

Analysis of work accidents data: A case study of the South African mining industry

Name : Masala Theron Masindi

Student Number : 11624701

Supervisor : Prof F Amponsah-Dacosta

Co-Supervisor : Dr Sphiwe Emmanuel Mhlongo

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DEDICATION

To

God Mount Zion for making it possible for me to complete this work.

To my mother Mmabotse Jane Ramaloko who never stop to encourage and inspire me

To my lovely husband, Alistair Lewis Prodigy Matika

To my wonderful daughter, Tshedza Fatima Anesu Matika

To my beloved family members

And

To my supervisors without them I wouldn't have completed this work

DECLARATION

I, **Masindi Masala Theron**, with student number 11624701 hereby declared that the research dissertation titled “***Analysis of Work Accidents Data: A Case Study of the South African Mining Industry***” submitted to the Department of Earth Sciences at University of Venda, has not been submitted previously for any degree at this or any other university. It is original in design and in execution, and all reference material contained therein has been duly acknowledged.



Signature:

Date: 07 September 2023

Masala Theron Masindi

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First and foremost, I would like to thank the almighty God of Mount Zion for giving me the opportunity and strength to write my dissertation with special reference to the quote by His Grace, The Right Reverend, Dr B.E Lekganyane stating “don’t lose hope keep the faith on whatever you do”. I am grateful to God for the good health and wellbeing that was necessary to complete this dissertation.

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ABSTRACT

For any industry to be successful, its production needs must be met while the highest safety standards are maintained. Mining accidents and their subsequent fatalities have enormous social and economic consequences. The current study was undertaken to better understand the fundamental causes of mine accidents so that major remedial actions can be developed and implemented to improve safety in the mining industry. The purpose of this study was to analyse work accident data of the South African industry that was compiled for the period 2008–2017.

Secondary data on accidents was requested from the Department of Mineral and Energy Resources (DMRE). Accident data obtained from DMR was summarized, characterized, and described in a meaningful manner to determine the variables or factors which contribute to accidents in the mining industry. Variables that contribute to accidents in the mining includes fall of ground/rock fall, machinery, transportation and mining, general, conveyance accidents, electricity, fires, explosive, heat sickness and miscellaneous. Descriptive statistics, figures, and tables were used to describe and understand the accidents within the mining industry.

A chi-square test was used to quantify the extent to which accident outcomes and commodities are independent of each other by year and injury type. This was done to examine the association between the dependent accident outcome and the independent variables such as year, commodity type, and casualty type. The study was significant in that its findings will contribute to building a culture of safety within the mining environment¹, which was not only to reduce the risks of miners being exposed to potential workplace accidents but also had an impact on their attitude and perceptions towards workplace safety and their perception of zero as this is one of the priorities which the mining industries need to achieve.

The study produced results that summarize the influence of year, commodity type, and casualty type on accident outcome. In particular, the analysis of accidents helped in establishing the relationship between the dependent accident outcome variable and several independent variables, such as year, commodity type, and casualty type, there was an increased number of accidents with respect to different commodities with different in years. The findings of this study

will be used in planning, designing, and implementing health and safety programmes that will contribute to decrease in the number of accidents for mining different commodities in South Africa.

Keywords: mining accidents, accidents data analysis, fatalities, Chi-Square test

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LIST OF ACRONYMS AND ABBREVIATIONS

DMRE	Department of Mineral Resources and Energy
FRAM	Functional Resonance Analysis Methods
FTA	Fault Tree Analysis
GDP	Gross Domestic Product
HFACS	Human Factor Analysis Classification System
ILO	International Labor Organization
OT	Other Minerals
PGM	Platinum Group Minerals
PPE	Personal Protective Equipment
SA	South Africa
SAMRASS	South African Mines Reportable Accidents Statistical System
SMS	Safety Regulation System
STAMP	Systemic Theoretic Accident Modeling and Processes
UIGC	Univen Innovation Growth Company
US	United State
FHDC	Faculty of Higher Degrees Committee
REC	Research and Ethics Committee

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

In many countries, the mining industry is an important part of the economy. It produces minerals and raw materials that are used and needed in many industries, such as construction, energy, agriculture, medicine, and electronics (Saxena, 2013). Several studies have shown that mining is one of the most dangerous jobs because of things like humidity, dust, falling rocks, and falls on the same level and on different levels. Ural (2008) and Patterson et al. (2008) found that human actions, mechanical problems, and environmental factors all influence how often and how bad accidents are.

Hollnagel et al. (2008) said that accidents are unplanned events that happen when there are unexpected changes in how a system works. Accidents in mines can lead to injuries, disabilities, death, serious damage to the environment, and even the loss of the whole system. It results from a variety of hidden issues, including poor maintenance, malfunctioning equipment, and human error. In safety-critical systems, where people's lives depend on how well the system works, significant accident analysis focuses on figuring out why the system failed so that similar disasters don't happen again, or their effects are lessened. (Sommerville, 2018). During the past two decades, there has been a growing recognition that small events and even near misses should be subjected to a similar methodical study, such as safety-critical software. Consequently, the volume, dependability, and accessibility of information that can be made accessible in this circumstance are increased (Bowen, 1993).

According to Reason (1991), when a mining accident happens, an accident analysis is performed to determine the proximal and enabling cause variables. This is done to identify preventative steps to be performed. This procedure includes the methodical gathering, recording, and dissemination of pertinent information. The scientific and scholarly study of the events that transpired during an accident is known as accident analysis. Analysis accident data is performed to determine the root cause of an accident to provide suggestions or take remedial steps to avoid the recurrence of the same incident in the future (Leveson, 2004). It is performed so that the accident dataset can be summarized in a meaningful way for everyone to understand the sequence on how accident happened.

Causal analysis uses the principle of causality to determine the cause of events. Though people speak of a "chain of events", which means trend which contributing factors follow to result to an accident. On the other hand, Expert analysis relies on the knowledge and experience of field experts. This form of analysis usually lacks a rigorous (formal/semiformal) methodological approach. This usually affects falsifiability; information, a document, or evidence to mislead and objectivity; the quality of being objective of analyses. This is of importance when conclusions are heavily disputed among experts. Organizational analysis relies on systemic theories of organization. Most theories imply that if a system's behavior stayed within the bounds of the ideal organization, then no accidents can occur. This is because one of the causes of accidents is machine itself (Hepworth, 2006). Choosing an organizational theory for accident analysis comes from the assumption that the system to be analyzed conforms to that theory.

Mining industries today are complex and dynamic social engineering systems. They pursue many goals: productivity, safety, reliability, and employee well-being and characterized by complex social structures, close connections, technological complexity, and environmental conditions. They integrate many cooperating parties from different social and technical disciplines, performing different tasks in a different time-space system. Modern "work activities" is highly specialized and potentially dangerous to both personnel and the environment. It is more and more difficult to define as wholly physical or mental, more and more often it requires an abstract understanding. Today's "tools" of work are becoming more and more complex and abstract. More computer systems and less practical work require an employee to be highly specialized and, at the same time, to understand the operation of the entire system (Eurofund, 2015)

For instance, mining of gold, coal, platinum, and other minerals differs with its lifecycle. Mining of gold has always been one of the most popular metals in the world. Mining for gold typically involves methods like panning, sluicing, dredging, hard rock mining and by-product mining. The most effective method used is hard rock mining since reserves are typically encased in deep underground rock. In the processing of mining such commodities lot can happen including fatalities, injuries and so much more which will be different from other commodities. This plays a role in an increased number of accidents occurring in the mining industry. South Africa's gold sector is a world leader in deep-level gold mining. Deep-level underground mining, however, brings with it risks and hazards which require constant commitment and adherence to safety and health standards and procedures. High temperatures and high humidity levels in some

underground mines create difficult working conditions and can decrease productivity. There is a great relationship between the different variables (as year, commodity type, and casualty type) in the accident dataset, reason being accident increase occurs differently in the mining industry depending on whether the operation was surface or underground.

1.2 Problem Statement

The mining industry presents several issues in terms of the safety of persons working inside, outside, and around mines, since mining is an adventure that is inherently dangerous. Miners travel to locations where no one has gone before, and the working environment, particularly in underground mines, is strange and dangerous. These hazards often result in significant accidents and other occurrences, with the consequences including property and equipment damage, suspension of operations, injuries, and even death, among other things. While significant progress has been made toward achieving zero employee injuries, accidents remain the mining industry's principal problem. However, deaths and injuries remain high, and repeated deadly incidents at most mines remain a major issue. A great deal of work is still required to meet the Mine Health and Safety Summit goals. High personnel turnover continues to be an issue for the Mine Health and Safety Inspectorate as a whole, owing mostly to skills shortages in the mining industry.

Amponsah-Tawiah (2011) said that the safety and well-being of employees are important parts of any business, no matter how dangerous the job is. Jones (1997) also said that safety is one of the most important things that needs focus and direction to improve safety management and make a safer culture. As a result, mishaps that risk human safety are unacceptable. Additionally, individuals are growing insensitive to safety warnings, exposing them to hazards such as injury, disability, death, and accidents. According to Grimaldi and Simonds (1989), this is a problem because an accident could violate South African law as well as be costly to a business in terms of medical claims, lost productivity time, and decreased staff efficiency. According to the preceding logic, the occurrence of mining accidents with the potential of fulfilling the ideal of a zero-harm mining sector remains a danger. Even if such disasters claiming multiple fatalities are not necessarily characteristic of the total accident experience in the mining industry, where casualties usually tend to mount in ones and twos, a glance at the casualties suffered in recent years in SA immediately invites comparison with experience in other major mining countries. Consequently, research that seeks to thoroughly assess accident dataset from the South African mining sector is required to determine the trend and pattern in the mine accident data. Accidents in the South African mining industry continue to be a danger, there was a need to check the

association between factors contributing to accidents with respect to different years. The study collected partially processed data from year 2008 to 2017 to determine the relationship between different variable in a dataset provided. The change in years also affect the total number of accidents occurring to different commodities in the south African mining industry as shown by the dataset provided by DMR.

1.3 Research Aim and Objectives

The purpose of this study was to analyse work accident data from 2008 to 2017 for the South African mining industry. The specific objectives of the study were:

- To summarise, characterise and describe the mine accident data in a more meaningful way.
- To examine the association between the dependent accident outcome and the independent variables such as year, commodity type, and casualty type.
- To determine the relationship between the different variables in the accident dataset.
- To establish the overall patterns and trends in the mine accident data

1.4 Research Questions

- How can the mine accident data be summarized, characterized, and described in a more meaning manner?
- What is the nature of the association between the dependent accident outcome and independent variables?
- What is the nature of the relationship between variables in a dataset?
- What are the overarching patterns and trends present in the mine accident data?

1.5 Justification and Significance of the Study

The study was significant as trends and pattern were determined after summarising the processed data from department of mineral resource. Descriptive statics was used to summarise, characterise, and describe the data in a meaningful way. It provided an overview of the central tendencies, such as mean, median, and mode, as well as measures of variability like standard deviation and range. The goal was to understand the distribution and characteristics of the variables, and this gave to gain insights into the overall patterns and trends in the data.

The study was significant as Chi square test was selected to investigate the interrelationship between a dependent variable (for example accident outcome) and independent variables (such as year, commodity type, and casualty type). This was done to examine the association between the dependent and the independent variables, so that a conclusion can be driven if there was a relationship between variables. This was done to ensure that safe technologies and mining practices are adopted given that a significant number of accidents occurred whilst opening or mining in old areas.

The significance of determining the relationship between the different variables in the accident dataset was to compare means across different groups or categories. The findings of the study will help inform the planning, design, and implementation of intervention programmes for minimizing the frequency of occurrence of accidents in the mining industry. In addition, the findings of the study can influence government policies and other legislative frameworks aimed at ensuring high safety standards at the workplace. This can be done by making practices in the South African mining industries by setting out clear principles for effective policy development and implementations. The Department should continue to enforce and monitor compliance of safety at mines by conducting focused inspections and audits.

The importance of establishing the overall patterns and trends in the mine accident data was because there was a lack of understanding of the trends in mining accident issues from 2008 to 2017. This was employed to facilitate the investigation of the factors influencing the total accidents. In conclusion, variables like year, commodity, or casualty name as predictors. The goal was to estimate the impact of these variables on the count of accidents.

CHAPTER TWO: LITERATURE REVIEW

This chapter aims to provide a literature review on analysis on work accident data. The subtopics discussed include the history of the South Africa mining industry and the background on safety of the South Africa mines, background of mine safety in South Africa, accidents in different operations and precautions in surface mines, accidents in underground working, Mine safety statistics and safety management system.

2.1 The South African Mining Industry

South African mining industry has played a critical role in the country's emergence as a regional and continental economic powerhouse. Mining accounts for one-third of South Africa's market capitalization, provides 51% of GDP, and functions in a free market twenty years after the country transitioned from a repressive apartheid regime to democracy in 1994. (Statistics South Africa, 2013). The finding of gold on the Witwatersrand highlands in 1886 was a watershed moment in South African history. It is here that an estimated 40% of all gold ever discovered in the world was discovered, swiftly transforming SA from an agrarian civilization to the world's greatest gold producer. South Africa is now the world's leading producer of minerals and raw commodities.

SA is also the world's third biggest coal exporter. Historically, the sector has been chastised for its poor safety records and high number of deaths, notably the harsh working conditions of many black South Africans under the former regime. The country's policies and routines under apartheid were drastically altered under the new administration. These adjustments were made not simply to help the economy flourish, but also to address the vast disparity between black and white workers in the sector, who all worked in the same conditions.

2.2 Background of Mine Safety in South Africa

The International Labor Organization (ILO) estimates the global yearly number of work-related deaths. Estimates of the number of work-related deaths in SA were among the data issued by the ILO. According to the International Labour Organization, 1,908 people died in work-related incidents in 2014. In the same year, 288 miners were killed in mining accidents (Leigh et al., 2015). Considering that miners account for less than 500 000 people (less than 4% of overall employment) in the national workforce of roughly 14 million, mining was responsible for a disproportionate number of work-related deaths (about 15%). Mutemerie et al., 2002).

According to comparisons of Australian and South African mortality statistics, miners in South Africa were 4-5 times more likely to die in mining accidents than in Australia. The depth of gold mines, the labor intensiveness of gold and platinum mining, and the enormous number of employees on a single mine (the latter of which offers substantial organizational and logistical issues) distinguished SA from other major mining nations (Gunnigham et al., 2013).

On the other hand, Australian mines were more automated, and fewer workers were directly exposed to mining risks. The South African coal sector's mortality rates were more equivalent to the national rates for Australian mines, showing better comparability in mining practices and circumstances. It is anticipated that the South African mining industry's safety performance needs to improve by at least 20% each year to match the average performance of Australia, the United States, and Canada in 2013. Chamber of Mines, 2014). In 2014, the biggest improvement in a single year was 16%. From 2001 to 2008, the mortality rate in gold mining fell dramatically. The pace of progress decreased from then until 2010. Improvements progressed slowly from 2011 to the present, with periodic reversals correlating to years when mining catastrophes occurred (Plummer, 2013).

Large mining accidents still occur today, and to assess the overall situation and offer information on major mine accidents in SA, a grand total of 31253 big mining incidents occurred between the years of 2008 and 2017, each of which resulted in more than 1117 deaths. In 2015, 77 deaths were documented, the fewest in the industry's history, despite employee numbers increasing during this time. Despite tremendous progress, the industry realizes that more work needs to be done. Each fatality is one too many. Mining can be difficult labor in difficult and sometimes dangerous conditions; SA's mining environment is unique and very difficult. Some miners work up to five kilometers underground, where temperatures in the virgin rock may exceed 60°C. In these and other cases, mine employees' safety must take precedence.

2.3 Accidents in different operations and precautions in surface mines

Mining is a dangerous occupation that poses a significant safety risk to miners (IOL, 1996-2023). Unsafe conditions in mines produce several mishaps, resulting in the loss and injury of human life, property damage, and production stoppage. Surface mining techniques are used when a vein of coal or other substance lies so close to the surface. It can be mined with bulldozers, power shovels, and trucks instead of using deep shaft mines, explosive devices, or coal gasification techniques. Surface mining is especially useful when the rock contains so little of the

ore being mined those conventional techniques, such as tunneling along veins, cannot be used. Surface mining removes the earth and rock that lies above the coal or mineral seam and places the overburden off to one side as spoil (Gardner et al., (2007)). The exposed ore is removed, and preliminary processing is done on site, or the ore is taken by truck to processing plants. After the mining operations are complete, the surface can be recontoured, restored, and reclaimed. The following are the significant accidents caused by various mining activities, as well as their prevention and control:

Surveying- fall from heights and are thrown from overturned vehicles. Because hazards are caused by ground formation, they are unlikely to be removed using properly constructed scaffolds.

Clearance- hit by a falling tree and dirt from a demolished structure, which may be prevented if a professional operator is used. The use of a power saw or other equipment for topsoil removal may be avoided if the operator wears complete personal protection.

Laying out- risks are frequent during building construction; a single-story building is less dangerous than a bigger multi-story one. Highway construction poses fewer risks than sloped terrain, whereas roadways on flat land pose fewer risks. Falling when working at a height, which may be prevented by driving along the edge of a construction road. Plants that are well-maintained may prevent going out of control, and well-maintained equipment decreases the danger of damage. Heavy earth-moving equipment will prevent those from being hit by moving vehicles, and vehicle drivers and those issuing signals should be adequately trained.

Drilling- falling from the edge of a bench, where training should include instructions to face the open edge of the bench so that any inadvertent backward step is away from the edge, provide suitable portable rail fencing that can be erected between the drilling operations and the edge of the mine, attach a safety line to the drilling rig, and provide a harness for the driller to wear. Inhalation of drilling dust, which may be prevented by using water during drilling operations and installing a ventilation system on the drilling rig with a dust filter to eliminate dangerous dust. Another concern is that noise and danger are greater in older machines. Newer drill machines are equipped with cabins that manage noise levels inside the cabins. Finally, to prevent noise, operators should be supplied with ear protection.

Explosives- poorly constructed rounds may result in misfires, early ignition, and flying rock, which can be prevented by preparing for a round of shots to ensure the face is adequately surveyed, holes are appropriately drilled, direction is noted, and the weight of explosion is sufficient for

excellent fragmentation. Finally, the blast design, charge, and fire surrounding of explosives should be performed by a skilled individual.

Face stability- rock fall or slide may be prevented by doing frequent examinations of the face, taking corrective actions to make it safe if there is any uncertainty that a collapse might occur, and finally, working should be progressed in consideration of the geology so that the face and quarry side stay stable.

Loading- It is the result of a rock falling on the driver, plants toppling over due to uneven ground, hydraulic system failure, fires, all while gaining access to the operating cabin, and so much more, which can be avoided by ensuring that the electrical supply to the dragline is properly installed with adequate earth continuity and earth leakage protection, the wire rope is suitable for the work undertaken and is examined on a regular basis, and loaders are positioned sufficiently away from face edges.

Transporting- failure of brakes, lack of all-around view from the driver's position, vehicle motions, especially when reversing, rollover, vibrations, noise, and, finally, dust maintenance. This issue may be prevented by utilizing visibility aids such as closed-circuit television and appropriate mirrors; edge protection is required to prevent unintended movement; and a seatbelt to protect the driver in the event of a vehicle rollover. Good maintenance and frequent testing are also required to limit the likelihood of brake failure.

Processing of minerals by using hydraulic hammers to break up blockages and offer noise isolators, as well as mechanical ventilation systems intended to remove any hazardous particles, crushing resulting in obstructions, excessive noise, dust, and vibrations may be prevented. Grinding produces noise, dust, entrapment, tight spaces, and chemical byproducts. By providing noise isolation devices and an air filtering system, noise and dust dangers may be mitigated. Additives may be decreased by modifying standard preventive methods such as replacement, automated pipe feeds, and personal protection. Lastly, during maintenance, screening causes dust, noise, vibration, and falls from great heights, which may be prevented by employing protective equipment to protect against inhalation of residual dust.

2.4 Accidents in underground working

Underground mining is a technique for extracting ore from beneath the earth's surface in a safe, cost-effective, and waste-free manner (Puhakka,1997). A horizontal or vertical tunnel, called as an adit, shaft, or decline, can be used to access an underground mine from the surface. Roof and side of work should be maintained in a secure condition, supports should be put up according to systematic

support regulations, a fence should be provided in unapproved areas, and workers should not be authorized to work under an unsupported roof. Collapse of pillars in coal mines may be prevented if appropriate space is given during depillaring. Air blast may be prevented by not allowing a significant area of uncollapsed roof to exist, keeping seams with strong and huge roof rocks open, providing shelters at appropriate locations, and installing a warning system to notify people about impending air blast.

Rope haulage- runaway of tubs is due to breakage of rope, failure of attachment to rope, failure of couplings and drawbars, and can be avoided by rope, which should be selected properly and maintained with care. Non-functionality of safety devices and raveling along haulage roadways can be avoided, and unauthorized travel on haulage roadways should be strictly prohibited. Uncontrolled movement of tubs and derailment of tubs can be avoided, and bad patches in the track should be corrected. Poor construction of curves can be avoided by haulage; curves should be properly designed and constructed.

Electrical hazards- electric shock and/or burn, ignition of firedamp or coal dust, and fire arising from electric defects This can be avoided by inspecting equipment regularly for signs of overheating, partial discharge, and mechanical damage; inspecting the earthing point regularly; using flameproof and intrinsically safe apparatus; and providing cables with double wire armoring.

Fire hazard- no petrol-powered equipment must be permitted, hard-held extinguishers should be provided in various places in mines, all underground equipment containing more than 100 liters of flammable hydraulic fluid must be fitted with an automatic suppression system with suitable manual activation, and storage of flammable substances must be minimized.

Inundations- no work shall be done vertically under any river, lake, or reservoir, and any abandoned shafts and boreholes that are no longer needed should be sealed with debris and sealing material. In the existence of highly water-bearing strata near the intended working area, mining should be organized so as not to disrupt the water-bearing strata.

Ventilation- failing of cooling system, oxygen deficiency (<19%), gas evolution from coal and presence of CO > 50ppm. Presence of CO₂ > 1%; presence of H₂S > 20ppm, presence of NO_x and increase in temperature due to rock temperature and heats from machines.

Illumination- Insufficient illumination system, this can be avoided by permanent lighting should be provided in places where equipment can be hazardous and separate and independent emergency light source should be provided at all places where a hazard could be placed by failure if light.

2.5 Mine safety statistics

Lenne *et al.* (2011) mentioned that the overall number of deaths in the South African mining industry has declined over the past decades, but the greatest impact of mining accidents is noticed amongst the family members and colleagues left behind after a mine worker lost his or her life. South Africa is known for its diverse wealth of minerals, but even better known for a very well-regulated mining industry. The Mine Health and Safety Inspectorate continuously imposed legislation and national mining standards to reduce mining deaths and occupational injuries. Between 1984 and 2005, more than 11 000 mine workers died in South Africa. In 2003, the death toll from mining accidents was approximately 270 fatalities and an agreement was reached to reduce mining fatalities by 20% per annum. The year 2010 was an achievement for the South African mining industry with a 24% reduction year-on-year since the 2003 agreement. Total number of accidents for all commodities from 2008 until 2017 is illustrated in figure 2.1.

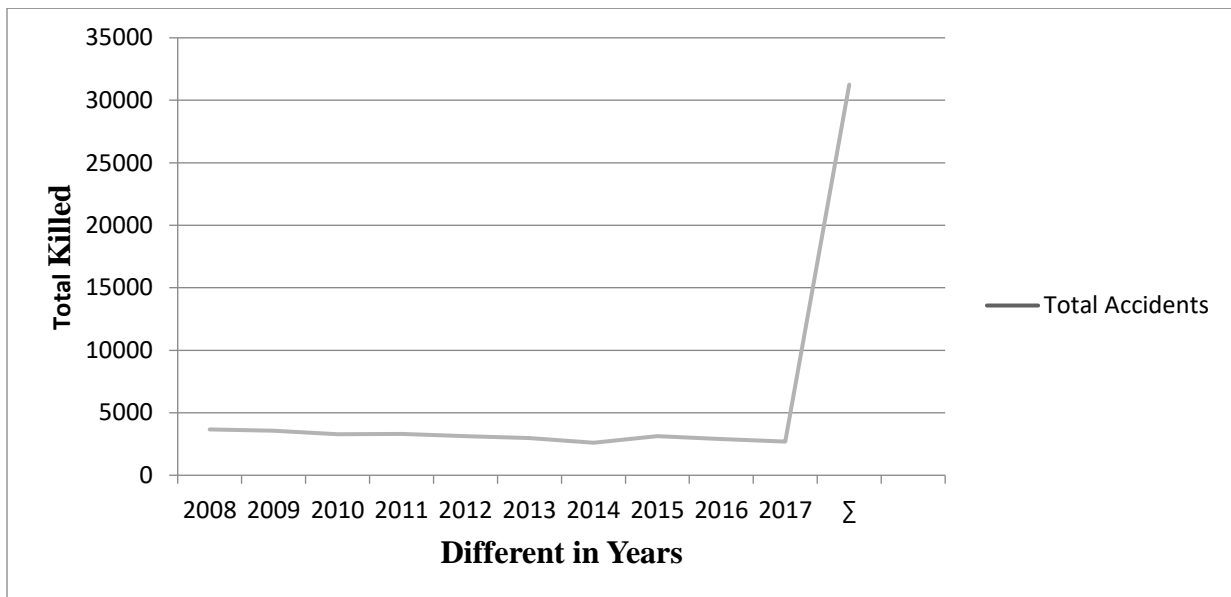


Figure 2.1 Total number of accidents versus different in years (Department of Mineral Resource, 2008-2017)

Department of mineral and resources indicated that in 2016 the sector saw the lowest ever number of fatalities on record at 73, unfortunately, there was a notable regression in 2017 with 90 fatalities largely in the gold sector. It was then concluded that there was a turnaround with 81 fatalities reported translating to a 10% improvement in the number of fatalities year-on year starting from 2018. There was a hope that this was the beginning of much needed turnaround in fatalities, and mines should continue to prioritize the safety issues moving forward. The fatalities per commodity in 2018 were as follows: 40 in the gold sector, 12 in platinum, 9 in coal with the remainder of other commodities accounting for 20 fatalities. These include the diamonds, chrome, copper, and iron ore operations. The platinum sector showed a commendable decrease of 59% in the number of fatalities from 29 in 2017.

There were three disasters noticed which were defined as accident where five or more employees were killed, and this occurred in the gold and copper sectors last year. Seven employees died in a seismic induced fall-of-ground accident at Sibanye Stillwater's Driefontein Gold mine in May 2018. In the following month five employees lost their lives in a heat-related accident at Sibanye Stillwater's Kloof Gold mine, and six employees lost their lives in a fire and explosion related accident at Palabora Mining Company's Copper mine in July 2018. Inquiries into each of the disasters are underway to assess the root causes and identify the necessary remedial action. So far in the current year 2019, the total number of fatalities reported by all mines is 5 versus 14 that were reported during same period in 2018, this translates to an improvement of 69% year on year. In 2018 there was a 12% reduction in the number of injuries from 2669 in 2017 to 2350 in 2018. Most of the injuries were mainly because of repeat accidents categorized as fall of grounds, transportation, mining, and general types of accidents (Department of Mineral Resources, 2017-2018)

According to Chamber of Mines (2019-2021), indicated that the number of fatalities in the South African mining industry regressed by 23% to 74 in 2021 as compared to 60 in 2020. This compares unfavorably with the 51 fatalities reported in 2019, the industry's best-ever safety performance. The 2021 regression in fatalities was the second consecutive annual regression and the worst recorded since 2003 when tripartite stakeholders first agreed health and safety milestones. Most fatalities occurred in the gold and platinum sectors, together accounting for 69% of fatalities. Only the coal mining sector reported a decline in the number of fatalities. General types of accidents (being struck, falling, drowning, inundation, mud rush, burning and scalding)

were the cause of most fatalities, overtaking falls of ground whose contribution to fatalities has plateaued in recent years.

In the year 2022, 49 fatalities were reported versus 74 in the year 2021, this translates to 34% improvement in the number of fatalities year on year. There was a 70% reduction of mine deaths from fall of ground accidents dropped from twenty in 2021 to six in 2022 and fall of ground fatal accident was reported from the gold sector for seven consecutive months, from January to July of 2022. The only three fatalities due to fall of ground in the gold sector occurred in August, November, and December of 2022 and only one fall of ground fatal accident was reported due to seismicity in 2022. Coal, Platinum, and Chrome underground mines, each reported only one fall of ground related fatality throughout the year 2022. There was a 100% reduction in machinery related fatalities, no fatalities were reported in 2022 under this category versus the three fatalities in 2021. No disasters have been recorded in the year 2022. Disasters are defined as accidents where five or more employees lose their lives in the same accident.

Breakdown of fatalities per commodity year on year (2021 versus 2022), the gold sector has improved by 50% from 30 fatalities in 2021 to 15 fatalities in 2022, while the platinum sector has improved by 14% from 21 fatalities in 2021 to 18 fatalities in 2022. The coal sector has improved by 50% from 10 fatalities in 2021 to 5 fatalities in 2022 whilst the other commodities sector has improved by 15% from 13 fatalities in 2021 to 11 fatalities in 2022. The three major contributors to fatalities year on year (2021 versus 2022) are transportation and mining (Trackless Mobile Machinery) increased from 16 in 2021 to 17 in 2022, general (slip and fall; rolling rocks; struck by an object; mud-rush, falling from height) decreased from 21 in 2021 to 16 in 2022 and lastly fall of ground (Gravity induced and Seismicity) decreased from 20 in 2021 to 6 in 2022. The total number of fatalities was also illustrated with appendice B to explain the content on how the accidents are occurring in the mining industry.

The number of injuries in the gold sector decreased from 738 in 2021 to 586 in 2022 whilst the number of injuries in the coal sector increased from 170 in 2021 to 180 in 2022. The number of injuries in the platinum sector increased from 1027 in 2021 to 1030 in 2022 whilst the number of injuries in other mines increased from 208 in 2021 to 260 in 2022 and major contributors to injuries year on year (2021 versus 2022) were transportation and mining (Trackless Mobile Machinery) increased from 329 in 2021 to 376 in 2022, general (slip and fall; rolling rocks; struck by an object; mud-rush, falling from height) decreased from 1171 in 2021 to 1124 in 2022 and fall of ground

(Gravity induced and Seismicity) decreased from 373 in 2021 to 295 in 2022 (Mine Health and Safety statistic, 2022). Appendice A will give a clear content on how the total injuries occurred from different commodities in the mining industry.

2.6 Safety Management System

A safety management system (SMS) is a full management system that is meant to deal with safety issues in the workplace. It includes policy, goals, plans, processes, organization, responsibilities, and other measures. It is used in industries with high safety concerns. Because the SMS is scalable, it can be changed to fit the size and complexity of the organization. SMS focuses on leveraging possibilities to constantly enhance the system's overall safety. SMS's major procedures include hazard identification, occurrence reporting, risk management, performance measurement, and quality and safety assurance (processes based on quality management concepts that assist continuous improvement of an organization's safety performance). Enhancing workplace safety is not simple, but taking the necessary measures will make it much easier and less expensive.

Komljenovic et al.,2008 indicated that safety management decisions must be made to select and prioritize problem areas and safety system weaknesses must be based on the recognition of hazards encountered in each activity of the mining process. For this reason, knowledge of the major occupational hazards, their causes, and factors, is necessary to improve the safety conditions of the employees. Occupational injury/accident datasets are often large and complex and require a tool able to handle large amounts of information for analysis.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Study Design

Creswell and Creswell (2017) define research design as a set of methods and procedures used in collecting and analysing measures of the variables specified in the research problem. Quite often, the format for the design of a research study follows the traditional research approach involving a problem statement, formulating research question/(s), data collection, analysis of the data, and finally, answering the research question/(s) (Kowalczyk, 2015). The study used a retrospective quantitative research design, in which secondary data on previous work accidents was collected from the Department of Minerals and Resources (DMR).

3.2 Research Method

The research study was carried out in two phases, namely, a literature review and an empirical study. The literature review phase focused on gathering relevant information regarding the occurrence of accidents at workplaces and the legislative frameworks for managing and controlling the occurrences of accidents in the work environment. The empirical phase of this proposed study comprised the research design, data collection and management, and statistical analysis. Secondary mine accident data was collected from the DMR and subjected to rigorous analysis using appropriate statistical methods and techniques.

3.3 Study Setting

The study looks at all the accidents that happened in the South African mining industry from 2008 to 2018. According to the Statistics South Africa 2019 report, the headcount for the entire South African mining industry stood at 343 057 in 2019. Therefore, this study was important as its findings was used to inform the planning, design, and implementation of safety intervention programs meant to safeguard and protect the lives of this significant proportion of the South African productive population.

3.4 Secondary data

The study used secondary accident data from the DMR and Energy from 2008 to 2018 to find out how accidents have changed over the past 10 years. Secondary data is information that is simple to obtain from numerous sources and that other researchers or businesses have gathered. Table 1 provides the full description of the data and all its variables.

Table 3.1: Variable names and types for the secondary data

Variable Name	Variable Type
Year	Categorical (1-10)
Commodity type	Categorical (1 -4)
Casualty type	Categorical (1 -13)
Number of Injuries	Scale/Counts
Number of deaths	Scale/Counts
Number of disabled	Scale/Counts
Accidents Outcome	Categorical (1 -3)

3.5 Statistical Data Analysis

Data collected from DMRE were extracted from DMRE reports, recaptured into Microsoft Excel, and prepared for data analysis. Descriptive statistics, figures and tables will be used to describe and understand accidents data. Chi-Square tests will also be used to test the association between accidents outcome (injured, killed, or disabled) and categorical variables such as year, commodity type and casualty type. Odds ratios and risk ratios will be used to give certain events happening relative to all other possible accident outcomes for year, commodity, and casualty type.

3.5.1 Descriptive Statistics

This study used descriptive statistics to describe and understand the data. These included measures of central tendency (mean, median, mode) and measures of dispersion (variance, standard deviation, range, etc.). The mean number of accidents per year, commodity type, and casualty type will enable the researcher to establish the expected or average number of accidents per year, per commodity type, as well as per casualty type. Similarly, the computation of variance and standard deviation enabled the researcher to understand how the number of accidents is spread around the mean.

3.5.2 Chi-Square Test

The data used in this study consists of both qualitative and quantitative variables. The qualitative variables such as year, commodity type, and casualty type were analyzed using the Chi-Square test for associations. Chi-square test was used to investigate the relationship between variables "*accident outcome*" (injured, killed, and disabled) and year (2008, 2009... and 2018), commodity type (gold, platinum, coal, and other minerals), and casualty type.

3.5.3 Analysis of Variance

Analysis of Variance (ANOVA) is a statistical technique for investigating the equality of means of observed injuries, deaths, and disabilities between categorizing variables such as year, commodity type, and casualty type. The study used the ANOVA technique to investigate how the number of accidents leading to injuries, deaths, and disabilities differs across year, commodity type, and casualty type. The null hypothesis that the mean number of accidents leading to injuries, deaths, or disabilities was equal across different years, commodity types, and casualty types was rejected or retained at the 5% level of significance. The null hypothesis was rejected whenever the p-values were found to be less than 0.05.

3.5.4 Tukey's HSD Test

If one of the ANOVA tests leads to rejection of the null hypothesis, Tukey's HSD test for mean difference comparison was used to find categories whose means statistically differ from each other. This follows from the statistical procedure that, whenever the ANOVA test results in the null

hypothesis being rejected, means for different categorical variables were compared to establish pairs whose mean differences are statistically significant. Therefore, Tukey HSD test was used to check how the different years, commodity types, and casualty types record accidents that lead to injuries, deaths, and disabilities in a statistically different way.

3.5.5 Loglinear Predictive Model

The study used the loglinear multinomial model to model the relationship between accident outcome (injuries, deaths, and disabilities) and year, commodity type, and casualty type. Accident outcome, year, commodity type, and casualty type are all multinomial categorical variables. The reason for using a log-linear model was due to the interpretation of interaction for complicated or more variables. The predictive model was used to investigate the extent to which a year, commodity type, and casualty type jointly influence the accident outcome. The loglinear predictive model of the following structure was used as the researcher is calculating the logarithms of dependent and independent variables:

$$\log(\mu_{ijkl}) = \lambda + \lambda i(Y) + \lambda j(C_1) + \lambda k(C_2) + \lambda l(AO) + \lambda ijkl(Y * C_1 * C_2 * AO)$$

Were,

- i represents the Year (2008: 2017)
- j represents the commodity type (gold, platinum, coal, other).
- k represents the casualty type and
- l represents the Accident Outcome (injuries, deaths, disability)
- λ represents an overall effect or grand mean.
- $\lambda i(Y)$, $\lambda j(C_1)$, $\lambda k(C_2)$ and $\lambda l(AO)$ represents the main effects of year, commodity type, casualty type and accident outcome variables.
- $\lambda ijkl(Y * C_1 * C_2 * AO)$ represents the association between the four variables and reflects departure from independence.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the findings of the study. The data consist of 8 variables: year, commodity, casualty name, total injured, total disabled, total killed, and total accidents. Descriptive statistics, tables, and graphs describe and understand accident data. This chapter is organized into 4 sections, namely, (1) descriptive statistics, (2) tests for association, (3) analysis of variance (ANOVA), and (4) negative binomial regression.

4.1 Descriptive Statistics

Table 4.1 presents the descriptive statistics for the 8 variables that describe accident data. The table 4.1 shows the average, standard deviation, minimum, and maximum values for each variable.

Table 4.1: Descriptive statistics

Statistic	Year	Commodity	Casualty	Total injured	Total disabled	Total killed	Total accidents
count	386	386	376	386	386	386	386
mean	4.59	1.61	5.85	83.01	0.078	2.904	80.980
std	2.870	1.102	3.665	161.46	0.321	5.112	152.620
min	0	0	1	0	0	0	1
25%	2	1	3	3	0	0	3
50%	5	2	5	15	0	1	14
75%	7	3	8	71.75	0	3.75	74.75
max	9	3	13	887	3	40	862

Table 4.1 shows that the minimum total number of injuries was 0, while the maximum total number of injuries recorded was 887. On average, the total number of injuries stood at approximately 83, with a reported standard deviation of 161 injuries. The minimum and maximum total number of injuries recorded were 0 and 3 disabilities, respectively. On average, 8% is the total number of disabled persons multiplied by the mean in every hundred persons, with a standard deviation of 32 disabilities per every 100 persons. The minimum and maximum total numbers of persons killed recorded were 0 and 40, respectively. On average, 3 persons were recorded, and a standard deviation of 5 persons was recorded. The minimum and maximum total number of accidents

observed were approximately 1 and 862, respectively. On average, nearly 81 accidents with a standard deviation of 153 were recorded.

4.1.1 Mean and Standard Deviations by Year

Table 4.2 shows the yearly mean and standard deviations for total injuries, total disabled, total killed, and total accidents. Based on standard deviations that are much higher than their averages, it was seen that injuries, disabilities, deaths, and accidents happen all over the place each year. It was noticed that the yearly distributions of injuries, disabilities, deaths, and accidents are to spread out. This can be seen in the way above average standard deviation numbers.

Table 4.2: Mean and Standard Deviations by Year

Year	Total Injured Mean (SD)	Total Disabled Mean (SD)	Total Killed Mean (SD)	Total Accidents Mean (SD)
2008	106.69 (202.9)	0.09 (0.28)	4.91 (7.87)	104.63 (193.18)
2009	98.0 (172.8)	0.19 (0.57)	4.49 (7.62)	96.0 (164.69)
2010	82.21 (165.4)	0.1 (0.48)	3.02 (5.52)	78.02 (149.0)
2011	94.53 (177.99)	0.11 (0.32)	3.42 (5.02)	92.06 (169.16)
2012	86.38 (177.2)	0.13 (0.34)	2.97 (4.41)	80.41 (153.68)
2013	84.22 (163.48)	0.11 (0.31)	2.51 (3.93)	80.3 (147.25)
2014	68.9 (126.47)	0.03 (0.16)	2.15 (3.9)	66.69 (121.36)
2015	78.45 (158.59)	0.02 (0.16)	1.92 (2.85)	78.45 (157.97)
2016	69.46 (143.18)	0.0 (0.0)	1.78 (3.17)	70.9 (144.76)
2017	66.72 (134.77)	0.02 (0.16)	2.25 (4.42)	67.5 (134.85)

4.1.2 Mean and Standard Deviations by Commodity

Table 4.3 shows means and standard deviations for total injuries, total disabled, total killed, and total accidents per commodity. There is evidence of over dispersion as witnessed by standard deviations that are much greater than their respective means.

Table 2.3: Mean and Standard Deviations by Commodity

Commodity	Total Injured Mean (SD)	Total Disabled Mean (SD)	Total Killed Mean (SD)	Total Accidents Mean (SD)
Coal Bituminous Rom Minus Discard	31.36 (41.1)	0.06 (0.24)	1.33 (1.97)	31.1 (40.35)
OT	32.27 (47.73)	0.06 (0.25)	2.1 (3.14)	33.16 (47.83)
PGM	120.46 (202.75)	0.05 (0.21)	2.85 (4.21)	113.44 (181.69)
Gold	130.3 (208.61)	0.13 (0.48)	4.86 (7.73)	129.2 (204.89)

4.1.3 Means and Standard Deviations by Casualty Name

Table 4.4 shows means and standard deviations for total injuries, total disabled, total killed, and total accidents per casualty. It was observed that the total killed and disabled variables remain widely over dispersed, while the total injuries and accidents variables have become under dispersed. Over dispersion clearly indicates how the number of casualties and disabilities recorded in the mining industry fluctuates between low and high extreme values.

Table 4.4: Means and Standard Deviations by Casualty Name

Casualty Name	Total Injured Mean (SD)	Total Disabled Mean (SD)	Total Killed Mean (SD)	Total Accidents Mean (SD)
Conveyance accidents	8.26 (6.65)	0.0 (0.0)	0.68 (1.92)	8.38 (6.54)
Diving sickness	1.0 (0.82)	0.0 (0.0)	0.25 (0.5)	1.25 (0.5)
Electricity	5.62 (3.66)	0.0 (0.0)	0.72 (1.04)	5.72 (3.4)
Explosives	5.35 (4.35)	0.0 (0.0)	0.89 (1.31)	4.38 (2.96)
Fires	2.98 (4.37)	0.0 (0.0)	0.07 (0.35)	2.32 (1.82)
General	405.55 (277.75)	0.18 (0.38)	6.45 (4.61)	380.9 (253.97)
Heat sickness	8.94 (17.38)	0.0 (0.0)	0.82 (1.38)	9.12 (18.25)
Machinery	56.4 (28.67)	0.0 (0.0)	1.4 (1.57)	57.38 (28.23)
Miscellaneous	20.32(13.82)	0.0 (0.0)	0.6 (0.9)	20.23 (13.4)
Occupational diseases	1.5 (1.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.0)
Rockfall	149.32 (146.03)	0.35 (0.74)	9.15 (9.98)	149.32 (144.88)
Subsidence or caving	1.11 (0.33)	0.0 (0.0)	0.11 (0.33)	1.0 (0.0)
Transportation and mining	144.52 (95.12)	0.22 (0.42)	7.82 (3.88)	150.02 (97.34)

4.1.4 Yearly distribution of accidents

Figure 4.1 presents the yearly distribution of accidents. The highest total number of 3662 accidents was recorded in 2008, while 2014 recorded the least number of 2601 accidents. On average, 3126 accidents were recorded, with a standard deviation of 343 accidents.

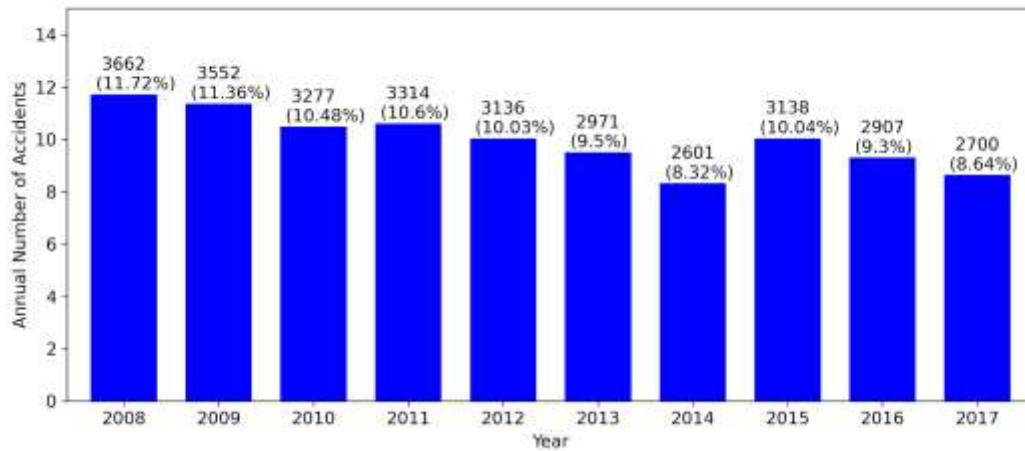


Figure 4.1: Yearly distributions of accidents

4.1.4.1 Yearly total number of injuries, disabilities, casualties, accidents by commodity

Figure 4.2 presents the yearly total number of injuries, disabilities, casualties, and accidents recorded by each commodity. As clearly shown on the graph, the number of injuries shows a gradual decrease with time for all commodities. The number of disabilities fluctuates between 0 and 5 for gold, 0 and 1 for PGM, 0 and 2 for coal, and 0 and 3 for OT. The number of casualties was highest in 2008 for all commodities and followed a downward trend until around 2015, when gold, PGM, and coal began to follow an upward trend.

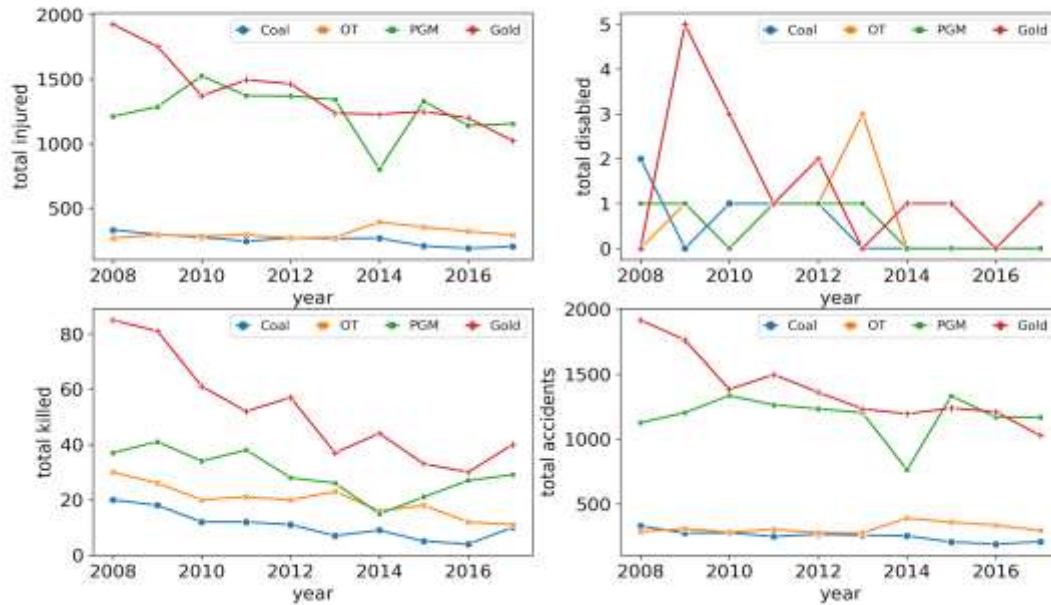


Figure 4.2: Yearly changes in total number of injuries, disabilities, casualties, and accidents by commodity

4.1.4.2 Yearly total number of injuries by casualty

Figure 4.3 shows yearly trends in the total number of injuries recorded by accident causal type. The bulk of accidents were caused by general incidents. There were three types of accidents that result in injuries that exceed 250 per year. These include general, transportation and mining, rock falls, and machinery. This was done to give alarming statistics and show how individuals should change with respect to injuries reported.

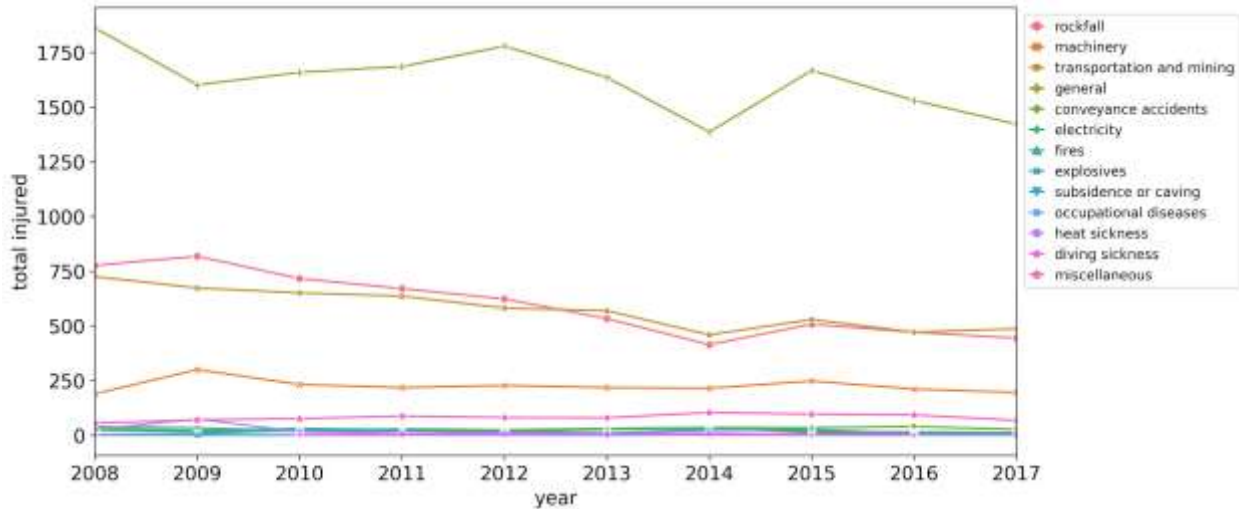


Figure 4.2: Yearly total number of injuries by casualty

4.1.4.3 Yearly total number of disabilities by casualty

Figure 4.4 presents yearly trends in the total number of disabilities recorded by the mining industry during the 2008–2017 period, by accident causal type. The bulk of accidents leading to disabilities arise from rock fall incidents. This was done to give a clear indication as to how accidents lead to disability.

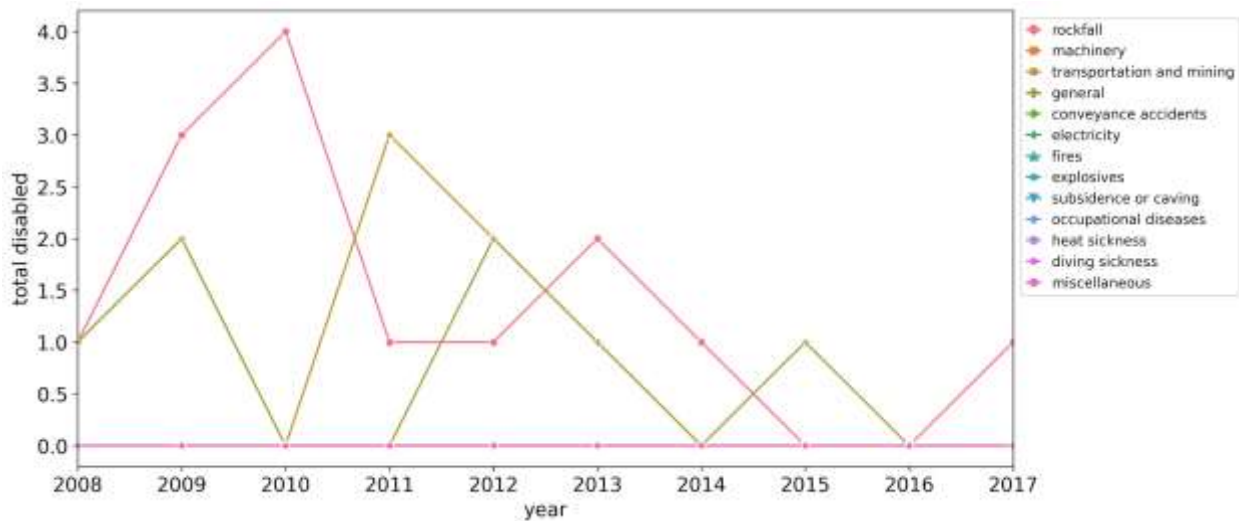


Figure 4.3: Yearly total number of disabilities by casualty

4.1.4.4 Yearly total number of casualties by casualty

Figure 4.5 presents yearly trends in the total number of mine workers who were killed by accidents in the mining industry during the 2008–2017 period according to accident causal types. The bulk of workers who were killed by accidents were mainly caused by transportation and mining, rockfalls, and general.

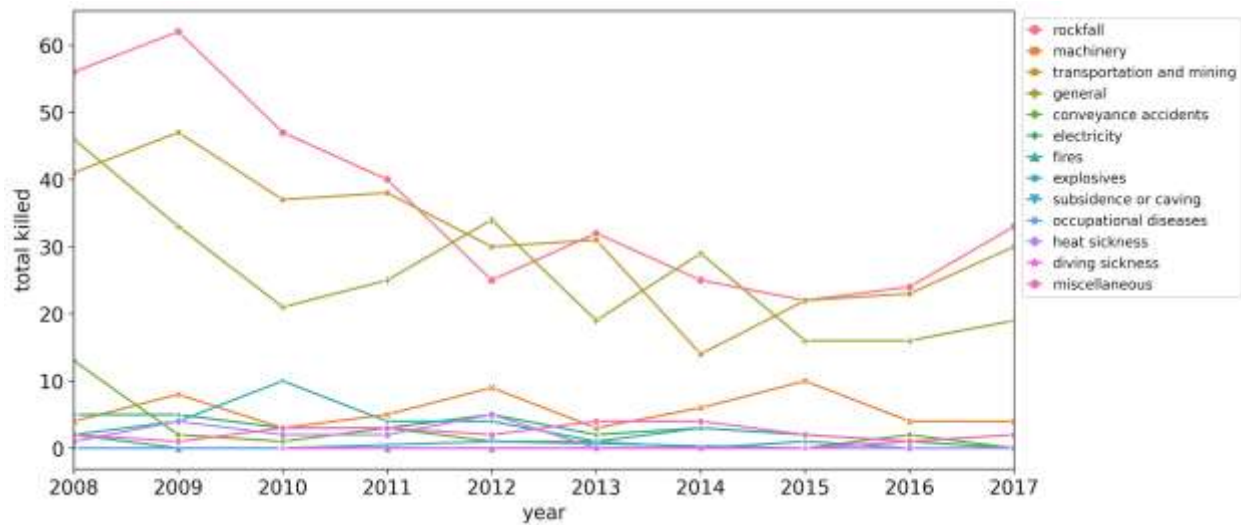


Figure 4.4: Yearly total number of casualties by casualty

4.1.4.5 Yearly total number of accidents by casualty

Figure 4.6 presents yearly trends in the total number of accidents recorded in the mining industry during the 2008-2017 period according to causes of accidents. The bulk of accidents were caused by transportation and mining, rockfalls, machinery, and other causes.

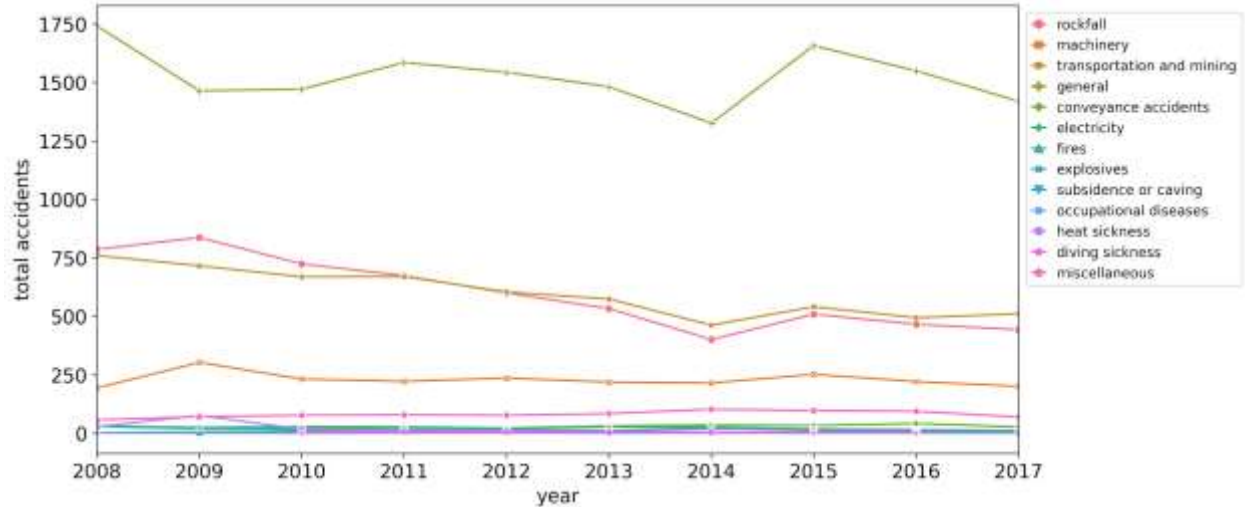


Figure 4.5: Yearly total number of accidents by casualty

4.1.5 Distribution of accidents by commodity

Figure 4.7 presents the distribution of accidents by commodity. Gold and PGM dominate most accidents in the mining sector. For these reasons, accidents may be due to specific agencies (e.g., rock bursts, track-bound vehicles); accidents may occur to personnel engaged in activities or employed in occupations (for example, drilling, walking, and pinch bar users); accidents may occur in specific types of places in the mines (for example, stope faces, shafts, ore passes); or accidents may cause particular types of injuries, for instance foot and hand injuries.

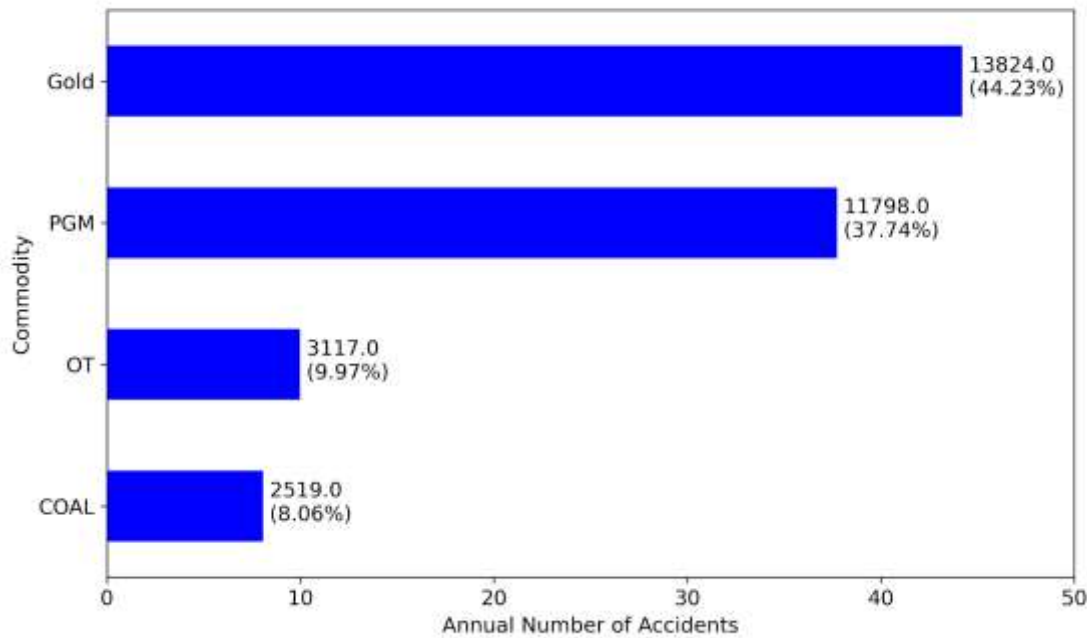


Figure 4.6: Distribution of accidents by commodity

Gold mining constitutes the highest proportion of accidents (44.23%), followed by PGM (37.24%), then OT (9.97%), and lastly, coal mining (8.06%). Thus, four out of every 10 accidents recorded between 2008 and 2017 resulted from gold mining activities. Nearly 4 of every 10 accidents recorded resulted from activities involving the platinum group of metals. The remaining 2 of every 10 accidents recorded during the same period were equally shared between OT and coal mining activities.

4.1.6 Distribution of accidents by casualty type

Figure 4.8 shows the distribution of accidents by casualty type. As clearly shown on the figure, general injuries constitute most accidents (49%), followed by transportation and mining-related accidents (19%), then falls off the ground or rockfall (19%), machinery (7%), miscellaneous (3%), and others (3%)

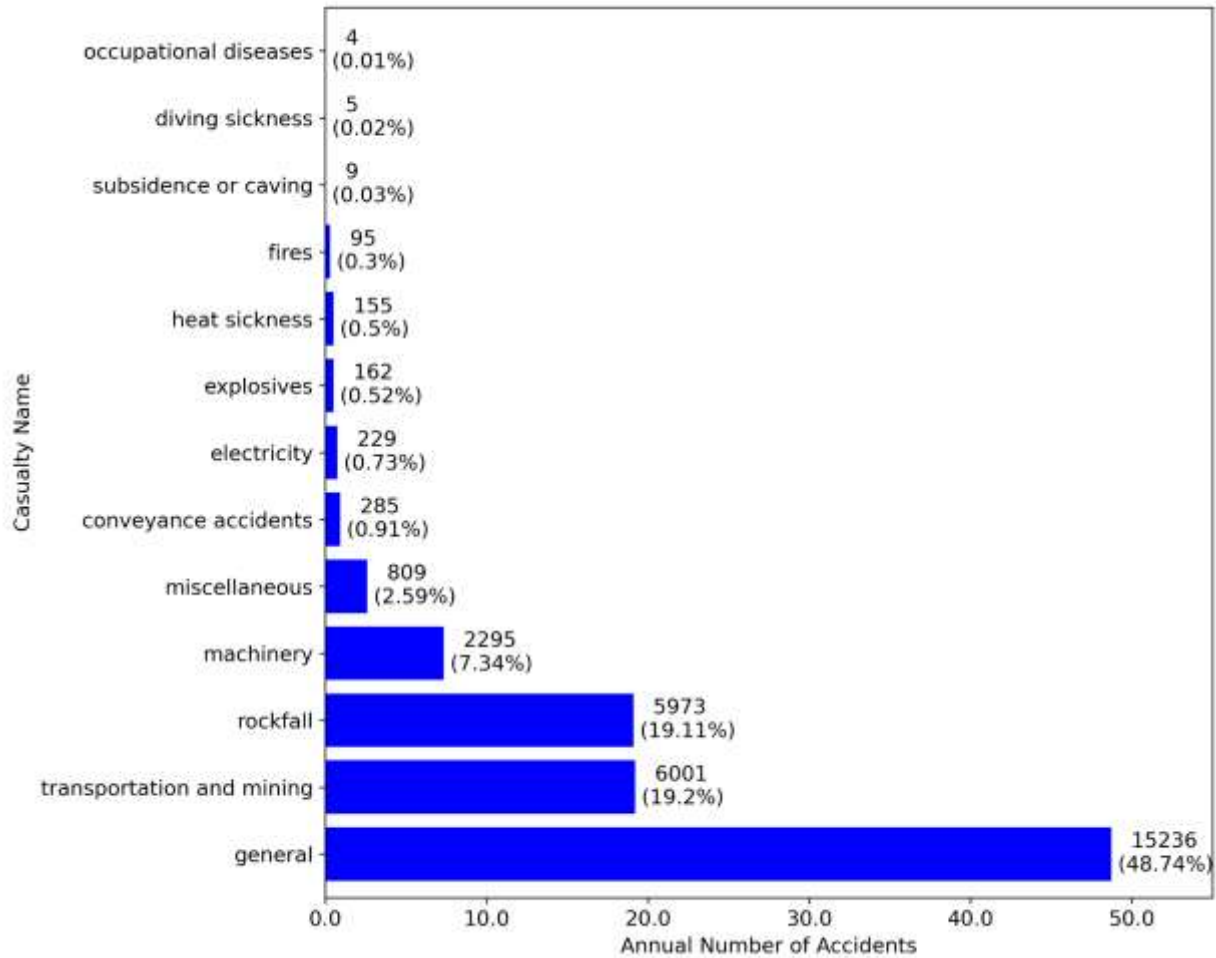


Figure 4.7: Distribution of accidents by casualty type

4.2 Tests for Association

In this section, results following the investigation on the role of year, commodity, and casualty on accident outcome (injured, disabled, killed) are presented. Specifically, the Chi-Square test was used to test the following hypotheses:

1. Is there an association between the year and accident outcome variables?
2. Is there an association between commodity and accident outcome variables?
3. Is there an association between casualty and accident outcome variables?

4.2.1 Year Versus Accident Outcome

The Chi-Square test revealed that accident outcome and year are statistically significant (Chi-Square = 58.187, df = 18, $p < 0.05$). This means that the accident outcome (injury, disability, or

death) depends on which year the accidents occurred. For instance, years 2008, 2009, 2015, and 2016 have statistically significant residuals on injury and death outcomes, while the residuals for all other years are statistically insignificant (see table 4.5). However, measures of the strength of the association reveal that the relationship between these variables is weak (Cramer's $V = 0.029$, $p < 0.05$).

Table 4.5: Year Versus Accident Outcome

			Accident Outcome			Total
			Total Injured	Total Disabled	Total Killed	
Year	2008	Count	3734	3	172	3909
		Expected Count	3773.5	3.5	132.0	3909.0
		Adjusted Residual	-3.7	-0.3	3.8	
	2009	Count	3626	7	166	3799
		Expected Count	3667.3	3.4	128.3	3799.0
		Adjusted Residual	-3.9	2.0	3.6	
	2010	Count	3453	4	127	3584
		Expected Count	3459.7	3.2	121.0	3584.0
		Adjusted Residual	-0.7	0.4	0.6	
	2011	Count	3403	4	123	3530
		Expected Count	3407.6	3.2	119.2	3530.0
		Adjusted Residual	-0.4	0.5	0.4	
	2012	Count	3369	5	116	3490
		Expected Count	3369.0	3.2	117.9	3490.0
		Adjusted Residual	0.0	1.1	-0.2	
	2013	Count	3116	4	93	3213
		Expected Count	3101.6	2.9	108.5	3213.0

		Adjusted Residual	1.5	0.7	-1.6	
	2014	Count	2687	1	84	2772
		Expected Count	2675.9	2.5	93.6	2772.0
		Adjusted Residual	1.2	-1.0	-1.1	
	2015	Count	3138	1	77	3216
		Expected Count	3104.5	2.9	108.6	3216.0
		Adjusted Residual	3.4	-1.2	-3.2	
	2016	Count	2848	0	73	2921
		Expected Count	2819.7	2.6	98.6	2921.0
		Adjusted Residual	3.0	-1.7	-2.8	
	2017	Count	2669	1	90	2760
		Expected Count	2664.3	2.5	93.2	2760.0
		Adjusted Residual	0.5	-1.0	-0.4	
Total		Count	32043	30	1121	33194
		Expected Count	32043.0	30.0	1121.0	33194.0

4.2.2 Commodity Versus Accident Outcome

The Chi-Square test revealed that accident outcome and commodity are statistically significant (Chi-Square = 134.077, df = 6, $p < 0.05$). This association was weak (Cramer's = 0.045, $p < 0.05$). This means that the accident outcome (injury, disability, or death) depends on the commodity type where the accident occurred, as indicated in Table 4.6.

Table 4.6: Commodity Versus Accident Outcome

			Accident Outcome			Total
			Total Injured	Total Disabled	Total Killed	
Commodity	Gold	Count	13942	14	520	14476
		Expected Count	13974.0	13.1	488.9	14476.0
		Adjusted Residual	-1.9	0.3	1.9	
	Coal	Count	2540	5	108	2653
		Expected Count	2561.0	2.4	89.6	2653.0
		Adjusted Residual	-2.3	1.8	2.1	
	OT	Count	3033	6	197	3236
		Expected Count	3123.8	2.9	109.3	3236.0
		Adjusted Residual	-9.2	1.9	9.0	
	PGM	Count	12528	5	296	12829
		Expected Count	12384.2	11.6	433.3	12829.0
		Adjusted Residual	8.9	-2.5	-8.6	
Total		Count	32043	30	1121	33194
		Expected Count	32043.0	30.0	1121.0	33194.0

The results displayed in Table 4.6 show that the residuals for gold and coal are statistically insignificant, that is, the residuals are either less than 2.5 or greater than -2.5. This means that in the case of gold and coal, the number of injuries, disabilities, and deaths observed was indistinguishable from the numbers we would expect to see if commodity and accident outcomes were independent. On the other hand, statistically significant residuals were observed for the number of injuries and deaths recorded in OT and PGM commodities. For OT, fewer injuries were observed than what one would expect to see if the two variables were independent. Further, more deaths were observed than what one would expect to see if these two variables were independent. In the case of PGM, it's the opposite, as more injuries and fewer deaths were

observed than what one would expect to see if commodity and accident outcomes were truly independent. This result suggests that accidents linked to OT commodities are more dangerous than accidents linked to other commodities such as PGM, gold, and coal.

4.2.3 Casualty Code Versus Accident Outcome

Chi-Square test revealed that accident outcome and casualty type are statistically significant (Chi-Square = 533.265, df = 24, $p < 0.05$). This means that accident outcome (injury, disabled or death) depends on which casualty type under which accidents was classified. This association was weak (Cramer's = 0.090, $p < 0.05$). It is illustrated in table 8.

Table 4.7: Casualty Code Versus Accident Outcome

			Accident Outcome			Total
			Total Injured	Total Disabled	Total Killed	
Casualty Code	Fall Of Ground/Rockfall	Count	5973	14	366	6353
		Expected Count	6132.6	5.7	214.7	6353.0
		Adjusted Residual	-12.2	3.8	11.7	
	Machinery	Count	2256	0	56	2312
		Expected Count	2231.8	2.1	78.1	2312.0
		Adjusted Residual	2.9	-1.5	-2.6	
	Transportation And Mining	Count	5781	9	313	6103
		Expected Count	5891.3	5.5	206.2	6103.0
		Adjusted Residual	-8.5	1.6	8.4	
	General	Count	16222	7	258	16487

		Expected Count	15915.0	14.9	557.1	16487.0
		Adjusted Residual	18.4	-2.9	-18.2	
	Conveyance Accidents (Shaft/Winze)	Count	281	0	23	304
		Expected Count	293.5	0.3	10.3	304.0
		Adjusted Residual	-3.9	-0.5	4.1	
	Electricity (Not Causing Fire)	Count	225	0	29	254
		Expected Count	245.2	.2	8.6	254.0
		Adjusted Residual	-6.9	-0.5	7.1	
	Fires	Count	104	0	3	107
		Expected Count	103.3	.1	3.6	107.0
		Adjusted Residual	0.4	-0.3	-0.3	
	Explosives	Count	198	0	33	231
		Expected Count	223.0	.2	7.8	231.0
		Adjusted Residual	-9.0	-0.5	9.2	
	Subsidence Or Caving	Count	10	0	1	11
		Expected Count	10.6	.0	.4	11.0
		Adjusted Residual	-1.0	-0.1	1.0	

	Occupational Diseases (non-diving)	Count	6	0	0	6
		Expected Count	5.8	.0	.2	6.0
		Adjusted Residual	0.5	-0.1	-0.5	
	Heat Sickness	Count	152	0	14	166
		Expected Count	160.2	.2	5.6	166.0
		Adjusted Residual	-3.5	-0.4	3.6	
	Diving Sickness	Count	4	0	1	5
		Expected Count	4.8	0.0	0.2	5.0
		Adjusted Residual	-2.0	-0.1	2.1	
	Miscellaneous	Count	813	0	24	837
		Expected Count	808.0	0.8	28.3	837.0
		Adjusted Residual	1.0	-0.9	-0.8	
Total		Count	32025	30	1121	33176
		Expected Count	32025.0	30.0	1121.0	33176.0
			0			0

The results above show that, for falls of ground or rocks, fewer injuries were observed than one would have expected to see if casualty and accident outcome were independent variables. Conversely, more disabilities and deaths were observed than what one would expect to see if the two variables were truly independent. The same observation is also made on transportation and mining, conveyance accidents (shaft and winze), electricity (not causing fire), and heat sickness. For machinery and general casualties, it is the opposite, as more injuries and fewer deaths were observed than what one would expect to see if casualty and accident outcomes were truly independent.

4.3 ANOVA Results

ANOVA results were presented. An ANOVA was performed to check if year, commodity, and casualty type influenced the variation in the number of accidents and/or injuries. The results demonstrate the insignificant role of year and the significant role of commodity and casualty type in influencing the number of injuries or accidents experienced by the mining industry between 2008 and 2017.

4.3.1 Total Accidents and Commodity

A one-way ANOVA between commodities was conducted to compare the effect of commodities (gold, pgm, other, and coal) on total injuries, total disabled, total killed, and total accidents. There was a significant effect of commodities on total accidents at the $p < 0.05$ level for the 4 commodities [$F(3, 382) = 12.04, p < 0.05$]. Post hoc comparisons using the Tukey HSD test indicated that the mean accident score for gold ($M = 129.2, SD = 204.89$) was significantly different from the mean accident score for coal ($M = 31.1, SD = 40.35$) and other minerals ($M = 33.16, SD = 47.83$). Similarly, the mean accident score for PGM ($M = 113.44, SD = 181.69$) was significantly different from the mean accident score for coal ($M = 31.1, SD = 40.35$) and other minerals ($M = 33.16, SD = 47.83$). However, the mean accident score for other minerals ($M = 33.16, SD = 47.83$) did not significantly differ from the mean accident score for coal ($M = 31.1, SD = 40.35$).

Taken together, these results suggest that commodities do influence the number of accidents recorded within the mining industry, as presented in Table 4.8. Specifically, the results suggest that gold and pgm produce a high number of accidents while coal and other minerals record a lower number of accidents on an average basis.

Table 4.8: Analysis of Variance Results

A - B	diff	lwr	upr	p adj
OT-Coal	2.060809	-55.22993	59.35155	0.9997132
PGM-Coal	82.343542	26.34219	138.34489	0.0009860
Gold-Coal	98.097496	42.44094	153.75406	0.0000430
PGM-OT	80.282733	26.50236	134.06311	0.0007894
Gold-OT	96.036687	42.61544	149.45794	0.0000285
Gold-PGM	15.753954	-36.28212	67.79002	0.8629634

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Commodity	3	774847	258282	12.04	1.51e-07 ***
Residuals	382	8192970	21448		

Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tukey multiple comparisons of means 95% family-wise confidence level

4.3.2 Total Killed and Commodity

A one-way ANOVA between commodities was conducted to compare the effect of commodities (gold, pgm, other, and coal) on the total number of people killed due to workplace accidents. There was a significant effect of commodities on the total number killed at the 5% level of significance for the 4 commodities [F (3, 382) = 9.095, $p < 0.05$]. Post hoc comparisons using the Tukey HSD test indicated that the mean killed score for gold (M = 4.86, SD = 7.73) was significantly different from the mean accident score for coal (M = 1.33, SD = 1.97), PGM (M =

2.85, SD = 4.21), and other minerals (M = 2.1, SD = 3.14). However, the mean accident score for other minerals (M = 2.1, SD = 3.14) did not significantly differ from the mean accident score for coal (M = 1.33, SD = 1.97) and PGM (M = 2.85, SD = 4.21). Taken together, these results suggest that commodities do influence the number of people who lost their lives due to workplace accidents in the mining industry, as illustrated in Table 4.9. Specifically, our results suggest that gold produces a significantly higher number of accident-induced deaths compared to coal, pgm, and other minerals, which is presented in Table 4.10.

Table 4.9: Analysis of Variance Results

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Commodity	3	671	223.63	9.095	7.91e-06 ***
Residuals	382	9393	24.59		

Signif. codes: 0 '****' 0.001 '***' 0.01 '**' 0.05 '.' 0.1 ' ' 1

Tukey multiple comparisons of means 95% family-wise confidence level

Table 30: Total Killed and Commodity

A- B	diff	lwr	upr	P adj
OT-Coal	0.7624113	-1.1773845	2.702207	0.7412377
PGM-Coal	1.5128205	-0.3833183	3.408959	0.1686907
Gold-Coal	3.5264798	1.6420152	5.410944	0.0000118
PGM-OT	0.7504092	-1.07053	2.571348	0.7120371
Gold-OT	2.7640684	0.9552888	4.572848	0.0005524
Gold-PGM	2.0136592	0.2517801	3.775538	0.0177253

4.3.3 Total Injured and Commodity

A one-way ANOVA between commodities was conducted to compare the effect of commodities (gold, pgm, other, and coal) on total injuries recorded due to workplace accidents. There was a significant effect of commodities on total accidents at the 5% level of significance for the 4 commodities [$F(3, 382) = 11.68, p 0.05$]. Post hoc comparisons using the Tukey HSD test indicated that the mean injury score for gold ($M = 130.3, SD = 208.61$) was significantly different from the mean injury score for coal ($M = 31.36, SD = 41.1$) and other minerals ($M = 32.27, SD = 47.73$). Similarly, the mean injury score for PGM ($M = 120.46, SD = 202.75$) was significantly different from the mean injury score for coal ($M = 31.36, SD = 41.1$) and other minerals ($M = 32.27, SD = 47.73$). However, the mean injury score for other minerals ($M = 32.27, SD = 47.73$) did not significantly differ from the mean injury score for coal ($M = 31.1, SD = 40.35$). Taken together, these results suggest that commodities do influence the number of injuries recorded within the mining industry. Specifically, our results suggest that gold and PM produce an equally high number of injuries while coal and other minerals record an equally low number of accidents, at least on an average basis. The two Table 4.11 and 4.12 below present a summary of the ANOVA and Tukey HSD test results.

Table 4.11: Summary of the ANOVA

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
commodity	3	843300	281100	11.68	2.45E-07***
Residuals	382	9194011	24068		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tukey multiple comparisons of means 95% family-wise confidence level.

Table 4.12: Tukey HSD test results

A- B	diff	Lwr	upr	P adj
OT-Coal	0.9079328	-59.78194	61.59781	0.9999793
PGM-Coal	89.1035138	29.77953	148.4275	0.00072
Gold-Coal	98.9410407	39.9823	157.89978	0.0001118
PGM-OT	88.195581	31.22434	145.16682	0.0004502
Gold-OT	98.033108	41.4423	154.62391	0.0000608
Gold-PGM	9.837527	-45.28591	64.96097	0.9675396

A one-way between casualty of ANOVA was conducted to compare the effect of casualty type on total accidents recorded within the mining industry. An ANOVA test shows that there was a statistically significant effect of casualty type on total accidents at the 5% level of significance [$F(3, 382) = 11.68, p < 0.05$]. Table 4.13 illustrates the ANOVA results supported by Table 4.14, illustrating total accidents in the mining industry.

Table 4.13: ANOVA Results

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Casualty Code	12	5156041	429670	41.6	<2e-16***
Residuals	363	3749264	10329		

Table 4.14: Total accidents in the mining industry

Casualty Name	Total Injured Mean (SD)	Total Disabled Mean (SD)	Total Killed Mean (SD)	Total Accidents Mean (SD)
Conveyance accidents	8.26 (6.65)	0.0 (0.0)	0.68 (1.92)	8.38 (6.54)
Diving sickness	1.0 (0.82)	0.0 (0.0)	0.25 (0.5)	1.25 (0.5)
Electricity	5.62 (3.66)	0.0 (0.0)	0.72 (1.04)	5.72 (3.4)
Explosives	5.35 (4.35)	0.0 (0.0)	0.89 (1.31)	4.38 (2.96)
Fires	2.98 (4.37)	0.0 (0.0)	0.07 (0.35)	2.32 (1.82)
General	405.55 (277.75)	0.18 (0.38)	6.45 (4.61)	380.9 (253.97)
Heat sickness	8.94 (17.38)	0.0 (0.0)	0.82 (1.38)	9.12 (18.25)
Machinery	56.4 (28.67)	0.0 (0.0)	1.4 (1.57)	57.38 (28.23)
Miscellaneous	20.32 (13.82)	0.0 (0.0)	0.6 (0.9)	20.23 (13.4)
Occupational diseases	1.5 (1.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.0)
Rockfall	149.32 (146.03)	0.35 (0.74)	9.15 (9.98)	149.32 (144.88)
Subsidence or caving	1.11 (0.33)	0.0 (0.0)	0.11 (0.33)	1.0 (0.0)
Transportation and mining	144.52 (95.12)	0.22 (0.42)	7.82 (3.88)	150.02 (97.34)

Table 4.15 presents Tukey HSD test results for post-hoc comparisons. Post-hoc comparisons whose differences were statistically significant are reflected by p-adj values that are less than 0.05. Statistically significant differences mean that the means **A** and **B** are different enough that the distance between them is huge enough to say that either **A** is greater than **B** or vice versa. On the other hand, post-hoc comparisons whose differences were statistically insignificant are reflected by p-adj values that are greater than 0.05. For instance, post-hoc comparisons between casualty type 1 (rockfall, mean = 149.32, SD = 144.88) and casualty type 9 (subsidence or caving, mean = 1.0, SD = 0.0) are statistically significant, implying that rockfall contributed to a significantly higher number of accidents compared to subsidence or caving. The same conclusion can also be reached between transportation and mining (casualty type 3; mean = 150.02, SD = 97.34) and subsidence or caving (casualty type 9; mean = 1.0, SD = 0.0). Tukey's multiple comparisons mean a 95% family-wise confidence level.

Table 4.15: Tukey HSD test results for post-hoc comparisons

A-B	Diff	Lwr	upr	p-adj
10-9	1.563194e-13	-203.67914	203.67914	1.0000000
12-9	2.500000e-01	-203.42914	203.92914	1.0000000
7-9	1.096774e+00	-127.24086	129.43441	1.0000000
8-9	3.378378e+00	-122.59620	129.35296	1.0000000
6-9	4.725000e+00	-120.32190	129.77190	1.0000000
5-9	7.382353e+00	-119.67495	134.43966	1.0000000
11-9	8.117647e+00	-131.60509	147.84038	1.0000000
13-9	1.922500e+01	-105.82190	144.27190	0.9999990
2-9	5.637500e+01	-68.67190	181.42190	0.9546877
1-9	1.483250e+02	23.27810	273.37190	0.0059935
3-9	1.490250e+02	23.97810	274.07190	0.0055841
4-9	3.799000e+02	254.85310	504.94690	0.0000000
12-10	2.500000e-01	-239.41859	239.91859	1.0000000
7-10	1.096774e+00	-178.97652	181.17007	1.0000000
8-10	3.378378e+00	-175.01848	181.77524	1.0000000
6-10	4.725000e+00	-173.01799	182.46799	1.0000000
5-10	7.382353e+00	-171.78071	186.54541	1.0000000
11-10	8.117647e+00	-180.23916	196.47445	1.0000000
13-10	1.922500e+01	-158.51799	196.96799	1.0000000
2-10	5.637500e+01	-121.36799	234.11799	0.9977811
1-10	1.483250e+02	-29.41799	326.06799	0.2147486
3-10	1.490250e+02	-28.71799	326.76799	0.2085336
4-10	3.799000e+02	202.15701	557.64299	0.0000000
7-12	8.467742e-01	-179.22652	180.92007	1.0000000
8-12	3.128378e+00	-175.26848	181.52524	1.0000000
6-12	4.475000e+00	-173.26799	182.21799	1.0000000
5-12	7.132353e+00	-172.03071	186.29541	1.0000000
11-12	7.867647e+00	-180.48916	196.22445	1.0000000
13-12	1.897500e+01	-158.76799	196.71799	1.0000000

2-12	5.612500e+01	-121.61799	233.86799	0.9978734
1-12	1.480750e+02	-29.66799	325.81799	0.2169984
3-12	1.487750e+02	-28.96799	326.51799	0.2107389
4-12	3.796500e+02	201.90701	557.39299	0.000000
8-7	2.281604e+00	-80.24593	84.80914	1.0000000
6-7	3.628226e+00	-77.47618	84.73263	1.0000000
5-7	6.285579e+00	-77.88542	90.45658	1.0000000
11-7	7.020873e+00	-95.27107	109.31282	1.0000000
13-7	1.812823e+01	-62.97618	99.23263	0.9999374
2-7	5.527823e+01	-25.82618	136.38263	0.5382113
1-7	1.472282e+02	66.12382	228.33263	0.0000003
3-7	1.479282e+02	66.82382	229.03263	0.0000002
4-7	3.788032e+02	297.69882	459.90763	0.0000000
6-8	1.346622e+00	-75.96426	78.65750	1.0000000
5-8	4.003975e+00	-76.51810	84.52605	1.0000000
11-8	4.739269e+00	-94.57181	104.05034	1.0000000
13-8	1.584662e+01	-61.46426	93.15750	0.9999755
2-8	5.299662e+01	-24.31426	130.30750	0.5285922
1-8	1.449466e+02	67.63574	222.25750	0.0000001
3-8	1.456466e+02	68.33574	222.95750	0.0000001
4-8	3.765216e+02	299.21074	453.83250	0.0000000
5-6	2.657353e+00	-76.40551	81.72022	1.0000000
11-6	3.392647e+00	-94.73900	101.52430	1.0000000
13-6	1.450000e+01	-61.28986	90.28986	0.9999885
2-6	5.165000e+01	-24.13986	127.43986	0.5384051
1-6	1.436000e+02	67.81014	219.38986	0.0000001
3-6	1.443000e+02	68.51014	220.08986	0.0000001
4-6	3.751750e+02	299.38514	450.96486	0.0000000
11-5	7.352941e-01	-99.94565	101.41624	1.0000000
13-5	1.184265e+01	-67.22022	90.90551	0.9999993
2-5	4.899265e+01	-30.07022	128.05551	0.6873643
1-5	1.409426e+02	61.87978	220.00551	0.0000005

3-5	1.416426e+02	62.57978	220.70551	0.0000004
4-5	3.725176e+02	293.45478	451.58051	0.0000000
13-11	1.110735e+01	-87.02430	109.23900	1.0000000
2-11	4.825735e+01	-49.87430	146.38900	0.9160878
1-11	1.402074e+02	42.07570	238.33900	0.0002014
3-11	1.409074e+02	42.77570	239.03900	0.0001805
4-11	3.717824e+02	273.65070	469.91400	0.0000000
2-13	3.715000e+01	-38.63986	112.93986	0.9179026
1-13	1.291000e+02	53.31014	204.88986	0.0000021
3-13	1.298000e+02	54.01014	205.58986	0.0000018
4-13	3.606750e+02	284.88514	436.46486	0.0000000
1-2	9.195000e+01	16.16014	167.73986	0.0042422
3-2	9.265000e+01	16.86014	168.43986	0.0037627
4-2	3.235250e+02	247.73514	399.31486	0.0000000
3-1	7.000000e-01	-75.08986	76.48986	1.0000000
4-1	2.315750e+02	155.78514	307.36486	0.0000000
4-3	2.308750e+02	155.08514	306.66486	0.0000000

{1: 'rockfall', 2: 'machinery', 3: 'transportation and mining', 4: 'general', 5: 'conveyance accidents', 6: 'electricity', 7: 'fires', 8: 'explosives', 9: 'subsidence or caving', 10: 'occupational diseases', 11: 'heat sickness', 12: 'diving sickness', 13: 'miscellaneous'}

4.3.4 Casualty and Total Injuries

A one-way between casualties of ANOVA was conducted to compare the effect of casualty type on total injuries recorded within the mining industry. ANOVA results show that there was a statistically significant effect of casualty type on total injuries at the 5% level of significance [F (12, 363) = 40.86, $p < 0.05$]. This means that there exist pairs of casualty types whose mean number of injury differences are huge enough to conclude that they are not equal. Consequently, the Tukey HSD test was used to perform post-hoc comparisons to allow for identification of those pairs of casualty types whose means were indifferent or otherwise, as illustrated in table 4.16.

Table 4.16: ANOVA Results

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Casualty code	12	5728730	477394	40.86	<2e-16***
Residuals	363	4240753	11683		

Table 4.17 presents results detailing post-hoc comparisons performed using the Tukey HSD test. Particularly, mean difference between casualty type 4 (general) and casualty type 12 (diving sickness) was statistically significant (p -adj 0.05). The mean number of injuries resulting from general casualties was by far greater than the mean number of injuries resulting from diving sickness. Similar conclusions were drawn for all pairs with p -adj values that are less than 0.05. Tukey's multiple comparisons mean a 95% family-wise confidence level.

Table 4.17: Results detailing post-hoc comparisons performed using Tukey HSD test.

A-B	Diff	lwr	upr	p-adj
9-12	0.1111111	-216.507153	216.72938	1.0000000
10-12	0.5000000	-254.394021	255.39402	1.0000000
7-12	2.3548387	-189.157970	193.86765	1.0000000
8-12	4.3513514	-185.378522	194.08122	1.0000000
6-12	4.6250000	-184.409465	193.65947	1.0000000
5-12	7.2647059	-183.280045	197.80946	1.0000000
11-12	7.9411765	-192.381372	208.26373	1.0000000
13-12	19.3250000	-169.709465	208.35947	1.0000000
2-12	55.4000000	-133.634465	244.43447	0.9989702
3-12	143.5250000	-45.509465	332.55947	0.3565840
1-12	148.3250000	-40.709465	337.35947	0.3040142
4-12	404.5500000	215.515535	593.58447	0.0000000
10-9	0.3888889	-216.229376	217.00715	1.0000000
7-9	2.2437276	-134.246809	138.73426	1.0000000

8-9	4.2402402	-129.737129	138.21761	1.0000000
6-9	4.5138889	-128.476861	137.50464	1.0000000
5-9	7.1535948	-127.975280	142.28247	1.0000000
11-9	7.8300654	-140.768838	156.42897	1.0000000
13-9	19.2138889	-113.776861	152.20464	0.9999995
2-9	55.2888889	-77.701861	188.27964	0.9757834
3-9	143.4138889	10.423139	276.40464	0.0216656
1-9	148.2138889	15.223139	281.20464	0.0143267
4-9	404.4388889	271.448139	537.42964	0.0000000
7-10	1.8548387	-189.657970	193.36765	1.0000000
8-10	3.8513514	-185.878522	193.58122	1.0000000
6-10	4.1250000	-184.909465	193.15947	1.0000000
5-10	6.7647059	-183.780045	197.30946	1.0000000
11-10	7.4411765	-192.881372	207.76373	1.0000000
13-10	18.8250000	-170.209465	207.85947	1.0000000
2-10	54.9000000	-134.134465	243.93447	0.9990585
3-10	143.0250000	-46.009465	332.05947	0.3623054
1-10	147.8250000	-41.209465	336.85947	0.3092809
4-10	404.0500000	215.015535	593.08447	0.0000000
8-7	1.9965126	-85.773749	89.76677	1.0000000
6-7	2.2701613	-83.986566	88.52689	1.0000000
5-7	4.9098672	-84.608266	94.42800	1.0000000
11-7	5.5863378	-103.203908	114.37658	1.0000000
13-7	16.9701613	-69.286566	103.22689	0.9999844
2-7	53.0451613	-33.211566	139.30189	0.6981586
3-7	141.1701613	54.913434	227.42689	0.0000068
1-7	145.9701613	59.713434	232.22689	0.0000026
4-7	402.1951613	315.938434	488.45189	0.0000000
6-8	0.2736486	-81.948562	82.49586	1.0000000
5-8	2.9133545	-82.724051	88.55076	1.0000000
11-8	3.5898251	-102.030185	109.20983	1.0000000
13-8	14.9736486	-67.248562	97.19586	0.9999934
2-8	51.0486486	-31.173562	133.27086	0.6846004

3-8	139.1736486	56.951438	221.39586	0.000026
1-8	143.9736486	61.751438	226.19586	0.000009
4-8	400.1986486	317.976438	482.42086	0.000000
5-6	2.6397059	-81.445783	86.72519	1.0000000
11-6	3.3161765	-101.049482	107.68183	1.0000000
13-6	14.7000000	-65.904567	95.30457	0.9999932
2-6	50.7750000	-29.829567	131.37957	0.6634102
3-6	138.9000000	58.295433	219.50457	0.000015
1-6	143.7000000	63.095433	224.30457	0.000005
4-6	399.9250000	319.320433	480.52957	0.000000
11-5	0.6764706	-106.400436	107.75338	1.0000000
13-5	12.0602941	-72.025194	96.14578	0.9999996
2-5	48.1352941	-35.950194	132.22078	0.7891650
3-5	136.2602941	52.174806	220.34578	0.000090
1-5	141.0602941	56.974806	225.14578	0.000033
4-5	397.2852941	313.199806	481.37078	0.000000
13-11	11.3838235	-92.981835	115.74948	1.0000000
2-11	47.4588235	-56.906835	151.82448	0.9517014
3-11	135.5838235	31.218165	239.94948	0.0013385
1-11	140.3838235	36.018165	244.74948	0.0006977
4-11	396.6088235	292.243165	500.97448	0.000000
2-13	36.0750000	-44.529567	116.67957	0.9570871
3-13	124.2000000	43.595433	204.80457	0.0000341
1-13	129.0000000	48.395433	209.60457	0.0000127
4-13	385.2250000	304.620433	465.82957	0.000000
3-2	88.1250000	7.520433	168.72957	0.0182980
1-2	92.9250000	12.320433	173.52957	0.0090575
4-2	349.1500000	268.545433	429.75457	0.000000
1-3	4.8000000	-75.804567	85.40457	1.0000000
4-3	261.0250000	180.420433	341.62957	0.000000
4-1	256.2250000	175.620433	336.82957	0.000000

{1: 'rockfall', 2: 'machinery', 3: 'transportation and mining', 4: 'general', 5: 'conveyance accidents', 6: 'electricity', 7: 'fires', 8: 'explosives', 9: 'subsidence or caving', 10: 'occupational diseases', 11: 'heat sickness', 12: 'diving sickness', 13: 'miscellaneous'}

4.3.5 Casualty and Total Killed

A one-way between casualties ANOVA was also conducted to compare the effect of casualty type on total deaths recorded within the mining industry. ANOVA results showed that there was a statistically significant effect of casualty type on total killed at the 5% level of significance [$F(12, 363) = 22.83, p < 0.05$]. This means that there exist pairs of casualty types whose mean number of death differences are huge enough not to be ignored. Consequently, the Tukey HSD test was used to perform post-hoc comparisons to allow for identification of those pairs of casualty types whose mean number of deaths were indifferent or otherwise; ANOVA results are presented in Table 4.18.

Table 4.18: ANOVA Results

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
casualty Code	12	4291	357.6	22.83	<2e-16***
Residuals	363	5686	15.7		

Table 4.19 shows a summary of how the Tukey HSD test was used to compare results after the fact. All rows with values less than 0.05 are comparisons between two groups where the difference in mean values was statistically significant. For example, the number of deaths caused by accidents and by diseases that people get on the job were very different. Specifically, the number of deaths recorded for general casualties was significantly higher than the number of deaths recorded for occupational diseases. Tukey uses multiple comparisons of means. 95% family-wise confidence level.

Table 4.19: Summary results for post-hoc comparisons using Tukey HSD test.

A-B	Diff	lwr	upr	p-adj
7-10	0.09677419	-6.9156998	7.109248	1.0000000
9-10	0.11111111	-7.8206296	8.042852	1.0000000
12-10	0.25000000	-9.0832540	9.583254	1.0000000
13-10	0.60000000	-6.3217264	7.521726	1.0000000
5-10	0.67647059	-6.3005568	7.653498	1.0000000
6-10	0.72500000	-6.1967264	7.646726	1.0000000
11-10	0.82352941	-6.5115239	8.158583	1.0000000
8-10	0.89189189	-6.0552977	7.839082	0.9999999
2-10	1.40000000	-5.5217264	8.321726	0.9999788
4-10	6.45000000	-0.4717264	13.371726	0.0961276
3-10	7.82500000	0.9032736	14.746726	0.0118570
1-10	9.15000000	2.2282736	16.071726	0.0009718
9-7	0.01433692	-4.9834298	5.012104	1.0000000
12-7	0.15322581	-6.8592482	7.165700	1.0000000
13-7	0.50322581	-2.6551690	3.661621	0.9999985
5-7	0.57969639	-2.6981187	3.857512	0.9999952
6-7	0.62822581	-2.5301690	3.786621	0.9999824
11-7	0.72675522	-3.2567317	4.710242	0.9999932
8-7	0.79511770	-2.4186970	4.008932	0.9998164
2-7	1.30322581	-1.8551690	4.461621	0.9772037
4-7	6.35322581	3.1948310	9.511621	0.0000000
3-7	7.72822581	4.5698310	10.886621	0.0000000
1-7	9.05322581	5.8948310	12.211621	0.0000000
12-9	0.13888889	-7.7928518	8.070630	1.0000000
13-9	0.48888889	-4.3807289	5.358507	1.0000000

5-9	0.56535948	-4.3825483	5.513267	1.0000000
6-9	0.61388889	-4.2557289	5.483507	0.9999999
11-9	0.71241830	-4.7287109	6.153548	0.9999998
8-9	0.78078078	-4.1249632	5.686525	0.9999985
2-9	1.28888889	-3.5807289	6.158507	0.9996307
4-9	6.33888889	1.4692711	11.208507	0.0012909
3-9	7.71388889	2.8442711	12.583507	0.0000167
1-9	9.03888889	4.1692711	13.908507	0.0000001
13-12	0.35000000	-6.5717264	7.271726	1.0000000
5-12	0.42647059	-6.5505568	7.403498	1.0000000
6-12	0.47500000	-6.4467264	7.396726	1.0000000
11-12	0.57352941	-6.7615239	7.908583	1.0000000
8-12	0.64189189	-6.3052977	7.589082	1.0000000
2-12	1.15000000	-5.7717264	8.071726	0.9999976
4-12	6.20000000	-0.7217264	13.121726	0.1319480
3-12	7.57500000	0.6532736	14.496726	0.0180737
1-12	8.90000000	1.9782736	15.821726	0.0016094
5-13	0.07647059	-3.0024217	3.155363	1.0000000
6-13	0.12500000	-2.8264341	3.076434	1.0000000
11-13	0.22352941	-3.5979459	4.045005	1.0000000
8-13	0.29189189	-2.7187742	3.302558	1.0000000
2-13	0.80000000	-2.1514341	3.751434	0.9995292
4-13	5.85000000	2.8985659	8.801434	0.0000000
3-13	7.22500000	4.2735659	10.176434	0.0000000
1-13	8.55000000	5.5985659	11.501434	0.0000000
6-5	0.04852941	-3.0303628	3.127422	1.0000000
11-5	0.14705882	-3.7736921	4.067810	1.0000000
8-5	0.21542130	-2.9202963	3.351139	1.0000000
2-5	0.72352941	-2.3553628	3.802422	0.9998932
4-5	5.77352941	2.6946372	8.852422	0.0000001

3-5	7.14852941	4.0696372	10.227422	0.000000
1-5	8.47352941	5.3946372	11.552422	0.000000
11-6	0.09852941	-3.7229459	3.920005	1.0000000
8-6	0.16689189	-2.8437742	3.177558	1.0000000
2-6	0.67500000	-2.2764341	3.626434	0.9999200
4-6	5.72500000	2.7735659	8.676434	0.000000
3-6	7.10000000	4.1485659	10.051434	0.000000
1-6	8.42500000	5.4735659	11.376434	0.000000
8-11	0.06836248	-3.7990424	3.935767	1.0000000
2-11	0.57647059	-3.2450047	4.397946	0.9999992
4-11	5.62647059	1.8049953	9.447946	0.0001025
3-11	7.00147059	3.1799953	10.822946	0.0000002
1-11	8.32647059	4.5049953	12.147946	0.000000
2-8	0.50810811	-2.5025580	3.518774	0.9999972
4-8	5.55810811	2.5474420	8.568774	0.0000002
3-8	6.93310811	3.9224420	9.943774	0.000000
1-8	8.25810811	5.2474420	11.268774	0.000000
4-2	5.05000000	2.0985659	8.001434	0.0000018
3-2	6.42500000	3.4735659	9.376434	0.000000
1-2	7.75000000	4.7985659	10.701434	0.000000
3-4	1.37500000	-1.5764341	4.326434	0.9424059
1-4	2.70000000	-0.2514341	5.651434	0.1119152
1-3	1.32500000	-1.6264341	4.276434	0.9560885

{1: 'rockfall', 2: 'machinery', 3: 'transportation and mining', 4: 'general', 5: 'conveyance accidents', 6: 'electricity', 7: 'fires', 8: 'explosives', 9: 'subsidence or caving', 10: 'occupational diseases', 11: 'heat sickness', 12: 'diving sickness', 13: 'miscellaneous'}

4.4 Negative Binomial Regression

The negative binomial regression results were presented. The negative binomial regression was used because it best suits overdispersed data. Using a negative binomial regression, the outcome variable for log were predicted (total injured) using a linear combination of the predictors or independent variables as follows:

$$\text{Log (total injured)} = \text{constant} + B1*\text{year} + B2*\text{commodity} + B4*\text{casualty}$$

Since year, commodity, and casualty were all categorical variables, the model results were interpreted by comparing them to certain reference categories. Consequently, for year variables, 2008 was used as a reference category; for commodity variables, coal was used as a reference category; and for casualty variables, conveyance accidents were used as a reference category. In Table 4.20, the results of a negative binomial regression model are shown, with the number of total injuries as the dependent variable and the type of commodity and type of injury as the independent variables. The effects of the independent variables on the dependent variable were determined by the regression coefficients, as clearly shown under the "coef." column in table 4.20.

Table 4.20: Negative Binomial Regression

Generalized Linear Model Regression Results						
=====						
Dep. Variable:	total_injured	No. Observations:	386			
Model:	GLM	Df Residuals:	361			
Model Family:	NegativeBinomial	Df Model:	24			
Link Function:	log	Scale:	1.0000			
Method:	IRLS	Log-Likelihood:	-1566.7			
Date:	Wed, 16 Mar 2022	Deviance:	163.69			
Time:	07:31:04	Pearson chi2:	175.			
No. Iterations:	13					
Covariance Type:	nonrobust					
=====						
	coef	std err	z	P> z	[0.025	0.975]

Intercept	1.3699	0.280	4.889	0.000	0.821	1.919
Year[T.2009]	0.1057	0.247	0.427	0.669	-0.379	0.591
Year[T.2010]	-0.1098	0.243	-0.452	0.651	-0.586	0.366
Year[T.2011]	-0.0987	0.250	-0.394	0.693	-0.589	0.392
Year[T.2012]	-0.2482	0.248	-1.003	0.316	-0.733	0.237
Year[T.2013]	-0.3169	0.250	-1.270	0.204	-0.806	0.172
Year[T.2014]	-0.1460	0.246	-0.593	0.553	-0.628	0.336
Year[T.2015]	-0.2736	0.246	-1.113	0.266	-0.755	0.208
Year[T.2016]	-0.4497	0.247	-1.818	0.069	-0.935	0.035
Year[T.2017]	-0.5554	0.248	-2.238	0.025	-1.042	-0.069
commodity[T.OT]	0.0993	0.166	0.600	0.549	-0.225	0.424
commodity[T.PGM]	1.1587	0.160	7.251	0.000	0.846	1.472
commodity[T.gold]	1.2158	0.160	7.612	0.000	0.903	1.529
casualty_name[T.DIVING_SICKNESS]	-2.0086	0.743	-2.705	0.007	-3.464	-0.553
casualty_name[T.ELECTRICITY]	0.1261	0.253	0.499	0.618	-0.369	0.622
casualty_name[T.EXPLOSIVES]	-0.2485	0.261	-0.953	0.340	-0.759	0.262
casualty_name[T.FIRES]	-0.9212	0.263	-3.499	0.000	-1.437	-0.405
casualty_name[T.GENERAL]	3.9817	0.245	16.273	0.000	3.502	4.461
casualty_name[T.HEAT_SICKNESS]	-0.2699	0.324	-0.834	0.404	-0.905	0.365
casualty_name[T.MACHINERY]	2.1500	0.246	8.753	0.000	1.669	2.631
casualty_name[T.MISCELLANEOUS]	1.1184	0.248	4.516	0.000	0.633	1.604
casualty_name[T.OCCUPATIONAL_DISEASES]	-1.1039	0.672	-1.642	0.101	-2.422	0.214
casualty_name[T.ROCKFALL]	2.7959	0.245	11.407	0.000	2.316	3.276
casualty_name[T.SUBSIDENCE_OR_CAVING]	-1.8919	0.496	-3.817	0.000	-2.863	-0.921
casualty_name[T.TRANSPORTATION_AND_MINING]	2.9819	0.245	12.171	0.000	2.502	3.462
=====						

Table 4.20 presents the negative binomial regression coefficients for each of the variables, along with standard errors, z-scores, p-values, and 95% confidence intervals for the coefficients. The indicator variable T.2009 is the expected difference in log count between T.2009 and the reference group T.2008. The expected log count for T.2009 of the year variable is 0.1057 higher than the expected log count for T.2008. The indicator variable T.2010 is the expected difference in log count between the year 2010 and the reference year 2008. The expected log count for 2010 is 0.1098 lower than the expected log count for 2008. All indicators' variables from T. 2009 to T. 2016 were statistically insignificant, as all their p-values exceeded 0.05. However, indicator variable T.2017, which represents the expected difference in log count between year 2017 and the reference year 2008, is statistically significant. The expected log count for 2017 is 0.5554 lower than the expected log count for 2008. Although there is evidence of gradual decreases in

the yearly total number of injuries, the model results shed light on the fact that the differences recorded between the baseline year of 2008 and all other successive years were not of statistical significance except for the year 2017.

The indicator variable T.OT is the expected difference in log count between T.OT and the reference group T.Coal. The expected log count for T.OT of the commodity variable is 0.0993 higher than the expected log count for T.Coal. The number of injuries resulting from mining other minerals is 10% higher than the number of injuries produced by coal mining activities. However, this parameter is not statistically significant, meaning that the number of injuries produced by other mineral activities is indistinguishable from those produced by coal mining activities. Similarly, the indicator variable T.PGM is the expected difference in log count between T.PGM and the reference group T.Coal. The expected log count for T.PGM of the commodity variable is 1.1587 higher than the expected log count for T.Coal. Thus, for every 100 injuries produced by coal mining activities, the platinum group of metals produces nearly 116 more than coal's injuries. The indicator variable T.Gold is the expected difference in log count between T.Gold and the reference group T.Coal. The expected log count for T.Gold of the commodity variable is 1.2158 higher than the expected log count for T.Coal. This means that if coal produces 100 injuries, gold's injuries will be 122 higher than coal's injuries. PGM and gold parameters are statistically significant, implying that the number of injuries produced by PGM, and gold is significantly higher than the number of injuries produced by coal.

The indicator variable T. diving sickness is the expected difference in log count between T. diving sickness and the reference category T. conveyance accidents. The expected log count for T.Diving Sickness in the casualty type variable is 2.0086 times lower than the expected log count for T.Conveyance accidents. The difference between the log counts for diving sickness and conveyance accidents was statistically significant ($p < 0.05$).

The indicator variable T. Electricity is the expected difference in log count between T. Electricity and the reference group t.Conveyance accidents. The expected log count for T.Electricity of the casualty type variable is 0.1261 times higher than the expected log count for T.Conveyance accidents. The difference in log counts between electricity and conveyance accidents was statistically insignificant ($p = 0.618$). This result suggests that the number of injuries arising from electricity and conveyance accidents was insignificant.

The indicator variable T. Explosives is the expected difference in log count between T. Explosives and the reference group T. Conveyance accidents. The expected log count for T.Explosives in the casualty type variable is 0.2485 times lower than the expected log count for T.Conveyance accidents. This parameter value is statistically insignificant ($p = 0.341$), which implies that the number of injuries arising from explosives and conveyance accidents is insignificant.

The indicator variable T.Fires is the expected difference in log count between T.Fires and the reference group T.Conveyance accidents. The expected log count for T.Fires in the casualty type variable is 0.9212 times lower than the expected log count for T.Conveyance accidents. This parameter value is statistically significant ($p < 0.05$), and it shows that the number of injuries arising from fires was 92% lower than the number of injuries that arise from conveyance accidents.

The indicator variable T.General is the expected difference in log count between T.General and the reference group T.conveyance accidents. The expected log count for T.Fires in the casualty type variable was 3.9817 times higher than the expected log count for T.Conveyance accidents. The parameter value for the indicator variable was statistically significant ($p < 0.05$), meaning that general injuries are 398 percent higher than conveyance accidents.

The indicator variable T.heat sickness is the expected difference in log count between T.heat sickness and the reference group T.conveyance accidents. The expected log count for T. heat sickness in the casualty type variable was 0.2699 times lower than the expected log count for T. conveyance accidents.

The indicator variable T. machinery is the expected difference in log count between T. machinery and the reference group T. conveyance accidents. The expected log count for T.machinery in the casualty type variable was 2.1500 times higher than the expected log count for T.conveyance accidents.

The indicator variable T. miscellaneous is the expected difference in log count between T. miscellaneous and the reference group T. conveyance accidents. The expected log count for T.miscellaneous of the casualty type variable was 1.1184 times higher than the expected log count for T.conveyance accidents.

The indicator variable T.occupational diseases is the expected difference in log count between T.occupational diseases and the reference group T.conveyance accidents. The expected log

count for T.occupational diseases in the casualty type variable was 1.1039 times lower than the expected log count for T.conveyance accidents.

The indicator variable T. rockfall is the expected difference in log count between T. rockfall and the reference group T. conveyance accidents. The expected log count for T.rockfall in the casualty type variable was 2.7959 times higher than the expected log count for T.conveyance accidents.

The indicator variable T. subsidence or caving is the expected difference in log count between T. subsidence or caving and the reference group T. conveyance accidents. The expected log count for T. subsidence or caving of the casualty type variable was 1.8919 times lower than the expected log count for T. conveyance accidents.

The indicator variable T. transportation and mining is the expected difference in log count between T. transportation and mining and the reference group T. conveyance accidents. The expected log count for T.transportation and mining of the casualty type variable is 2.9819 times higher than the expected log count for T.conveyance accidents.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

This chapter provides summary of the study and give some concluding and recommendation remarks.

5.1 Summary of the study

This study was undertaken to analyse work accident data of the South African mining industry. One of the expectations of the study was to improve safety for personnel working at the mines. Accidents would be avoided if adequate procedures for operating mining equipment were followed, technology to notify operators were put on the mining machines, and safety management rules were in place in an operation. Operational procedures would remove all potential dangers, and these procedures would be always followed. The job would be consistent and predictable, with no inherent dangers. Sadly, since the reality of people, machines, and the mining worksite were continuously pushing one or more of these elements outside of the ideal, this was an impossible ideal. Identifying and regulating the cause variables in transportation and mining accidents, as well as general accidents, is critical to lowering the likelihood of accidents happening.

Safety of people remains a top priority for the mining business. Safety issues with fixed and mobile equipment lead to serious injuries, property damage, and operational mishaps. Most serious accidents, property damage, non-conformances, and near-misses on mobile surface equipment were caused by errors in judgment, failure to follow standard operating procedures, a lack of caution and speed, insufficient maintenance, a lack of concentration and negligence, poor observation, fatigue, poor visibility, and poor communication.

Responsible agencies must make significant efforts in addressing concerns such as seismicity and ground fall accidents related to deep level mining, as well as basic and applied research and knowledge transfer. This will also include health and safety seminars to teach and guide health and safety representatives on how to exercise their rights and authority under the Mine Health and Safety Act. There should also be a higher degree of knowledge, which will have an influence on boosting awareness and improving commitment to zero harm using the existing approach created for analyzing accident data in the South African mining sector.

Communication is another important part of any educational or training program. It is not only a way to teach, but also a way to teach employees what they need to know and get them to think the right way. South Africa has many different languages and dialects, which makes it hard to explain new ways of doing things or customs. General work experience and knowledge of how to use machines do help people avoid accidents and understand risks, but the number of injured experienced workers shows that experience alone does not stop accidents.

5.2 Conclusion

South African Mine accident dataset from 2008 to 2017 was analysed to identify the major variables that affect the severity of mine accidents. To create a good classification, variables that describe accident data were tabulated. Descriptive statistics was used to summarize the data set provided by DMRE. Using such method, it emerged that injuries, disabilities, death, and accidents happen in the mining industry each year. The total number of casualties was high in 2008 for all the commodities and was followed with a downward trend until 2015 where gold, platinum and coal began to follow an upward trend, and this was found after summarizing the dataset from DMR. It was also concluded that most injuries by casualty results from general, transportation and mining, rockfall and machinery. Distribution of accidents by commodity stated that gold and PGM dominates most accidents in the mining industry. Accident results due to specific agencies such as rock bursts, track bound vehicles. Accidents also occurred because of personnel activities such as drilling, walking and pinch bar user. Accidents may also result in specific areas in the mines such as the stope, faces, shaft and ore pass.

There is an association between years and the accident outcome variables. Results demonstrate the insignificant role of year and the significant role of commodity and casualty type in influencing the number of injuries or accidents experienced by the mining industry between 2008 and 2017. The type of commodities does influence the number of accidents recorded within the mining industry. Gold and PGMs produce a high number of accidents while coal and other minerals record a lower number of accidents on an average basis. It was concluded that accident outcomes depend on commodity type and where the accident has occurred. The accident outcome also depend on which casualty type under which accident was classified.

Commodities influence the number of accidents in the South African mining industry whilst gold and PGMs have high number of accidents with low number of accidents in coal and other minerals. Commodities play a role in influencing number of people who lost their lives due to

workplace accidents in the mining industry, where gold gave significantly high number of accidents induced compared to coal, PGMs and other minerals. The test of association revealed that there was a statistically significant effect of casualty type on total number of accidents at 5% level of significance.

In conclusion, there is an upward trend or pattern with regards to total accidents occurring in the mining industry as compared to the commodity type. Casualty type (for example general, fall of the ground, transportation, and mining, and so much more) play a vital role in upward trend of accidents in the South African mining industry. The study showed a great trend or pattern as to how accidents occurred, and which factors do contribute to total accident in the mining industry. Although there is evidence of gradual decreases in the yearly total number of injuries, the results shed light on the fact that the differences recorded between the baseline year of 2008 and all other successive years were not of statistical significance except for the year 2017. Notwithstanding the limitations the study still provides important insights on the unique and important features related to analysis of work accident data in South African mining industry.

5.3 Limitations of the study

Limited data access- Confidential data is defined as data that cannot be released directly to the public research community due to possible risk(s) to study participants as well as the confidentiality promised to them. Gaining dataset from Department of Mineral Resource and energy was a challenge. Supervisors had to intervene so that they can grant access to unprocessed mine accident dataset. The data was deemed confidential as it contained accident investigation reports from different mines, research topic was then sent to the seniors so that they will understand the need for such data to be provided to the researcher.

Time was one of the limitations as the study has a limited timeframe for it to be completed. The study was supposed to be conducted for two years period to observe the long-term effects of an intervention, or to collect enough data to draw accurate conclusions. Time required was stretched as there was a change of topic to suit the level of study. Future researchers should make it a point that research topic they want to study should be met within specified period.

5.4 Recommendations

5.4.1 Recommendations for practice

The Department of Mineral Resources should recommit to constantly ensuring and prioritizing the safety of all mine personnel, which will be accomplished by reducing fire, heat, and oxygen deficiency related accidents, as well as rock-burst and rock fall related mishaps. To ensure that these guidelines are followed, the department should plan to monitor and enforce compliance via inspections and audits.

It is therefore recommended that the Department of Mining and Energy (DME) should require all mobile mining equipment to include a collision avoidance system to avoid accidents to occur in the mining industry.

5.4.2 Recommendations for further research

This study has contributed to understanding the analysis of work accident data in the South African mining industry as context regarding the accident analysis has been defined. Variables such as year, commodity type, and casualty type were studied to give the overall accident outcomes. This study overcome the decisive issue of work accident data specifically in other mining accident contexts, and other related areas more of construction, energy, agriculture, medicine, and electronics as the results detailed how accident occurred. This study would assist mine workers and owners together with the Department of Mineral resources and Energy in providing a better understanding regarding the trend/patterns, association and relationship between the variables compared.

It is suggested that further analysis of accident should be conducted to identify factors such:

- The financial impact towards mine accidents in the mining industries.
- The financial bearing of decreased worker productivity caused by decreased assurance, as well as the relationships between productivity and safety of workers.

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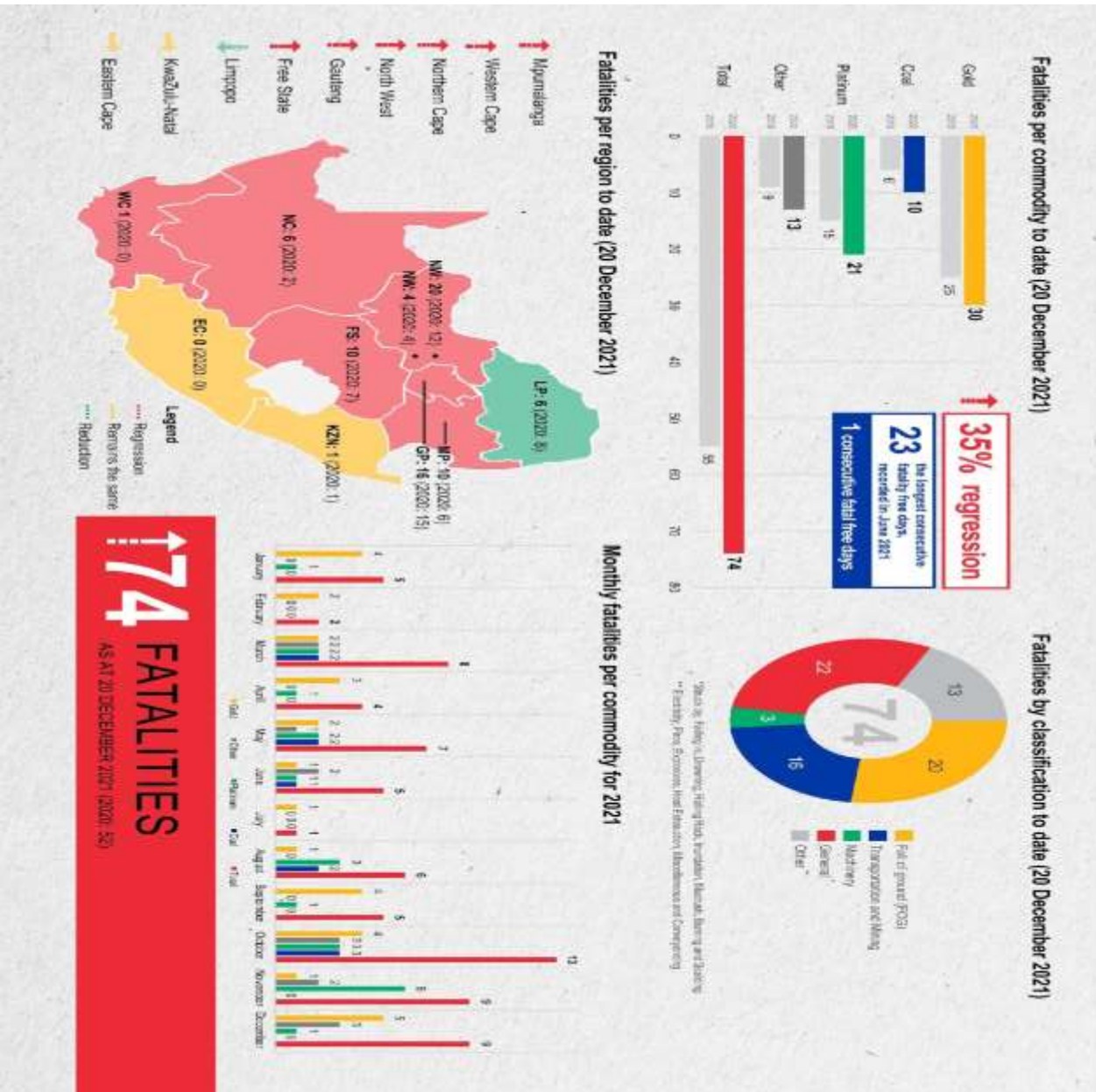
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Appendix A: Safety Dashboard Fatalities

SAFETY DASHBOARD: FATALITIES



Appendix B: Safety Dashboard Injuries

SAFETY DASHBOARD: INJURIES

