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Workload, Time Efficiency, and Fatigue on Miners' Safety Behavior: A Literature Review

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Abstract
Introduction: *The mining industry contributes substantially to Indonesia's economy but exposes workers to high mental demand, time pressure, and prolonged shifts that may compromise safe performance. Previous studies examined workload, the speed–accuracy trade-off, and fatigue in isolation, mostly in manufacturing or laboratory settings, leaving their combined influence on miners' safety behavior poorly understood.* ***Objective:*** *This research aimed to synthesize existing evidence on how workload, time efficiency, and fatigue relate to the safety behavior of mining workers, and to clarify the gap in the current literature, within a human factors and ergonomics framework.* ***Methods:*** *A narrative literature review was conducted on peer-reviewed articles published between 2016 and 2025, retrieved from major scientific databases; sources were analyzed thematically around four constructs, namely human factors, workload, time efficiency, and fatigue, and their link to safety behavior.* ***Results and Discussion:*** *The literature shows that excessive workload, an unfavorable speed–accuracy trade-off, and accumulated fatigue each reduce accuracy and weaken safety compliance and participation; however, these factors have largely been examined in isolation and outside the mining sector, so their integrated influence on miners' safety behavior remains unaddressed.* ***Conclusion:*** *Workload, time efficiency, and fatigue jointly shape safety behavior, yet an integrated accuracy model for high-risk mining environments is still a clear gap that future empirical research should address.*

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Introduction

Over the past few decades, the mining industry has become one of the key pillars of Indonesia's economy due to its potential as a strategic natural resource (Harun et al., 2023). In 2017 the sector contributed approximately 10% of Gross Domestic Product and 33.2% of national export value (Tui & Adachi, 2021), while at the regional level the mining and quarrying sector in Morowali Regency recorded a Gross Regional Domestic Product of IDR 28,114.26 billion in 2023 (Badan Pusat Statistik Kabupaten Morowali, 2024). However, behind this economic contribution, mining workers face mental pressure, high workload, and long working hours that can trigger stress and reduce safe performance (Sankar, 2024; Friedman et al., 2019). The central issue examined in this review is how the management of workload, time efficiency, and fatigue affects the safety behavior of workers in high-risk operational environments.

A number of previous studies have highlighted the relationship between workload and performance. In teleoperation tasks, a 0.8-second response delay significantly increased workload and reduced performance (Lu et al., 2019), whereas in data-entry work high time pressure increased both perceived workload and error rates (Mazloum et al., 2008). Fatigue caused by long shifts has been shown to impair psychomotor function and increase the risk of accidents in mining (Friedman et al., 2019), as well as to reduce alertness and work accuracy (Gander, 2015; Shao et al., 2025). At the same time, the speed–accuracy trade-off phenomenon indicates that fast decisions tend to be less accurate, whereas accurate decisions require more time (Cosman et al., 2016; Vandierendonck, 2017).

Nevertheless, most of these studies analyze workload, time efficiency, and fatigue separately and generally focus on the manufacturing, office, or laboratory settings (Mazloum et al., 2008; Song et al., 2018; Fan et al., 2022). Mining workers face distinctive complexity, namely extreme environmental conditions, heavy physical demands, and the need for rapid field decision-making, so that findings from other sectors cannot be readily generalized. Studies that integrate these three factors simultaneously into a single accuracy model in mining operational environments remain very limited, creating a clear gap in the current literature.

Based on this gap, this literature review aims to synthesize and map the scientific evidence on the influence of workload, time efficiency, and fatigue on the safety behavior of mining workers, while clarifying the research gap that remains open, within the framework of human factors and ergonomics (HFE). The novelty of this study lies in the effort to integrate the three constructs—previously discussed separately—into a single operational accuracy model framework in the mining sector. The findings are expected to provide theoretical benefits for the development of occupational safety and health science and to serve as a foundation for further empirical research to close this gap.

Method

This study uses a literature review approach of the narrative review type to synthesize scientific evidence related to workload, time efficiency, fatigue, and safety behavior. This approach was chosen because it allows the integration of findings from various study designs and industrial contexts into a single, coherent conceptual framework. The search for and management of references were carried out systematically so that the resulting synthesis is accountable.

Research Design: The design used is a descriptive-analytical literature review. The study focuses on the search, appraisal, and thematic synthesis of scientific articles relevant to four main constructs, namely human factors and ergonomics, workload, time efficiency–accuracy, and fatigue, in relation to occupational safety behavior. The focus of the study is directed toward high-risk work contexts, particularly the mining sector.

Data Sources and Search Strategy: The data sources are indexed journal articles and scientific proceedings obtained from electronic databases such as Scopus, ScienceDirect, SpringerLink, and Google Scholar. The search used a combination of keywords in English and Indonesian, including 'mental workload', 'speed–accuracy trade-off', 'occupational fatigue', 'safety behavior', and 'mining'. All references were managed using Zotero software to avoid duplication and to maintain consistency in citation formatting.

Inclusion and Exclusion Criteria: The inclusion criteria comprise articles published between 2016 and 2025, written in English or Indonesian, and addressing at least one of the main constructs in the context of human work or performance. Classic articles that are fundamental to theory building are still included as conceptual references, for example the foundational formulation of the human factors and ergonomics field (Stanton et al., 2004). Articles were excluded if they were not relevant to the theme, were opinions without supporting data, or were not available in full.

Data Extraction and Analysis: The extracted data include each article's researcher name, year of publication, objective, method, instruments, and main findings. The analysis was conducted thematically by grouping findings into four themes according to the constructs, then examining the relationships among themes to build an argument regarding the accuracy model in operational environments. The synthesis was directed toward comparing and contrasting results across studies and connecting them to the HFE theoretical framework.

Results and Discussion

Human Factors and Ergonomics as an Analytical Framework

Human factors and ergonomics (HFE) is a multidisciplinary field that studies the interaction between humans and system elements to optimize performance, safety, and work comfort (Stanton et al., 2004). Through a combination of psychology, industrial engineering, and systems design, HFE places human capabilities and limitations at the center of work-system design, thereby increasing efficiency and reducing the potential for error (Salvendy, 2012). This field encompasses three main approaches, namely physical ergonomics, cognitive ergonomics, and organizational ergonomics, which complement one another in creating an adaptive work system. In the mining context, the cognitive ergonomics approach is the most relevant because it addresses the processes of perception, attention, and decision-making that underlie workload, time efficiency, and fatigue. Thus, HFE serves as the theoretical umbrella that connects these three constructs with safety behavior.

Workload and Safety Behavior

Mental workload is a multidimensional construct influenced by the characteristics of the task, the individual, and the work environment, and is understood as the result of the interaction between task demands, individual capabilities, and subjective perceptions of the effort required to achieve a certain level of performance (Nino et al., 2023). An imbalanced workload has a negative impact on performance: excessive workload increases mental stress, reduces accuracy, and slows system response (Doost & Zhang, 2022; Mazloum et al., 2008). In the mining context, high workload has the potential to weaken safety compliance and participation because it consumes the cognitive resources needed to act safely. Nevertheless, most of this evidence comes from non-mining sectors, so the relationship between workload and the safety behavior of mining workers has rarely been studied specifically.

Time Efficiency, Accuracy, and the Speed–Accuracy Trade-off

Time efficiency and accuracy are two interrelated dimensions of performance that often exhibit a trade-off pattern. In complex cognitive tasks, the level of accuracy initially increases rapidly with response time, then declines more slowly (Chen et al., 2018), and individuals oriented toward precision are willing to spend more time for accurate results (Stoeber et al., 2010). The speed–accuracy trade-off phenomenon describes the balance between speed and precision in decision-making (Georgiev et al., 2016): fast decisions tend to be less accurate, while accurate decisions require more time due to the process of information accumulation (Cosman et al., 2016; Moiron et al., 2016). However, this relationship is not always linear, because adding time does not always predict an increase in accuracy in non-experimental contexts (Domingue et al., 2022). In mining operations, the speed–precision dilemma becomes real when workers operate heavy equipment or respond to emergency situations, and this balance even weakens in extreme age groups (Statsenko et al., 2020). The ability to maintain the speed–accuracy balance therefore becomes a form of cognitive adaptation that supports safe work behavior.

Fatigue and Safety Behavior

Fatigue is defined as a physiological condition that reduces the capacity for mental and physical performance due to lack of sleep, prolonged wakefulness, circadian phase, or workload (Gander, 2015; León-Carrión et al., 2020). Fatigue reduces alertness and the ability to work safely, thereby increasing the likelihood of errors, incidents, and accidents (Satterfield & Van Dongen, 2013; Gander, 2015). In mining, the application of 10–12-hour shifts worsens psychomotor disturbances and reduces work accuracy (Friedman et al., 2019), aggravated by heat exposure and heavy physical work in open-pit mines (Nunfam et al., 2021). Task interruptions among heavy-equipment operators in mines have even been shown to strengthen the relationship between fatigue and unsafe behavior (Shao et al., 2025). However, studies that place fatigue alongside workload and time efficiency within a single analytical framework of safety behavior are still rarely found, so its simultaneous role has not been clearly mapped.

Research Gap and an Integrated Accuracy Model

The synthesis of the four themes shows a common thread connecting workload, time efficiency, and fatigue with safety behavior through an accuracy mechanism. Safety behavior consists of two dimensions, namely safety compliance and safety participation (Amponsah-Tawaih & Adu, 2016; Burt et al., 2018); high workload consumes cognitive capacity, time pressure forces workers into a less accurate trade-off, and fatigue reduces alertness, so that all three converge on a decline in accuracy that weakens both dimensions. Nevertheless, the literature review shows that these three factors are almost always studied separately and predominantly in the manufacturing, office, transportation, or laboratory sectors (Mazloum et al., 2008; Song et al., 2018; Fan et al., 2022). Studies that integrate workload, time efficiency, and fatigue simultaneously into a single accuracy model in the mining context are still very rare, even though the characteristics of mining work—extreme environments, high physical demands, and rapid decision-making—differ fundamentally from other sectors. This gap is the main focus of this review, namely the absence of an integrated framework explaining how these three human factors jointly shape the accuracy and safety behavior of mining workers. The HFE framework, particularly the theory of the speed–accuracy trade-off and mental workload, has the potential to unify these relationships into a single accuracy model in operational environments, consistent with findings that the combination of workload and fatigue affects safe behavior in high-risk industries (Jame Chenarboo et al., 2022; Rante Ada' et al., 2025).

Table 1
Summary of Main Reviewed Studies, Differentiated by Sector (Mining vs. Non-Mining)

Study (Author, Year)	Sector / Setting	Construct(s) Examined	Design / Method	Key Finding Relevant to Safety Behavior
Friedman et al. (2019)	Mining, USA	Fatigue; long working hours	Cross-sectional injury analysis	Long working hours impair psychomotor function and increase injury and accident risk
Nunfam et al. (2021)	Mining, Ghana (open-pit)	Physical demand; heat exposure	Field risk assessment	Heat exposure and heavy physical work raise health and safety risk for miners
Shao et al. (2025)	Mining, coal	Fatigue; task interruption; unsafe behavior	Survey (moderation model)	Task interruptions strengthen the fatigue–unsafe behavior relationship in equipment operators
Lu et al. (2019)	Non-mining, teleoperation (lab)	Workload	Experimental	Response delay increases workload and reduces task performance
Mazloum et al. (2008)	Non-mining, office / data entry	Workload; time pressure	Experimental	Time pressure raises perceived workload and error rates
Doost & Zhang (2022)	Non-mining, office	Workload; interruptions	Experimental (physiological)	Interruptions increase mental workload
Fan et al. (2022)	Non-mining, laboratory	Workload; noise	Experimental	Noise exposure and workload jointly alter physiological response
Nino et al. (2023)	Non-mining, industrial (lab)	Mental workload	Experimental	Perceived mental workload affects work body posture
Song et al. (2018)	Non-mining, power-grid dispatch	Workload	Assessment-method study	Proposes multidimensional workload measurement for dispatchers
Chen et al. (2018)	Non-mining, cognitive testing (lab)	Speed–accuracy	Experimental	Accuracy shows a curvilinear dependence on response time
Cosman et al. (2016)	Non-mining, laboratory (visual search)	Speed–accuracy	Electrophysiological experiment	Traces the information flow underlying the speed–accuracy trade-off
Domingue et al. (2022)	Non-mining, education (real-world)	Speed–accuracy	Large-scale observational data	Speed–accuracy relationship is inconsistent outside experimental settings
Statsenko et al. (2020)	Non-mining, laboratory	Speed–accuracy	Experimental	Speed–accuracy balance weakens in extreme age groups

Study (Author, Year)	Sector / Setting	Construct(s) Examined	Design / Method	Key Finding Relevant to Safety Behavior
	(aging)			
Gander (2015)	Non-mining, transport	Fatigue	Review (regulatory)	Reviews fatigue-risk-management approaches for transport operations
Satterfield & Van Dongen (2013)	Non-mining, occupational (general)	Fatigue	Review	Describes sleep and circadian mechanisms underlying occupational fatigue
Jame Chenarboo et al. (2022)	Non-mining, automobile industry	Workload → safe behavior	Survey	Physical and mental workload influence employees' safe behavior
Rante Ada' et al. (2025)	Non-mining, construction	Fatigue → safety compliance	Survey	Fatigue is associated with reduced safety compliance
Amponsah-Tawaih & Adu (2016)	Non-mining, healthcare	Work pressure → safety behavior	Survey	Management commitment moderates the work-pressure–safety-behavior link

Note. Only three of the reviewed studies were conducted directly on mining workers (Friedman et al., 2019; Nunfam et al., 2021; Shao et al., 2025), and each examined a single constru t fatigue or physical/heat load rather than the integrated workload–time efficiency–fatigue accuracy model. The remaining evidence is cross-sectoral (office, laboratory, transport, power-grid, automobile, construction, and healthcare settings), underscoring the scarcity of direct mine-worker evidence and reinforcing the research gap identified in this review.

Conclusion

This literature review concludes that workload, time efficiency, and fatigue are three interrelated human factors that jointly have the potential to influence the safety behavior of mining workers through the mechanism of work accuracy: excessive workload, an imbalanced speed–accuracy trade-off, and the accumulation of fatigue each erode safe performance. However, the existing literature still examines these three factors separately and largely outside the mining sector, so there is a clear gap in the form of the absence of an integrated accuracy model for mining operational environments. The main contribution of this review is to map this gap and propose the HFE framework as a basis for integration, while recommending further empirical research to test and validate an integrated accuracy model in the context of mining workers.

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