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Original Article

Analysis of Injuries in the Ghanaian Mining Industry and Priority Areas for Research

Eric Stemn^{1,2}¹Mineral Industry Safety and Health Centre, Sustainable Minerals Institute, The University of Queensland, Brisbane 4072, QLD, Australia²Environmental and Safety Engineering Department, University of Mines and Technology, Tarkwa, Ghana

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ABSTRACT

Background: Despite improvements in safety performance, the number and severity of mining-related injuries remain high and unacceptable, indicating that further reduction can be achieved. This study examines occupational accident statistics of the Ghanaian mining industry and identifies priority areas, warranting intervention measures and further investigations.

Methods: A total of 202 fatal and nonfatal injury reports over a 10-year period were obtained from five mines and the Inspectorate Division of the Minerals Commission of Ghana, and they were analyzed.

Results: Results of the analyses show that the involvement of mining equipment, the task being performed, the injury type, and the mechanism of injury remain as priorities. For instance, mining equipment was associated with 85% of all injuries and 90% of all fatalities, with mobile equipment, component/part, and hand tools being the leading equipment types. In addition, mechanics/repairmen, truck operators, and laborers were the most affected ones, and the most dangerous activities included maintenance, operating mobile equipment, and clean up/clearing.

Conclusion: Results of this analysis will enable authorities of mines to develop targeted interventions to improve their safety performance. To improve the safety of the mines, further research and prevention efforts are recommended.

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1. Introduction

The mining industry remains a vital contributor to the global economy. The products of mining have significantly improved human livelihood and are the bedrock of several other industries including aviation, power generation, electronics, cement production, steel production, agriculture, and even medicine [1]. In Ghana, several sources indicate that the mining industry was the most important contributor to the nation's economy in terms of employment, direct and indirect revenues, exports, and investments [2–5] until the recent discovery and exploitation of oil in commercial quantities. However, despite these positive contributions, the industry is typically associated with hazardous working conditions, which affect the health and safety of workers. The industry has been regarded as one of the safety-critical domains with dangerous operations and an environment in which the operator is exposed to a plethora of risks and hazards [6]. The International Labour Organization estimates that mining employs around 1% of the global workforce; it accounts for 8% of the global work-related

fatalities [7,8]. In the United States, Marse and Layne's analysis of 16-year fatality data indicated that the industry had the highest fatality rate of 30.3 per 100,000 workers. Similarly, in Australia, Safe Work Australia [9] acknowledged that despite the reduction in fatality rate from 12.4 in 2003 to 4.4 in 2015, the number of death in the industry still remains high at a yearly average of 9.

As a result of the severity and frequency of mining-related incidents, they have been regarded as the costliest [10]. The cost is usually categorized into two: direct cost and indirect cost [11]. The direct cost usually consists of cash payment under national laws and regulation, in the form of compensation and other benefits. The indirect cost that is usually greater consists of several things, such as the cost of time for treating an injured person, cost of lost time of an injured person, cost due to damage to property and equipment, and even cost of investigating the accident. The direct cost has been seen to significantly impact the economy of countries. For instance, the International Labour Organization estimates that mining deaths cost the global economy a staggering amount of \$240 billion [12]. It was estimated that mining-related accidents were costing the

E-mail addresses: e.stemn@uq.edu.au; estemn@umat.edu.gh (E. Stemn).

European Union 15-member states \$527 million [13]. Leigh et al [14] ranked the lignite and bituminous mining as the second in the US in terms of the average cost per employee for both fatal and nonfatal injuries.

Despite these disturbing statistics, significant safety improvements have been made in the mining industry over the last century. Recent scholarly works indicate a continuous decline in the frequency and severity of mining accidents [1,10,15–22]. In the US, the number of fatalities has declined from 164 in 1984 to 25 in 2017 [10]. In Australia, the fatality rate has reduced from 12.4 in 2004 to 4.4 in 2015 [23]. Similar reductions have been made in other countries including India [24], South Africa [25], Spain [26], and Poland [27]. Despite these records of improvements, the frequency and severity of mining accident are still undesirable. As Kecojevic et al [10] acknowledged, further progress can be made through a synergy of traditional, fundamental, and innovative interventions. However, such improvement strategies should target specific areas, and those areas can be determined when past accidents are analyzed thoroughly. This study was therefore undertaken to examine and more thoroughly characterize mining injuries in Ghana and perform descriptive analyses of injuries that had occurred over the past 10 years, from 2008 to 2017. Investigation reports, for fatal and nonfatal injuries, obtained from underground and surface mines were analyzed together.

2. Brief overview of Ghana's mine safety statistics

In Ghana, by law, mining incident/accident reports are to be submitted to the Inspectorate Division of the Minerals Commission [28]. Thus, there should have been the existence of a database that catalogs all reported incidents occurring within the industry, and such a database should be readily accessible to the public. However, accessibility to such data still remains a challenge and has been identified as the number one problem that hinders research in this area [29]. It is therefore not surprising that accidents and injuries in Ghana's mining industry have been sparsely studied, although the industry was long identified as a major safety-critical domain [6,30]. Information on major topics such as causes, types, effects, and consequences of accidents is difficult to find. Most of the research studies carried out so far consider only individual mines [29,31,32]. Hence, studies that consider the entire industry across different commodities and mine type using rich data will be a significant contribution for improving health and safety.

Fig. 1 shows the number and frequency rate of fatalities and serious injuries from 2004 to 2015. It depicts an average annual fatality of five and serious injury of 51, with the highest figures

recorded in 2011 and 2012 for fatality and 2010–2012 for serious injury. Although the cause of this rise has not been studied, thereby making it difficult to offer a research-based explanation, it is possible that the increase in employment around those years could have contributed to this development because those high values coincide with the boom period. It appears that the number and frequency rate of incidents mimic the growth of the industry because the least values were recorded during the downturn years with the highest numbers recorded during the prosperous periods. The figure shows that there has been a decrease in the frequency rate of serious injury against that of fatality. The difference between the highest and the lowest serious injury rate is 1.54, representing 86% reduction, whereas that of fatality is 0.1, representing 75% reduction. Reduction in serious injury rate is more than 10% better than that of fatality. A similar observation is made when the number of fatalities and the number of serious injuries are compared. Thus, a careful examination of the figure indicates that more people are fatally injured than involved in nonfatal injuries.

In addition, comparing the fatality frequency rate of Ghana with that of other major mining countries indicates that Ghana's rate is relatively higher than that of the other countries (Fig. 2). For instance, the 10-year fatality frequency rate of Ghana (0.0711) far exceeds that of Australia (0.0279) and the USA (0.0569). For half of the 10-year period (2004–2013), the fatality rate of Ghana was consistently higher than that of Australia and the USA. It can be observed from the figure that Ghana's minimum frequency rate (0.0353) exceeds that of Australia (0.0131) and that its maximum frequency rate (0.1471) exceeds that of both Australia (0.0556) and the USA (0.085). Furthermore, correlation analysis indicates that there is a stronger positive correlation between the number of fatalities and the hours worked in Ghana ($r = 0.607$) and the USA ($r = 0.609$) than in Australia ($r = 0.056$). This indicates that more people are fatally injured as the hours worked increase in Ghana and the USA than in Australia. The high work-related injury rate in the Ghanaian mining industry suggests that research is needed to offer an overall understanding and identify priority issues.

3. Materials and methods

3.1. Data source

Currently, there are 12 active large-scale mines belonging to nine different companies that are members of the Ghana Chamber of Mines. Out of these 12 mines, five gold mines provided the data that were used for this research. The mines were selected based on the following criteria:

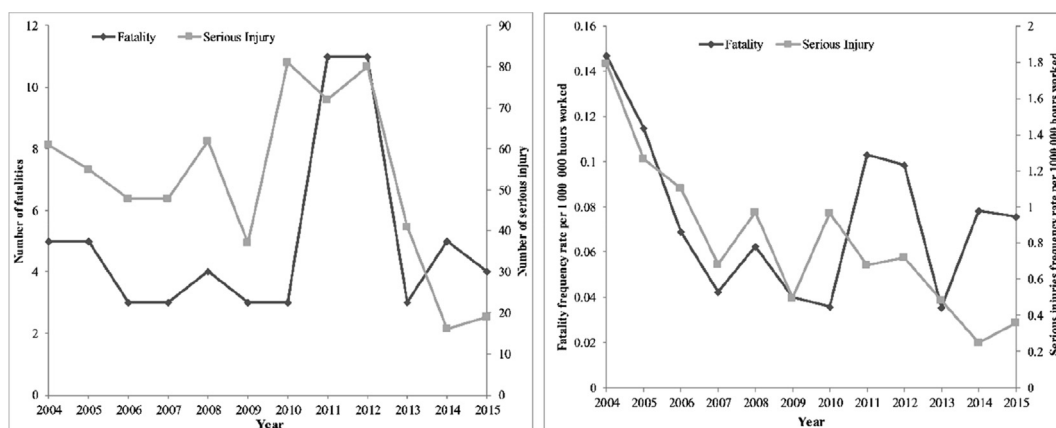


Fig. 1. Injury statistics of the Ghanaian mining industry from 2004 to 2015.

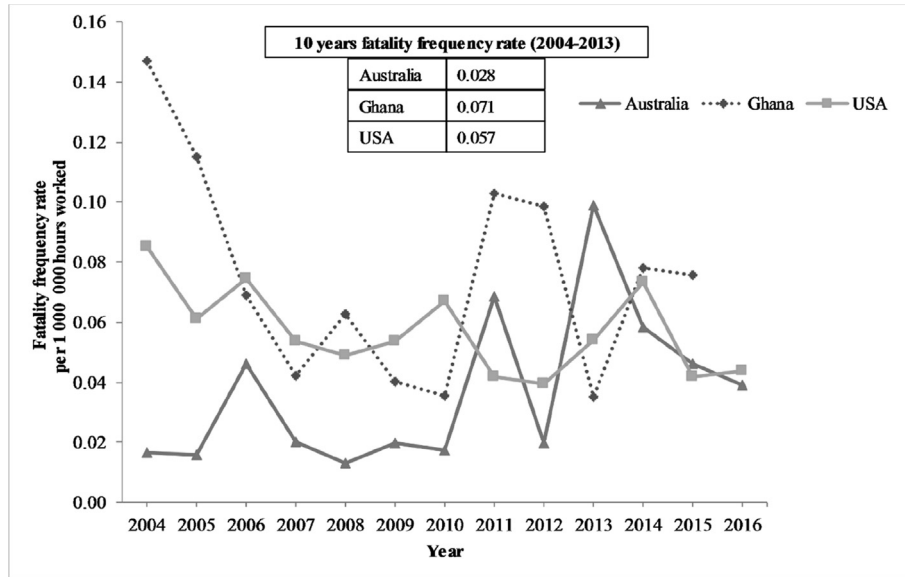


Fig. 2. Fatality frequency rate of the mining industry of Ghana, Australia, and the USA.

- being a member of the Ghana Chamber of mines and reporting incidents/accident data to the Inspectorate Division of the Minerals Commission of Ghana
- operating for at least 10 continuous years
- having instituted an internationally recognized safety management system such as OHSAS 18001

After an initial invitation letter was sent to 10 mines with several follow-ups, five consented to participate in the research and gave the researcher access to their incidents/accidents data. A total of 650 investigation reports from 2008 to 2017 were obtained from the mines. The reports covered all categories of incidents investigated by the mine sites such as near miss, property damage, and injuries of all types. There were differences in the details of the reports because of the differences in investigation and reporting techniques used by different companies. However, all the reports contained information about the victim(s), the task being performed, the incident itself, and the type of equipment if there was an involvement of mining equipment.

3.2. Data screening to select relevant reports

A screening process was used to select samples of the investigation reports for further analysis. Because the focus of the

analysis was specific to injuries, first was to select incidents which had resulted in an injury. Second, the analysis focused on injuries that occurred within the mining lease/concession of the mines. Thus, reports related to accidents occurring outside the mining lease/concession were rejected. The study also had a focus on work-related injury. However, some reports had nothing to do with work-related activities (for example, drowning of a local resident in a pond on the mining concession); such reports were also discarded from the analysis. Fig. 3 shows the screening and selection process.

3.3. Data classification

After selecting the relevant reports, the next stage was to classify the reports by a coding process. Based on the research questions, the content of the selected reports, and relevant literature [1,10,15], it was observed that information could be extracted into 17 user-centered classes grouped under the major topics of the injured, task/activity, equipment, and injury, as shown in Table 1. For each class, several codes were identified based on the Mine Safety and Health Administration (MSHA) and the Department of Natural Resources and Mines (DNRM), Queensland, Australia, accident classification code. The codes were repeatedly refined by constant comparison as the reports were read [33,34]. A flowchart

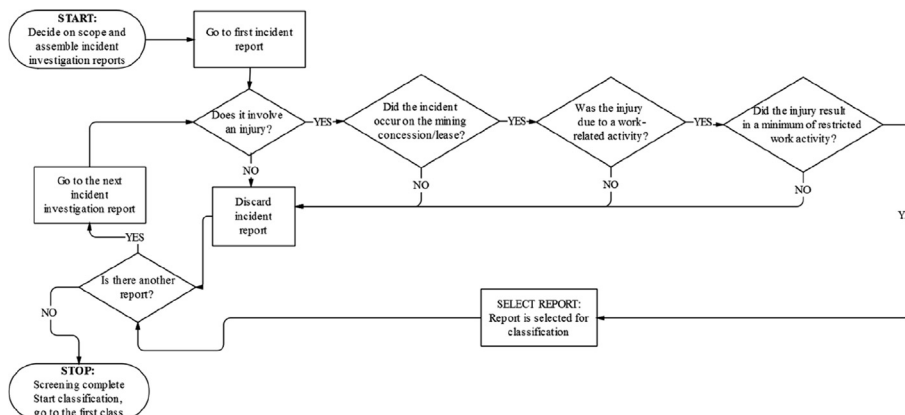


Fig. 3. Process of screening and selection of reports for onward classification.

Table 1
Topics and classes identified in the reports for classification and coding

Topics			
Injured	Task/activity	Equipment	Injury
Age	Worksite location	Involvement of equipment	Accident time
Experience	Shift start time	Equipment type	Day of week
Employment type	Hours into work		Degree of injury
Job title	Task being performed		Accident type class
			Body part affected
			Injury type
			Injury mechanism

detailing the classification and coding process including iterative changes to codes is shown in Fig. 4.

3.4. Data analysis

A single variable analysis was carried out on the individual classes, without any form of variable combination. This was carried out using basic descriptive statistics to identify broad patterns and trends in accordance with the research questions.

3.4.1. Do the characteristics of the injured person show any trend and deserve further examination? If so, which specific characteristics should be considered?

Within the literature, there is divergent opinion whether certain characteristics of workers are determinants of their injury experience. Some authors have found associations between the severity of an injury and the age and experience of the injured [10,35,36], whereas others have said otherwise [18,37]. Analyzing the characteristics of the injured was necessary because the industry in recent times has experienced significant growth with the expansion of existing operations and the commencement of new operations. This expansion has led to high labor turnover, where old and experienced workers leave old mines and move to new ones and are replaced with young and less-experienced recruits [38]. By examining injury experiences and workers' characteristics, interventions can be implemented to address vulnerable groups.

3.4.2. Does the task/activity being performed remain a priority issue? If so, which specific areas ought to be considered?

Some works indicate that within the mining industry, certain task and occupation are more dangerous than others, and workers

engaged in those tasks have an increased risk of being injured [39,40]. Some have also found differences in the rates of injury among different job titles and have identified specific occupations that merit attention [15,41,42]. Coding the task being performed may yield some useful information, especially when combined with other classes. For example, it might allow a safety officer to determine the task mostly associated with an injury affecting a particular body part.

3.4.3. Does the involvement of mining equipment in injuries remain a priority? If so, which types of equipment should be prioritized?

The involvement of mining equipment in injuries has been studied in detail [1,10,20,24]. Some authors have identified specific mobile mining equipment as high priorities [1,10]. Because the injury investigation reports contained information on equipment, it was coherent to determine if the situation in Ghana follows the global trend or had some deviations. This could provide information on the types of equipment that should be prioritized for further studies and prevention efforts.

3.4.4. Do some characteristics of the injury deserve priority investigation? If so, which specific issues remain significant?

Some scholars have found differences in the causal factors of fatal and nonfatal injuries [19,43–45]. Others have identified that certain body parts, injury mechanism, and accident type remain a priority [15,16,22,42]. By analyzing characteristics of the injury, broad trends could be identified for subsequent investigation. For instance, priority body parts, injury mechanism, degree and nature of injury, and accident type associated with specific injuries can be determined. Importantly, characteristics of the injury could yield more useful information and identify specific priority areas when combined with other variables.

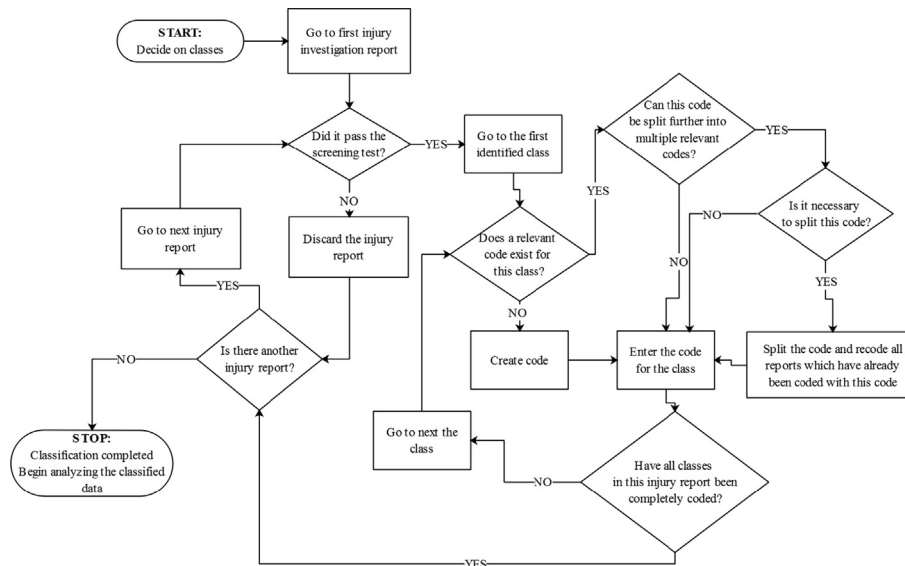


Fig. 4. A flowchart of classification and coding of selected injury reports.

4. Results

4.1. Severity of selected injury reports

After screening all 650 incident investigation reports, 202 reports of different degrees of injuries were selected for subsequent classification and coding. The selected reports covered a period of 2008–2017. Two-thirds of the selected reports were from 2012 to 2014, with 2008 and 2017 having the lowest number of two reports each. The reports included 30 fatalities and 172 nonfatal injuries as shown in Fig. 5.

4.2. Do the characteristics of the injured person show any trend that deserves further examination? If so, which specific characteristics should be considered?

There were more operators (76.7%) and surface operations workers (70.3%) than contractors (23.3%) and underground workers (29.7%). The age and experience (Table 2) of the injured miners show differences with respect to surface/underground locations and operator/contractor workers, although the differences are marginal. Most injured operators aged 38–47 years (34.8%), whereas most injured contractors aged 28–37 years (36.2%). The most affected age group for both surface and underground operations was 38–47 years (35.9% and 23.3%, respectively). Similarly, for the whole cohort, the most affected age group was 38–47 years (32.2%). Generally, it can be observed that the top affected age group is 38–47 years, followed by 28–37 years, with ≥ 58 years being the least. Hence, the age distribution of the injured miners (see Fig. 6) appears symmetrical. This is such that the percentage of injured workers increases with increase in age from 18–27 years until a peak is reached at 38–47 years, and then there is a decrease in the percentage of injured workers with an increase in age from 38–47 years to >58 years. More than 30% of the reports had no information on age; this was more pronounced in underground mines than surface mines and among operators than contractors.

Similar to the age class, most of the reports had no information on the work experiences of the injured miners. This was mostly associated with underground mines than surface mines and with operators than contractors. Information on this would have contributed to understanding the data better. Despite this lack of information, the data show that workers with less experience (≤ 9 years) were involved in injuries more than their experienced counterparts (>10 years). Fig. 7 indicates that the modal age group for both fatal and nonfatal injuries was 38–47 years. Similarly, the modal experienced group for both fatal and nonfatal injuries was >9 years. In addition, old workers (≥ 38 years) were often involved in both fatal and nonfatal injuries than young workers (<38 years). Similarly, less-experienced miners (<5 years) were often involved in both fatal and nonfatal injuries than experienced workers (≥ 20

years). Fig. 8 shows that more contractors (29.8%) and underground employees (18.3%) were involved in fatal injuries than operators (10.3%) and surface employees (13.4%).

The breakdown of the job title of the injured at the time of the incident is shown in Fig. 9. Mechanics (22.5%), welders (10.6%), and truck operators (18.3%) make up over half of the surface mining injuries, whereas supervisors (15%), drillers (26.7%), and blasters (11.7%) make the majority of the injuries logged from underground locations. The figure shows several differences, such as injury to underground drillers (26.7%) and surface drillers (1.4%). Similarly, a mechanic/repairman shows a significant difference, with 22.5% of all surface injuries against 10% of all underground injuries. Overall, the top five most affected job titles were mechanics/repairmen (18.8%); truck operators (13.9%); and drillers, laborers, and supervisors (8.9%). This figure generally identifies specific job titles that merit consideration for prioritizing research and prevention efforts.

4.3. Does the task/activity being performed remain a priority issue? If so, which specific issues ought to be considered?

Fig. 10 shows details of the task/activity being performed and the location of the task at the time of the incident. For surface operations, the top five tasks were machine maintenance/repair (19.7%), operating mobile equipment (16.9%), cleaning up/clearing (10.6%), lifting/lowering by hand (7.7%), and directing moving equipment (7%), altogether making up 61.9% of all surface injuries. The top five tasks for underground locations were drilling (20%), charging up (10%), walking (8.3%), barring/scaling (5%), and changing/adjusting (5%), totaling 48.3% of all underground injuries. This is logical as occupations associated with such tasks were related to most of the injuries. The top five tasks in descending order for the whole cohort were machine maintenance/repair, operating mobile equipment, cleaning up/clearing, drilling, and lifting/lowering by hand, which are responsible for 51.5% of all injuries. Sixty percent of the underground injuries occurred at the stope mining area (45%) and the shaft area (15%). For surface operations, the majority of the accidents (54.2%) occurred at workshops (23.2%), in processing plants (17.6%), and on haul roads (13.4%). This gives a broad indication for prioritizing prevention measures as specific tasks and locations related to most of the injuries have been determined.

Details of hours of work before the accident occurred and the shift are shown in Fig. 11. The trend is somehow similar for both surface and underground mines. Incidents predominated in the initial 8 hours of a workday for both surface (73%) and underground (85%) mines. However, a large portion of surface mines compared with underground mines experienced injury after 8 hours of work. A further breakdown of the first 8 hours of a workday shows that most injuries occurred after 4 hours but less than 8 hours into a

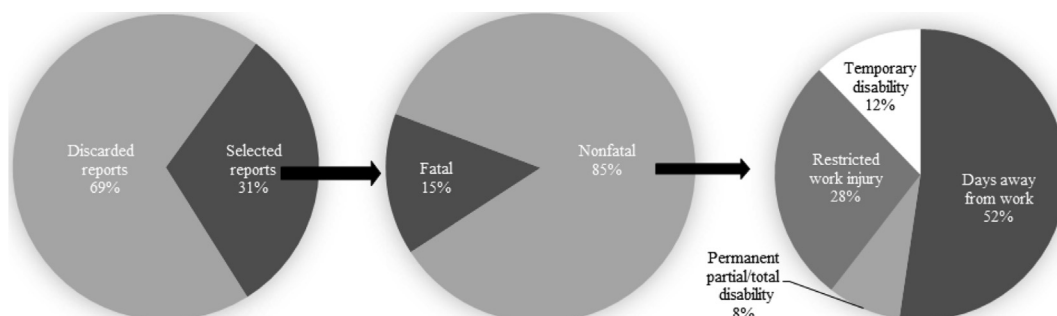


Fig. 5. Injury severity of selected reports.

Table 2
Age and experience of injured miners by employment and mine type

Class	Operators (n,%; 155, 76.7)	Contractors (n,%; 47, 23.3)	Surface (n,%; 142, 70.3)	Underground (n,%; 60, 29.7)	Overall (n,%; 202, 100)
<i>Age (y)</i>					
18–27	8 (5.2)	3 (6.4)	10 (7)	1 (1.7)	11 (5.4)
28–37	28 (18.1)	17 (36.2)	41 (28.9)	4 (6.7)	45 (22.3)
38–47	54 (34.8)	11 (23.4)	51 (35.9)	14 (23.3)	65 (32.2)
48–57	10 (6.5)	2 (4.3)	7 (4.9)	5 (8.3)	12 (5.9)
≥58	3 (1.9)	3 (6.4)	5 (3.5)	1 (1.7)	6 (3)
Unknown	52 (33.5)	11 (23.4)	28 (19.7)	35 (58.3)	63 (31.2)
<i>Total mining experience (y)</i>					
<1	4 (2.6)	3 (6.4)	7 (4.9)	0 (0)	7 (3.5)
1–4	21 (13.5)	13 (27.7)	34 (23.9)	0 (0)	34 (16.8)
5–9	38 (24.5)	10 (21.3)	45 (31.7)	3 (5)	48 (23.8)
10–14	17 (11)	1 (2.1)	16 (11.3)	2 (3.3)	18 (8.9)
15–19	1 (0.6)	4 (8.5)	2 (1.4)	3 (5)	5 (2.5)
20–24	3 (1.9)	2 (4.3)	1 (0.7)	4 (6.7)	5 (2.5)
≥25	6 (3.9)	0	4 (2.8)	2 (3.3)	6 (3)
Unknown	65 (41.9)	14 (29.8)	33 (23.2)	46 (76.7)	79 (39.1)
<i>Current mine experience (y)</i>					
<1	10 (6.5)	19 (40.4)	24 (16.9)	5 (8.3)	29 (14.4)
1–4	38 (24.5)	14 (29.8)	46 (32.4)	6 (10)	52 (25.7)
5–9	39 (25.2)	1 (2.1)	36 (25.4)	4 (6.7)	40 (19.8)
10–14	6 (3.9)	2 (4.3)	5 (3.5)	3 (5)	8 (4)
15–19	2 (1.3)	3 (6.4)	2 (1.4)	3 (5)	5 (2.5)
20–24	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
≥25	3 (1.9)	0 (0)	2 (1.4)	1 (1.7)	3 (1.5)
Unknown	57 (36.8)	8 (17)	27 (19)	38 (63.3)	65 (32.2)
<i>Total experience in job title (y)</i>					
<1	7 (4.5)	5 (10.6)	12 (8.5)	0 (0)	12 (5.9)
1–4	25 (16.1)	15 (31.9)	40 (28.2)	0 (0)	40 (19.8)
5–9	27 (17.4)	6 (12.8)	29 (20.4)	4 (6.7)	33 (16.3)
10–14	21 (13.5)	1 (2.1)	21 (14.8)	1 (1.7)	22 (10.9)
15–19	1 (0.6)	2 (4.3)	0	3 (5)	3 (1.5)
20–24	7 (4.5)	2 (4.3)	3 (2.1)	6 (10)	9 (4.5)
≥25	3 (1.9)	3 (6.4)	5 (3.5)	1 (1.7)	6 (3)
Unknown	64 (41.3)	13 (27.7)	32 (22.5)	45 (75)	77 (38.1)

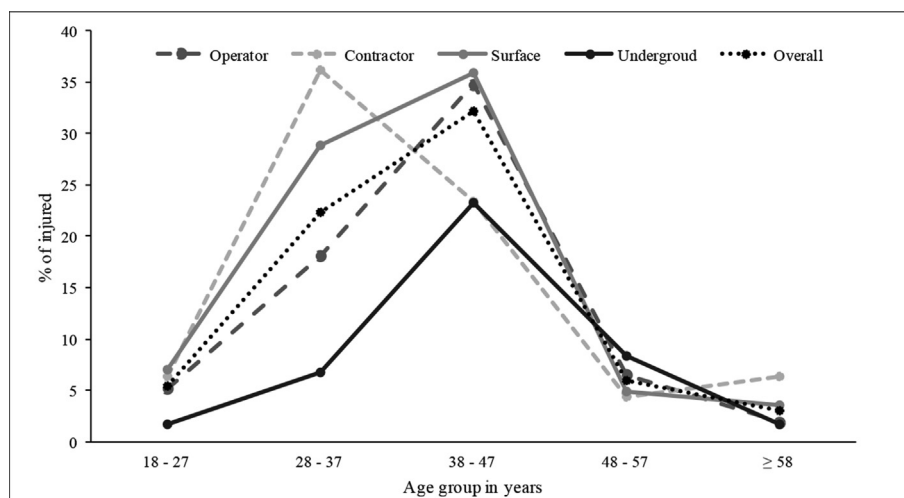


Fig. 6. Age distribution of injured miners based on employment and mine type.

workday. Most injuries were recorded during the morning shift for both surface (82%) and underground (63%) mines; however, more injuries occurred during evening shift in underground mines (35%) than in surface mines (18%) (Fig. 11). There was no incident during afternoon shift in surface mines because almost all surface mines in Ghana operate a two-shift system of morning and evening.

4.4. Does the involvement of mining equipment in injuries remain a priority? If so, what types of equipment should be prioritized?

Mining equipment was involved in 96% and 62% of the surface and underground mining injuries, respectively. Of all mine types, 86% of the injury reports involved mining equipment of some sort,

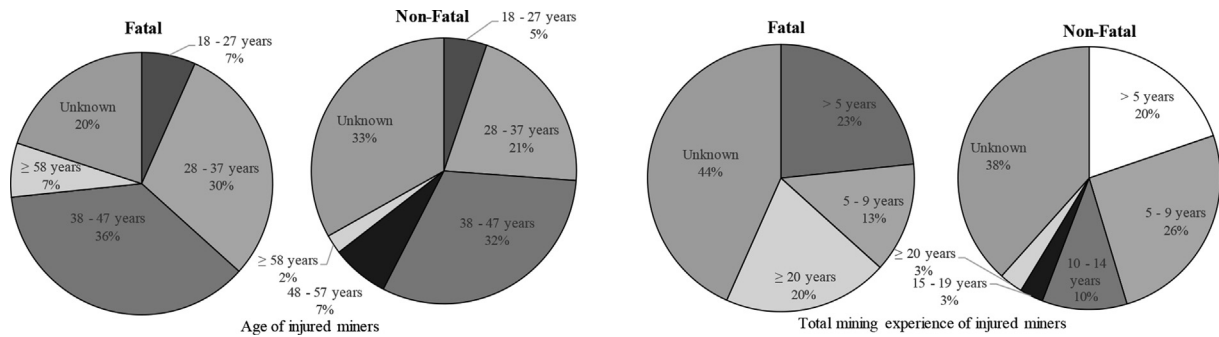


Fig. 7. Age and mining experience of injured miners by injury category.

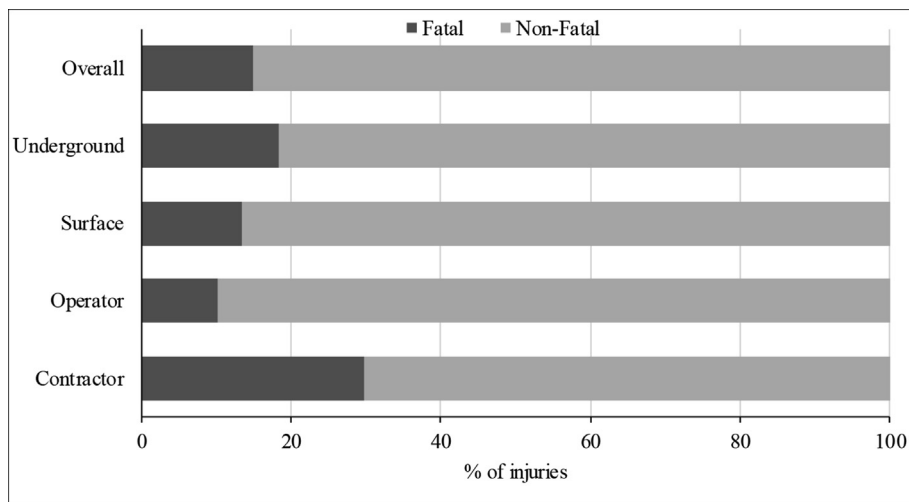


Fig. 8. Injury category based on employment and mine type.

that is, 90% and 86% of fatal and nonfatal injuries, respectively, involved equipment. This identification of a large proportion of accidents involving mine machinery is consistent with other works [1,10,20]. A breakdown of the specific equipment types as per the DNRM classification of equipment/tools is shown in Fig. 12. Among the equipment subclasses, haul trucks (16.8%), components/parts (13.9%), nonpower hand tools (7.3%), and light vehicles (5.8%) made up a majority (43.8%) of the surface mining injuries, whereas component/parts (17.9%), drill rigs (12.8%), rock drills/borers (12.8%), and other earth-moving equipment (10.3%) made up a majority (53.8%) of the underground injuries. Mobile equipment such as haul trucks, excavators, graders, and drill rigs were the most identified equipment. The involvement of these equipment subclasses is not surprising because they are prevalent in the mining environment. Although the nature of component/part subclass can make it difficult to focus prevention efforts, specific intervention strategies can target the more specific drill rigs, nonpower hand tools, light vehicles, and haul trucks provided. The more specific equipment subclasses such as haul trucks have been extensively studied, and several recommendations have been made to improve the safety of truck operators [46–48].

4.5. Do the characteristics of the injury deserve priority investigation? If so, which specific issues remain significant?

Concerning the degree/severity of injury (Fig. 13), there were more underground mining fatalities (18%) than surface mining fatalities (13%). The breakdown of the nonfatal injuries shows that for

underground mines, the injuries lead to a minimum of days away from work, whereas for surface mines, the minimum outcome of the injuries was a restricted work activity. The percentage of permanent disability is identical for both underground and surface mines (8%), whereas there were more temporary disabilities in surface (14%) than in underground mines (8%). Injuries resulting in days away from work showed a large difference, with 84% of all underground mining injuries versus 40% of surface mining injuries.

Fig. 14 shows broad peaks in the percentage of injury for the following times.

- 11 AM–12 PM, that is 5–6 hours into the morning shift (assuming the shift start at 6 AM) for both surface and underground mining.
- 1–2 PM for both surface and underground mining, this is, however, more pronounced in surface mines than in underground mines.
- 9–10 PM and 2–3 AM for underground mines.

The day of the week during which the incident occurred is shown in Fig. 15. Thursday (31.7%) remains the peak in underground mines, whereas for surface mines, it is Friday (26.1%). The percentage of incidents for these two days is quite significant, and further investigation is required to identify explanations for these peaks. Saturday and Tuesday appear to be the safest days for both underground and surface mines. The top three days for surface mines were Friday (26.1%), Wednesday (15.5%), and Monday (14.1%) and accounted for 55.7% of the total surface

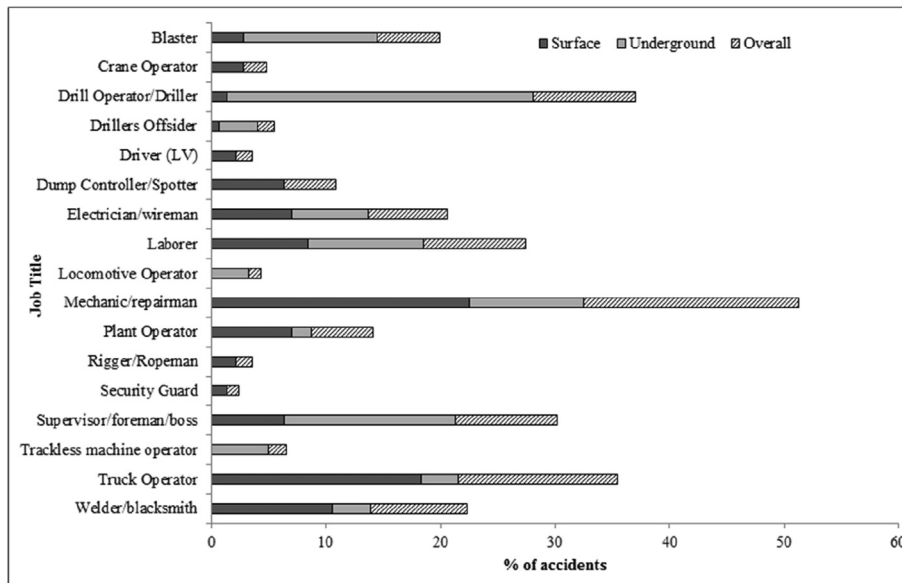


Fig. 9. Job title of the injured at the time of the accident.

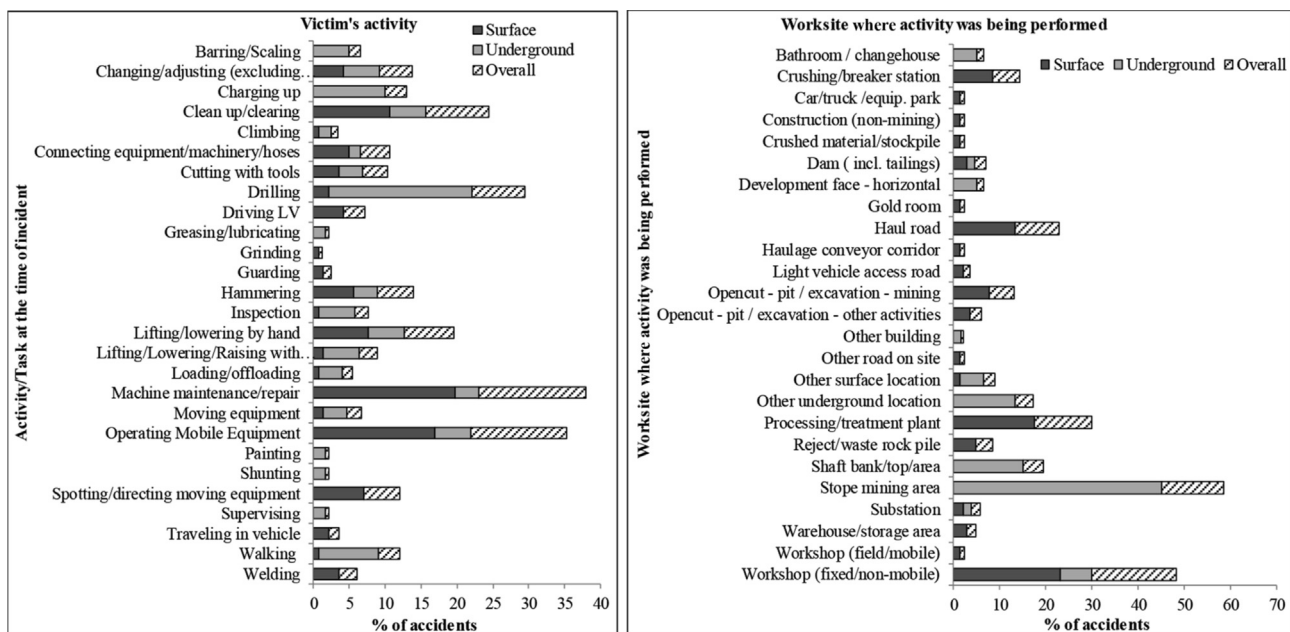


Fig. 10. Victim's activity and location of activity at the time of the accident.

injuries. For underground mines, 65.1% of the incidents occurred on Thursday (31.7%), Wednesday (16.7%), and Friday (16.7%).

Fig. 16 shows the classification of the injuries based on the MSHA classification for the accident type and nature of an injury and the DNRM classification for the affected body part and mechanism of injury. For underground operations, machinery (25%), falling/rolling rock/material (21.7%), and slip/fall of the person (18.3) were associated with more than half of the injuries. For surface operations, power haulage (21.1%), hand tools (19%), and machinery (17.6%) were equally associated with more than half of the injuries. This trend agrees with previous results. For instance, the identification of power haulage as a major issue is not surprising as earth-moving equipment such as haul trucks was identified as one of the major mining equipment commonly associated with injuries. For the whole cohort, machinery, power haulage,

hand tools, slip/fall of the person, and handling of materials were the top five accident types. Concerning specific regions of the body that injuries affected, the majority of the injuries for both surface and underground locations affected the hand/finger (31% and 15%, respectively) and multiple body parts (16.2% and 25%, respectively). Regarding the injury type, the majority of the surface injuries were laceration (29.6%), fracture (18.3%), and multiple injuries (17.6%). Similarly, 70% of the underground injuries were laceration (43.3%), contusion (11.7%), and multiple injuries (15%). Burns (9.9%), contusion (9.2%), and traumatic amputation (7%) were also significant in surface mines. The frequent injury mechanisms in surface mines were being struck by a metallic object (26.1%), being hit by a moving object (9.9%), motion of a moving vehicle (9.2%), and trapped between stationary and moving objects (8.5%). Fall/slip/trip from height (18.6%), being hit by a moving object (15.3), struck

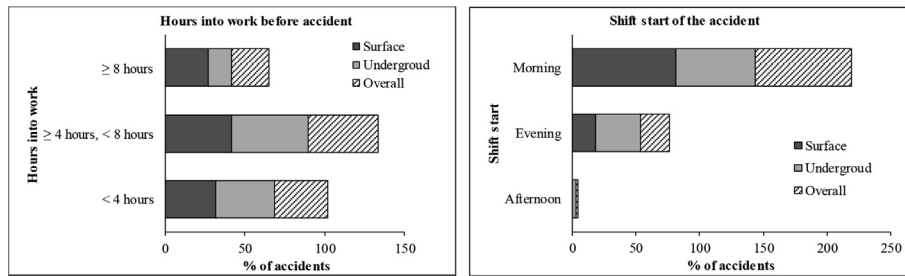


Fig. 11. Shift start time and hours of work just before the accident occurred.

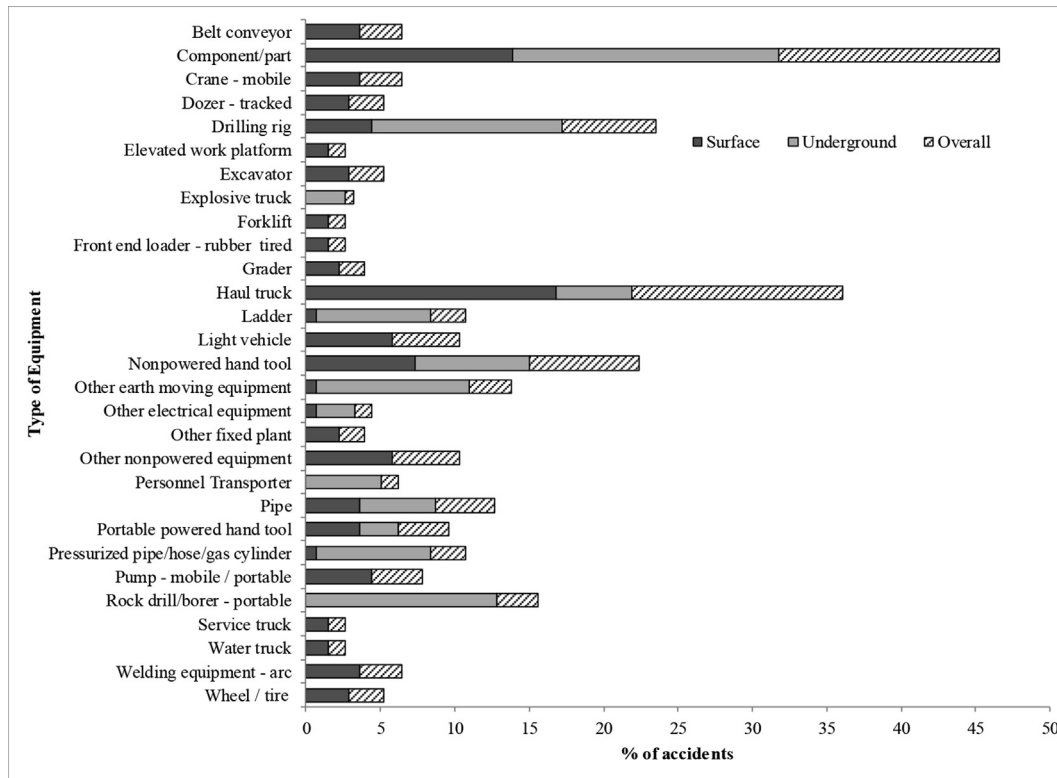


Fig. 12. Equipment-related injuries.

by a rock (13.6), and being hit by a fallen object (10.2%) contributed to most of the underground injuries. For the whole cohort, struck by a metallic object (20.9%), being hit by a moving object (11.4%), fall/slip/trip on the same level (8.5%), and motion of a moving vehicle (7%) were the top injury mechanisms.

5. Discussions

The findings of this study agree with as well as deviate from those of previous studies. These agreements and deviations are discussed in this section. The section also focuses on areas that deserve attention for prioritizing research and prevention efforts. To identify such areas, some form of variable combination was carried out, particularly focusing on the various classes/categories and their contribution to fatal injuries. Details of the identified priority areas have been listed in Table 3.

5.1. The injured person

An examination of the age and work experience of the victims indicated that old miners (>47 years) were less involved in fatal

injuries than middle-aged (38–47 years) and young (<38 years) miners. The middle-aged miners were the most affected group in both fatal and nonfatal injuries. In addition, old miners were mostly involved in fatal injuries than in nonfatal injuries. A number of studies support these observations. For instance, Phiri [49] found that young miners were 2% more probable of sustaining an injury than old miners. In addition, Salminen [50] observed that young workers had a higher nonfatal injury rate and a lower fatal injury rate. On the contrary, Bennet [40] found no relationship between injury severity and the age of workers. The results further indicate that less-experienced workers were involved in fatal accidents than in nonfatal accidents. In addition, less-experienced workers were more involved in fatal injuries than their experienced counterparts. Similarly, most of the nonfatal injury victims were less experienced; however, a significant portion (20%) of the fatal accident victims had a total mining experience of more than 20 years. In an analysis of equipment-related fatalities, Kecojevic et al [10] found that the most affected group was of less-experienced miners, that is, those with less than 5 years of mining experience. Similarly, Butani [51] reported that the severity of injuries sustained by coal workers related more to their mining experiences than their age.

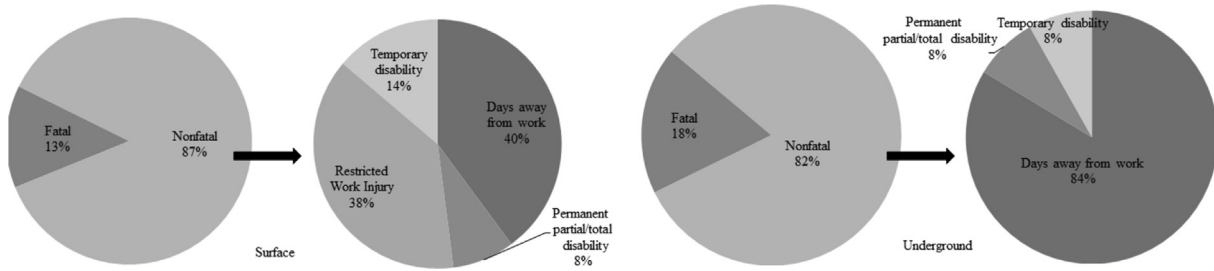


Fig. 13. Degree/severity of injuries by mine type.

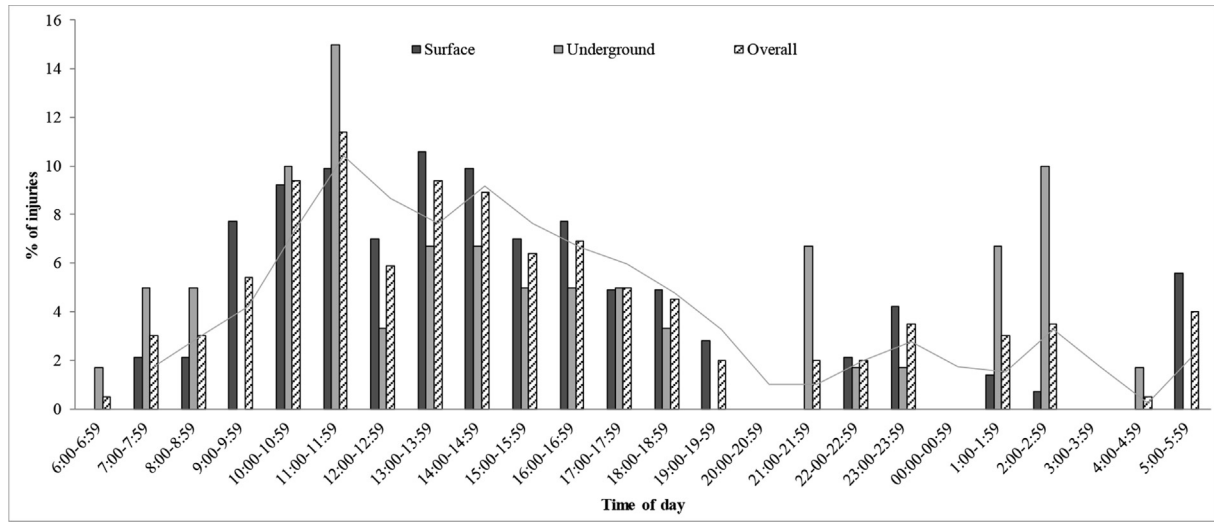


Fig. 14. Percentage of injuries by time of the day during which the accidents occurred.

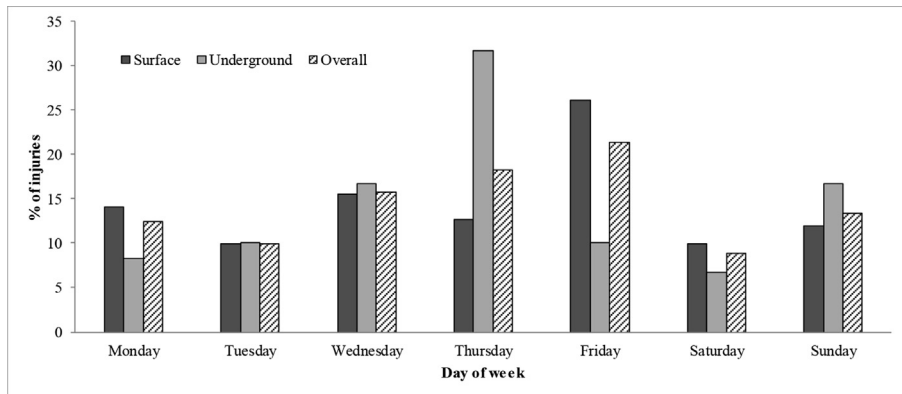


Fig. 15. The day of the week during which the accidents occurred.

On the contrary, Bennett and Passmore [37] observed that the severity of injury does not relate to the mining experience of the victims. In this study, it is hard to conclude whether any significant relationship exists between the severities of injury a miner sustains and his age and experience because no such analysis was carried out as a large portion (more than one-third) of the reports had no information on the age and mining experience of the accident victims. However, broad patterns and trends were observed, and it may be important to focus on such patterns and trends. Consistently, among different injury severity, mine types, and employment types, 38–47 years remained the most affected age group and may merit consideration for prioritizing research and prevention

efforts. Concerning the job titles of the injured, mechanics/repairmen, truck operators, drillers, supervisors, and laborers were identified as the most affected ones, which is supported by other studies [15,18,39,49,52]. These occupations remain a priority warranting intervention efforts; however, such efforts should be specific to the mine type as there were major differences between surface and underground location. The study further showed that contractors have an increased risk of being fatally injured than operators because contractors were involved in fatal accidents more than operator workers. Randolph and Boldt [42] observed that contractors consistently had a higher rate of being involved in haul truck fatalities than operators. Similarly, analysis of injuries

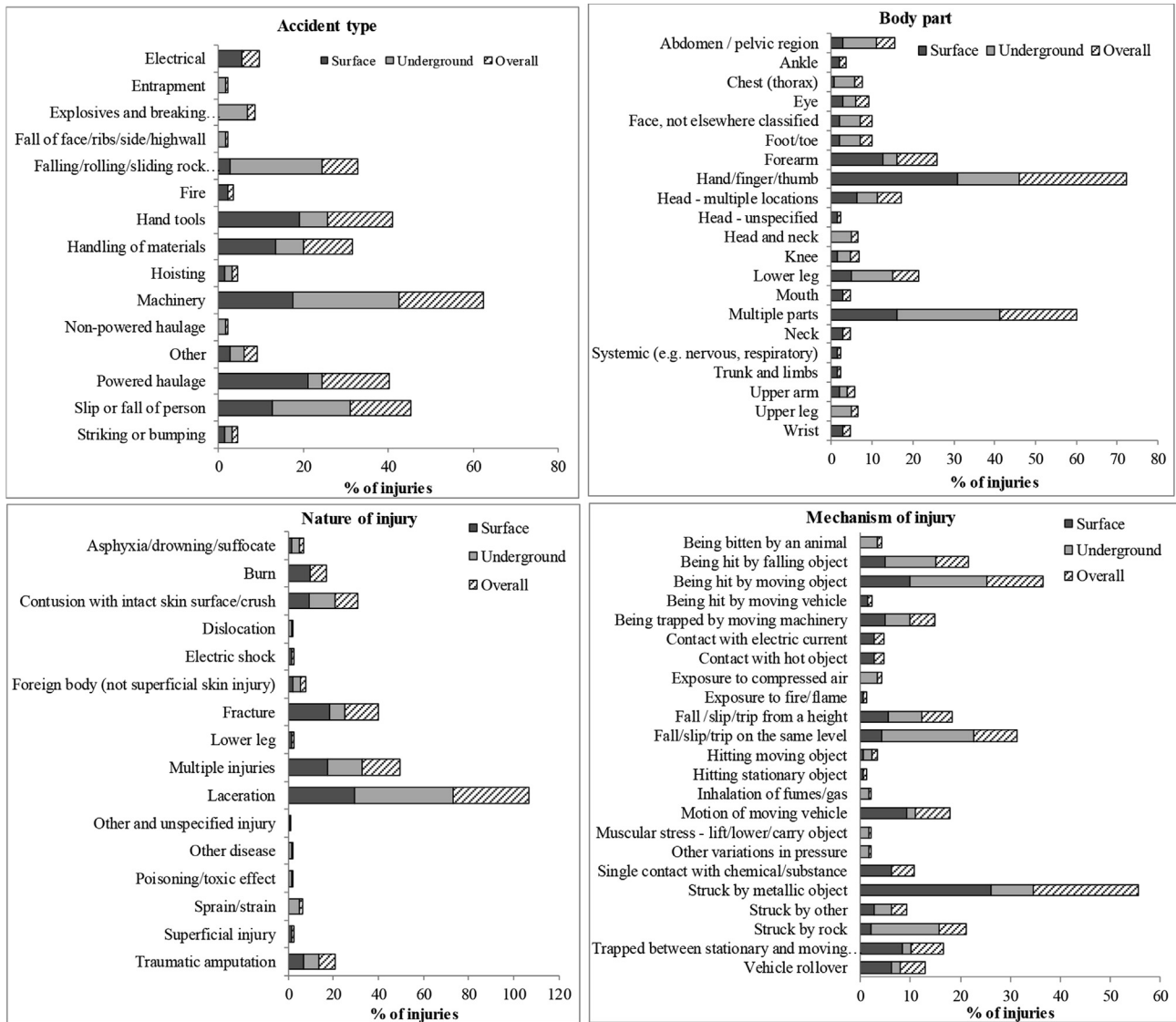


Fig. 16. Surface and underground injury classes: accident type, body part injured, and nature and mechanism of injury.

statistics by Muzaffar et al [52] indicated that contractors had a higher proportion of fatal injuries than operators. These results support the need to focus on improving contractor safety, especially with the recent increased employment of independent contractors in the industry [53,54].

5.2. The task being performed

Consistent with other works, this study found that machine maintenance, operating mobile equipment, drilling, cleaning up/clearing, and lifting/lowering by hand were the most dangerous activities. In their study of machine-related injuries in US mines, Ruff et al [20] observed that operating machine and maintenance/repairs were the most dangerous activities and accounted for 46% and 26%, respectively, of all the accidents that they analyzed. Similarly, Muzaffar et al [52] and Coleman et al [15] identified machine maintenance and operating mobile equipment as part of the top activities resulting in both fatal and nonfatal injuries. However, unlike other works, this study observed that directing mobile equipment (13%), moving equipment (10%), inspection (10%), and connecting equipment/machinery/hoses (10%) resulted in fatal injuries more than any other activities. These indicate that

workers' interaction with equipment/machinery, especially mobile equipment, continue to remain as a priority. Therefore, further research is required in this area to better understand the situation, enabling the development of specific and targeted intervention that will limit such interaction. It was further observed that most of the injuries were specific to particular locations, such as the stope mining area and shaft area for underground operations and processing/treatment, haul road, crushing station, and open-cut pit for surface operations. More than 70% of the fatal accidents occurred in these locations, indicating that some work locations are more dangerous than others. This is strongly supported by the works of Muzaffar et al [52] and Coleman et al [15]. To safeguard the safety of workers who work in such hazardous locations, there is an urgent need to implement and improve methods of detecting worker proximity to those locations as and to ensure accountability for following prerequisite safe practices. In addition, additional state-of-the-art controls including devices that sense human presence causing workers to stay in a safe buffer zone while working in dangerous locations should be explored [20]. The injuries dominated during the morning shift and mostly after 4 hours but less than 8 hours into the day's work. The relationship between risk of injury and shift schedule and overtime has been reported in other

Table 3
Summary of suggested areas deserving attention and focus for prioritizing research and prevention efforts

Topic	Class/Category	Suggested areas meriting consideration for prioritizing research and prevention efforts
Characteristics of the victim	Age and mining experience	37–38 y was the most affected age group; it was the modal group for operators in surface and underground locations as well as for fatal and nonfatal injuries. Old miners (>57 y) were involved in fatal injuries than in nonfatal injuries. Less-experienced workers were equally involved in fatal injuries than in nonfatal injuries.
	Employment type	More contractors (29.8%) were involved in fatal accidents than operators (10.3%). There were more injured young contractors (<38 y = 42.6%) than young operators (<38 y = 23.3%). Similarly, there were more old injured contractors (>47 y = 11%) than old injured operators (>47 y = 8.4%). Therefore, there should be a focus on the safety performance of contractors.
	Job title	Mechanics/repairmen, truck operators, drillers, supervisors, and laborers were the most affected ones at both surface and underground locations and remain a priority for research and intervention efforts. However, efforts should be specific to the mine type as there were major differences between surface and underground mines. For instance, surface mechanics were affected more than those at underground; and underground drillers were also affected more than those at surface mines. Dump controllers also remain a priority occupation as 13% of the fatalities affect them, same as supervisors and drillers.
Characteristics of the task being performed	Activity being performed	Machine maintenance, operating mobile equipment, clean up/clearing, drilling, and lifting/lowering by hand accounted for 51% of all injuries. Directing moving equipment (13%), moving equipment (10%), inspection (10%), and connecting equipment/machinery/hoses (18%) resulted in more fatalities than any other activity. These activities remain a priority and warrant further investigation and intervention strategies. Job titles related to these activities were also identified as a priority area, which further supports the need to focus on these activities.
	Location of activity	54.1% of all the injuries occurred at the stope mining area, processing/treatment plant, haul road, and workshops. 70% of all fatal accident occurred at five location: preparation/treatment plant (20%), stope mining area (16.7%), shaft area (13.3%), breaking/crushing station (10%), and open-cut pit (10%). It may be important to focus on these areas as they are the dangerous locations within a mining environment.
	Shift start time and hours into work	Injuries occurred more in the morning shift (75.7%) and mostly occurred after 4 hours but less than 8 hours of work. Most (43.6%) of the injuries occurred within the second 4 hours of work. This trend is similar for both fatal (50%) and nonfatal (45.3%) injuries. Over 75% of both fatal and nonfatal injuries occurred during the morning shift. Thus, the morning shift and second 4 hours into work merit consideration for prioritizing further investigation and improvement efforts.
Equipment	Involvement of equipment and equipment types	Mining equipment was associated with over 85% of the injuries with respect to both mine type and injury severity. Thus, the involvement of equipment/machinery should receive special attention. Specific equipment that deserves focus is mobile equipment, component/part, and nonpowered hand tools. Specific mobile equipment is haul truck, drill rigs, cranes, dozers, and excavators. Haul trucks and portable rock drill/borers were involved in fatalities more than any other equipment type.
Characteristics of the injury	Severity of injury	There were more underground fatalities (18%) than surface fatalities (13%). In addition, there were more severe (disability) nonfatal injuries in surface (20%) than in underground (8%) locations. Therefore, underground fatalities and surface severe injuries were identified as priority areas.
	Time of accident	10–11 AM, 11 AM–12 PM, and 1–2 PM, which are 4–5 hours, 5–6 hours, and 7–8 hours into the morning shift (assuming morning shift begins at 6 AM), respectively, were the peak times for both underground and surface locations. In addition, 9–10 PM remained a peak time at underground mines. 26.7% and 30% of all fatalities occurred at 10 AM–12 PM and 1–2 PM respectively, further indicating that those periods deserve further attention.
	Day of the week of accident	Fri (21.3%) and Thu (18.3%) were identified as the peak days for injuries. Similarly, most fatal accidents occurred on those days, 26.6% for Fri and 23.3% for Thu. A further investigation of those days may yield important results to ensure improvements.
	Accident type	Machinery (19.8%), power haulage (15.8%), hand tools (15.3%), slip/fall of the person (14.4%), and handling materials (11.4%) accounted for 76.7% of all injuries. The top accident types for the fatal injuries were machinery (36.7%), power haulage (16.7%), and slip/fall of person (16.7%), indicating that these accident types remain priorities.
	Affected body part	The hand/finger/thumb (26.2%), multiple parts (18.8%), and the lower leg (9.9%) were the most affected body parts. 60% of all fatalities affected multiple body parts, whereas 23.3% affected the neck and head. Hand injuries affected mechanics/repairmen (32.1%) and truck operators (22.6%) more than any other occupation.
	Injury type	75% of the injuries were laceration (33.7%), multiple injuries (16.8%), fractures (14.9%), and contusion (9.9%). All permanent disability injuries (14) were traumatic amputation, affecting either the hand/finger/thumb (13) or the foot/toe (1).
	Mechanism of injury	Being struck by a metallic object (20.9%), being hit by moving object (11.4%), fall/slip/trip on the same level (8.5%), and motion of a moving vehicle (7%) accounted for 47.8% of all injuries. Fall/slip/trip from height (20%), being struck by a metallic object (16.7%), being struck by rock (13.3%), vehicle rollover (13.3%), and being hit by a moving vehicle (3.3%) caused 76.5% of the fatalities. This shows that falls/slips/trips and worker–vehicle interaction merit consideration for prioritizing research and prevention efforts

studies [52,55–58]. Possible intervention to address this increased risk of injury with long working hours includes work hour restriction; an introduction of short breaks; development and implementation of a comprehensive fatigue management plan; and increased awareness of the worker's right to voice safety concern related to shift schedule, working hours, and fatigue.

5.3. The involvement of mining equipment

The involvement of equipment/machinery in mining fatalities and serious injuries have been studied in depth and have long been identified as a priority area deserving further research [1,10,15,20,22,24,41,42,52]. Mining equipment was involved in 86%

of all injuries and 90% of all fatalities. These figures exceed those reported in other studies, such as in Australia (46% of all underground injuries from 2005 to 2008) [59] and the USA (69% of underground fatality from 1995 to 2007 and 37%–88% of total mining fatalities from 1995 to 2005) [10,60]. Despite these difference between the figures reported here and those of other works, they give an indication that mining equipment remains a priority causal factor of accidents, and the situation is even more conspicuous and severe in Ghana. This emphasizes the need to address equipment safety issues, as highlighted in other countries [20,22,61–63]. Specific priority equipment subcategories identified include mobile equipment (36.3% of injuries), component/part (14.8% of injuries), and nonpowered/powering hand tools (10.7% of injuries). Among the mobile equipment subcategory, haul trucks (14.2% of all injuries and 20% of all fatalities), drill rigs (6.3% of all injuries), cranes (2.8% of all injuries), dozers (2.3% of all injuries), and excavators (2.3% of all injuries) had the greatest proportion of injuries. Other studies agree with these findings. Analysis of equipment-related fatalities in the US by Kecojevic et al [10] identified haul trucks to be involved in 22.3% of the fatalities. Ruff et al [20] identified haul trucks and loaders as the most frequently involved in injuries involving mobile equipment. The need to focus attention on these equipment subcategories has been emphasized in the literature. By focusing on them, in-depth knowledge can be obtained so that intervention can be specific. For instance, Md-Nor et al [64] assessed the risk of loader- and dozer-related fatalities and found that the two machines had different hazards. Failure in following maintenance procedure and failure of machine components was the most frequent hazard for loaders, whereas failure to identify adverse conditions was the most frequent hazard for dozers. By focusing on machine-related injuries, Ruff et al [20] identified that most of the injuries occurred during either the operation of the machine or its maintenance/repairs. They further identified issues more specific to particular equipment, such as loss of control/visibility issues of haulage equipment in motion and safeguard of moving part of stationary equipment. Unlike in other countries, there has been no focus on machine-related injuries in Ghanaian mines, and this is the first attempt that gives a broad overview. To ensure improvement in machine safety, more research is therefore required. There is the need to understand the specific hazards associated with these machines, the position of the injured person on the equipment, specific tasks that were being performed, and the injury mechanism among others to support the development of intervention strategies. Although the works of Zhang and Kecojevic [48], Zhang et al [65], Kecojevic and Md Nor [66], and Md-Nor et al [64] offer some insight into improving the safety of mining equipment, studies specific to the Ghanaian mining industry will be invaluable to improving the safety performance of the industry.

5.4. The injury

Consistent with other research [20,63], being struck by a metallic object (20.9% of all injuries), being hit by a moving object (11.4% of all injuries), fall/slip/trip on the same level (8.5% of all injuries), and motion of a moving vehicle (7% of all injuries) were the major mechanisms through which the injuries occurred. The major mechanisms through which the fatal injuries occurred were fall/slip/trip from height (20%), being struck by a metallic object (16.7%), being struck a by rock (13.3%), vehicle rollover (13.3%), and being hit by a moving object (13.3%). This suggests that falls/slips/trips and worker–vehicle interaction merit consideration for prioritizing research and prevention efforts. Similarly, machinery (19.8% of all injuries and 36.7% of fatalities), power haulage (15.8% of all injuries and 16.7% of fatalities), hand tools (15.3%), and slip/fall of the person (14.4% of all injuries and 16.7% of fatalities) were the

most frequent accident types. Additional safety interventions should be directed toward these areas, particularly machinery and power haulage. Most of the nonfatal injuries affected the hand/finger/thumb (26.2%) and the lower leg (9.9%); however, the fatal injuries frequently affected multiple body parts (60%) and the head/neck (20%). The hand injuries mostly affected mechanics/repairmen (32.2%) and truck operators (22.6%). By combining classes/categories in the injury analysis, it was possible to reveal more specific issues to address them. Many human factors models emphasize that it is only the combination of a number of factors that impact real-world performance. For instance, by combining the affected body part with the occupation of the victims, it was possible to identify that hand injuries frequently affect mechanics and truck operators. Similarly, by combining the mine type with the injury severity, it was observed that there were more fatalities in underground locations (18.3%) than at surface (13.4%) locations. In addition, underground injuries had a minimum of days away from work, whereas injuries from surface mines resulted in a minimum of restricted work activity only, indicating that underground injuries tend to be more severe than those that happen on surface locations. There should be a focus on the safety of workers in underground mines, particularly with the recent transition of several surface mines to underground operations [67–69] and the commencement of new underground operations [70] in Ghana.

6. Conclusion

Although significant improvement has been achieved in safety in the mining industry, the frequency and severity of mining accidents are still unacceptable. In Ghana, injury statistics of the industry far exceeds that of major mining countries such as Australia and the USA. Unfortunately, little is known about the safety performance of Ghana's mining industry although the country has long been a major producer of gold, ranking 10 globally. This research was, therefore, to provide a broad overview of the safety statistics of the industry by analyzing 202 injury reports using descriptive statistics. Results of the analysis indicate that the involvement of mining equipment, certain characteristics of the task being performed, the accident victim, and the injury itself deserve attention for prioritizing research and prevention efforts. It was identified that at both surface and underground mines as well as for both fatal and nonfatal injuries, the most frequently affected age group was of those between 37 and 48 years. Less-experienced workers were involved in fatal accidents more than nonfatal accidents. In addition, contractors had an increased risk of being fatally injured than operators, supporting the need to focus on contractor safety particularly with the recent rise in contract mining. Furthermore, certain occupations were most often involved in injuries than others. The significant occupations included mechanics/repairmen, truck operators, drillers, and laborers.

With regard to the task being performed at the time of the injury, machine maintenance, operating and directing mobile equipment, drilling, and lifting/lowering by hand resulted in more fatal and nonfatal accidents than other activities. In addition, injuries dominated at the shaft and stope mining areas for underground mines and at the treatment plant, crushing station, haul road, and workshops at surface locations. About 75% of the injuries occurred during the morning shift. There were more underground injuries during night shifts than surface injuries. The study showed that 86% of the injuries and 90% of fatalities had the involvement of mining equipment/machinery, the equipment that dominated was mobile mining equipment (haul trucks, drill rigs, excavators, and dozers), hand tools (powered/nonpowered) and components/parts. For the mobile equipment, and most fatal injuries occurred during the motion of the machines. These emphasize the need to focus on

equipment safety, and special attention must be paid to mobile equipment and hand tools as they resulted in fatalities more than any other equipment.

Finally, concerning the injury itself, underground fatalities far exceed surface fatalities, and 10 AM–12 PM and 1–2 PM (that is 4–8 hours into work) were the peak injury periods at both underground and surface mines. Based on MSHA classification of accident types, machinery, power haulage, hand tools, slip/fall of the person, and handling materials were the leading accident types. The leading injury mechanisms were being struck by a metallic object/rock, falls/slips/trips, motion of a moving vehicle, and vehicle rollover, with the hand/finger/thumb and head/neck being the most affected body part. This study presents a broad overview using single variable analysis, with only a few variable combinations. However, to reveal specific human factor issues and specific injury-related information, further research effort that uses the combination of multiple variables would be a significant contribution. In addition, to ensure safety improvement of the mines, significant resources must be allocated toward prevention efforts that address the behavior, knowledge, and competencies of the workers; the design of the task being performed; the work environment; and the equipment and machinery being used.

Conflicts of interest

All authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.shaw.2018.09.001>.

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