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Original Article

Work Fatigue Risk Modeling Based on Environmental, Individual, and Operational Factors in the Coal Mining Industry

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Abstract

The coal mining industry demands high physical and mental endurance from workers, as they must face exhausting work schedules, heavy activity loads, and high job demands. Previous research has examined factors such as shift work systems, workload, and work environment, but most were conducted separately and have not yet considered the specific context of mining or the role of external factors such as housing conditions. This study aims to analyze the influence of work schedules, work activities, and job demands on fatigue, with housing conditions as a moderating variable. This study uses a quantitative approach with a cross-sectional survey design. Respondents were heavy equipment operators at coal mining contractor companies in East Kalimantan. Of 243 workers surveyed, 213 respondents met the inclusion criteria and were analyzed. Data were collected through questionnaires based on a 1-5 Likert scale and analyzed using PLS-SEM. The research results show that work schedules and work activities have a significant effect on fatigue, while job demands do not show a significant direct relationship. Additionally, housing conditions were proven to significantly moderate the relationship between personal factors and job demands, where better living environments can reduce the negative impact of high demands. These findings emphasize the importance of work schedule management, effective activity planning, and improvement of housing facilities to reduce fatigue levels and enhance worker welfare in the coal mining industry.

Keywords: Burnout, Coal Mining Industry, Job Stressors, Living Environment, Worker Well-being.

1. Introduction

The coal mining industry is a sector that demands a lot of physical and mental labor, with workers often facing long work schedules, heavy work activities, and high job demands. This can lead to fatigue, which in turn affects workers' performance, productivity, and health. Fatigue in this context is a physical and mental condition that arises from excessive workload, which can be caused by various factors, such as work schedules, work activities, and high job demands. The Demand-Control theory (Karasek, 1979) and Job Demands-Resources (Bakker & Demerouti, 2007) emphasize that high job demands without adequate resources or control can increase stress and fatigue. This framework has been widely applied in the healthcare, logistics, and manufacturing sectors.

Furthermore, the Work-Life Balance Model suggests that external factors such as housing conditions also play a role in moderating burnout levels, as an unsupportive housing environment can exacerbate the impact of job demands. Poor housing conditions, such as remote locations or lack of social facilities, have the potential to reduce workers' recovery quality, as they have difficulty accessing resources that support their well-being. In the context of the coal mining industry, workers often work in remote locations, with limited housing conditions, which have the potential to increase burnout levels. This study aims to explore the factors that influence work burnout in the coal mining industry, focusing on how work schedules, job activities, and job demands interact to influence burnout, and how housing conditions moderate these relationships. These findings are expected to provide insights into how work management and the living environment can be improved to reduce burnout and improve worker well-being in this industry.

The coal mining industry is one of the sectors that has significant challenges related to worker welfare, especially in terms of work fatigue. Workers in this industry often face long work schedules and heavy work activities that require them to work in challenging physical conditions. Not infrequently, workers have to face high demands, both in terms of the amount of work that must be completed in a limited time and according to the quality standards expected by the company. These large work demands are often not commensurate with adequate rest time, increasing stress levels and fatigue.

Work fatigue experienced by workers can be viewed as a physical and mental condition that arises due to excessive workload, which has the potential to reduce productivity, work quality, and can cause various health problems in the long term. However, although there have been many studies examining the factors that contribute to fatigue, a deeper understanding of the interaction between work schedules, work activities, and job demands is still limited, especially in the context of the highly demanding coal mining industry. Existing studies tend to focus on individual or job factors without integrating workers' living conditions which also have the potential to affect their fatigue levels.

Previous research on work fatigue has predominantly examined individual factors in isolation, such as work shifts and environment among nurses (Dewanti et al., 2022), work position in logistics (Yudisianto et al., 2021), or physical workload and climate in manufacturing (Mustofani & Dwiyanti, 2019). Other studies have explored a broader set of variables like mental workload and noise (Rahmawati & Tualeka, 2019) or working hour thresholds in nursing (Kida & Takemura, 2022), yet often within specific professional contexts like healthcare or manufacturing.

In addition, although Karasek (1979) Demand-Control theory and Bakker & Demerouti (2007) Job Demands-Resources (JD-R) theory underscore the relationship between job demands and burnout, little research has explored how job demands act as mediating variables in the relationships between work schedules, job activities, and burnout. In many cases, high job pressure, in the absence of adequate resources or control, can exacerbate the effects of intense work schedules and job activities.

This study addresses a clear gap by moving beyond these singular or sector-specific analyses to investigate the complex interplay of work schedules, work activities, and job demands within the underexplored context of Indonesia's coal mining industry. The novelty of this research is twofold: firstly, it employs a sophisticated PLS-SEM approach to model these interactions simultaneously, providing a more holistic understanding than the bivariate correlations common in prior studies. Secondly, it introduces housing conditions as a novel moderating variable, a factor previously unexamined in this capacity, revealing that a positive

living environment can mitigate the impact of job demands, a finding that extends fatigue mitigation strategies beyond the workplace itself.

Most workers in the coal mining industry are placed in very remote locations with limited living conditions. Inadequate facilities, long distance from family, and minimal social facilities can exacerbate the negative impacts of high workloads. This not only hinders workers' physical recovery after work, but also affects their mental well-being. For example, remote locations with less supportive environmental conditions can increase stress levels, reduce sleep quality, and worsen fatigue, which in turn can affect workers' ability to cope with work demands.

A decent and supportive living environment can accelerate the recovery process while improving workers' quality of life. Nevertheless, studies that specifically examine the interaction between work factors and living conditions in the context of the coal mining industry are still relatively limited. Environmental factors such as physical conditions and ergonomics of underground mines (Jiskani, 2020a) as well as heat exposure that affects cognitive function (Hancock, 2020) have been studied, but have not yet been integrated into fatigue risk models. From an individual perspective, studies show that workload, nutritional status, and mental health are related to fatigue (Russeng, 2020; Winifred, 2022), while family resources and personal characteristics also contribute to burnout (Parent-Lamarche, 2019; Załuski, 2024). However, this approach is still partial and less applied to miners. Research related to operational factors also emphasizes more on work scheduling, role demands, or technology use (Andrade-Pineda, 2020; Di, 2022; Emamialeagha, 2025; Zhang, 2022), but has not specifically linked these variables to work fatigue risk. Additionally, studies in the mining sector are more dominated by discussions of occupational safety and musculoskeletal disorders (Jiskani, 2020b), mine management (Peng, 2024), and the impact of energy transition (Černý, 2023; Weber, 2020), so that worker fatigue aspects have not become the main focus.

Therefore, further investigation is still needed that develops a comprehensive work fatigue risk model by integrating environmental, individual, and operational factors, especially in the coal mining industry. This study aims to analyze the impact of work schedules and activities on fatigue, test the mediating role of job demands, and evaluate the moderating role of living conditions. Thus, this study seeks to provide deeper insights into the management of work and living environments to reduce fatigue, improve health, and increase productivity in the coal mining sector.

2. Literature Review

2.1. Job Fatigue in the Mining Industry

Job fatigue is a physical and mental condition caused by excessive work pressure, both physically and psychologically. In the context of the coal mining industry, the work is often very heavy and full of risks. Workers in this sector usually face high physical loads, such as working in harsh conditions, as well as work demands that require high concentration for long periods of time. According to Karasek (1979) Demand-Control Model, worker stress and fatigue will increase when job demands are high and job control is low. Research by Mustofani & Dwiyanti (2019) shows that workers who are exposed to heavy physical work and irregular work schedules tend to experience higher levels of fatigue, which are at risk of causing health problems and work accidents. However, existing research predominantly focuses on individual factors rather than examining the complex interplay between work characteristics and environmental conditions specific to mining operations.

2.2. Work Schedules and Fatigue

Research establishes strong connections between work arrangements and fatigue outcomes. Dewanti et al. (2022) demonstrated that shift workers exhibited higher fatigue levels than fixed-schedule counterparts, while Knauth (2007) linked extended work hours to decreased physical and mental performance. The Job Demands-Resources (JD-R) theory (Bakker & Demerouti, 2007) indicates that high physical demands without adequate resources exacerbate fatigue conditions. While studies examine work schedules and activities separately, limited research investigates their combined effect on mining worker fatigue, particularly regarding how job demands mediate these relationships.

2.3. Job Activities and Fatigue

Heavy work activities, such as coal mining, material transportation, and other physical tasks, are closely related to the level of physical fatigue. According to the Work-Life Balance Model, the level of fatigue will increase when workers spend a very long time doing heavy physical activities without sufficient rest time. Bakker & Demerouti (2007) in the Job Demands-Resources (JD-R) theory stated that high job demands, such as heavy physical activity, can worsen fatigue if not balanced with sufficient resources, such as social support, control over work, and rest time. In the context of coal mining, high-risk and high-intensity physical work worsens the potential for worker fatigue.

2.4. Work Demand as a Mediating Variable

High job demand can function as a mediating variable in the relationship between work schedules, work activities, and fatigue. Characteristics of job demands, such as work volume, time pressure, and targets to be achieved, can worsen the level of fatigue experienced by workers. In the Job Demands-Resources (JD-R) theory, Bakker and Demerouti (2007) stated that high job demand without adequate resources will worsen worker stress and fatigue. Previous research, such as the study by Bazazan et al. (2023) on offshore workers, effectively identified that high physical and psychological job demands are direct, significant predictors of fatigue. However, such studies typically analyze these factors in isolation and focus primarily on workplace variables. This research functions to address this gap by investigating the interaction between work schedules, activities, and demands, and crucially, introduces housing conditions as a novel moderating variable.

2.5. Living Environment as a Mediating Variable

Workers' living conditions, especially in the often isolated and remote coal mining industry, can act as a moderating factor in the relationship between work schedules and fatigue. Research by Friedman & Kern (2014) revealed that unsupportive living conditions, such as remote locations, limited access to social facilities, and minimal recreational and recovery facilities, can exacerbate the impact of demanding work. Hagerup et al. (2024) also added that a comfortable and supportive living environment can help the recovery process from physical and mental fatigue. Therefore, poor living conditions can moderate the relationship between job factors and workers' fatigue levels, by increasing the level of fatigue experienced, while better living conditions can mitigate the impact.

2.6. The Effect of Fatigue on Worker Performance and Health

Recent research highlights that groups such as shift workers, temporary employees, and those of lower socioeconomic status face a greater fatigue burden due to irregular hours, limited access to fatigue management resources, and socioeconomic barriers. This underscores a critical gap in occupational safety, revealing a pressing need for targeted interventions that address the unique causes of fatigue within these vulnerable populations to

improve health equity and safety outcomes (Cunningham et al., 2022). Hockey (2013) revealed that fatigue affects a person's capacity to make the right decisions, which can be fatal in high-risk industries such as coal mining.

Overall literature conclusion, work fatigue in coal mining industry is a complex phenomenon influenced by various factors, including long work schedules, heavy work activities, and high job demands. Poor living environment has the potential to worsen the impact of fatigue caused by these work factors. Therefore, it is important to consider the interaction between these factors in an effort to manage fatigue and improve worker well-being. This study focuses on exploring the relationship between these variables in the hope of providing recommendations for improving workforce management in the coal mining industry.

2.7. Conceptual Framework

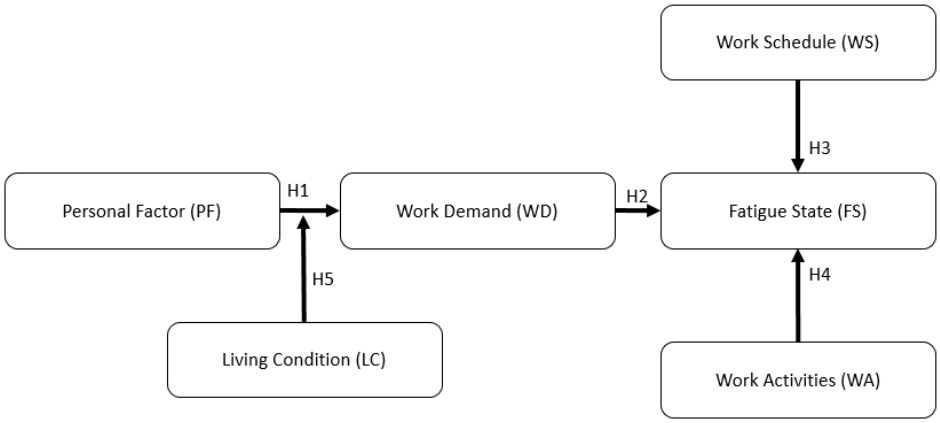

Figure 1. Conceptual Framework

The hypotheses of this study are explained as follows:

Personal factors such as physical condition, mental health, personality, and self-regulation abilities have been proven to influence workers' perception of job demand. Alhainen (2024) shows that physical activity is related to injury risk that increases workload, while Russeng (2020) found that BMI and work duration affect fatigue, thus increasing job demands. From a psychological perspective, certain personalities strengthen work stress (Parent-Lamarche, 2019), while low resilience makes workers more vulnerable to workload (Oware, 2024). Self-regulation ability also determines the extent to which individuals feel work pressure (Rasskazova, 2019), and burnout is often influenced by limitations in personal capacity (Snarr, 2022). These findings confirm that personal factors significantly influence job demand.

H1: The Influence of Personal Factors on Job Demand.

High job demand, whether in the form of physical, mental, or organizational demands, has been proven to contribute significantly to increased worker fatigue. Billiau (2024) shows that high job demands directly impact the health of critical care nurses, while Chang (2022) found that physical burden due to shift patterns is related to perceived job demands that trigger fatigue. Dettmers (2020) confirms that high demands at the beginning of the workday increase fatigue and decrease performance, while Di (2022) identifies job stress as the main factor causing fatigue in mine workers. Additionally, research by Russeng (2020) also supports that workload significantly affects nurse fatigue. These findings confirm that the higher the job demand, the greater the level of fatigue experienced by workers.

H2: The Influence of Job Demand on Fatigue.

Long, irregular work schedules and shift systems have been proven to significantly influence increased worker fatigue. Cannizzaro (2020) shows that night work in security personnel triggers stress and physiological responses that increase fatigue, while Chang (2022) found that three-shift systems in nurses increase physical demands related to fatigue. Gates (2023) highlights that medical residency schedules with long working hours add physical and mental burden, while Marek (2019) links on-call work responsibilities with sleep disturbances and burnout. This evidence confirms that the more unbalanced the work schedule, the higher the level of fatigue experienced by workers.

H3: The Influence of Work Schedule on Fatigue

The type and intensity of work activities are closely related to the level of fatigue experienced by workers. Saavedra-Robinson (2023) confirms that repetitive work activities without sufficient breaks increase the risk of fatigue, while Teixeira (2020) found that psychosocial factors in motorcycle taxi driver activities are related to physical activity levels and fatigue. Turvill (2024) shows that work activities requiring non-ergonomic postures trigger musculoskeletal complaints and fatigue in educators. Additionally, Biswas (2020) reveals that changes in work activities are related to decreased physical activity, which impacts reduced worker energy. These findings confirm that the intensity and characteristics of work activities significantly influence fatigue.

H4: The Influence of Work Activities on Fatigue

The living environment plays an important role as a moderating factor in the relationship between work conditions and fatigue. Załuski (2024) shows that family resources and living conditions can reduce burnout levels in male workers, while Winifred (2022) found that environmental factors, including housing and social support, affect the impact of work factors on mine workers' mental health. Jiskani (2020a) also confirms that physical environmental conditions, including living comfort, can worsen or reduce work-related fatigue. Thus, workers who have good living environmental conditions tend to be better able to restore energy and reduce the negative impact of job demand on fatigue, hence living environment can serve as a moderator that weakens the link between work factors and fatigue.

H5: The Effect of Living Environment as a Moderator.

3. Methods

3.1. Research Design

Research design serves as a guide to achieve research objectives, which determines the success of the research (Nursalam, 2003). Research design includes planning and implementation steps of the study (Sukardi, 2004), as well as explaining variable relationships, data collection, and analysis processes. This study uses a causal approach with a cross-sectional design under natural conditions in coal mining companies in Indonesia. The research strategy includes surveys and is quantitative in nature, where data is generated in numerical form (Saunders et al., 2012).

3.2. Data Collection Time

Based on data collection time, there are cross-sectional studies (data collected once to answer research questions) and longitudinal studies (data collected repeatedly to analyze phenomena over time) (Bougie & Sekaran, 2016).

3.3. Unit of Analysis, Population, and Research Respondents

This study uses heavy equipment operators at coal mining contractor companies in East Kalimantan Province as the unit of analysis at the individual level. An initial survey was

conducted on 243 operators, then through a screening process (age 20-55 years, healthy, no history of illness in the last year, and willing to be respondents), 213 respondents who met the criteria were obtained and used in the analysis. Thus, this study uses 213 respondents as the actual sample. In order to become one of the respondents, there are several requirements that must first be met, namely: (a) Respondents have never had an illness (proven by the results of a medical check-up < the last 1 year); and (b) Respondents are in a fit condition, do not suffer from illness and are ready to carry out a series of activities that have been previously notified. For the implementation time, it will be adjusted to the availability of free time for respondents.

3.4. Research Variables

Operational variables are variables that have the purpose of confirming that it is important to use in operations to review the variable data itself. In this study, six research variables were used. The six research variables are three independent variables, namely work schedule, work activities, and personal factors; one moderating variable, namely living conditions, and one mediating variable, namely work demand.

3.5. Data Collection Techniques

Data were collected through questionnaires to obtain accurate information from respondents. The questionnaire consists of questions about research variables and respondent information, using a 1-5 Likert scale. Data were analyzed with IBM SPSS Statistics to test reliability, validity, internal consistency, and hypothesis testing.

3.6. Data Analysis Techniques

After respondent data were collected, the data were processed with descriptive statistics (mean, standard deviation, percentage) for initial interpretation, presented in graphs and their meanings explained. Analysis was conducted to evaluate questionnaire results and OPA data related to fatigue conditions, including intrinsic and extrinsic factors.

Reliability and validity checks are carried out using PLS-SEM. In general, hypothesis testing focuses on an assumption about a population parameter that is then tested. This process involves evaluating two different things that are more supported by sample data. For example, we can assume that the average age of students in a class is 30 years or that there are more male students than female students. All of these assumptions need to be tested using statistical methods to ensure their truth. Therefore, hypothesis testing is essential to draw mathematically valid conclusions.

In the final stage, conclusions are drawn related to the results of the analysis and discussion. This conclusion should answer the previously set research objectives. In addition, this section also includes suggestions related to the analysis and new findings of new measuring instrument research related to fatigue measuring instruments, to be used in further research.

4. Results and Discussion

4.1. Research Results

4.1.1. Respondent Characteristics

From 243 survey respondents, 30 met the screening criteria, and after the data cleaning process, 213 respondents were used in the analysis. The respondents were operators working at coal mining contractors in East Kalimantan Province, distributed across several areas such as Sangatta, Berau, Batu Kajang, and Loa Janan, with 100% being male. The age distribution

was predominantly in the 21-25 years range (42.6%), followed by 31-35 years (25.5%), 36-40 years (13.9%), 26-30 years (10%), and under 21 years (5.2%), while the remainder were over 40 years old. This distribution is consistent with previous findings that age and work experience affect fatigue risk and work safety in the mining sector (Di, 2022; Winifred, 2022).

The majority of respondents' education was high school (98.4%), followed by Diploma (0.8%), and a small portion had bachelor's degrees. Marital status was dominated by married individuals (55.8%), and the majority lived in company dormitories (57.8%), while the rest lived outside the dormitories. This choice of residence is relevant to the physical and psychological recovery of shift workers (Załuski, 2024; Zhang, 2022). Most respondents had work experience of ≤5 years (56.9%), and the rest >5 years, with the 2-shift work system dominating (84.1%) compared to 3-shift. This shift work pattern is known to affect fatigue, stress, and worker health, especially in the mining industry (Cannizzaro, 2020; Chang, 2022). These respondent characteristics provide a picture of a mining worker population that is relatively young, has secondary education, and mostly lives in company facilities, all of which can influence responses to workload, fatigue risk, and operational performance.

4.1.2. Measurement Model

The measurement items were tested for validity and reliability before the questionnaire was distributed. The results of the validity test showed that all items had a factor loading exceeding 0.6 and were statistically significant with Average Variance Extracted (AVE) ≥ 0.5. The results of the reliability test showed that all items met the criteria for Cronbach's Alpha (CA) and Composite Reliability (CR), both of which were greater than 0.7. These results confirm that all variables meet the requirements for reliability and validity tests (Hair Jr. et al., 2021), as shown in Table 1.

Table 1. Construct Reliability and Validity Results

Variable	Items	Factor Loading	Cronbach's Alpha (>0.7)	Composite Reliability (>0.7)	AVE (>0.5)
Fatigue State	FS 1	0.838	0.904	0.929	0.723
	FS 2	0.878			
	FS 3	0.825			
	FS 4	0.862			
	FS 5	0.847			
Living Condition	LC 1	0.850	0.872	0.908	0.666
	LC 2	0.901			
	LC 3	0.703			
	LC 4	0.745			
	LC 5	0.863			
Personal Factor	PF 1	0.783	0.891	0.920	0.698
	PF 2	0.775			
	PF 3	0.868			
	PF 4	0.912			
	PF 5	0.832			
Work Activities	WA 1	0.764	0.786	0.855	0.549
	WA 2	0.764			
	WA 3	0.824			
	WA 4	0.824			
	WA 5	0.866			
Work Demand	WD 1	0.866	0.921	0.941	0.761
	WD 2	0.856			
	WD 3	0.906			
	WD 4	0.924			

Variable	Items	Factor Loading	Cronbach's Alpha (>0.7)	Composite Reliability (>0.7)	AVE (>0.5)
	WD 5	0.804			
Work Schedule	WS 1	0.848	0.906	0.930	0.726
	WS 2	0.850			
	WS 3	0.825			
	WS 4	0.842			
	WS 5	0.895			

Based on Table 2, all constructs show fairly high correlations but remain distinct from one another, indicating that discriminant validity is fulfilled. For example, Fatigue State has the highest correlation with Work Activities (0.851), and Work Schedule has the highest correlation with Work Demand (0.868). This shows that each construct has relevant relationships but can still be distinguished from other constructs.

Table 2. Discriminant Validity

	Fatigue State	Libing Condition	Personal Factor	Work Activities	Work Demand	Work Schedule
Fatigue State						
Libing Condition	0.599					
Personal Factor	0.693	0.747				
Work Activities	0.851	0.679	0.692			
Work Demand	0.741	0.701	0.765	0.848		
Work Schedule	0.843	0.702	0.834	0.848	0.868	

The results of the discriminant validity analysis indicate that several constructs are strongly interrelated. Fatigue State shows the highest correlations with Work Schedule (r = 0.843) and Work Activities (r = 0.851), suggesting that scheduling patterns and the intensity of activities are closely tied to workers' fatigue levels. Similarly, Personal Factor has a strong correlation with Work Schedule (r = 0.834), indicating that individual characteristics influence how work schedules affect employees. Work Demand also demonstrates high correlations with Work Schedule (r = 0.868) and Work Activities (r = 0.848), reflecting the strong connection between workload, task intensity, and scheduling in shaping job conditions. In contrast, Living Condition exhibits comparatively lower correlations with other variables, implying that it functions more as an independent moderating factor rather than being directly intertwined with operational aspects. Overall, the findings highlight that Work Schedule and Work Demand are the most interrelated constructs, both of which play a central role in influencing fatigue within the coal mining industry.

4.1.3. Structural Model

This model was further developed using structural methods to ensure explanatory relationships through testing with the PLS-SEM application (Hair Jr et al., 2021). The results of the PLS-SEM analysis (Figure 3) show that Living Condition and Personal Factor contribute 54.4% to Work Demand (R^2 = 0.544). In addition, 66% of Fatigue State is explained by Work Schedule, Work Demand, and Work Activities (R^2 = 0.660).

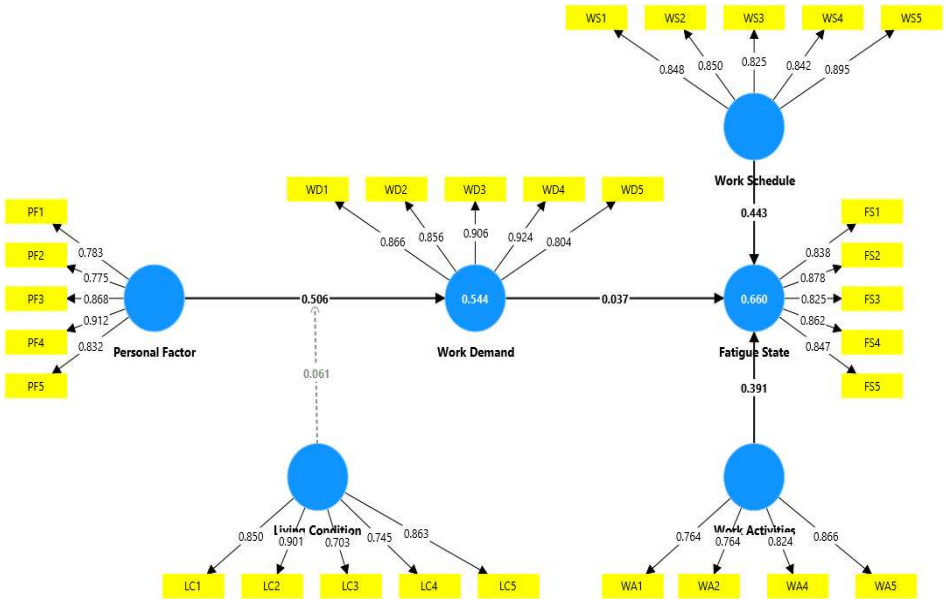

Figure 3. PLS Results and Structural Model

Based on the results of data processing using PLS-SEM, it was found that the H1 hypothesis, which focuses on the relationship between Personal Factor (PF) and Work Demand (WD) has a significant relationship with a p-value = 0.000 and t = 6.812. However, based on the results of data processing, it shows that the H2 hypothesis is rejected. This hypothesis focuses on the relationship between Work Demand (WD) and Fatigue State (FS) with a p-value = 0.318 and t = 0.473

In addition, the results of the study found that in H3, the relationship between Work Schedule (WS) and Fatigue State (FS) has a significant relationship with a p-value = 0.000 and t = 6.015. For the H4 hypothesis, the relationship between Work Activities and Fatigue State has a significant influence with a p-value = 0.000 and t = 5.130. Meanwhile, the interaction between Instrumental Coworkers Support (ICS) and Positive Intergenerational Affect (PIA) on Transactive Memory System Collaboration (TMSC) is also accepted, with p-value = 0.246 and t = 0.687. Furthermore, hypothesis H5, which examines the relationship between Personal Factor (PF) and Work Demand (WD) moderated by Living Condition, shows an accepted relationship with p-value = 0.024 and t = 1.970 so that the Living Condition variable has a significant influence on the relationship between the Personal Factor and Work Demand variables.

Table 3. Hypothesis Testing Result

Hypothesis	Path	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics	P Value	Conclusion
H1	Personal Factor -> Work Demand	0.506	0.506	0.074	6.812	0.000	Accepted
H2	Work Demand -> Fatigue State	0.037	0.038	0.079	0.473	0.318	Rejected
H3	Work Schedule -> Fatigue State	0.443	0.435	0.074	6.015	0.000	Accepted
H4	Work Activities -> Fatigue State	0.391	0.400	0.076	5.130	0.000	Accepted
H5	Libing Condition -> Personal Factor -> Work Demand	0.061	0.063	0.031	1.970	0.024	Accepted

4.2. Discussion

The findings show a clear distinction between structural fatigue predictors (work schedules and work activities) and quantitative perceptions of workload. Personal factors prove to have a positive and significant association with job demands. This result is consistent with the view that self-development initiatives and psychological empowerment encourage individuals to take on additional responsibilities and engage in job crafting, which ultimately expands the perceived workload (Kar, 2021; Matsuo, 2019; Zhao, 2021). In an increasingly digitalized work context, digital competencies and technology-based work learning patterns can also increase performance expectations and enrich the spectrum of tasks undertaken, thus strengthening the personal factors-demands relationship (Kar, 2021; Zhao, 2021).

In line with the Job Demands-Resources model, good personal conditions, such as physical health, stress management, and energy availability, can help individuals manage job demands (Bakker & Demerouti, 2007). This means that operators who are able to maintain health, manage stress, and have sufficient energy will be able to face job demands without experiencing excessive fatigue. High workloads can be handled with good personal condition management, including adequate rest during working hours. However, the interaction between job demand and operator fatigue conditions does not show a significant relationship. In other words, high quantities of work or work that must be completed in a short time, although potentially causing stress, does not always directly affect operator fatigue levels (Lazarus & Folkman, 1984). This finding shows that the initial expectation that workload would directly cause fatigue is not proven and is even contradictory; the impact of stressors is more determined by individual coping strategies, for example through work time management or the ability to detach from work demands outside working hours (Dettmers, 2020; Skurak, 2021).

Conversely, the direct relationship between job demands and fatigue shows insignificant results. This means that when compared to other predictors in the model, perceived workload alone is not strong enough to explain the emergence of fatigue. There are two reasons that can explain this. First, the ability to manage time and have control over work schedules makes the impact of demands on fatigue manageable. Diary-based research shows that flexibility in managing time can prevent morning workload from turning into fatigue when starting work (Dettmers, 2020). Second, a person's ability to truly detach from work matters outside working hours also helps break the path to fatigue, even when job demands remain high. This is consistent with findings that the ability to 'detach' from work serves as a buffer in the relationship between work engagement and dual role conflict (Skurak, 2021). Thus, the absence of direct influence here more reflects the existence of a work ecosystem that provides space for control and detachment, rather than meaning that job demands play no role at all.

Unlike job demands, work time management proves to be much more influential on fatigue. Long work schedules, shifts that do not match the body's biological rhythms, or uncertainty in scheduling prove to increase the accumulation of fatigue. This is consistent with previous findings showing that uncertainty in work rhythms, especially in crisis situations, can accelerate the depletion of workers' psychological energy (Dima, 2021) and reduce the resilience of social workers in disaster fields (Alston, 2019). Additionally, changes in mobility patterns after the pandemic, such as denser commuting and traffic congestion during rush hours, make work duration feel longer than formal working hours, thereby worsening fatigue related to time factors (Christidis, 2021).

Furthermore, task quality and intensity are directly related to fatigue. Work activities show significant positive effects. This indicates that cognitive load due to multitasking, frequency of task-switching, and continuous attention demands become more proximal

fatigue generators compared to mere quantity of demands. Evidence during the VUCA pandemic period shows that diversity and complexity of activities increase the risk of strain and burnout (Dima, 2021), consistent with field work reports in emergency situations that pile up task intensity above daily norms (Alston, 2019).

Findings regarding the indirect pathway from living conditions provide additional insight into how fatigue mechanisms are formed. Although its influence on job demands through personal factors is relatively small, this result shows that the living environment plays an important role in preparing individual capacity to manage and interpret workload. Factors such as sleep quality, temperature comfort, and minimal disturbances in living spaces prove to affect executive function and working memory. Under uncomfortable thermal conditions, cognitive load increases sharply, as seen in research on personal protective equipment use, but this principle also applies more broadly in daily work contexts (Hancock, 2020). From a disaster ergonomics perspective, mismatch between situational demands and environmental support, including adequate recovery space, can create systemic friction that is ultimately translated through individual personal capacity (Sasangohar, 2020). Thus, living conditions can be understood as a background that shapes personal readiness and affects how job demands are perceived.

From a modeling perspective, the coefficient pattern suggests a fatigue architecture that is better understood as a combined function of structural-task factors (schedule, activities) and background conditions that resonate through personal resources, rather than a linear demand function. This also helps explain why the demand-fatigue pathway disappears when schedule and activities are present simultaneously: these two variables absorb the most proximal variance component to fatigue, while demands leave more distal and context-dependent components (Dettmers, 2020; Skurak, 2021). Findings related to living conditions add a subtle but consistent upstream route, namely personal habitat quality, personal capacity, perceived burden, aligned with situational ergonomics frameworks (Hancock, 2020; Sasangohar, 2020). In organizational ecosystems, prolonged stressor constellations if not buffered by personal and temporal resources correlate with strain symptoms that become precursors to weakened commitment and turnover intentions (Charman, 2022; Diaz, 2023), although these pathways are outside the endogenous variables currently modeled.

Overall, the results of this study show three important points. First, personal factors not only function as buffers, but actually become the main drivers in shaping how someone interprets and responds to job demands. This factor expands the scope of perceived task burden by affecting how individuals organize and take over responsibilities (Kar, 2021; Matsuo, 2019; Zhao, 2021). Second, fatigue levels are more sensitive to factors related to time and work activities, because both directly reduce recovery opportunities and increase cognitive pressure that workers must bear (Alston, 2019; Dima, 2021). Third, environmental or living conditions provide important contextual roles, because they can affect personal readiness and ultimately shape how job demands are perceived and felt (Hancock, 2020; Sasangohar, 2020). Research findings show that fatigue is more influenced by work schedules and work activities, while personal factors play a role in shaping how someone feels job demands. Conversely, job demands themselves do not directly cause fatigue. This shows that causes of fatigue are closer to direct things, such as task burden and work time management, while personal factors and environmental conditions function as backgrounds that affect how these demands are perceived and felt.

Conceptually, the results of this study show that work fatigue in the mining industry cannot be reduced to high workload alone. Temporal factors, activity characteristics, and interactions between personal and environmental conditions form more complex

configurations in explaining the emergence of fatigue. This finding is consistent with recent studies showing the ambiguous role of mining work, on one hand contributing economically and supporting development (Genetu, 2024; Peng, 2024), but on the other hand potentially causing significant psychosocial and ergonomic impacts on workers (Jiskani, 2020a, 2020b; Winifred, 2022). This ambiguity confirms that the mining industry is not only an arena for economic value creation, but also a space where risks to worker health and welfare continue to be reproduced (Černý, 2023; Di, 2022).

This discourse has important implications in the context of energy transition. As reminded by Weber (2020), environmental policies that pressure the coal sector need to be analogized with trade policies, namely continuing to accommodate the interests of affected workers. Garner (2023) even emphasizes the urgency of strengthening financial guarantees to mitigate risks that have often been transferred to workers. Thus, the contribution of this research not only expands theoretical understanding regarding determinants of work fatigue, but also presents empirical foundations for broader debates about energy transition justice and the future of the mining industry.

5. Conclusion

This study shows that personal factors significantly influence job demands, while work schedules and work activities prove to have direct effects on fatigue. Conversely, job demands are not directly related to fatigue, indicating that workload alone is not the main determinant of fatigue. Housing conditions serve as a moderating factor, where adequate living environments can reduce the impact of workload and support worker recovery. This finding confirms the novelty of the research by integrating work and living environment dimensions in fatigue analysis in the coal mining industry, which has rarely been studied before. The results emphasize that fatigue prevention cannot focus solely on work factors, but requires a multidimensional approach that also considers environmental conditions. This contribution provides new insights for future research and supports the development of more comprehensive fatigue management strategies in high-risk industries.

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