDP) of nations at large, the recognition of healthy workforce by many countries has over the years deepened to ensure the continuous positive contributions. As a result, several studies have sought to describe, analyze and quantify accidents and related risk and mitigation factors in various mining industries.

For instance, the analyses of the mining accidents at Anglogold Ashanti Limited (Obuasi Mine) by [4] reveal that; causes of accidents on the mine are mostly due to ground fall, machinery, electrocution, and slip fall; the body parts most susceptible to injuries are the hand, legs and head; disabling injuries have some effects on the production of gold on the mine. [5], in his analysis of the perception of occupational accident in the mining and quarry sectors in Malaysia found that the level of perception of workers towards occupational accidents in the mining and quarry sectors is in the moderate levels. They therefore recommended risk assessment procedures to help prevent accidents. According to [6], about 41% of all severe accidents in the US mining industry between 2000 and 2007 are machine – related.

In most cases the occurrence of an uncertain incident to a worker leads to various levels of injuries. The severity of accidents injuries may be classified based on the degree of physical damage and suffering a victim goes through [7]. [8] has discussed the levels of accident severity as fatality, permanent incapacity and temporal incapacity. According to him, a permanent incapacity occurs when an accident victim losses the earning ability permanently due to loss of body parts; temporal incapacity describes a temporal loss of earning of a victim due injuries; and fatality describes higher likelihood of death of a victim due to accident. [9] classified accidents severity as; minor – accident with no lost days or hospitalization; moderate – accident with no lost days but hospitalization; serious – accident with one out of three lost days; severe – accident with four out of ten days; critical – accidents with more than ten lost days; and fatal – accidents that lead to death. The Personal – Injury Accident report and the Monthly Accident report forms provided by the Inspectorate Division of the Minerals Commission for capturing accident cases in the mining industries in Ghana automatically classify the severity levels of accidents as minor, serious and fatal injuries.

1.2 Mining as a High Risk Job

Despite several regulations and guidelines instituted to enhance occupational safety and health, the mining industry is still labeled as one of the riskier industries in the world in terms of occupational accidents. Several comparative studies have placed the mining industry on top of the risk chart. [10] undertook a comparative analysis of fatal and non – fatal occupational injuries of workers in the mining and construction sectors in Spain using Relative Risk (RR) and Odds Ratio (OR). In their Study they found out that mining workers have higher risk of occupational injuries and lose more working days than construction workers. The comparative analysis of occupational accidents in the *mining*, *construction* and *metal* sectors in Turkey by [11] have revealed that the mining industry is "very inadequate" in work safety since it has high incident rate, permanent incapacitation rate and fatal incidence rate as compared to the other sectors. [12] analyzed the number of accident fatalities from the International Mining Fatalities Database between 1980 and 2008 from 16 countries. One of the conclusions made was that even though there are several improved safety systems in the Mining Industry, mining fatalities still occur regularly.

1.3 Odds Ratio (OR) as a Measure of Risk

A common practice in assessing statistical association between variables has been the use of the chi – square test of association. The Chi – square test is unable to determine the strength of association if it exist. A measure of the strength of association between the occurrence of an event (accident) and a given condition is the Odds Ratio (OR). [13] used OR to calculate the likelihood of fatal and serious accident among own crew copper miners and those workers on contracts in Poland. The results indicated that own crew copper miners are 5.917 times more likely to be involved in fatal and serious accidents. [14] and [15] have independently discussed the appropriate use and interpretations of OR using logistic regression analysis. [15] holds the view that the use of OR as a measure of risk can give a misleading inference and that a proper way to assess risk is to take into account both relative and absolute effects. [14] has also recommended that to be able to understand and analyze OR correctly and clearly one should convert all ORs less than 1 to those greater than 1 by taking their inverses.

1.4 Accident Causation Models

Accident causation has over the years gained great attention and has led to the construction of several causation analysis tools to assist in effective investigation of occupational accidents. [16] proposed 'the axioms of industrial safety' to attempt to deal with accident causations. The axiom states that *the occurrence of an injury results from a complicated sequence of factors, the last one of which being the accident itself.* He later presented a model known as the *'domino theory'* as an accident causation sequence such that if one domino is removed from the middle then accident is avoided. The sequence is: *injury, caused by an; accident due to an; unsafe and/ or mechanical or physical hazard, due to the; fault of the person, caused by their; ancestry and social environment.* [17] introduced two new concepts to support already existing Domino theory known as the loss causation model; such as: the influence of management and managerial error; loss, as a result of an accident could be production losses, property damage or wastage of other assets, as well as injuries. [18] reports that every accident event has many contributing factors and that every accident causation model really, is a combination of both the 'domino' and 'multi – causality theories'. On the premise of the above understanding, the Epidemiological Model was structured. [19] has said the central focus of epidemiological studies is to quantify association between exposures and outcomes. [20] has discussed some limitations and issues in the usage of inferences derived from epidemiological studies such as bias and confounding. According to him confounding may occur when the observed result of association between exposure and event differs from the true association because of the presence of a 'third variable' while bias may be due to wrong selection of participants or wrong information from participants. [21] have presented an extensive strategy on epidemiological design to help researchers to make correct hypothetical and exposure on outcome conclusion.

2. Materials and Methods

In this study, mining accident cases were investigated and their exposure status established at the time the accident occurred. The Odds Ratio (OR) was used to determine whether a particular exposure is a risk factor for a particular accident injury. In doing so, the predictive power of exposures in predicting the nature of injury sustained was measured. Granted injury - exposure dependency, the Chi – square test for trend was used to specify the nature of dependency between accident injury and exposure status.

2.1 The Odds Ratio (OR)

The OR is a statistic that measures the degree of association between two dichotomous variables [22]. It is used in Epidemiological studies as a measure of risk [23]. For example, in the 2 X 2 contingency table of mine accident injury – exposure association given in Table 1.

Table 1: Injury – Exposure Cross Classification

Injury	**Shift Time**		**Total**
	Evening	**Morning**	
Serious	n_{11}	n_{12}	$n_{1.}$
Fatal	n_{21}	n_{22}	$n_{2.}$
Total	$n_{.1}$	$n_{.2}$	$n_{..}$

Given k 2 X 2 contingency tables of injury-exposure cross classification the Mantel-Haenszel estimate of a common OR is given by:

$$OR_{MH} = \frac{\left(\sum_{i=1}^{k} \frac{n_{11(i)} n_{22(i)}}{n_{\bullet\bullet(i)}} \right)}{\left(\sum \frac{n_{12(i)} n_{21(i)}}{n_{\bullet\bullet(i)}} \right)} \qquad 1.0$$

The variance of the logarithm of OR_{MH} is given by

$$\mathrm{V}\left(\ln OR_{MH}\right) = \frac{\sum_{i=1}^{k} P_i R_i}{2\left(\sum_{i=1}^{k} R_i\right)^2} + \frac{\sum_{i=1}^{k} Q_i S_i}{2\left(\sum_{i=1}^{k} S_i\right)^2} + \frac{\sum_{i=1}^{k} \left(P_i R_i + Q_i S_i\right)}{2\sum_{i=1}^{k} R_i \sum_{i=1}^{k} S_i} \qquad 1.1$$

Where

$$\mathrm{P}_i = \frac{n_{11(i)} + n_{22(i)}}{n_{\bullet\bullet(i)}}, \qquad \mathrm{Q}_i = \frac{n_{12(i)} + n_{21(i)}}{n_{\bullet\bullet(i)}}, \qquad \mathrm{R}_i = \frac{n_{11(i)} \times n_{22(i)}}{n_{\bullet\bullet(i)}}, \quad \mathrm{P}_i = \frac{n_{12(i)} \times n_{21(i)}}{n_{\bullet\bullet(i)}}$$

A 100(1-α)% confidence interval for OR_{MH} [24] is given by;

$$\mathrm{OR}_{MH} \exp\left\{ \pm Z_{1-\frac{\alpha}{2}} \times SE\left(InOR_{MH}\right) \right\} \qquad 1.2$$

The plausibility of the measures of association using the Odds Ratios were ascertained through hypothesis testing approach. Thus, in each of the two – by – two constructs of injury – exposure associations, the OR values are statistically tested for the presence of significance associations. The Mantel – Haenszel test statistic with Chi square distribution with one (1) degree of freedom was used. With this test we are able to control the presence of possible confounding factors. The associated hypotheses for the test are that;

$\mathbf{H_0}$: There is no association between exposure and injury levels.
$\mathbf{H_1}$: There is association between exposure and injury levels.

The required Test Statistic is given by;

$$X_1^2 = \frac{\left(\left[\,\left|\sum_{i=1}^{k} n_{11(i)} - \sum_{i=1}^{k} {}^{n_{1.(i)}n_{.1(i)}}\!/_{n_{..(i)}}\right| - 0.5\right]^2\right)}{\left(\sum_{i=1}^{k} {}^{n_{1.(i)}n_{2.(i)}n_{.1(i)}n_{.2(i)}}\!/_{n_{..(i)}^2(n_{..(i)}-1)}\right)} \qquad 1.3$$

The null hypothesis of no association was rejected for $X_1^2 > X_{1(\alpha)}^2$ at a pre-selected level of significance α and a conclusion of a statistically significant association between exposure and injury levels was drawn.

2.2 Predictive Measure

The study is also interested in knowing how much ones' knowledge of the classification of one of the variables improve one's ability to predict the classification on the other variable. For instance, with a knowledge on the classification of Experience (most experience, moderately experience, less experience etc.), how well can one predict the Injury levels (Fatal, Serious and Minor)? [25] presents a measure of the Predictive power of the knowledge of one classification on another variable. Suppose the information in a row categorizations say level of Experience (E) is required to predict the values of the column categorization say Injury degree (I), the Goodman and Kruskal's index of predictive ability is given by:

$$\lambda_I = \frac{\left(\sum_{i=1}^{r} \max_j n_{ij}\right) - \max_j n_{.j}}{n_{\bullet\bullet} - \max_j n_{\bullet j}} \qquad 1.4$$

The value of λ_I measures the relative decrease in the probability of an error in guessing the degree of injury sustained during accident as between Experience unknown and known. On the other hand, the predictive power in using the column categorization (Injury degree) to guess the experience is estimated by reversing the roles played by the column and row variables. Thus,

$$\lambda_E = \frac{\left(\sum_{j=1}^{c} \max_i n_{ij}\right) - \max_i n_{i\bullet}}{n_{\bullet\bullet} - \max_i n_{\bullet i}} \qquad 1.5$$

The values of λ_E and λ_I range between 0 and 1. If the information about the predictor variable does not reduce the probability of making an error in guessing the category of the other variable, the index is zero, it is then concluded that there is no *predictive* association between the two variables. On the other hand, if the index is unity no error is made, given knowledge of the predictor variable, and consequently there is complete predictive association. Attention is now turned to a gross symmetric measure in the reduction of error in prediction without specifying which variable is used to predict the other. This coefficient measure is given by;

$$\lambda = \frac{\left(\sum_{j=1}^{c} \max_i n_{ij}\right) + \left(\sum_{i=1}^{r} \max_j n_{ij}\right) - \max_i n_{i\bullet} - \max_j n_{\bullet j}}{2n_{\bullet\bullet} - (\max_i n_{i\bullet} + \max_j n_{\bullet j}} \qquad 1.6$$

This coefficient shows the relative reduction in the probability of an error in guessing the category of either variable as between knowing and not knowing the category of the other.

2.3 Chi Square Test for Trend Analysis

The OR and the associated hypotheses only tell whether there is association between exposure and injury type without knowing how the two are associated. The Chi Square Test for Trend was used to test how the probability of occurrence of a particular injury is associated with the exposure levels given that there is significant association between them. By "how", we mean whether for instance the proportion of 'fatalities' increases with 'age'. The hypotheses are to test the null of no ordering trend association against one of the alternatives:

$\mathbf{H_1}$: Proportion of specific injuries increase with increasing exposure ordering
$\mathbf{H_2}$: Proportion of specific injuries decreases with increasing exposure ordering

The test Statistic was constructed by first assigning a numerical ordering scores to the exposure classifications and grouping the injury levels into two where our specific interest is labeled 1 and the other injuries put together and labeled 2. The 2 X r contingency table (Table 2) was constructed.

Table 2: Injury – Exposure Ordering

Injury		**Exposure**	**Ordering**		**Total**
	1	**2**	**…**	**r**	
Fatal (1)	n_{11}	n_{12}	…	n_{1r}	$n_{1.}$
Others (2)	n_{21}	n_{22}	…	n_{2r}	$n_{2.}$
Total	$n_{.1}$	$n_{.2}$	…	$n_{.r}$	$n_{..}$
Score (x_j)	x_1	x_2	…	x_r	
P_j	P_{11}	P_{12}	…	P_{1r}	

The test statistic is given by

$$X^2_{TREND} = \frac{[n_1 x]^2}{[x^2]p(1-p)} \qquad 1.7$$

Where $p = \frac{n_{1.}}{n_{..}}$ represent the proportion of fatalities in the population,

$$[n_1 x] = \sum_{j=1}^{r} n_{1j} x_j^2 - \frac{n_{1.} \sum_{j=1}^{r} n_{.j} x_j}{n_{..}} \qquad 1.8$$

$$[x^2] = \sum_{j=1}^{r} n_{.j} x_j^2 - \frac{\left(\sum_{j=1}^{r} n_{.j} x_j\right)^2}{n_{..}} \qquad 1.9$$

The null hypothesis of no ordering was rejected for $X_{TREND}^2 > X_{1(\alpha)}^2$ and the alternative hypothesis concluded for a particular test.

2.4 Data Description

The Minerals Commission receives all injury cases monthly from all licensed producing mining companies in Ghana. The data for this study have been the extracted information from all the accident cases forms submitted to the Inspectorate Division of the Minerals Commission. The forms report injuries case by case and contain data such as type of injury (fatal, minor, or serious), shift type, location where injury occurred (underground or surface), age of injured person, experience and many relevant information. The data captured are from eight active producing mining companies between 2005 and 2015. As previously discussed, our causation factors have been those of human and environmental which are clearly captured on the forms. The [26] categorization of human error: skill - based, rule - based and knowledge - based shall form the basis of understanding for our human factor classifications. For instance, knowledge is acquired over time and so the number of years of working experience shall be considered a factor. Another human factor which has a relation with one skills and mental orientation is the age which is also captured on the form. The environmental factors captured on the forms included the shift type and location from where the accident occurred. The study aimed at establishing the relationship between these factors and accident injury severity.

3. Results and Discussions

3.1 Accident Statistics

A total of 110 accident cases were taken from eight Gold mining companies in Ghana out of which 55 of them were minor accidents representing 50%, 33 serious accidents representing 30% and 22 fatal accidents representing 20% of all the accident cases (Figure 1). Majority of the injuries were sustained by individuals in the 30 – 39 age brackets with a frequency of 41 counts followed by those less than 30 years and between 40 and 49 all recording 31 counts. Those in the age bracket of 50 – 59 years recorded the lowest count of 7 accident cases (Table 3). Anecdotally, the work force in the mining companies in Ghana capture majority of people between the ages 25 and 40 at the operational level where most of the physical and machine related activities are undertaken.

Attention now is turned to observing how fatality of accident is distributed across experience level of workers. In the table below (Table 4), one can observe a decreasing trend of accident fatalities with increasing level of experience. Thus, the lesser the level of experience in the sector, the greater the fatality rate. It can be observed that 50% (11 cases) of all fatalities occurred with individuals with working experience less than 6 years.

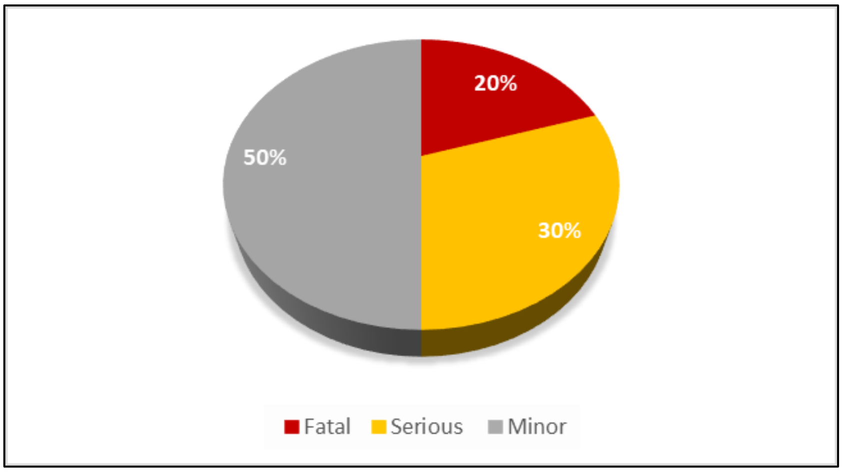

Figure 1: Pie Chart of Frequency Degree of Injury

Table 3: Cross tabulation of Age and Injury Degree

Age	Degree of Injury			Total
	Fatal	Serious	Minor	
<30	3	14	14	31
30-39	7	12	22	41
40-49	10	6	15	31
50-59	2	1	4	7
Total	22	33	55	110

Even though there is a general decreasing trend of accident with increasing experience, expected results having to do with highly experience workers less likely to sustain fatal injuries were observed by the figures in Table 4. From Table 5, it is observed that majority of fatalities were associated with whole body, upper body and the head. The most dangerous part of the human body in terms of accident is the whole body since it has the highest fatality rate of about 78% followed by the head with 41.6 % and finally the upper body with 21.4% fatality rate. Even though the eye and the hand recorded some injuries, none resulted in fatalities.

Table 4: Distribution of Fatalities with Experience

Experience	Degree of Injury	
	Fatal	Non Fatal
< 6	11	35
6 – 10	5	31
11 – 15	2	9
16 – 20	1	8
21 – 25	3	3
26 – 30	0	1
>30	0	1
Total	**22**	**88**

Table 5: Distribution of Fatalities with Body Part

Body part	Degree of Injury	
	Fatal	Non fatal
Eye	0	3
Hand	0	25
Head	5	7
Leg	2	14
Lower Body	2	15
Upper Body	6	22
Whole Body	7	2

From Table 5 and Figure 2, one can observe that the most susceptible part of the human body parts to injuries are the upper body, hand, lower body, leg and head; a result similar to those obtained in similar studies by [4].

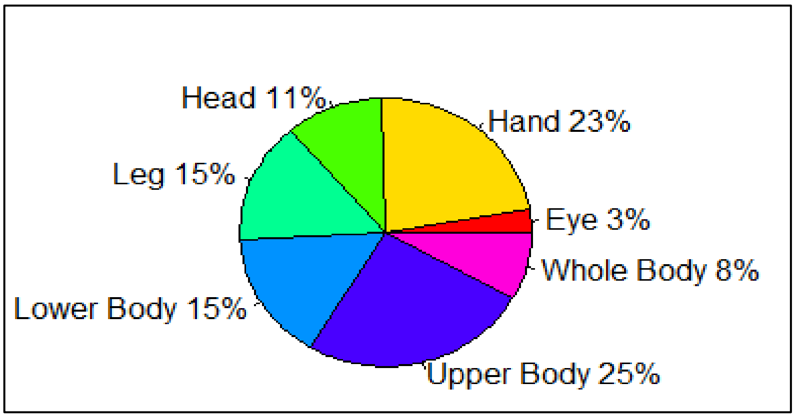

Figure 2: Pie Chart Showing Susceptibility of Body Parts to Injuries

3.2 Analysis of Accident and Labour Cross Classification

WHO's assertion of a healthy workforce being vital for sustainable social and economic development on global, national, and local levels [1] coupled with the understanding that organizations may be considered as a system which may contain hazards which must be under control to minimize risk [3] makes it imperative for us to look into the distribution of accident and injuries across the labour workforce. From the extracted data 53.6% (59 cases) of the accident cases occurred with contractors whilst 46.4% (51 cases) were associated with employees (Table 6). With the level of severity, contractors recorded the highest fatality rate (20.3%) compared to employees with 19.6% of all employee related accidents.

Table 6: Injury Distribution across Labour

Labour Type	**Fatal**	**Non fatal**	**Total**
Contractor	12 (20.3)	47 (79.7)	59 (100)
Employee	10 (19.6)	41 (80.4)	51 (100)
Total	22	88	110

Note: Marginal Percentages in bracket.

We now employ a statistical test to assess whether contractors have higher percentage of accident fatalities. We test here to see if the two labour populations have the same probability of experiencing a fatal accident. Given that contractors have 12 fatalities out of 59 accidents and employees with 10 fatalities out of 51 accidents, the *Fisher's Exact test* results gave a P – value of 1.00. We conclude the null hypothesis that the probability of a fatal accident is the same in the two labour populations. Similarly, a Chi-square test for fatal proportions with Yates's continuity correction factor in the two samples gave a Chi-squared statistic of 5.7677e-31 and a P-value of 1.00. Again, we fail to reject the null hypothesis of equal fatality proportion and conclude that proportion of fatal accidents among contractors and employees are not significantly different.

3.3 Analysis of Accident and Shift Time Cross Classification

One natural factor which is always present in the event of an accident is shift time which actually determines the concentration of light in the system. We establish here how the shift time affects the nature of injury sustained in accident. Table 7 gives a breakdown of accident injuries against shift of accident occurrence.

Table 7: Injuries and Shift time

Shift Time	**Degree of Injury**		**Total**
	Fatal	**Non fatal**	
Morning	19	50	69
Evening	3	38	41

The Fisher Exact test gives a *P-value* of 0.013 indicating that the probability of fatal accident differs for different shift hours at 0.05 significant level. Also, the Chi-square test gave a Chi-square statistic of 5.37 and a p-value of 0.021 leading to the rejection of equal fatality proportion for Morning and Evening shift hours. The results obtained above indeed declares the environmental factor, light condition, as having a statistically significant dependent relation with accident injuries.

3.4 Analysis of Accident and Mine Location Cross Classification

Table 8: Injuries against Location of Mine Site

Location	Degree Of Injury		Total
	Fatal	Non Fatal	
Surface	16	70	86
Underground	6	18	24

Table 8 presents the distribution of injuries across underground and surfaces mine sites. Figure 3 also give a pictorial view of the counts of accidents among underground and surface mine workers. Marginal analysis of fatality rate reveals that 16 out of 86 (18.6%) surface mining accidents are fatal and 6 out of 24 (25%) underground mining accidents are fatal. On the face of this analysis, even though surface mining recorded more accidents (78.2%) than the underground mining, we can say most underground mining accidents results in fatalities as compared to its counterpart surface mining accident.

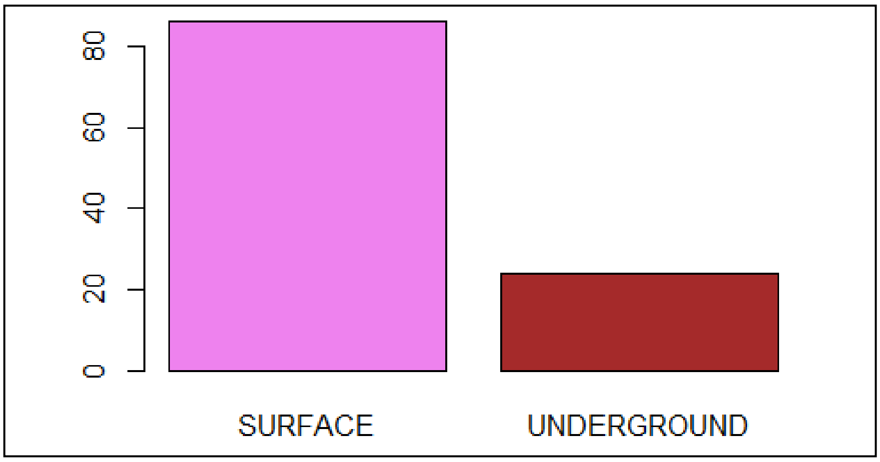

Figure 3: Bar Plot of Count of Accidents for Underground and Surface Mining

We assess here the null hypothesis that Fatalities are the same for both surface and underground mining accident cases using the Fisher's Exact test with continuity correction. The test gave a p-value of 0.57 leading to acceptance of the null hypothesis of equal distribution of fatalities for both underground and surface mining. The same statistically insignificant result at 0.05 significant level is confirmed by the Chi-square test of equal fatality proportion which gave a score of 0.163 and a p-value of 0.686.

3.5 Measure of Associations Using Odds Ratio (OR)

The Odds Ratio as a measure of association was employed to compare the odds of a specific accident injury of miners possessing certain characteristics to the odds of the injury in those who do not possess the characteristics of interest. Thus, we are able to state here, how much risk is associated with a miner possessing a certain characteristic at the point of accident in sustaining an injury. It has been estimated for example that, underground mining increases the risk of accident fatality by a factor of 1.46 (OR = 1.46)

(Table 9). Thus, miners working in the underground mining environment are 1.46 times riskier in sustaining fatal injury in accident than their surface miners' counterparts; morning shift increases the risk of accident fatality by a factor of 4.81 (OR = 4.81). Also, morning shift workers are 4.81 times likely to sustain fatal injury compared with evening shift workers; the risk associated with being a contractor or employee in sustaining fatal injury in accident do not differ much. Contract work only increases the risk of fatal accident by a factor of 1.05. Now, taking a reciprocal of the former gives the risk associated with employee work (1/1.05 = 0.95) in sustaining fatal injury in accident. These two figures give an impression of no association between labour and fatality.

Table 9: Measure of Association Using Crude ORs

UNDERGROUND MINING AND FATALITY

	FATAL	NON FATAL
UNDERGROUND	6	18
SURFCAE	16	70

OR = 1.46 (0.50, 4.26)

MORNING SHIFT AND FATALITY

	FATAL	NON FATAL
MORNING	19	50
EVENING	3	38

OR = 4.81 (1.33, 17.46)

CONTRACTORS AND FATALITY

	FATAL	NON FATAL
CONTRACTOR	12	47
EMPLOYEE	10	41

OR = 1.05 (0.41, 2.68)

The crude OR obtained in Table 9 gives an overall measure of association between the variables in context without paying attention to the presence of a third variable capable of hiding the true association. For instance, within a given age interval the average fatal accidents may be greater than the average fatal accidents of another age interval of the same general population. This would mean that the observed association can actually be explained by age categories. The deciding factor here is whether the values obtained in each of these age levels say, are the same or vary from the crude OR. The Breslow – Day test for the same degree of association across different groups was employed. Table 10 was obtained for the Location – Injury relationship across age categories.

Table 10: Injury – Location Association Stratified by Age

AGE	LOCATION	FATAL	NON FATAL	OR
< 30	UNDERGROUND	1	2	6.5
	SURFACE	2	26	
30 - 39	UNDERGROUND	3	11	1.57
	SURFACE	4	23	
40 - 49	UNDERGROUND	2	4	1.06
	SURFACE	8	17	
50 - 59	UNDERGROUND	0	1	0.00
	SURFACE	2	4	

A graph of Odds ratios and the associated confidence intervals are plotted for age levels as shown Figure 4. It can be observed from table 4.9 and that the stratum ORs do not vary greatly though different from the crude OR. This is an indication of the presence of the confounding effect of the third variable, Age. The Breslow – Day test statistic computations test for equal strata ORs follows from Table 11;

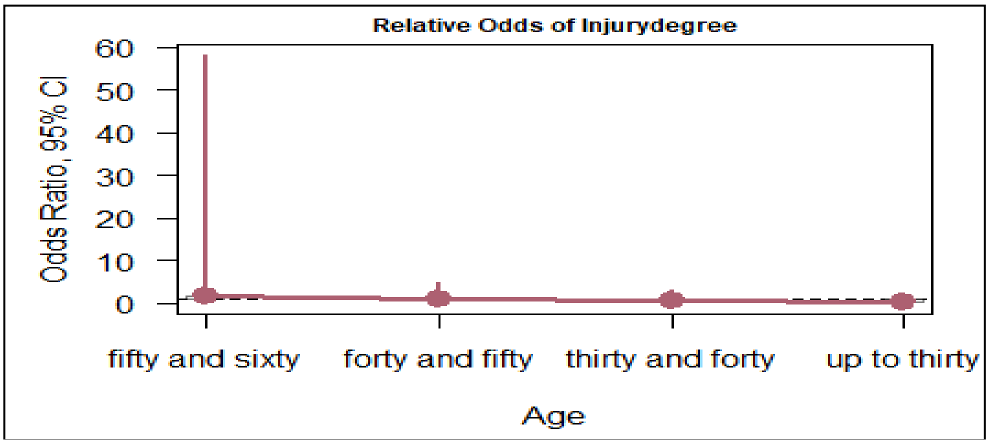

Figure 4: Graph OR across Age Levels for Injury against Location of Mining Site

Table 11: Statistics for Test of Homogeneity

Age level (i)	OR	ln OR	s_i^2	$\frac{1}{s_i^2}$	$\frac{\ln OR}{s_i^2}$	$\frac{\ln OR^2}{s_i^2}$
1	6.3600	1.8500	1.5044	0.6647	1.2297	2.2750
2	1.5894	0.4634	0.6374	1.5688	0.7270	0.3369
3	1.1438	0.1343	0.7970	1.2569	0.16850	0.0226
4	0.6000	- 0.5108	3.2889	0.3041	- 0.1553	0.0793
Total				3.7945	1.9699	2.7138

The observed value of the test statistics from the table above can be found to be 1.69 and a p – value of 0.639. The value is now compared with Chi – square distribution with 3 degrees of freedom at $\alpha = 0.05$ level of significance which gives a critical value of 7.82 from Chi-square distribution tables. Since the observed value of the test statistic is smaller than the critical value, we fail to reject the null hypothesis of homogenous association between age groups at 0.05 level of significance. The stratify analysis based on age groups has revealed that age does not statistically modify the association between injury and location of mining operation (Underground or Surface). The absence of effect modification implies the need to adjust for the presence of age as a confounder. The Mantle – Haenszle estimation technique was adopted and gave an estimate of 1.44. Again, Mantle – Haenszle test of overall association between Injury and location while controlling for the effect of age levels gave a Chi – square value of 0.42 and a p – value of 0.52. We thus conclude that, on average there is no statistically significant association between the level of injury one sustains and the location of mining site. Similar results were obtained for the other injury – exposure association measures. In each case stratifications were done to assess how other variables say, Age, Experience and Company Type mask the OR values. The results are captured in the Appendix (Tables 1A – 1I).

3.6 Trend Analysis: Age and Fatality

Given that the contingency table for age and fatalities forms a sample from a bivariate population where age is allowed to follow its natural order. Regression analysis technique was used to detect linear and higher order trends in the contingency table by allotting numerical values to the table categories. A pictorial view of the nature of association was observed by plotting the numerical scores against the proportion of fatalities in each category (Figure 5). The results are shown in Table 12.

Table 12: Fatality Categorization with Age

Injury	Age ordering				Total
	< 30	30 - 39	40 - 49	50 - 59	
Fatal (1)	3	7	10	2	22
Non-fatal (2)	28	34	21	5	88
Total	31	41	31	7	110
Score	1	2	3	4	
Pj	0.097	0.171	0.323	0.286	

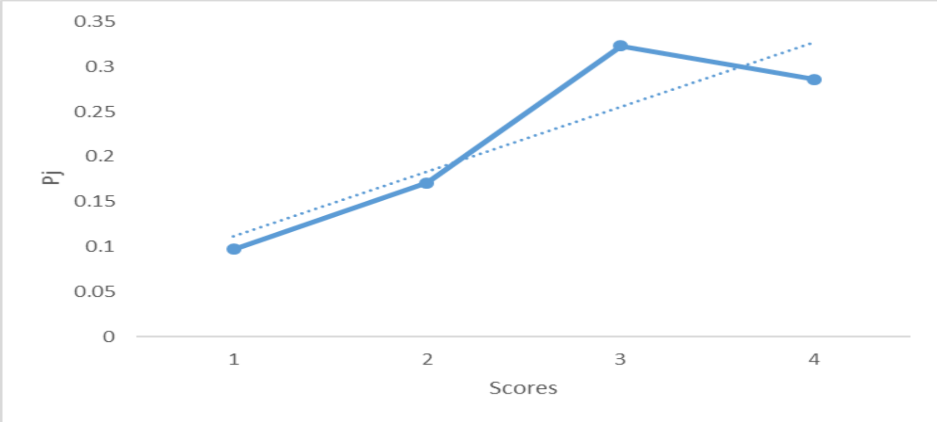

Figure 5: Line Graph of Proportion of Fatalities with Age Categorization Showing Trend

A careful inspection of the values obtained in Table 10 and the trend from the line graph (Figure 5) indicate that the proportion of fatalities increase with increasing age of miners involved in accident. Meanwhile, a Chi – square test of independence between age and injury degree gave a critical value of 5.52 and a p – value of 0.14 at 3 degrees of freedom leading to the failure of rejection of the null hypothesis of independence. The seemingly confusing results was cured by employing a trend analysis test which places much emphasis on the order of dependence or independence. The Chi – square observed value due to linear trend was 4.76 which is still insignificant at 0.05 level of significance and one degree of freedom. But at 0.1 level of significance, a significant statistical result was obtained. We conclude at 0.1 significance level that there is a significant increase in accident fatalities with increasing age of miners.

Similar analyses were carried out to ascertain the direction of dependence between experience of miners and fatalities. The results are captured in the Appendix (Table J and Figure 7J).

3.7 Predictive Measures

At this point we go beyond establishing just the relationship between variables and look into how useful the knowledge of one variable is in predicting the outcome of another variable. The Goodman and Kruskal predictive measure were used in the exercise. The interest here is to draw conclusions on how well one can guess the injury outcome of an accident knowing certain characteristics of the miner involved in the accident. The variables considered were those without any natural ordering. For example, we analysed how the knowledge of one's body part injured could help reduce the errors of predicting the level of injuries sustained during accident. The injuries were categorized as fatal, serious and minor whilst body parts were categorized as Eye, Head, Hand, Leg, Upper body, Lower body and Whole body. The 7 X 3 contingency table results (Table 13) were as follows;

Table 13: Contingency Table for Injuries and Body Part Injured

Body part	**Injury degree**			**Total**
	Fatal	**Minor**	**Serious**	
Eye	0	1	2	3
Hand	0	13	12	25
Head	5	6	1	12
Leg	2	10	4	16
Lower body	2	8	7	17
Upper body	6	15	7	28
Whole body	7	2	0	9
Grand Total	**22**	**55**	**33**	**110**

The analysis gave a predictive measure of injuries from body part injured to be 0.402. This means that one can predict the nature of injury sustained in accident with a probable error reduced by 40.2% when there is available information on the part of the body injured.

Similarly, using Table 14, the nature of accident injury that occur can be predicted from the type of company where the accident occurred with a predictive power of 0.358. Thus, the probability of making an error when guessing the outcome of an accident injury from the knowledge of the company involved can be reduced by 35.8%.

Table 14: Contingency Table for Injuries and Company

Company	**Injury**			**Total**
	Fatal	**Minor**	**Serious**	
Adamus Resources Ltd	2	13	14	29
Adansi Gold	1	0	0	1
Anglogold Ashante Obuasi	5	11	6	22
Chirano Mines	1	3	2	6
Golden Star, Prestea-Bogoso	6	11	7	24
Goldfields Ghana Ltd, Abosso	5	16	4	25
New Century Mine	1	1	0	2
Newmont Ghana Ltd, Ahafo	1	0	0	1
Grand Total	**22**	**55**	**33**	**110**

Table 15: Contingency Table for Injuries and Accident Classification

Classification	**Injury**			**Total**
	Fatal	**Minor**	**Serious**	
Electrical	0	2	1	**3**
Explosive	0	2	0	**2**
Fall	1	3	3	**7**
Falling	2	2	3	**7**
Fire	1	1	0	**2**
Handling material	2	6	4	**12**
Haulage equipment	0	0	2	**2**
Hoisting	0	1	1	**2**
Inhalation	0	1	0	**1**
Machinery	4	14	10	**28**

Slip	2	3	1	**6**
Vehicular	8	16	7	**31**
Others	2	4	1	**7**
Total	**22**	**55**	**33**	**110**

Finally, the predictive measure of injuries from the knowledge of the classification of accident from Table 15 was found to be 0.342. Which again means that knowing the kind of accident classification, one can guess the level of injury sustained with the probability of guessing it wrongly reduced by 34.2%.

4. Discussions

A retrospective statistical analysis of accidents in eight gold mining companies was undertaken. This was done through measures of association, hypothesis testing, trend analysis and predictive measurements. Due to the great losses and disadvantages pose to mining companies, our passion was triggered to statistically investigate some accident characteristics that were present in the system before the accident occurred. It has been opined by many researchers that the nature and level of losses and damages caused by accidents depend on the gravity of injury one sustains in accident. This makes it imperative to find those factors which are likely to influence injury levels in accident. Many studies have placed the mining industry on top of risk chart in terms of accident rates and attributes it to a number of characteristics such as humidity, dust exposure, danger of injury from falling rocks, explosive chemicals, location of operation (underground) etc. associated with the occupation [27, 28]. It is not surprising however that in Ghana underground mining workers are 1.46 riskier in sustaining fatal accidents compared with surface miners as revealed by the study. Literature also has it that occurrence of accidents have been the results of lack of safety education and training, lack of enforcement of rules and regulations for safety production and lack of supervision and inspection [29]. Adherence to safety protocols can be said to be company specific in the sense that management and supervision levels differ with different companies. In the study, it is revealed that knowing the company type can help one reduce the errors in predicting accident injury levels. Supervision from the regulatory agencies like the Minerals Commission should be strong to ensure strict adherence to health and safety regulations. In all working environment it takes time for one to be accustomed to the environment and the control system and procedures in the work space. The number of years one has spent doing the same thing or operating a machine becomes an inherent factor to consider in accident occurrence. It is captured in [30] and that experience is a major factor in accident occurrences. The study has revealed a general negative trend between fatalities and levels of experience. Supervision of less experience miners should be deepened in order to reduce the proportion of fatalities associated with them. Occurrence of accident is due to a number of factors that need to be studied simultaneously. The study recommends a multivariate statistical analysis of accident injuries which will simultaneously model and predict the various accident injuries and the causative factors.

5. Conclusions

A numbers of conclusions have been drawn from the study:

- Accident severity was classified under Fatal, Serious and Minor injuries. 20 % of accident cases considered resulted in deaths, 30% were serious and 50 % minor accidents.
- Higher experience is associated with lesser probability of dying from mining accident.
- Fatal injuries mostly occur when the accident involve the whole body. Thus, 77.8% of the accidents that involve the whole body results in fatalities. The next most susceptible body part to fatal injuries is the head which has 41.7% of its accidents resulting in fatalities. Accidents that occur with the hand and the eye do not usually lead to death.
- Labour type does not have a significant statistical relationship with nature of accident. Both contractors and own crew miners have the same chance of dying in accident though contractors are mostly involved in accidents than employees.
- The time of shift has a statistically significant dependent relation with accident injuries. Apart from the fact that most accidents occur during the morning shift (about 62.7%), accident deaths also occur mostly in the morning. Thus, whilst 27.5% of all accidents that occur in the morning shift resulted in deaths only 7.3% of evening accidents led to deaths. Morning shift increases the risk of fatal accident by 4.81. We believe individual workers in the morning work within rush hours and at higher pressure to deliver than their counterpart in the evening shift. This and other factors such as biorhythm of human biological system can be a factor.
- Marginally, fatalities are highly associated with underground than surface mining as 25% of underground mining accident led to deaths whilst 18.6% of surface mining accidents led to deaths. We can conclude that underground mining increases the risk of fatal accident by 1.46. The risky nature of underground mining is so clear and lies in the restrictive nature of movements in the tunnels. Nevertheless, the distribution of fatalities across the two mining locations is not statistically different.
- The part of body injured can predict the degree of injury by reducing the error of prediction by 40.2%. Thus, by knowing the body part involved in the accident, we can guess whether the injury will be fatal, serious or minor at such a reduced error.
- Knowing the type of company, we can guess the degree of injury at a reduced error of 35.8%.
- Knowing the type of accident classification, we can guess the degree of injury at a reduced error of 34.2%.

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Conflict of Interest
The authors declare no conflict of interest in the study.

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Appendix

Table 1A and Figure 1A: Labour – Injury Association Stratified by Company and Associated Graph of Odds Ratios at each Company Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Adamus Resources Ltd	0.286957	0.458014	0.6265	0.5310
Adansi Gold	3.000000	7.745967	0.3873	0.6985
Anglogold Ashante Obuasi	3.666667	5.772077	0.6352	0.5253
Chirano Mines	0.030303	0.066825	0.4541	0.6497
Golden Star, Prestea-Bogoso	1.800000	1.642591	1.0958	0.2732
Goldfields Ghana Ltd, Abosso	0.403509	0.419554	0.9618	0.3362
New Century Mine	1.000000	2.309401	0.4330	0.6650
Newmont Ghana Ltd, Ahafo	3.000000	7.745967	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 5.2867,
df = 7,
p-value = 0.625

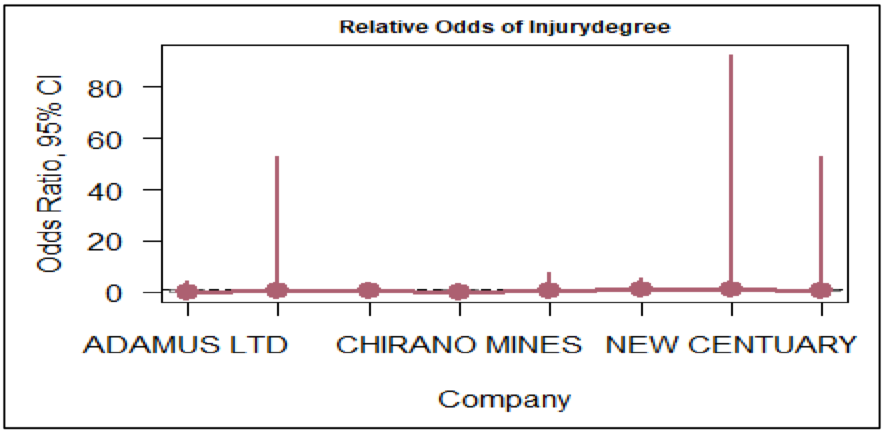

Table 1B and Figure 1B: Shiftime – Injury Association Stratified by Company and Associated Graph of Odds Ratios at each Company Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Adamus Resources Ltd	0.186207	0.296942	0.6271	0.5306
Adansi Gold	0.333333	0.860663	0.3873	0.6985
Anglogold Ashante Obuasi	0.466667	0.493313	0.9460	0.3442
Chirano Mines	0.030303	0.066825	0.4541	0.6497
Golden Star, Prestea-Bogoso	0.340659	0.539069	0.6319	0.5274
Goldfields Ghana Ltd, Abosso	0.864662	0.810172	1.0673	0.2859
New Century Mine	1.000000	2.309401	0.4330	0.6650
Newmont Ghana Ltd, Ahafo	0.333333	0.860663	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 2.463,
df = 7,
p-value = 0.9299

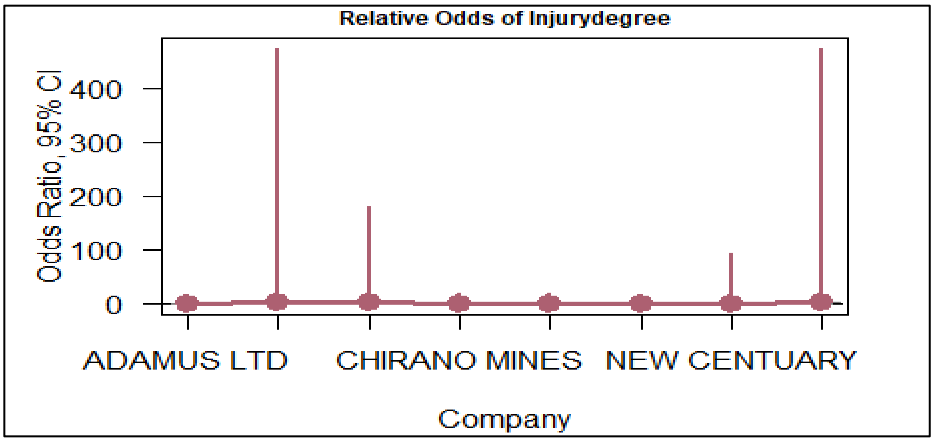

Table 1C and Figure 1C: Location – Injury Association Stratified
by Company and Associated Graph of Odds Ratios at each Company Level

Company	**Estimate**	**Std. Error**	**Z-value**	**Pr(>z)**
Adamus Resources Ltd	0.090909	0.191479	0.4748	0.6349
Adansi Gold	3.000000	7.745967	0.3873	0.6985
Anglogold Ashante Obuasi	3.181818	6.550962	0.4857	0.6272
Chirano Mines	0.272727	0.600526	0.4541	0.6497
Golden Star, Prestea-Bogoso	0.351351	0.720733	0.4875	0.6259
Goldfields Ghana Ltd, Abosso	0.268293	0.551836	0.4862	0.6268
New Century Mine	1.000000	2.309401	0.4330	0.6650
Newmont Ghana Ltd, Ahafo	3.000000	7.745967	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 2.6319,
df = 7,
p-value = 0.9168

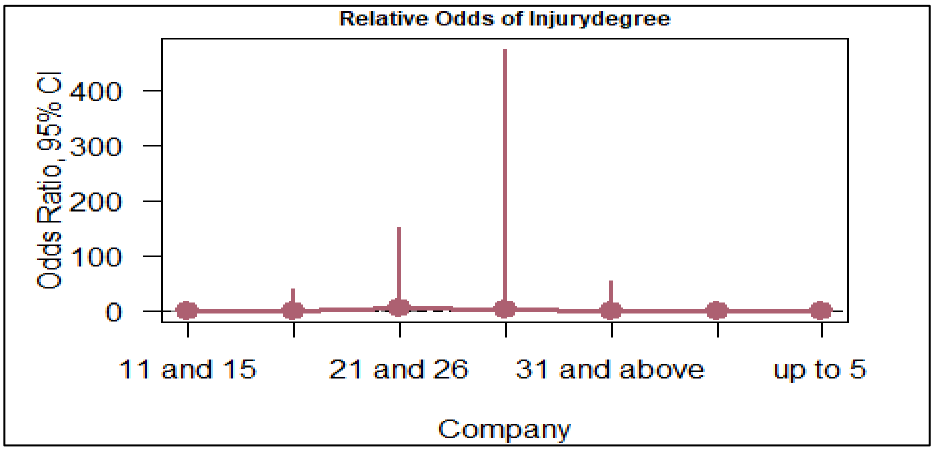

Table 1D and Figure 1D: Location – Injury Association Stratified
by Experience and Associated Graph of Odds Ratios at each Experience Level

Experience	Estimate	Std. Error	Z-value	Pr(>z)
Up to 5	0.34694	0.28128	1.2334	0.2174
6 - 10	0.50638	0.46574	1.0873	0.2769
11 - 15	0.33333	0.45542	0.7319	0.4642
16 - 20	1.15385	2.07067	0.5572	0.5774
21 - 25	4.20000	7.68999	0.5462	0.5850
26 - 30	3.00000	7.74597	0.3873	0.6985
31 and above	0.33333	0.86066	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 2.3373,
df = 6,
p-value = 0.8862

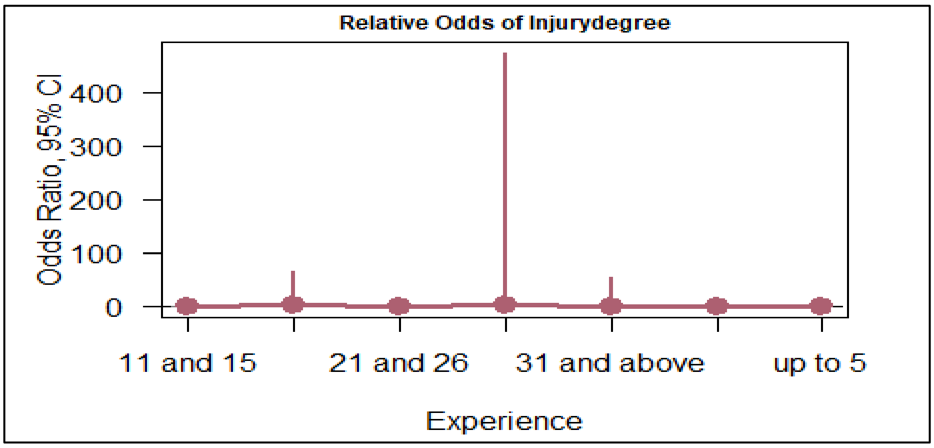

Table 1E and Figure 1E: Shiftime – Injury Association Stratified
by Experience and Associated Graph of Odds Ratios at each Experience Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Up to 5	0.348048	0.273734	1.2715	0.3221
6 - 10	0.520000	0.525218	0.9901	0.2036
11 - 15	0.107692	0.181472	0.5934	0.5529
16 - 20	1.666667	3.103164	0.5371	0.5912
21 - 25	0.020408	0.043634	0.4677	0.6400
26 - 30	3.000000	7.745967	0.3873	0.6985
31 and above	0.333333	0.525218	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 3.802,
df = 6,
p-value = 0.7035

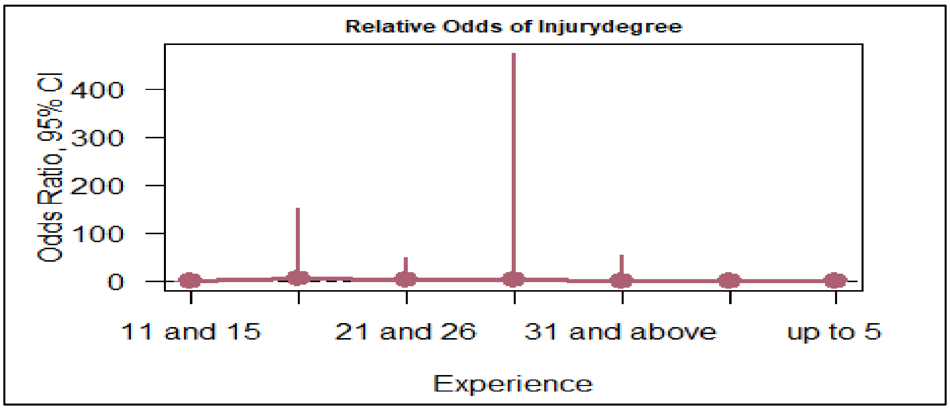

Table 1F and Figure 1F: Labour – Injury Association Stratified by Experience and Associated Graph of Odds Ratios at each Experience Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Up to 5	0.89357	0.59873	1.4924	0.1356
6 - 10	0.59184	0.53325	1.1099	0.2671
11 - 15	0.81818	1.07844	0.7587	0.4480
16 - 20	4.71429	8.34602	0.5679	0.5722
21 - 25	2.77778	4.05720	0.6847	0.4936
26 - 30	3.00000	7.74597	0.3873	0.6985
31 and above	0.33333	0.86066	0.3873	0.6985

Homogeneity of Odds Ratios
X-squared = 2.0085,
df = 6,
p-value = 0.9189

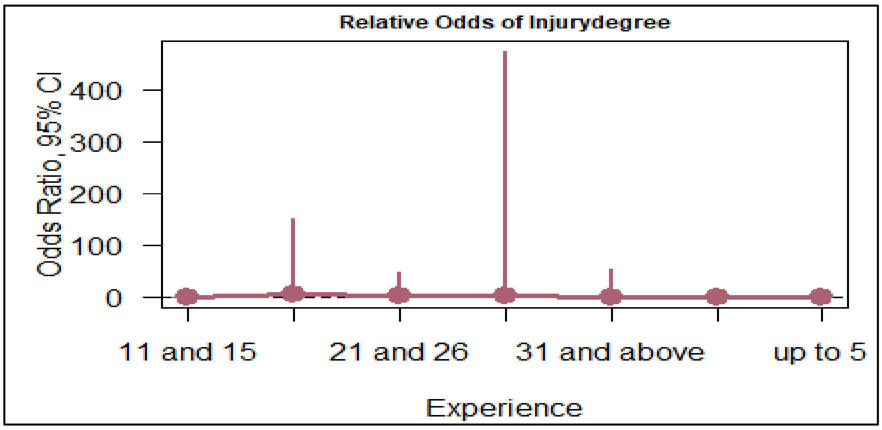

Table 1G and Figure 1G: Labour – Injury Association Stratified
by Body Part and Associated Graph of Odds Ratios at each Body Part Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Eye	1.66667	3.75154	0.4443	0.6569
Hand	0.79310	1.61683	0.4905	0.6238
Head	2.33333	2.75771	0.8461	0.3975
Leg	1.30769	1.65661	0.7894	0.4299
Lower Body	0.68421	0.68421	0.7924	0.4281
Upper Body	0.55556	0.55556	1.1207	0.2624
Whole Body	0.25714	0.25714	0.5864	0.5576

Homogeneity of Odds
X-squared = 1.6844,
df = 6,
p-value = 0.9463

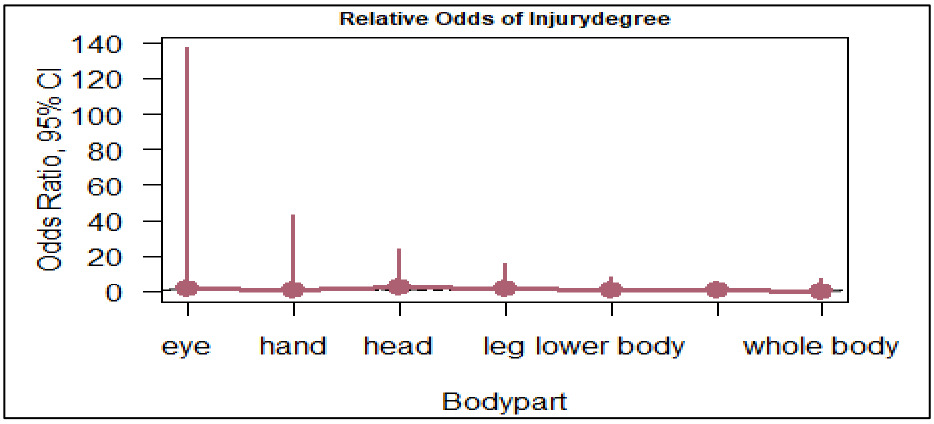

Table 1H and Figure 1H: Shiftime – Injury Association Stratified
by Body Part and Associated Graph of Odds Ratios at each Body Part Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Eye	7.00000	17.549929	0.3989	0.6900
Hand	2.46667	5.047566	0.4887	0.6251
Head	0.42857	0.506517	0.8461	0.3975
Leg	0.26154	0.287326	0.6118	0.5407
Lower Body	0.17647	0.350014	0.6142	0.5391
Upper Body	0.39095	0.350014	1.1169	0.2640
Whole Body	0.06667	0.124127	0.5371	0.5912

Homogeneity of Odds Ratios
X-squared = 3.3423,
df = 6,
p-value = 0.7648

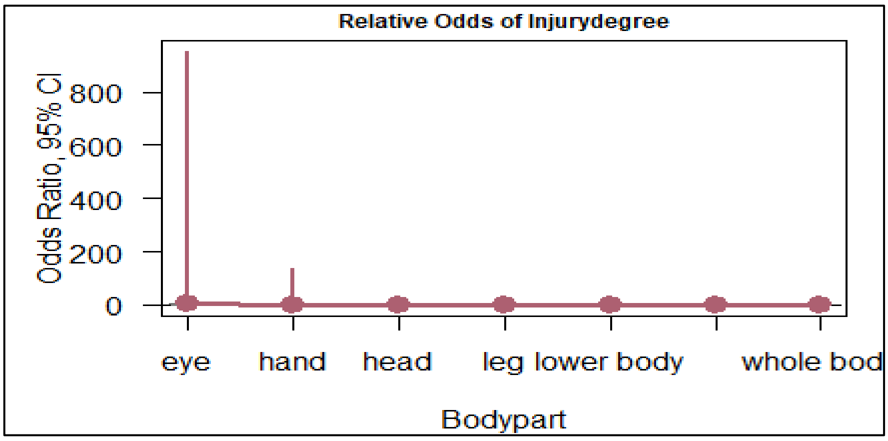

Table 1I and Figure 1I: Location – Injury Association Stratified
by Body Part and Associated Graph of Odds Ratios at each Body Part Level

Company	Estimate	Std. Error	Z-value	Pr(>z)
Eye	1.66667	3.75154	0.4443	0.6569
Hand	0.79310	1.61683	0.4905	0.6238
Head	2.33333	2.75771	0.8461	0.3975
Leg	1.30769	1.65661	0.7894	0.4299
Lower Body	0.68421	0.86342	0.7924	0.4281
Upper Body	0.55556	0.49570	1.1207	0.2624
Whole Body	0.25714	0.43850	0.5864	0.5576

Homogeneity of Odds Ratios
X-squared = 1.6844,
df = 6,
p-value = 0.9463

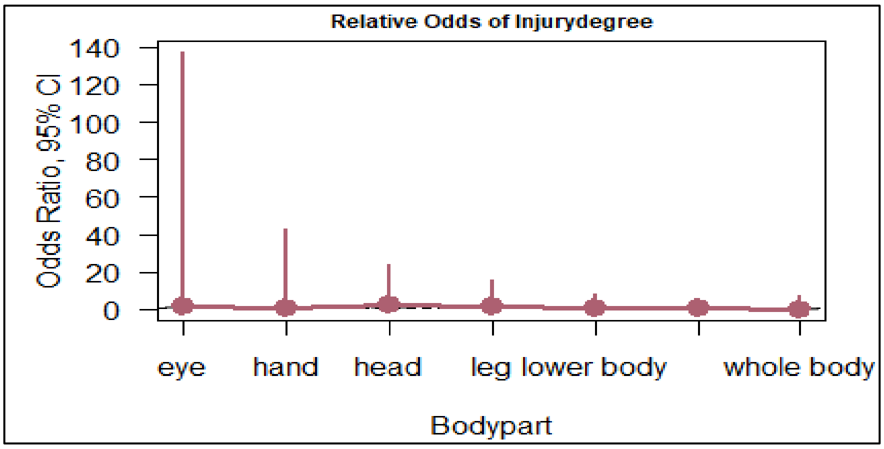

Table J: Fatality Categorization with Experience

			Experience	Ordering				
Injury	< 6	6 - 10	11 - 15	16 - 20	21 - 25	26 – 30	>30	Total
Fatal (1)	11	5	2	1	3	0	0	22
Non-Fatal	35	31	9	8	3	1	1	88
Total	**46**	**36**	**11**	**9**	**6**	**1**	**1**	**110**
Score	1	2	3	4	5	6	7	
P_j	0.239	0.139	0.182	0.125	0.500	0.00	0.00	

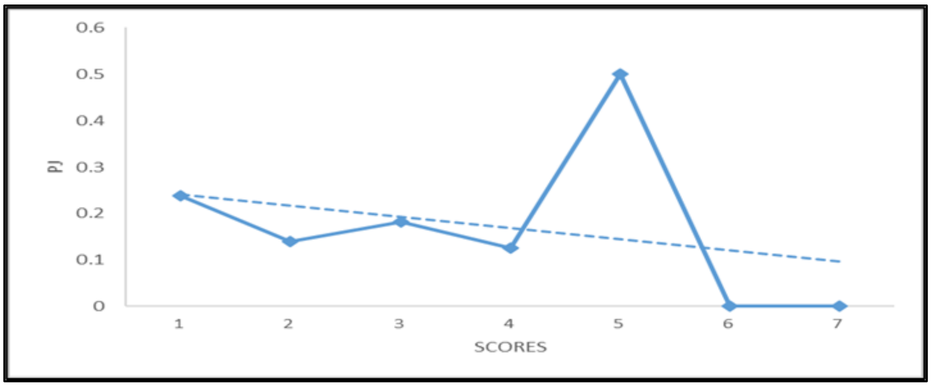

Figure 7J: Line Graph of Proportion of Fatalities with Experience Categorization Showing