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Analysis of risk factors and prevention strategy in accidents among coal hauling trucks: a scoping review

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ABSTRACT

Powered hauling equipment is one of the most critical operational elements in the mining sector. Haulage is a significant hazard for the mining industry, accounting for over half of all mining-related fatal accidents yearly. Identifying safety risk variables is the foundation of risk assessment and accident prevention. This study aimed to identify risk variables and prevention techniques to reduce occurrences among truck drivers in coal mining. This research approach is a scoping review with the PRISMA Extension for Scoping Reviews (PRISMA-ScR). Thirty-five articles were reviewed based on the results of inclusion and exclusion criteria. Data analysis was performed using content analysis. The results show that human, environmental, machine, and organizational factors contribute to the risk among truck drivers in coal mining. Safety culture, staffing and scheduling, training and education, policy and procedure implementation, and technology deployment are all part of the accident prevention plan. The central government should pay particular attention to the employment conditions of workers in cities with decreased resources and develop policies to prevent mining-related diseases in local communities.

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1. INTRODUCTION

Coal is widely used for the production of energy in various countries. Numerous developing countries rely on coal as an energy source [1]. Coal remains second in the worldwide energy supply, accounting for over a quarter of the total (162 EJ in 2019) [2]. G20 states continue to invest approximately US$39 billion in coal production annually [3]. In 2019, coal remained the dominating fuel for power generation, supplying 37% of worldwide energy production, ten percentage points ahead of renewables [2].

Coal mining has been regarded as a fundamentally high-risk sector worldwide with substantial health and safety risks for its workers [4]. Coal mining poses numerous severe concerns for workers and the local ecosystem [5]. According to International Labour Organization estimates, mining employs only 1% of the worldwide labor but contributes 8% of all job-related fatalities [6]. Major international coal industries are experiencing tragic accidents. Since 2000, the number of deaths in coal mines in India has been less than 100 per year, in Russia less than 100 per year, in the United States less than 50 per year, and in Australia less than 10 per year [7].

Powered hauling equipment is one of the most essential operational elements in the mining sector. These sorts of technologies have become challenging and costly assets, emphasizing the importance of their proper operation [8]. Furthermore, automating these types of equipment has produced significant obstacles and potential for mining operations [9]. In addition, these events altered the foundations of the whole mining

industry and traditional fleet management [8]. Haulage is a significant hazard for the mining industry, accounting for over half of all fatal mining accidents yearly [10]. Deadly accidents are frequently the result of a loss of control or collisions triggered by a combination of causes [11]. Common workplace mishaps during carrying include dump trucks reversing, catching fire, colliding with other vehicles, and exposing drivers to dangerous materials. Coal mining businesses have had to pay significant compensation fees due to their losses [12]. As a result of the considerable expense of workplace accidents, such as the reimbursement of compensation, treatment of an injured employee, lost time, and substituting a wounded employee, among others, preventing accidents remains an essential concern in most organizations [13].

Identifying safety risk variables is the foundation of risk assessment and accident prevention. Accident lessons for risk prevention and minimizing repercussions are gained from investigations of many incidents [14]. Although the settings of varied workplaces might vary, there is a chance to gain knowledge from workplace incident investigations and suggested procedures from different countries, industries, or distinctions within the same sector (for example, metalliferous and coal mining) [13]–[15]. Prevention strategies have been developed, but questions still need to be answered about why accidents still happen, why accidents have not been halted, and what risk factors lead to injuries.

There is an extensive amount of literature on coal truck accidents that continue to occur, risk factors, and accident prevention. To enhance research arguments, a scoping assessment of the literature on risk factors and prevention measures for coal-hauling truck accidents using VOSviewer software is necessary to identify theme linkages and state-of-the-art this research. Figure 1 depicts the initial analysis of thematic association data, which reveals a highly complex association pattern for coal transporting truck accidents. Figure 2 shows the distribution of publications based on keywords.

The novelty of this research lies in the research model approach used. A scoping review is a sort of evidence synthesis that identifies and maps relevant evidence that fulfills pre-determined inclusion criteria for the topic, field, context, concept, or issue under examination [16]. Figures 1 and 2 show the results of the visualization analysis of the density display in yellow and green, which means the item is essential to analyze. Research variables are necessary to explore, and more in-depth research is still needed.

Based on the above explanations, the author wants to continue discussing the risk factors and prevention techniques in accidents among coal haul vehicles. This research paper aimed to determine the risk factors and prevention strategies to lessen haul coal truck incidents. The outcomes of this study can be used as a theoretical framework for academics and practitioners in reducing coal-hauling truck accidents.

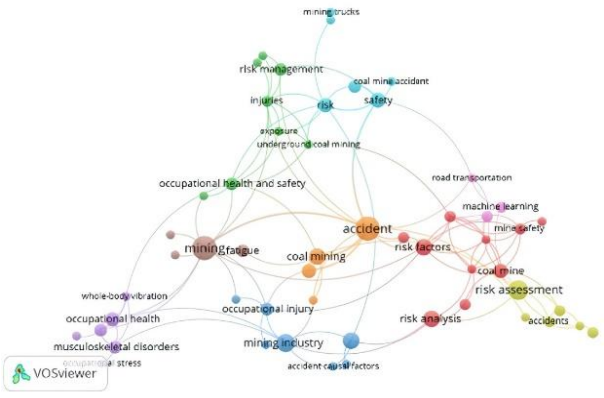

Figure 1. Initial network visualization

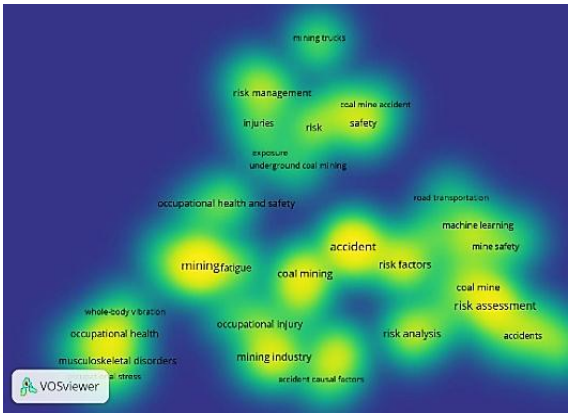

Figure 2. Visualization of article distribution

2. METHOD

This research strategy involves conducting a scoping review of the literature. The author used the PRISMA extension for scoping reviews (PRISMA-ScR) [17]. The author used the Science Direct, Google Scholar, and Web of Science databases to look up journal articles. The journal search used the following keywords: coal mining, accident, risk factor, prevention strategies, and dump truck. The inclusion criteria for selected journals are i) English language journal papers published between 2020 and 2024, ii) a study including the analysis of risk factors and prevention strategy in accidents among coal hauling trucks, and iii) original research. Data analysis was performed using content analysis, which helps comprehension by evaluating the text of each article and literature references. Flow diagram of the article search process utilizing PRISMA-ScR as illustrated in Figure 3.

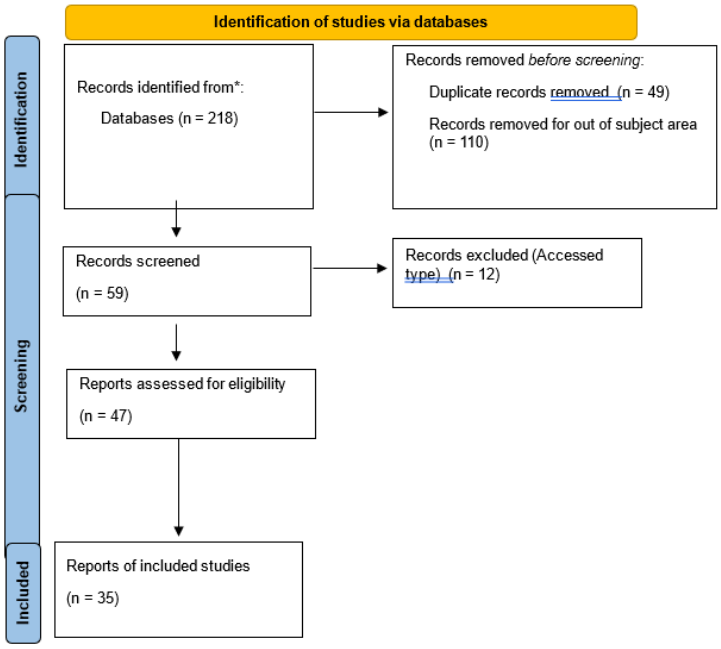

Figure 3. PRISMA-ScR flow diagram

3. RESULTS AND DISCUSSION

3.1. Results

The results section presents the outcomes of a synthesized examination of the 35 selected papers. The researcher outlines previous theoretical frameworks or significant constructs used by other scholars. After analyzing the data, the researcher identified publications on risk factors and prevention techniques for coal haul truck accidents. Table 1 (see Appendix) shows the review results of papers chosen based on inclusion and exclusion criteria [12], [18]–[51].

Table 1 (see Appendix) shows the selected article references, nation of research location, research aims, methodologies, samples, and fundamental research findings. Based on Table 1 [12], [18]–[51], 15 articles were researched in China (15), followed by Indonesia (9), the United States (3), Australia (2), not mentioned (2), India (2), Pakistan (1), Iran (1), and Mongolia (1). Thirteen articles were reviewed using the survey approach; six articles used experiment; four articles used fuzzy; four articles used a case study; one article used a pilot study; one article used a cluster analysis; one article used a qualitative; one article used case-control; one article used a longitudinal; one article used a mix-method, and one article used a coupling model.

3.2. Discussion

3.2.1. Accidents among coal hauling trucks

As the coal mine manufacturing process becomes more complicated, the number of fatalities caused by a single factor decreases dramatically. However, the proportion of incidents caused by multifactor risk coupling grows [35]. Accidents among coal-hauling trucks are divided into four categories [18]:

a. Subjective corrective

The accident is affected by persons' expertise and level of safety awareness. The control of such human elements should include actions to tighten supervision, repair the lack of professionalism of the corresponding individuals, and increase personnel at all levels' awareness of the necessity of security.

b. Perceived corrective

The accident exhibited in the method of coal mine production, a lack of risk legislation, and awareness of risks, resulting in accidents with a high likelihood of happening. The control of this sort of human component should be measured in terms of education, including science and training.

c. Associated corrective

Accidents are closely associated with other human elements, frequently in statistics. Actions should be taken to control the frequency in conjunction with the other three categories.

d. Critical corrective

Accidents are closely associated with other human elements, frequently in statistics. Actions should be taken to control the frequency and educational control in conjunction with the other three categories.

3.2.2. Risk factor of accidents among coal hauling trucks

a. Human factor

Workers in transportation activities are more susceptible to injury than the other two groups [23]. Dump truck drivers who violate company safety rules are the leading cause of occupational accidents in transportation [12], [47]. One explanation is that they have greater mobility in mines than others [23]. Several risk factors that cause incidents are speed and aggressive driving, alcohol intake, physical limitations of drivers, violation operating, lacking a self-rescuer, age, experience of miners, underground smoking, and lack of awareness [5], [6], [20]. Long hours on the job, shift work, and working under fly-in fly-out (FIFO) or drive-in drive-out (DIDO) conditions (a practice employed in more remote, isolated mines, requiring staff to travel to the worksite and to reside in temporary lodging between shifts and the block of shifts) may compound risky behavior [34].

Cognitive factors such as work experience, job unhappiness, negative affectivity, and supervisors' ratings of work safety performance have been linked to unsafe behaviors among dump truck drivers [12]. Workers indicate that a lack of facilities is a crucial worry despite the hazardous working circumstances. Employee unhappiness with their jobs and the environment remains high following an accident [23]. Coal mining operators have high levels of mental tiredness, highlighting the necessity for effective control mechanisms [24]. Brain tiredness is a significant element that influences long-term cognitive focus [26]. The operator's mental tiredness was related to various factors, including the nature of the driving activity [37]. Operators must maintain alertness whether driving alone on lonely roads or in crowded pit areas [24]. As the work time progresses, the worker's thinking workload rises, leading to exhaustion. After the 45th and 90th minutes of continuous work, subjective and objective data indicate that the worker grows a more excellent spoken state of neural tiredness [26].

b. Environment factor

The amount of coal extracted grew, as did the levels of particles, metals, and nitrogen oxides [28], [42]. The average amount of dust rises by 8.03 times when trucks unload compared with when they do not unload. When unloading under a particular quality of coal and circumstances, the dust density increases by 25-30 times that of when not unloaded [29]. There are significant variations in particle size and composition among coal dust from tailings handling, road traffic, and coal working front sites. Moisture composition and debris production significantly affect particle size and dust emission opportunities [27]. Coal seams with high amounts of quartz, tiny mine diameters, and a rise in work shifts leading to coal and silica dust deposition could contribute to the increasing occurrence of pneumoconiosis disease [36]. PM10 exposure rates were substantially higher in mining areas compared to urban or rural non-mining populations. Vulnerables may be at the most significant risk of mining-related pollution [28]. To prevent dust disasters caused by mining trucks, a minimum safety distance of 45 meters is achievable. The dust disaster impact area exhibits a linear decline in the longitudinal direction. It shows an initial rise and then a drop as the vertical height grows [46].

c. Machine factor

The causal factors responsible for mining truck accidents are overloading poor lighting, and improper vehicle maintenance [8], [20]. There are two significant issues in the maintenance element: poor maintenance and technical failure of components. The latter could be due to inadequate upkeep. Considering events that can be resolved by a technical component, especially at the task level. Causal variables include a lack of visibility, proper signage/signaling, and an unwillingness to maintain suitable berms. However, references to characteristics such as road layout, breadth, slope, and preservation state are merely incidental and need more significant information that can be regarded directly for traffic path planning. More illumination and task-appropriate equipment were also mentioned [52].

d. Organizational factor

Organizational factors such as unsafe supervision and unsafe state can contribute to accidents [48], [50]. Organizational influence, hazardous supervision, and the dangerous state of miners have different degrees of impact on unsafe behavior [50]. Ineffective supervision by government agencies and other external supervisory may result in a dangerous state of internal management, such as not enough safety education and irrational labor associations, which will continue to cause leaders to issue illegal instructions and not investigate or rectify encoded risks, resulting in low employee safety awareness and behavioral violations [48].

3.2.3. Prevention strategy

a. Implementation of safety culture

Focus on implementing the safety commitment and improving the role of functional departments from both the inside and outside [40]. The benefits of safe communication of information are fully realized in conjunction with the multi-channel communication path, organized communication platform, mobile terminals information communication system, and other efficient interaction modes [5]. Management demonstrated their commitment to workplace health and safety through numerous actions and initiatives staff [40]. Enhancing coworker safety inside the coal mine industry is a crucial approach to developing a positive safety culture, and

it is an example of an effective exchange of safety information among employees. Incentivizing staff engagement is also a valuable safety measure. Furthermore, the impact of external supervision on the corporate safety culture should be noticed; it may drive the current safety culture to adapt [5]. Drivers unhappy with their current positions may conduct unsafe acts due to discomfort, leading to poor decision-making. In response, the company should devise an effective plan to preserve employee satisfaction for dump truck drivers by fostering a positive work atmosphere [12].

b. Training and education

Management efficiently avoids the intervention of other influencing factors to most effectively regulate miners' dangerous behaviors [25]. Educational programs boost understanding of the usage of personal safeguards and punish workers on issues such as ergonomics (of hand-carrying equipment, for example) [20], [52]. Coal mining companies should construct intelligent equipment skills education programs and actively promote coal mine awareness to strengthen coal workers' comprehensive abilities [25]. Furthermore, the socialization of weariness emphasizes the necessity of getting enough and good quality performance [31].

c. Staffing and scheduling

Dump trucks are at significant risk of developing tiredness due to the intense work pressures. Management must offer optimal resting time, offer operators audio music that improves energy and enhances job focus, and add an afternoon shift to balance the working hours [21]. In addition, limiting time at work and shifts to three shifts over 24 hours improves the well-being of haul dump truck workers [31]. A work shift strategy can reduce the delay in changing shifts. Delay Change Shift refers to delays in coal transportation due to work shifts that exceed target times or unexpected delays in moving coal from the mine to the port [38].

d. Implementation of policy and procedure

Hazard identification is essential for risk management in the mining sector [44]. The company must conduct a risk assessment. The risk factors describe the numerous characteristics or dimensions associated with mining truck accidents and must be selected depending on their relevance, significance, and measurability [19]. Managers and personnel must also identify workplace potential dangers [44].

Risk mitigation is an activity that avoids or decreases the severity of prospective dangers. In contrast, risk minimization is a step that prevents a risk from developing in the first phase [8]. The best ways to mitigate management are to conduct operations in alignment with the standard operating procedure, supply adequate illumination during nighttime activities, and employ personal protective equipment [33].

Stringent monitoring and enforcement of safety standards may be more realistic and cost-effective in the short run [20]. Making norms for driving laws can cut transportation expenses by 5% [43]. An alternative transportation system may be more appropriate in the long term [20]. Monitoring pressure, temperature, and tire parameters is essential to prevent dump truck tires from bursting [39]. Preventive upkeep for drivers' equipment helps reduce occurrences [19]. Corrective maintenance is recommended for low-risk, electrical-start, mechanical, and pneumatic failure modes. Time-based preventative care is recommended for fuel failures due to their high criticality and severity [32].

e. Implementation of technology

Implementing technology can support reducing incidents among truck drivers in coal mining [8], [45]. Self-driving trucks are one of the most intriguing possibilities for tackling safety issues throughout the cargo handling process [8]. Text mining technology is utilized to identify the main mishap-causing variables from large amounts of accident reports, and the risk control model in a sociotechnical framework is used to categorize the factor hierarchies [22].

Training that incorporates technology can be more effective than traditional training. The applications developed as part of this project give heavy-equipment operators training that improves their grasp of procedures and the relevance of pre-shift inspections. Although the mine staff was involved in every phase of the project/system's development and testing in the mine, it is intended to conduct a more scientific assessment of the usefulness and satisfaction with the established system and calculate return on investment (ROI) [30].

4. CONCLUSION

Human, environmental, machine, and organizational factors contribute to the risk among driver trucks in coal mining. Human risk factors include aggressive driving, alcohol use, driver physical limits, operational violations, a lack of a self-rescuer, age, miners' experience, underground smoking, and a lack of awareness. An environmental factor is a coal dust explosion. Overloading, lousy lighting, and incorrect vehicle maintenance are some machine factors. It is essential to address the multifaceted causes of workplace injuries through effective preventative initiatives. Safety culture, staffing and scheduling, training and education, policy and procedure implementation, and technology deployment are all part of the accident prevention plan. The central government should pay particular attention to the employment conditions of workers in cities with decreased resources and develop policies to prevent mining-related diseases in local communities.

APPENDIX

Table 1. Journal articles reviewed

No.	Ref.	Country	Research purposes	Method	Sample	Important results
1.	[12]	Indonesia	Cognitive impact on dump truck drivers' decision-making before engaging in risky behavior.	Pilot study	120 dump truck drivers	Cognitive factors such as work experience, job unhappiness, negative affectivity, and supervisors' ratings of work safety performance have been linked to unsafe behavior among dump truck drivers.
2.	[18]	China	Human aspects of coal mine incidents	Cluster analysis	685 coal mine accident	K-Means clustering analysis classified 29 human factors into four categories: subjective corrective, perceived corrective, associated corrective, and critical corrective.
3.	[19]	Indonesia	The impact of routine upkeep on the operation of K3 transportation	Survey	2,145 workers	The impact of proactive upkeep, congestion control, worker concerns, technology, and communication support on transportation performance
4.	[20]	China and India	Examination of elements that lead to incidents in mining involving vehicles	Fuzzy	accidents report	Risk factors are risky behavior, working schedule, unsafe climatic conditions, and improper truck maintenance.
5.	[21]	Indonesia	Analyze the level of fatigue by dump truck operators	Survey	28 HD operators	HD operators showed low/mild fatigue due to the little impact caused by fatigue-related factors.
6.	[22]	China	Analysis risk factor	Survey	307 accidents report	Managerial authority is the most critical aspect of accident causation; gas incidents and adequate safety oversight mechanisms are lacking.
7.	[23]	Pakistan	Miners' behavior effect on injury	Survey	350 workers	Workers in transportation activities are more susceptible to injury than the other two groups.
8.	[24]	Indonesia	Mental fatigue after 1-year COVID-19	Survey	480 operators	Operators experiencing moderate stress and operating in the mine area showed significant associations with mental tiredness.
9.	[25]	China	Factor effect on unsafe behavior	Fuzzy	Shaanxi Coal	Management efficiently avoids the intervention of other influencing factors to regulate miners' dangerous behaviors.
10.	[26]	China	Impact of Brain fatigue on visual display terminal (VDT) operator	Experiment	17 VDT operator	Brain tiredness is a significant element that influences long-term focus in cognitive VDT operations.
11.	[27]	China	Evaluation of coal mine dust	Experiment	Seven tailing and coal-working zones	Significant particle size and composition variations exist among coal dust from tailings handling, road traffic, and coal working front sites.
12.	[28]	Australia	Analysis of air pollutants from coal mining	Experiment	Australia National Pollutant Inventory Report 2008-2018	The amount of coal extracted grew during the research period, as did the levels of particles, metals, and nitrogen oxides.
13.	[29]	Mongolia	Dust concentration in open-pit	Experiment	Ha'erwu Su open-pit	The average amount of dust rises by 8.03 times when trucks unload compared with when they do not unload.
14.	[30]	US	Training with application	Experiment	Surface mine	The computer-based task training (CBTT) and virtual reality (VR) applications developed as part of this project give Heavy-Equipment Operators training that improves their grasp of procedures and the relevance of pre-shift inspections.
15.	[31]	Indonesia	Relationship between mental workload and sleep quantity	Survey	123 workers	Limiting time at work and shifts to three shifts over 24 hours improves the well-being of haul dump truck workers.
16.	[32]	Iran	Mining equipment maintenance program	Case study	5-758 Komatsu dump-truck	Corrective upkeep is recommended for low-risk, electrical-start, mechanical, and pneumatic failure modes.
17.	[33]	Indonesia	Analysis of risk factors and risk mitigation	Fuzzy	Manager and staff	Conduct operations in alignment with the Standard Operating Procedure in the first rank, supply adequate illumination during nighttime in the second rank, and employ PPE entirely in the third level of mitigation management.

Table 1. Journal articles reviewed (*continued*)

No.	Ref.	Country	Research purposes	Method	Sample	Important results
18.	[34]	Australia	Alcohol intake among workers	Survey	1799 miners	Risky alcohol behavior is higher among younger and high-stress
19.	[35]	China	Multifactor risk in preventing coal mine accidents.	Coupling model	375 accidents	the risk created by the combination of the human-environment-management is the biggest in the three-factor risk coupling of coal mines
20.	[36]	US	The impact of mining characteristics on the prevalence of pneumoconiosis.	Longitudinal	123,589 mines	Coal miners in underground coal seams are more likely to contract pneumoconiosis than workers in surface coal operations.
21.	[37]	US	Antecedents of operators' weariness	Case study	Fatigue Report in 2016-2020	Factors such as the number of cycles, extra time, labor hours, and other manufacturing variables may add to physical or physiological stressors for operators.
22.	[38]	Indonesia	Effective hours for carrying coal	Observation	Maruwai coal	The work shift strategy for improving delay metrics is to reduce the change work delay.
23.	[39]	Not mentioned	Leading causes of dump truck tire breaking.	Fuzzy	Dump truck driver	Monitoring pressure, temperature, and tire parameters is crucial to prevent dump truck tires from bursting.
24.	[40]	China	Management Practices in safety in the workplace	Survey	493 staff	Management's dedication to safety, education, and participation, as well as their understanding and drive, influence employee safety behavior.
25.	[41]	China	Safety risk evaluation	Survey	170 staff	Efficient safety manufacturing requires firms to fulfill their primary responsibilities.
26.	[42]	Not mentioned	Risk assessment	Survey	OHS supervisors	Noise, tension, and dust are risks worldwide, affecting all workplaces.
27.	[43]	China	Evaluation of driver behavior	Experiment	Mining truck	Standardizing driver behavior can enhance the precision of mining automobile data by 7–12% and reduce the cost of transportation by around 5%.
28.	[44]	China	Identification hazard	Case study	Yima coal	Hazard identification is essential for risk management in the mining sector.
29.	[45]	Indonesia	Risk analysis	Mix method	Contractor and project owner	Risk analysis that mitigation is a strength of supply chain management and application technology
30.	[46]	China	Impact dust on the driver	Longitudinal	Mining truck	To prevent dust disasters caused by mining trucks, a minimum safety distance of 45 meters is achievable.
31.	[47]	China	Evaluate risk factor	Survey	Constructor	risky behavior and machinery failure are the primary causes of accidents, and a poor management system is a fundamental component determining the safety risk status.
32.	[48]	China	Trajectories leading to accidents	Case study	883 accidents	Ineffective supervision by government agencies and other external supervisory departments may result in an unsafe state of internal management.
33.	[49]	India	Risk factor of incident	Case-control	135 workers	it is essential to address the multifaceted causes of workplace injuries through effective preventative initiatives.
34.	[50]	China	Unsafe behaviour	Survey	1,150 workers	Environmental variables, institutional influence, unsafe supervision, and miners' dangerous conditions were the primary risk factors influencing unsafe conduct among deep coal miners.
35.	[51]	Indonesia	Unrealized policy to build coal transportation	Qualitative	Coal truck drivers and stakeholders	Immediate building of a separate road for coal transportation is necessary to alleviate the burden on the surrounding area.

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