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Occupational exposure and severity of workplace accidents in mining companies

Exposición laboral y severidad de los accidentes de trabajo en las empresas mineras

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Pedro Alejandro Vásquez Maldonado
https://orcid.org/0000-0002-0712-8424
48300029@undc.edu.pe
Universidad Nacional de Cañete. Cañete, Lima, Peru

Abstract

Occupational exposure is a key factor for understanding accident patterns in the mining industry, since it captures both the size of the workforce and the cumulative amount of operational time involved. This study set out to determine the relationship between occupational exposure and the severity of workplace accidents in Peruvian mining companies during 2025. A quantitative, correlational, non-experimental, and retrospective study was carried out through documentary analysis of 19,617 monthly records published by the Ministry of Energy and Mines. Descriptive results showed an average of 161.68 workers per record, 31,040.84 person-hours worked, and a 22.71% rate of contractor participation. Over the study period, 1,264 disabling accidents, 22 fatal accidents, and 184,058 lost workdays were recorded; considerable dispersion was also found in the exposure and severity indicators across the operations assessed. Inferential results revealed positive, significant relationships between occupational exposure and the severity index, with the strongest coefficients for total workers ($\rho = 0.299$) and person-hours ($\rho = 0.296$). Disabling accidents and lost workdays followed comparable patterns, whereas fatal accidents showed significant but very weak associations. The study concludes that greater occupational exposure tends to track with higher accident severity, although the associations were weak and do not imply causation.

Keywords: occupational exposure, severity of accidents, human resources.

Resumen

La exposición laboral constituye un componente relevante para comprender el comportamiento de los accidentes de trabajo en la actividad minera, debido a que expresa la magnitud de la fuerza laboral y del tiempo acumulado de operación. El objetivo del estudio fue determinar la relación entre la exposición laboral y la severidad de los accidentes de trabajo en las empresas mineras del Perú durante 2025. Se desarrolló una investigación cuantitativa, correlacional, no experimental y retrospectiva, basada en el análisis documental de 19 617 registros mensuales publicados por el Ministerio de Energía y Minas. Los resultados descriptivos mostraron un promedio de 161,68 trabajadores por registro, 31 040,84 horas-hombre trabajadas y 22,71 % de participación contratista. Durante el periodo analizado se registraron 1 264 accidentes incapacitantes, 22 accidentes mortales y 184 058 días perdidos; asimismo, se identificó una elevada dispersión en los indicadores de exposición y severidad entre las operaciones evaluadas. Los resultados inferenciales evidenciaron relaciones positivas y significativas entre la exposición laboral y el índice de severidad, con mayores coeficientes para el total de trabajadores ($\rho = 0,299$) y las horas-hombre ($\rho = 0,296$). Los accidentes incapacitantes y los días perdidos presentaron comportamientos semejantes, mientras que los accidentes mortales mostraron asociaciones significativas, pero de magnitud muy baja. Se concluye que una mayor exposición laboral tiende a relacionarse con una mayor severidad de los accidentes, aunque las asociaciones fueron bajas y no implican causalidad.

Palabras clave: exposición laboral, severidad de accidentes, talento humano.

Introduction

Worker safety is a core responsibility within human capital management, since the continuity of operations depends as much on staff capabilities as on the conditions under which they carry out their duties. Occupational health and safety is itself part of human resource management, given that leadership commitment, training, and worker participation all shape preventive performance (Lu et al., 2020). In mining, this responsibility takes on added weight because of underground work, heavy machinery, and constantly shifting work environments, factors that keep the sector among the highest-risk lines of work (Cruz-Ausejo et al., 2024). Although mining employs only a small share of the global workforce, it accounts for a disproportionate share of work-related fatalities (Baraza et al., 2023).

Occupational exposure captures the extent of personnel involvement in productive activities and the length of time workers remain exposed to the hazards inherent to the operation. This study examines it through the total number of workers, the share of contractor personnel, person-hours worked, and exposure intensity. None of these elements is inherently unsafe; however, when they rise without a corresponding strengthening of preventive measures, the likelihood of adverse events can grow. Injuries occurring after nine hours on shift were more likely to result in fatalities and to involve multiple workers in a single event (Friedman et al., 2019). Fatality was likewise associated with contractor status, less experience at the mining unit, and accidents occurring after more than eight hours on shift (Muzaffar et al., 2013).

Alongside exposure, severity captures the magnitude of the consequences produced by an accident rather than simply the number of events recorded. The severity of mining accidents can be classified by outcome, minor, serious, or fatal, and these outcomes are tied to personal, occupational, and organizational characteristics (Baraza et al., 2023). Disabling accidents reflect a temporary or permanent loss of working capacity, whereas fatal accidents represent the most critical outcome for the worker, their family, and the organization. Lost workdays offer a useful measure of safety performance, since they capture recovery time and the disability caused by the injury (Nowrouzi-Kia et al., 2018). The severity index likewise relates lost workdays to person-hours worked, making it possible to compare operations with different activity levels; this indicator has been used to assess accident severity in underground mining, surface mining, and processing plants (Sanmiquel et al., 2021).

Available evidence shows that the relationship between occupational exposure and severity can vary depending on the type of operation and how work is organized. The number of fatalities was positively associated with hours worked in mining operations in Ghana and the United States, suggesting that greater work activity can coincide with an increase in serious consequences (Stemn, 2019). In small contractor-operated mines, the adjusted rate of traumatic injuries was 57% higher than in comparable operations managed directly by their owners (Buessing & Boden, 2016). Contractor workers were also 2.8 times more likely to suffer a fatal accident than personnel employed directly by mining operators (Muzaffar et al., 2013).

However, the number of workers and person-hours worked do not, by themselves, explain accident patterns. Mines with lower incidence rates showed higher levels of safety culture maturity, along with a negative relationship between the two measures (Stemn et al., 2019). Shortcomings in risk assessment, weaknesses in management systems, and economic pressures appeared repeatedly in the serious accidents analyzed in Australian mining operations (Jackson, 2023). Worker experience, hours completed during the shift, and the position held also influenced the accidents examined using data-mining techniques (Altındiş & Bayram, 2024).

Peru maintains official monthly records on workers, person-hours, disabling accidents, fatal accidents, and lost workdays, yet research integrating these measures at the level of companies and mining units within the same period remains scarce. A national study drawing on Ministry of Energy and Mines data from 2015 to 2024 examined associations between economic activity indicators and standardized accident measures, under an aggregate, non-causal interpretation (Vergaray et al., 2026). That same study also noted that frequency, fatality, and severity indicators can serve as monitoring signals for mining safety

management (Vergaray et al., 2026). In response to this gap, the present study set out to determine the relationship between occupational exposure and the severity of workplace accidents in Peruvian mining companies during 2025.

Methodology

This research followed a quantitative approach, given that it examined numerical data on the number of workers, person-hours, workplace accidents, and lost workdays through statistical procedures designed to test the proposed hypotheses (Hernández-Sampieri & Mendoza, 2018). The study was correlational in scope, seeking to establish the direction and strength of the relationships between occupational exposure indicators and accident severity, without attributing causality between them (Hernández-Sampieri & Mendoza, 2018).

The design was non-experimental, since the variables were analyzed exactly as recorded by the Ministerio de Energía y Minas (2025), without any intervention or manipulation on the part of the researchers (Creswell & Creswell, 2018). The study was also retrospective, drawing on information about workplace events and accidents that occurred between January and December of 2025, which were available before statistical processing began (Manterola et al., 2019).

The population consisted of all the monthly records on workers, person-hours, and accident rates reported by mining companies to the Ministry of Energy and Mines during 2025. A census sample was used, since the study drew on the entirety of available records meeting the defined inclusion and quality criteria (Hernández-Sampieri & Mendoza, 2018).

The unit of analysis was each company–month record, understood as the information corresponding to a company, license holder, or mining unit during a given month. As a result, the same operation could contribute up to twelve observations over the course of the year. Records from 2025 with available labor and accident data were included, while empty rows, repeated ‘headers,’ duplicate entries, and observations in which a calculation required the number of workers or person-hours but that figure was zero or lower were discarded.

Occupational exposure refers to the extent and degree to which personnel are involved in specific tasks within mining operations. It was examined through the total number of workers, obtained by adding mining company staff, mining contractors, and other firms; the share of contractor workers, calculated as the proportion of external personnel relative to the total; person-hours worked each month; and exposure intensity, expressed as person-hours per worker.

The severity of workplace accidents reflected the magnitude of the consequences produced by the recorded events. Its overall indicator was the severity index, calculated from lost workdays per million person-hours worked; more specifically, the study considered disabling accidents, fatal accidents, and lost workdays. The latter make it possible to estimate the burden imposed by injuries and represent an objective measure of their consequences for both the worker and the organization (Nowrouzi-Kia et al., 2018).

The technique used was documentary analysis, since the data came from administrative records that had already been compiled and published, without administering surveys, interviews, or direct measurements to workers. This technique allows for the systematic examination of information contained in documents related to the problem under study (Arias, 2021).

The instrument was a documentary record sheet organized as a digital matrix, used to extract and standardize identification data along with figures on workers, person-hours, disabling accidents, fatal accidents, lost workdays, and safety indices. This record sheet promotes uniform data collection and reduces inconsistencies when integrating multiple sources (Arias, 2021).

The data source consisted of the twelve official monthly files on mining accident statistics published by the Ministry of Energy and Mines for 2025. These files were consolidated into a single database, variable names were standardized, and derived indicators were calculated using previously defined formulas.

Data processing included integrity checks, duplicate identification, field standardization, verification of missing values, and calculation of derived indicators. The descriptive analysis included frequencies; means and standard deviations were reported when the distribution of the data allowed for it.

The normality of the indicators was assessed prior to the inferential analysis. Because disabling accidents, fatal accidents, and lost workdays tend to show a concentration of zero values, skewness, and extreme observations, Spearman's rho correlation was used. This test determines the direction and strength of a monotonic relationship between two indicators without requiring a normal distribution (Schober et al., 2018).

The rho coefficient can range from -1 to +1: a positive value indicates that the indicators move together, while a negative value reflects an inverse relationship (Schober et al., 2018). A significance level of 0.05 was applied, and the coefficient, two-tailed significance, direction, and strength of each association were reported. Results were interpreted as statistical relationships rather than causal ones.

This research does not involve human subjects. The data used are real, official secondary data, publicly available and free of any information that could identify individual workers. Consequently, there was no direct contact with individuals, nor was any informed-consent process required.

The original records were preserved without altering values in ways that would favor the hypotheses, and the removal of a subset of observations was based solely on technical grounds related to duplication or a missing or invalid denominator. Both the Ministry of Energy and the Ministry of Mines were duly credited as data sources; authorship of the published materials used in this research was respected, and results were reported at an aggregate, comparative level, without assigning individual responsibility or drawing causal conclusions about specific companies.

Results

Table 1 shows considerable heterogeneity in the occupational exposure of the mining operations analyzed. The total number of workers averaged 161.68, with a standard deviation of 778.97, ranging from 0 to 14,547 workers; this wide range reflects the coexistence of records corresponding to operations of very different sizes.

Contractor participation averaged 22.71%, though it ranged from 0% to 100%, pointing to substantial differences in workforce composition. Person-hours averaged 31,040.84, with a maximum of 3,120,461, while exposure intensity averaged 183.46 hours per worker. The high standard deviations observed, particularly for workers, person-hours, and intensity, reveal considerable dispersion and the presence of extreme observations that would need to be taken into account in the inferential analysis.

Table 1. *Descriptive statistics of occupational exposure indicators in Peruvian mining companies, 2025.*

Indicator	n	Mean	SD	Minimum	Maximum
Total workers	19,617	161.68	778.97	0.00	14,547.00
Contractor participation (%)	15,484	22.71	36.91	0.00	100.00
Person-hours worked	19,617	31,040.84	149,614.75	0.00	3,120,461.00
Exposure intensity (hours per worker)	15,484	183.46	1,269.97	0.03	55,542.86

Note. SD = standard deviation. Author's own elaboration based on MINEM data, 2025.

Table 2 shows that 1,264 disabling accidents, 22 fatal accidents, and 184,058 lost workdays were recorded during 2025. Per-record averages were low for both disabling and fatal accidents, since most observations recorded no events at all; even so, some records concentrated as many as 14 disabling accidents and 2 fatal accidents within a single month.

Lost workdays averaged 9.38, with a standard deviation of 251.73 and a maximum of 12,116 days, reflecting substantial dispersion tied to events with exceptional consequences. The severity index showed the most variable behavior, with a mean of 2,032.79 and a maximum value of 31,250,000; this wide range reflects the influence of records with few workers or person-hours combined with a high number of lost workdays. Taken together, these results reveal a distribution concentrated at low values, accompanied by a small number of observations with extreme severity.

Table 2. *Descriptive statistics of accident severity indicators in Peruvian mining companies, 2025.*

Indicator	n	Mean	SD	Minimum	Maximum	Annual total
Disabling accidents	19,617	0.06	0.41	0.00	14.00	1,264
Fatal accidents	19,617	0.001	0.03	0.00	2.00	22
Lost workdays	19,617	9.38	251.73	0.00	12,116.00	184,058
Severity index	19,617	2,032.79	225,365.02	0.00	31,250,000.00	—

Note. SD = standard deviation. Author's own elaboration based on MINEM data, 2025.

Table 3 shows that all indicators produced significance values below 0.05, leading to rejection of the assumption of normal distribution. The highest statistics corresponded to disabling and fatal accidents, consistent with the high concentration of records with no accidents and the small number of cases with higher values.

Occupational exposure indicators likewise departed from normality, particularly exposure intensity and contractor participation. These results, together with the dispersion and extreme values observed in the descriptive tables, justified the use of Spearman's rho to examine the relationships among the indicators.

Table 3. *Normality test for occupational exposure and accident severity indicators.*

Indicator	n	K–S Statistic	*p*	Distribution
Total workers	19,617	0.418	< 0.001	Not normal
Contractor participation (%)	15,484	0.419	< 0.001	Not normal
Person-hours worked	19,617	0.418	< 0.001	Not normal
Exposure intensity	15,484	0.443	< 0.001	Not normal
Disabling accidents	19,617	0.525	< 0.001	Not normal
Fatal accidents	19,617	0.512	< 0.001	Not normal
Lost workdays	19,617	0.485	< 0.001	Not normal

Severity index	19,617	0.498	< 0.001	Not normal

Note. K–S = Kolmogorov–Smirnov; p < 0.05 indicates a departure from normality.

Table 4. *Correlations between occupational exposure indicators and accident severity in Peruvian mining companies, 2025.*

Occupational exposure indicators	Severity index ρ (*p*)	Disabling accidents ρ (*p*)	Fatal accidents ρ (*p*)	Lost workdays ρ (*p*)
Total workers	0.299 (< 0.001)	0.301 (< 0.001)	0.048 (< 0.001)	0.299 (< 0.001)
Contractor participation	0.216 (< 0.001)	0.221 (< 0.001)	0.031 (< 0.001)	0.218 (< 0.001)
Person-hours worked	0.296 (< 0.001)	0.299 (< 0.001)	0.047 (< 0.001)	0.297 (< 0.001)
Exposure intensity	0.110 (< 0.001)	0.112 (< 0.001)	0.019 (0.020)	0.110 (< 0.001)

Note. ρ = Spearman's rho; two-tailed significance is shown in parentheses.

Table 4 shows that every occupational exposure indicator maintained a positive, statistically significant relationship with the severity index. The highest coefficients corresponded to the total number of workers (ρ = 0.299) and person-hours worked (ρ = 0.296), while contractor participation reached a relationship of ρ = 0.216. Exposure intensity showed the weakest association (ρ = 0.110). Taken together, these results indicate that operations with larger workforces and greater work activity tended to register higher severity, although the magnitudes observed were small.

A similar pattern emerged for disabling accidents. The strongest relationship corresponded to the total number of workers (ρ = 0.301), followed by person-hours (ρ = 0.299) and contractor participation (ρ = 0.221); exposure intensity again showed the lowest coefficient (ρ = 0.112). A larger workforce and greater operational activity were thus associated with a higher number of disabling accidents.

Relationships with fatal accidents were significant but of very small magnitude. Coefficients ranged from ρ = 0.019 for exposure intensity to ρ = 0.048 for total workers, reflecting a weak statistical association with limited practical relevance. This pattern may be related to the low frequency of fatal accidents recorded in the dataset analyzed.

Finally, lost workdays showed positive relationships with all exposure indicators. The largest coefficients corresponded to total workers (ρ = 0.299) and person-hours worked (ρ = 0.297), followed by contractor participation (ρ = 0.218) and exposure intensity (ρ = 0.110). These results thus indicate that greater occupational exposure was accompanied by an increase in the accumulated consequences of accidents, although the associations were predominantly weak.

Discussion

Occupational exposure and accident severity

The results revealed positive, statistically significant relationships between all four occupational exposure indicators and the severity index; the strongest associations corresponded to total workers and person-hours, while exposure intensity yielded the lowest coefficient. This pattern suggests that larger-scale operations tended to concentrate more severe consequences, although the small magnitude of the coefficients confirms that exposure alone does not account for safety outcomes. A larger workforce and

more hours worked extend both the time and the number of people in contact with hazards, but the final outcome also hinges on preventive management, supervision, and operating conditions.

This is consistent with the positive relationship observed between hours worked and fatalities in other mining contexts, although exposure is only part of the picture and must be weighed alongside management practices. Injuries resulting from longer shifts likewise showed a greater probability of causing fatalities or involving multiple workers, particularly when schedules were irregular or workers were newly hired, possibly under contractor arrangements (Stemn, 2019). From a human resource management standpoint, these findings show that increases in staffing or hours must be matched by corresponding planning for supervisors, rest periods, rotation, training, and fatigue control (Friedman et al., 2019).

Occupational exposure and disabling accidents

Disabling accidents showed the strongest associations, primarily with the number of workers and person-hours. This aligns with the notion of cumulative exposure, since more people and more time mean greater contact with equipment, transit activities, maintenance work, and geomechanical hazards. Even so, the small magnitude of the coefficients shows that operation size does not, on its own, determine injury severity: an organization can handle a larger volume of work under strong controls with favorable outcomes, while another with a smaller workforce may still suffer setbacks.

Underground conditions, equipment-related work, organizational size, and certain job conditions all increase the likelihood of a lost-time injury through a combination of exposure and underlying factors (Nowrouzi-Kia et al., 2018). Similarly, long shifts can impair psychomotor response and heighten injury risk through fatigue, particularly after several continuous hours of activity (Friedman et al., 2019). For this reason, the contribution of human resource management lies not merely in counting workers or accidents, but in linking hours worked to shift distribution, rest periods, job experience, and training received.

The association with contractor participation also deserves attention, since external personnel may be subject to different selection, induction, supervision, and retention processes. Sound human resource management on the part of the subcontracted firm, or others involved, could keep subcontracting from producing uneven preventive standards among workers on the same operation. This calls for bringing subcontracted personnel into the induction program, assessing their competencies, communicating risks, and monitoring their performance, all while keeping responsibilities clearly defined and coordination strong between contractor firms and the parent company.

Occupational exposure and fatal accidents

Correlations with fatal accidents were positive and significant, though at a low level. Some caution is warranted in interpreting this correlation, since deaths accounted for only a small share of the 19,617 records; when a variable contains a high proportion of zeros, its measured relationship with other variables tends to weaken. In this case, significance was bolstered by the large number of cases, but the coefficients themselves point to limited practical relevance.

Even so, prior evidence shows that fatalities can be associated with shifts exceeding eight hours, less experience at the mining unit, and contractor status (Muzaffar et al., 2013). It has also been observed that accidents occurring after nine hours of work were more likely to prove fatal, with a greater share of contractor workers among injuries sustained during extended shifts (Friedman et al., 2019). This body of evidence helps explain why the relationship with fatalities should not be judged by statistical magnitude alone; every fatal event carries a human and organizational weight that outstrips its numerical frequency.

Taken together, this evidence reinforces the point that shifts exceeding eight hours, limited experience at the unit, and contractor status can all factor into fatal outcomes (Muzaffar et al., 2013). Accidents occurring after nine hours on the job were likewise more likely to prove fatal, and shifts longer than eight hours worked by contractor personnel featured prominently among the injuries in that sample (Friedman et al., 2019). This underscores why fatality-related associations should never be read through

statistical magnitude alone; every incident with a fatal outcome represents a human and organizational loss that goes well beyond its numerical frequency.

Occupational exposure and lost workdays

Lost workdays showed a positive correlation with all exposure indicators, with values nearly identical to those recorded for the severity index. As these figures show, the larger the workforce and the more person-hours a site operates, the more non-worked days tend to accumulate whenever an accident occurs. Lost workdays offer a better sense of how long an employee has been away from work because of an injury than the mere count of events does.

In percentage terms, serious injuries can carry disproportionate weight in the number of lost workdays or the cost of recovery, even when they occur infrequently (Nowrouzi-Kia et al., 2018). This is a meaningful indicator for human resource management, from which an organization can infer consequences such as absenteeism, the need to find replacements, task redistribution, and return-to-work planning. An organization that tracks only the number of accidents will see two otherwise similar periods as equivalent whenever the accident count matches, even if the disability caused by a single incident differed sharply between the two periods.

Contribution, implications, and limitations

This study shows that it is possible to combine records on workers, contractors, and person-hours with severity indicators in ways that can support human talent management in Peruvian mining. It further demonstrates that worker safety hinges not only on technical standards but also on managerial commitment, adequate training, and worker participation, all of which help build knowledge, motivation, and safe behavior (Lu et al., 2020).

These findings can help decision-makers size training, supervision, and shift schedules according to the number of workers and the types of contracts in place. They also point to a way of jointly managing in-house staff and contractors. External personnel cannot simply be treated as a bureaucratic percentage figure, since their presence shapes outcomes; competencies must be standardized, and inductions delivered and supervised consistently.

Among the study's limitations, the data used are secondary and depend on the reliability of the reports submitted to MINEM for 2025; in addition, the high concentration of zero values and extreme observations shaped the distribution of the indicators. The company–month structure spans a long panel, which allows for broad coverage, but the same operation can appear across several periods, meaning the observations in those cases are not fully independent. Finally, the correlations reported reflect association rather than causation, since the analysis did not include variables such as sex, job experience, shift, occupation, effective training, or safety culture. These limitations do not invalidate the results, but they do reveal their boundaries and point to the need for further studies that combine administrative records with more specific information on human talent management.

Conclusions

Accident severity showed a positive, significant relationship with several measures of occupational exposure across Peruvian mining companies in 2025. This held for the total number of workers as well as person-hours, in connection with disabling accidents and lost workdays. Although significant, the association was of low intensity, reflecting the lower frequency of fatal accidents relative to disabling ones, particularly among direct-contractor employees. The consistency of these results makes clear that a definite, though not causal, relationship exists between the scale of mining operations and the number of consequences stemming from workplace accidents.

The growth in the number of employees, shifts, and contractors underscores the importance of supervision, worker training, fatigue management, and risk communication in an era when occupational

injuries can no longer be treated as an acceptable cost of doing business from a talent management standpoint. The losses stemming from workplace activity must be linked to human resource systems through absenteeism tracking, rehabilitation, worker reintegration, and safeguarding operational sustainability.

Finally, future research should incorporate variables such as age, experience, occupation, shift type, contract status, training quality, and safety culture, among others, and analyze them using multivariate models capable of estimating the relative weight of each factor and disentangling the effects of occupational exposure from other conditions, such as organizational characteristics.

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