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Fatigue Risk Management in Fast Moving Coal Mining Units: A Narrative Review of Operational Risks and Control Strategies

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Abstract

***Introduction**: Fatigue in coal mining operations has become important operational safety issue because prolonged shift systems, monotonous tasks, environmental exposure, and high-risk heavy equipment activities increase the risk of human error and fatal accidents. **Objective**: This study aimed to examine fatigue as a systemic operational hazard in fast moving coal mining units and to synthesize evidence-based fatigue risk management strategies. **Method**: This study employed a narrative review approach by analyzing 13 references from scientific databases, government regulations, and international safety guidelines using thematic synthesis based on Fatigue Risk Management System concepts, the Swiss Cheese Model, and the Context, Input, Process, and Product evaluation framework. **Result and Discussion**: The review identified physiological, occupational, environmental, and individual factors as the major contributors to fatigue, while also revealing that most previous studies focused mainly on individual determinants without integrating operational risk management approaches. Fatigue Risk Management Systems were identified as the most comprehensive strategy because they combine fatigue monitoring, roster management, worker training, reporting systems, and organizational safety culture. **Conclusions**: Fatigue should be viewed as a systemic operational hazard rather than solely an individual health issue, therefore, integrated fatigue management strategies are essential to improve safety performance and prevent fatigue-related incidents in coal mining operations.*

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Introduction

The mining industry is widely recognized as one of the most hazardous occupational sectors because of its exposure to operational, environmental, and human-related risks. According to the International Labour Organization (ILO), although mining employs only approximately 1% of the global workforce, it accounts for nearly 8% of occupational fatalities worldwide (Ismail *et al*., 2021). In open-pit coal mining operations, workers are required to maintain sustained vigilance and make rapid decisions while operating heavy equipment in dynamic environments. In Indonesia, human factors continue to contribute substantially to occupational accidents, with fatigue-related human error frequently associated with reduced alertness, slower reaction times, and impaired decision-making during equipment operation. These conditions are particularly critical in fast moving mining units where a decline in operator performance may result in severe operational consequences. Therefore, fatigue has become an important concern in mining safety management and operational risk control.

Fatigue is not merely a temporary feeling of tiredness but a progressive decline in physical and cognitive performance resulting from the interaction of sleep deprivation, circadian rhythm disruption, and accumulated workload (Jamal *et al*., 2020). From a human factors perspective, fatigue can reduce attention, situational awareness, reaction speed, and decision-making capacity, thereby increasing the likelihood of operational errors. Pizarro *et al*. (2024) further explained that fatigued workers may experience anosognosia or self-perceptual blindness, a condition in which individuals fail to recognize their own impairment despite significant reductions in cognitive performance. In mining operations, such impairment becomes particularly hazardous because operators are responsible for controlling large-scale mobile equipment under high-risk conditions. The Swiss Cheese Model suggests that fatigue can function as a latent organizational failure that interacts with weaknesses in other safety barriers and contributes to accident occurrence. Consequently, fatigue should be viewed as a systemic operational hazard rather than solely an individual health issue.

To address fatigue-related risks, many high-risk industries have adopted Fatigue Risk Management Systems (FRMS) as a systematic and evidence-based approach for monitoring, managing, and mitigating fatigue hazards (Techera *et al*., 2020). Unlike conventional working-hour limitation approaches, FRMS recognizes that worker fitness is influenced by multiple factors, including sleep quality, circadian rhythm stability, workload accumulation, and recovery effectiveness. Effective FRMS implementation therefore requires integrated controls that combine organizational policies, fatigue monitoring technologies, worker training, roster management, reporting mechanisms, and continuous evaluation. Bauerle *et al*. (2022) identified these components as essential elements for preventing fatigue from escalating into operational incidents. The adoption of FRMS also reflects a shift from reactive accident response toward proactive risk prevention strategies. As a result, FRMS has become increasingly relevant for industries that rely heavily on continuous operations and high-risk equipment activities.

Previous studies have consistently demonstrated that fatigue is prevalent among mining workers and is influenced by multiple interacting factors. A systematic literature review by Ramdhani and Soraya (2024) identified sleep deprivation, excessive workload, shift systems, environmental exposure, and individual lifestyle factors as major contributors to fatigue in mining settings. Bauerle *et al*. (2022) further emphasized that mining environments possess distinctive fatigue-related characteristics that require specialized mitigation approaches. In addition, Drews *et al*. (2020) found that organizational culture influences fatigue management practices because workers may hesitate to report fatigue symptoms due to fear of sanctions. Studies conducted in Indonesia have primarily examined fatigue through correlational analyses involving sleep duration, mental workload, and shift schedules (Nurahma *et al*., 2022; Mulyati *et al*., 2020; Sitanggang *et al*., 2024). Collectively, these findings indicate that fatigue is influenced not only by physiological factors but also by organizational and operational conditions.

The importance of fatigue management is also reflected within the Indonesian occupational safety framework. Law Number 3 of 2020 concerning Mineral and Coal Mining requires mining companies to implement Good Mining Practice principles, including systematic management of occupational safety and health risks. Furthermore, Decree of the Minister of Energy and Mineral Resources Number 1827K/30/MEM/2018 requires mining organizations to identify and control hazards associated with operational activities and human performance. Government Regulation Number 50 of 2012 concerning Occupational Safety and Health Management Systems (SMK3) additionally establishes minimum requirements for safety management implementation across industrial sectors. However, unlike the aviation industry, which has adopted internationally standardized fatigue management guidance through ICAO/IATA/IFALPA, the Indonesian mining sector still lacks specific regulations governing FRMS implementation. This regulatory gap creates challenges for organizations seeking to systematically manage fatigue risks in mining operations. Consequently, the development and evaluation of structured fatigue management approaches remain highly relevant within the mining sector.

Despite growing attention to fatigue in mining industries, important research gaps remain. Previous studies have largely focused on fatigue prevalence and individual-level determinants without comprehensively examining fatigue management from a systemic operational perspective (Sitanggang *et al*., 2024; Nurahma *et al*., 2022; Mulyati *et al*., 2020). Moreover, limited attention has been given to evaluating fatigue management practices using broader organizational frameworks such as the Context, Input, Process, and Product (CIPP) model proposed by Stufflebeam (2003). The CIPP framework offers a comprehensive approach for assessing policy context, operational resources, implementation processes, and program outcomes within fatigue management systems. Therefore, this narrative review aims to examine fatigue as an operational risk in fast moving coal mining units and to synthesize evidence-based control strategies reported in previous studies. This review also seeks to identify critical gaps and future directions for strengthening fatigue risk management practices in high-risk mining environments.

Method

This study employed a narrative review design to comprehensively analyze fatigue risk management within fast moving coal mining operations. A narrative review approach was selected because the objective of this study was not to measure a single statistical relationship, but rather to synthesize and critically interpret multidisciplinary evidence related to fatigue as an operational safety risk in mining industries. According to Bauerle *et al*. (2022), fatigue management in mining requires the integration of physiological, operational, organizational, and technological perspectives, making narrative synthesis highly suitable for exploring the complexity of the issue. The narrative review method also allows broader theoretical interpretation compared with conventional systematic reviews that primarily focus on quantitative effect sizes. Through this approach, the study was able to compare operational fatigue management concepts across different industries, particularly between aviation and coal mining sectors.

The review process was conducted systematically through several stages consisting of literature identification, screening, eligibility assessment, critical evaluation, and narrative synthesis. Literature sources were obtained from internationally recognized scientific databases, including ScienceDirect, Proquest, SpringerLink, and Clinical Key. Government regulations, international safety guidelines, and institutional reports related to fatigue management were also included to strengthen the operational and regulatory perspectives of the discussion. The literature search focused on publications issued between 2019 and 2025 to ensure that the analysis reflected the most recent developments in fatigue management research within high-risk industries. The literature selection process emphasized relevance to mining operations, fatigue risk management, operational safety, shift work, microsleep, and heavy equipment operations. Through this process, the study sought to construct a comprehensive understanding of fatigue risks within fast moving coal mining units.

The keywords used during the literature search process included combinations of "fatigue risk management system," "fatigue in mining," "coal mining safety," "microsleep," "heavy equipment operator fatigue," "shift work fatigue," "human factors in mining," "Swiss Cheese Model," and "fatigue-related incidents." Additional searches were conducted using terms such as "aviation fatigue management," "FRMS implementation," "safety culture," "fatigue monitoring technology," "sleep deprivation," "circadian rhythm disruption," and "haul truck operator fatigue" to obtain broader comparative perspectives from other high-risk industries. Boolean operators including AND, OR, and NOT were utilized to optimize search specificity and relevance. The inclusion criteria covered peer-reviewed journal articles, conference proceedings, government regulations, and international safety guidelines discussing fatigue management in operational contexts. Studies focusing exclusively on unrelated medical disorders, laboratory-based sleep experiments without operational relevance, or non-industrial fatigue contexts were excluded from the review. In addition, the selected literature had to provide clear discussions regarding fatigue determinants, operational impacts, mitigation strategies, or fatigue management systems. This filtering process ensured that the final literature pool remained directly aligned with the objectives of this narrative review.

A total of 13 references were identified and cited throughout this narrative review based on their direct relevance to fatigue management, mining operational safety, human factors, and FRMS implementation. Figure 1, shows the prisma diagram toward narrative review in this research.

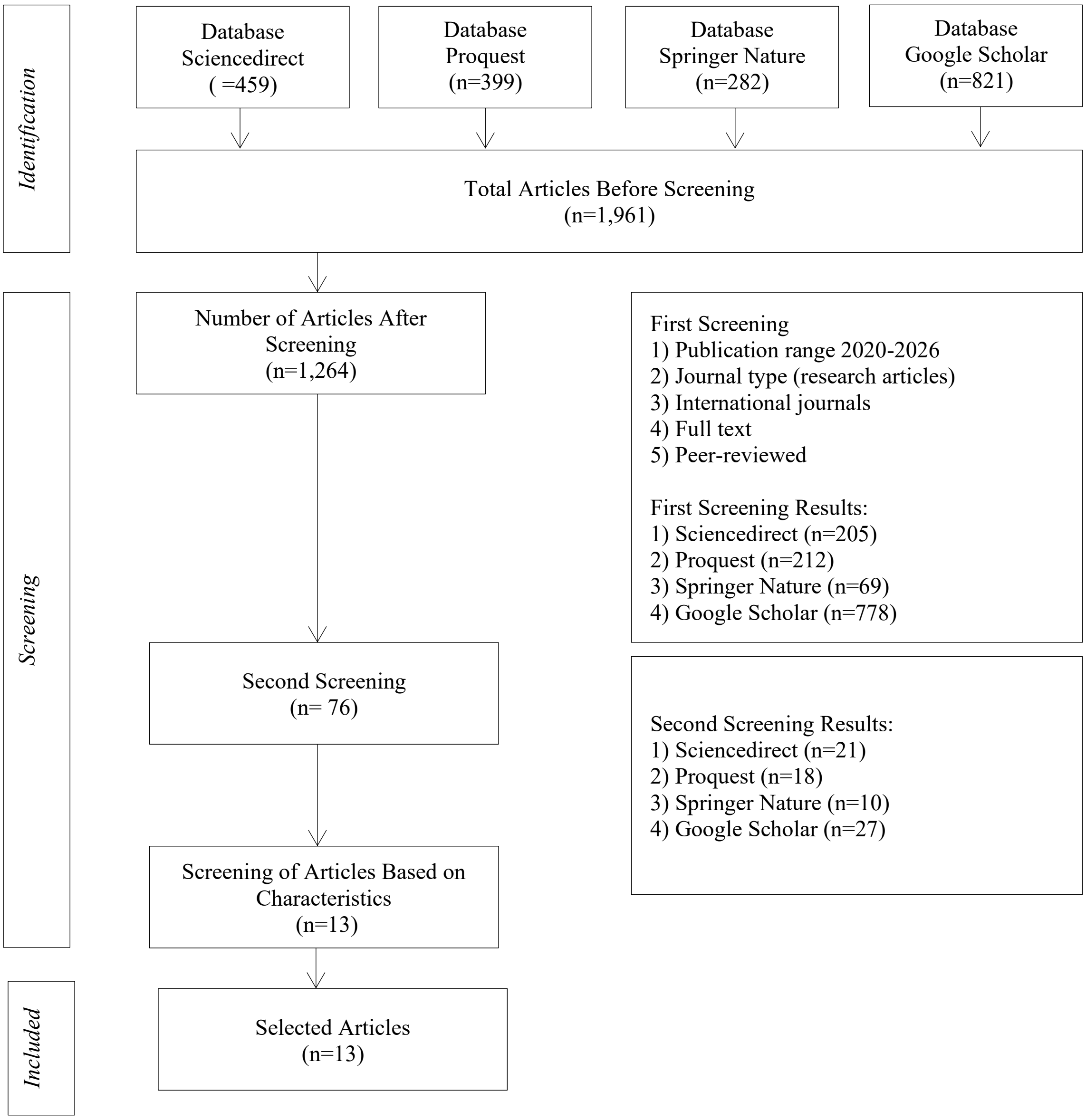

Figure 1. Prisma Diagram in the Research

The references consisted of international journal articles, systematic literature reviews, observational studies, cross-sectional analyses, focus group discussions, government regulations, and theoretical frameworks. Core references included studies by Ramdhani and Soraya (2024), Sitanggang *et al*. (2024), Bauerle *et al*. (2022), Nurahma *et al*. (2022), Mulyati *et al*. (2020), Drews *et al*. (2020), Jamal *et al*. (2020), and Techera *et al*. (2020), which directly discussed fatigue risk factors and operational fatigue management within mining industries. Additional comparative references from aviation fatigue management literature such as Caldwell *et al*. (2019) and ICAO/FAA/EASA operational concepts were incorporated to strengthen the discussion regarding FRMS adaptation into coal mining environments. Supporting literature concerning environmental exposure, physiological fatigue mechanisms, and individual risk factors such as Butlewski *et al*. (2020), Li *et al*. (2022), Pelders and Nelson (2019), Chen *et al*.

(2023), and Pizarro *et al*. (2024) were also included to provide multidisciplinary analytical perspectives.

The analytical framework of this study was primarily based on the Fatigue Risk Management System (FRMS) concept, the Swiss Cheese Model developed by Reason, and the Context, Input, Process, Product (CIPP) evaluation model proposed by Stufflebeam (2003). FRMS was utilized as the principal conceptual framework because it emphasizes systematic, evidence-based approaches for identifying, monitoring, and mitigating fatigue-related operational risks (Techera *et al*., 2020). The Swiss Cheese Model was employed to explain how fatigue can interact with failures across multiple organizational defense layers, ultimately contributing to operational incidents or fatal accidents. Meanwhile, the CIPP evaluation framework was used to structure the narrative analysis into four interconnected dimensions: policy and organizational context, operational and technological inputs, implementation processes, and operational outcomes. The framework additionally facilitated comparisons between aviation FRMS practices and coal mining operational environments.

Data analysis in this narrative review was conducted qualitatively through thematic synthesis and comparative interpretation of findings across the selected literature. The analysis focused on identifying recurring themes related to fatigue risk factors, operational consequences, organizational culture, monitoring technologies, microsleep phenomena, and FRMS implementation strategies. Findings from various studies were categorized into several analytical dimensions, including physiological fatigue mechanisms, operational risk exposure, environmental contributors, managerial controls, and safety culture factors. Comparative analysis was also conducted between aviation and mining fatigue management systems to identify transferable practices and contextual limitations. The synthesis process emphasized interpretation comprehensive operational understanding of fatigue management in fast moving coal mining units.

Results and Discussion

Previous studies have examined fatigue from physiological, occupational, environmental, and organizational perspectives, revealing that fatigue arises from the interaction of multiple risk factors rather than a single determinant. However, much of the existing literature remains focused on identifying fatigue causes and prevalence, while relatively limited attention has been given to evaluating fatigue management from an integrated operational risk perspective. To provide a clearer synthesis of the existing evidence, Table 1 shows the characteristics, major findings, and limitations of the studies included in this review.

Table 1

Previous Studies on Fatigue in Mining Operations

Authors	Year	Scope	Findings	Limitations
Ramdhani & Soraya	2024	Fatigue determinants in mining workers	Sleep deprivation, excessive workload, shift systems, and environmental exposure were identified as major contributors to fatigue.	Focused primarily on individual risk factors without organizational risk management analysis.
Sitanggang *et al*.	2024	Heavy equipment operator fatigue	Shift work significantly affected fatigue levels among operators.	No evaluation of FRMS implementation or organizational controls.

Bauerle *et al.*	2022	Fatigue Risk Management System (FRMS)	FRMS and the Swiss Cheese Model provide comprehensive systemic approaches for fatigue control.	Not specifically contextualized within Indonesian mining operations.
Nurahma *et al.*	2022	Sleep duration and fatigue	Sleep duration below seven hours was associated with higher fatigue levels.	No integration with broader operational risk management frameworks.
Mulyati *et al.*	2020	Night-shift fatigue	Night-shift haul truck operators experienced significantly higher fatigue levels.	Limited to a single operational setting.
Drews *et al.*	2020	Fatigue reporting culture	Workers often concealed fatigue symptoms because of fear of sanctions.	Did not apply a structured operational evaluation framework.
Jamal *et al.*	2020	Fatigue development mechanisms	Fatigue develops through interactions among circadian disruption, workload accumulation, and sleep deprivation.	Primarily theoretical without mining-specific operational validation.
Pizarro *et al.*	2024	Chronic fatigue and anosognosia	Chronic fatigue may reduce workers' ability to recognize their own impairment.	Limited discussion regarding organizational mitigation measures.
Djamalus *et al.*	2021	Occupational fatigue factors	Long working hours, repetitive tasks, and mental workload increase fatigue risk.	Focused on general occupational settings rather than integrated mining systems.
Butlewski *et al.*	2020	Environmental fatigue factors	Heat, vibration, and humidity intensify worker fatigue.	Did not evaluate fatigue management interventions.
Li *et al.*	2022	Mining environmental conditions	Noise exposure and poor air quality significantly contribute to fatigue.	Limited consideration of behavioral and organizational dimensions.
Chen *et al.*	2023	Worker health and fatigue	Worker health conditions influence fatigue levels and recovery capacity.	Focused mainly on physiological aspects rather than operational controls.
Techera *et al.*	2020	FRMS implementation	FRMS provides a systematic framework for identifying and mitigating fatigue hazards.	Limited empirical evidence regarding implementation in mining operations.

Based Table 1, that fatigue in mining operations is influenced by physiological, occupational, environmental, and organizational factors. Most studies consistently identified sleep deprivation, shift work, workload accumulation, and environmental exposure as major fatigue determinants. However, the literature also reveals several important limitations. Many studies focused primarily on individual-level factors, while organizational controls, fatigue reporting systems, and operational risk management mechanisms received comparatively less attention. Although studies such as Bauerle *et al*. (2022) and Techera *et al*. (2020) emphasized the importance of FRMS as a systemic approach, empirical evaluations of its implementation within coal mining operations remain limited.

Fast moving units in open-pit mining operations represent one of the highest-risk operational environments for fatigue-related incidents. These units, including dump trucks, high dump trucks (HDT), and hauling vehicles, operate continuously within demanding production cycles and require sustained concentration throughout extended shifts (Mulyati *et al*., 2020). Operators frequently work under roster systems such as 14-days-on/7-days-off or 21-days-on/7-days-off arrangements, often combined with operational durations reaching 10-12 hours per shift. Such conditions create cumulative physical and mental fatigue, particularly when repetitive hauling routes and monotonous tasks reduce cognitive stimulation and situational awareness. Bauerle *et al*. (2022) emphasized that monotonous operational patterns significantly increase the risk of microsleep and vigilance decline among operators. In addition, the enormous mass and kinetic energy of fast moving mining equipment mean that even minor operational errors can lead to severe property damage, production disruption, or fatal accidents.

Fatal accidents in mining industries represent not only occupational safety failures but also major operational and organizational crises. According to Government Regulation Number 50 of 2012 concerning Occupational Safety and Health Management Systems, fatality accidents refer to workplace incidents resulting in worker death either immediately or within a causally related period after the event. Mining companies experiencing fatal incidents are often required to suspend operational activities temporarily for investigation purposes, resulting in significant productivity losses. Furthermore, disruptions in coal production may negatively affect long-term contractual obligations and stakeholder confidence. In the fatigue-related incidents, these risks become more severe because fatigue often develops gradually and invisibly before eventually manifesting as catastrophic operational failures.

Fatigue is a multidimensional phenomenon involving physiological, occupational, environmental, and individual factors. Kayser *et al.* (2022), defined fatigue as a progressive decline in physical and cognitive performance caused by inadequate recovery and sleep deficiency. Jamal *et al*. (2020) further emphasized that fatigue is non-linear and develops through interactions between circadian rhythm disruption, mental workload accumulation, and sleep deprivation. Bauerle *et al*. (2022) categorized fatigue into acute fatigue and chronic fatigue, each possessing distinct operational implications. Acute fatigue is generally reversible through adequate rest periods, whereas chronic fatigue develops progressively due to cumulative sleep debt and insufficient recovery between shifts. Pizarro *et al*. (2024) described chronic fatigue as particularly dangerous because operators often experience anosognosia or self-perceptual blindness, where they inaccurately perceive themselves as fit for work despite significant cognitive impairment. This phenomenon explains why fatigue-related incidents frequently occur without operators consciously recognizing their declining performance capacity.

The major fatigue risk factors identified in mining operations can be grouped into four principal categories, namely physiological, occupational, environmental, and individual factors. Ramdhani and Soraya (2024) synthesized evidence from international studies and showed that sleep duration below seven hours, circadian disruption, and cumulative exhaustion are among the most significant physiological contributors to fatigue. Occupational factors include long working hours exceeding 10 hours per shift, rotating shift systems, repetitive tasks, and high mental workload (Mulyati *et al*., 2020; Bauerle *et al*., 2022; Djamalus *et al*., 2021). Environmental conditions such as excessive heat, vibration, noise exposure, oxygen deficiency, and humidity further intensify operator fatigue during prolonged mining operations (Butlewski *et al*., 2020; Li *et al*., 2022). Individual characteristics including age, body mass index, smoking habits, alcohol consumption, and health conditions also contribute to variations in fatigue susceptibility among workers (Pelders & Nelson, 2019; Chen *et al*., 2023). These findings indicate that fatigue management strategies should adopt holistic approaches capable of addressing interacting operational and human factors simultaneously. Therefore, effective fatigue prevention requires integration between engineering controls, work scheduling strategies, environmental management, and worker behavioral interventions.

Table 2
Major Fatigue Risk Factors in Mining Operations

Category	Factors	References
Physiological	Sleep deprivation, circadian disruption, microsleep, cumulative fatigue	Ramdhani & Soraya (2024); Nurahma *et al*. (2022); Jamal *et al*. (2020); Pizarro *et al*. (2024); Mulyati *et al*. (2020)
Occupational	Shift work, excessive working hours, repetitive tasks, mental workload, roster systems	Sitanggang *et al*. (2024); Bauerle *et al*. (2022); Mulyati *et al*. (2020); Djamalus *et al*. (2021); Techera *et al*. (2020); Ramdhani & Soraya (2024)
Environmental	Heat, vibration, humidity, noise, poor air quality, environmental exposure	Butlewski *et al*. (2020); Li *et al*. (2022); Ramdhani & Soraya (2024)
Individual	BMI, age, smoking, alcohol use, health conditions, self-awareness of fatigue	Chen *et al*. (2023); Pizarro *et al*. (2024); Drews *et al*. (2020)
Organizational and Safety Culture	Fear of sanctions, underreporting of fatigue, lack of non-punitive reporting systems, weak fatigue monitoring	Drews *et al*. (2020); Techera *et al*. (2020); Bauerle *et al*. (2022)

The implementation of Fatigue Risk Management Systems (FRMS) has emerged as one of the most comprehensive approaches for addressing operational fatigue risks within high-risk industries. Techera *et al*. (2020) described FRMS as a systematic, evidence-based framework designed to monitor, manage, and continuously mitigate fatigue-related operational hazards. Unlike traditional work-hour limitation systems, FRMS recognizes that worker fitness depends on sleep quality, circadian rhythm stability, workload accumulation, and recovery adequacy rather than solely on working duration. The conceptual foundation of FRMS aligns closely with the Swiss Cheese Model where operational accidents occur when multiple organizational defense layers fail simultaneously. Within mining operations, these defensive layers include policies, fatigue detection technologies, worker training, reporting mechanisms, roster management, and organizational leadership commitment. Bauerle *et al*. (2022) emphasized that effective FRMS implementation requires integrated interactions between operational procedures and organizational culture. Therefore, the effectiveness of fatigue management depends not only on technological tools but also on organizational commitment toward proactive safety management practices.

The aviation industry has played a critical role in shaping the evolution of FRMS and provides valuable lessons for mining operations. Caldwell *et al*. (2019) noted that fatigue management in aviation developed primarily because numerous accident investigations repeatedly identified crew fatigue as a significant contributing factor in operational failures. Similar to mining industries, aviation operations involve continuous 24-hour activities, long shifts, high cognitive demands, and severe consequences arising from human error. However, important contextual differences exist between the two sectors. Aviation industries operate under highly standardized international regulations issued by ICAO, FAA, and EASA, whereas fatigue management regulations within Indonesian mining industries remain relatively general and non-mandatory. Furthermore, aviation possesses more advanced fatigue monitoring systems, including predictive scheduling software and validated circadian fatigue models, while mining industries still rely largely on fragmented technologies such as dashcams, smart watches, and fatigue alarms. These differences indicate that although aviation FRMS principles can be adapted into mining operations, substantial contextual modifications are required to accommodate the environmental complexity and operational characteristics of coal mining industries.

Table 3

Comparison of FRMS Between Aviation and Coal Mining Industries

Dimension	**Aviation Industry**	**Coal Mining Industry**
Regulation	Mandatory international regulations (ICAO, FAA, EASA)	Human factors regulated generally, FRMS not mandatory
Operations	8-12 hour duty periods with regulated rest	10-12 hour shifts with long roster systems
Safety Culture	Mature just culture and fatigue reporting systems	Reporting culture still limited
Monitoring Systems	Predictive fatigue algorithms and FDM systems	Partial systems such as dashcams and fatigue alarms
Guidelines	Comprehensive FRMS implementation manuals	No specific FRMS guideline in Indonesia

Despite contextual differences, adapting aviation-based FRMS principles into coal mining operations offers several strategic advantages. One of the most significant strengths lies in the availability of scientifically validated fatigue management models that have evolved over more than three decades within aviation safety systems. These models provide clear operational definitions, fatigue reporting mechanisms, and evidence-based scheduling approaches that can strengthen mining safety management systems. Additionally, the just culture concept widely implemented in aviation industries may help transform fatigue reporting practices within mining organizations where operators often hesitate to report fatigue symptoms because of fear of punishment (Drews *et al*., 2020). Nevertheless, several challenges remain, particularly regarding the absence of mandatory FRMS regulations, the complexity of mining environmental conditions, and the lack of integrated predictive monitoring systems. Mining operations also possess unique roster patterns such as 14:7 and 21:7 systems that have no direct equivalent in aviation operations.

Table 4
Advantages and Challenges of Adapting Aviation FRMS into Coal Mining

Advantages	Challenges
Scientifically validated fatigue management framework	No mandatory FRMS regulations in mining
Precise operational definitions and fatigue standards	Mining environmental complexity not captured in aviation models
Just culture and non-punitive reporting concepts	Immature fatigue reporting culture
Effective fatigue awareness training models	Limited predictive data infrastructure
Efficient integration with safety management systems	Unique mining roster systems

Microsleep represents one of the most dangerous manifestations of fatigue within fast moving mining operations because it can occur involuntarily and often without operator awareness. Microsleep episodes typically last between 1 and 30 seconds and are strongly associated with chronic fatigue and acute sleep deprivation conditions. Drews *et al*. (2020) highlighted that even a three-second microsleep episode at an operational speed of approximately 40 km/h may cause a heavy vehicle to travel more than 33 meters without effective operator control. In mining environments characterized by steep haul roads, limited visibility, and massive equipment dimensions, such loss of control can easily escalate into collisions, rollovers, or fatal pit accidents. The literature consistently identifies microsleep as a critical precursor of catastrophic incidents in haulage operations because operators frequently fail to recognize warning signs before cognitive shutdown occurs. Consequently, operational fatigue management programs should prioritize microsleep prevention through integrated strategies involving fatigue monitoring technologies, optimized roster systems, pre-shift assessments, and organizational reporting cultures.

Conclusion

The fatigue in fast moving coal mining operations constitutes a systemic operational hazard rather than merely an individual health problem. Fatigue is influenced by multidimensional factors involving physiological conditions, shift systems, excessive working hours, environmental exposure, and individual characteristics, all of which may contribute to reduced vigilance, microsleep incidents, operational errors, and fatal accidents. Previous studies have largely focused on descriptive or correlational analyses without comprehensively integrating fatigue management into operational risk management frameworks. The findings further indicate that the implementation of Fatigue Risk Management Systems (FRMS), supported by organizational culture, fatigue monitoring technologies, scientifically designed roster systems, and proactive reporting mechanisms, provides a more comprehensive approach for mitigating fatigue-related risks in mining operations. In addition, aviation-based FRMS principles offer valuable conceptual references for mining industries, although contextual modifications are necessary to accommodate the operational complexity of coal mining environments. Therefore, fatigue management should be positioned as an integral component of operational safety, business continuity, and enterprise risk management strategies within high-risk mining industries.

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