



## ANALYSIS OF THE EFFECT OF WORK SCHEDULE, WORK ACTIVITIES, AND PERSONAL FACTORS ON FATIGUE WITH WORK DEMAND AS A MEDIATOR AND LIVING CONDITIONS AS A MODERATOR IN HEAVY EQUIPMENT OPERATORS AT PT. PAMAPERSADA NUSANTARA

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### ABSTRACT

Work fatigue among heavy equipment operators in the mining industry is an important issue due to its impact on safety and productivity. Fatigue is influenced by work-related and individual factors, however, previous studies have generally remained partial in scope. This study aims to analyze the influence of work schedule, work activities, and personal factors on fatigue state among heavy equipment operators, with work demand as a mediator and living condition as a moderator. The method employed is a quantitative approach with a survey design involving 415 operators of PT Pamapersada Nusantara. Data were collected through questionnaires and analyzed using PLS-SEM. The results indicate that work schedule and work activities do not have a significant effect on fatigue state. In contrast, work demand has a significant effect on fatigue state. Personal factor has a significant effect on work demand, but does not directly affect fatigue state. Mediation analysis shows that work demand fully mediates the relationship between personal factor and fatigue state. Meanwhile, living condition does not have a significant effect either as a direct variable or as a moderator. In conclusion, operator fatigue is more influenced by the perception of work demands shaped by personal factors than by structural work factors. This study affirms the importance of managing work demand and enhancing individual capacity in controlling work fatigue.

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## INTRODUCTION

The coal mining sector plays a strategic role in supporting national economic growth and energy security (Awaliah & Sembiring, 2025; Suaidah et al., 2025). Operational activities in this industry involve long working hours, shift systems, and intensive use of heavy equipment, requiring high levels of physical and mental readiness from operators. However, fatigue among heavy equipment operators has become a critical issue, as it significantly reduces productivity and increases occupational accident risks (Al-Mekhlafi et al., 2021; Drews et al., 2020).

Fatigue is defined as a decline in physical, cognitive, and emotional capacity resulting from excessive workload, insufficient recovery time, and individual-related factors (Bauerle et al., 2018; E. Talebi et al., 2021). In mining environments characterized by extreme conditions, remote locations, and high job demands, fatigue risk becomes even more pronounced. Empirical evidence suggests that shift work particularly night shifts and extended 12-hour systems disrupts circadian rhythms and increases vulnerability to microsleep episodes, especially between 02:00–07:00 and 13:00–16:00 (Akerstedt, 2003; Folkard & Akerstedt, 2004).

At PT Pamapersada Nusantara (PAMA), fatigue incidents present significant safety and financial implications. Internal data (2016–2024) recorded 494 fatigue-related incidents, predominantly involving heavy equipment operators. A single fatigue-related accident involving a HD 785 haul truck may result in production losses of 3,465 BCM per day, equivalent to approximately IDR 142.9 million in daily revenue loss. If downtime extends to six days, losses may exceed IDR 857 million. These figures indicate that fatigue management is not only a safety concern but also a strategic business sustainability issue.

Despite the implementation of a Fatigue Management Program since 2016 strengthened by a Fatigue Management Knowledge System, electronic monitoring, shift evaluations, fit-to-work policies, and employee well-being initiatives fatigue incidents persist. Data analysis shows that younger operators (<30 years old) and those with less than one year of experience are more vulnerable. Furthermore, 61% of incidents occur under a two-shift 12-hour system, with 79% during night shifts, confirming the influence of circadian disruption.

Fatigue is influenced not only by work schedules but also by monotonous and high-concentration work activities (Bakker & Demerouti, 2007), as well as personal factors such as health condition, psychological stress, and sleep habits (E. Talebi et al., 2021). The Job Demands–Resources (JD-R) model explains that fatigue emerges when job demands exceed available recovery resources. Additionally, living conditions particularly in remote mining sites may moderate recovery quality and overall well-being (Friedman et al., 2014; Virtanen et al., 2019).

Previous studies in the mining sector tend to examine fatigue determinants in a partial manner, often focusing on direct relationships between limited variables without integrating mediating or moderating mechanisms. Research in the Indonesian mining context, particularly among heavy equipment operators, remains limited. Therefore, a research gap exists in developing a comprehensive model integrating work schedule, work activities, and personal factors, with work demand as a mediating variable and living condition as a moderating variable.

This study aims to address this gap by developing an integrated conceptual framework based on the Job Demands–Resources (JD-R) model, the Effort–Recovery Model, and the Demand–Control Model. By empirically examining heavy equipment operators at PT Pamapersada Nusantara, this research seeks to provide a more comprehensive understanding of fatigue mechanisms and contribute both theoretically and practically to fatigue risk management in the Indonesian mining industry.

This investigation is founded on the synthesis of several key theoretical perspectives within the domain of occupational fatigue research, specifically the Job Demands–Resources (JD-R) Model, the Demand–Control Model, and the Effort–Recovery Model. According to the JD-R framework established by Demerouti and Bakker, employee well-being and performance are shaped by the equilibrium between job demands and job resources, operating through two principal pathways: the health impairment process, wherein elevated job demands lead to fatigue, and the

motivational process, which is sustained by the presence of job resources. Within the framework of this research, elements such as work schedule, work activities, and personal factors are conceptualized as job demands that may contribute to increased fatigue, whereas living condition is regarded as a resource capable of alleviating such adverse effects.

To strengthen the analytical framework, this study also refers to the Demand-Control Model proposed by Karasek, which emphasizes that the combination of high job demands and low job control produces a high-strain job condition that increases the risk of stress and fatigue. This is relevant to the condition of heavy equipment operators in the mining industry who are faced with high production targets and strict operational procedures. In addition, the Effort-Recovery Model by Meijman and Mulder explains that continuous work effort depletes physical and mental resources, so that without adequate recovery it will cause an accumulation of fatigue that impacts performance decline and long-term health risks. This perspective is highly relevant in the context of remote mining with long shift work systems and limited recovery time.

Conceptually, fatigue is defined as a multidimensional condition that encompasses a decline in physical energy, cognitive alertness, and psychological motivation (Phillips, 2015). Fatigue is not only related to drowsiness, but also involves physiological, psychological, and behavioral aspects (Williamson et al., 2011), and can be either acute or chronic depending on work intensity and the adequacy of recovery (Akerstedt et al., 2004). In high-risk industries such as mining, fatigue contributes to reduced alertness, slowed reaction time, increased operational errors, and a heightened risk of work accidents.

Fatigue is influenced by various factors, including work schedule, work activities, personal factors, work demand, and living condition. Work schedules such as shift systems, long working hours, and night work are known to disrupt circadian rhythms and sleep quality, thereby increasing the risk of fatigue. Work activities that are monotonous, repetitive, and require high concentration, as well as exposure to extreme environmental conditions such as noise and vibration, further increase physical and mental load. Personal factors such as age, health condition, sleep quality, and psychological resilience also determine an individual's level of vulnerability to fatigue (Hadiyanto & Prasadjaningsih, 2025). Meanwhile, work demand reflects the physical, cognitive, and emotional pressure arising from production targets, time pressure, and operational responsibilities. On the other hand, living condition, particularly in remote mining areas, plays an important role in supporting the recovery process through the quality of accommodation, rest facilities, nutrition, and social support.

Drawing from the synthesis of these three theoretical frameworks, this research formulates a conceptual model that conceptualizes fatigue as an outcome of the interplay between occupational and individual factors, operating both directly and indirectly via mediating and moderating pathways. Within this proposed model, work schedule and work activities are hypothesized to exert a direct influence on fatigue, while personal factors are posited to shape the perception of work demand. Additionally, work demand is conceptualized as a mediating variable in the link between personal factors and fatigue, whereas living condition is expected to function as a moderator, either intensifying or mitigating the relationship between personal factors and work demand. Consequently, this study presents a holistic analytical framework for examining the complex dynamics of fatigue among heavy equipment operators within the mining sector, while also laying a robust theoretical groundwork for subsequent empirical validation using Structural Equation Modeling (SEM) or Partial Least Squares (PLS) techniques.

Work-related fatigue has been widely recognized as a primary contributor to occupational accidents in the mining industry. Empirical studies identify shift work, long working hours, and repetitive physical and cognitive activities as dominant fatigue determinants (Bauerle et al., 2018; Drews et al., 2020; E. Talebi et al., 2021). These factors lead to reduced productivity and increased safety incidents (Al-Mekhlafi et al., 2021).

At PT Pamapersada Nusantara (PAMA), one of Indonesia's largest mining contractors, fatigue represents a significant operational concern. Internal Fatigue Management Knowledge reports (2016–2024) recorded 494 fatigue-

related incidents, with the highest frequency occurring during Shift 2 (night shift). Internal investigations indicate that incidents are associated with extended work schedules, monotonous and high-concentration tasks, health-related issues, and poor sleep quality. In addition, environmental and residential factors such as accommodation quality, rest facilities, and distance from rest areas are frequently identified as contributing elements influencing operator fatigue.

Although these factors are empirically observed, the relationship between working conditions and fatigue is not always direct. Based on the Job Demands–Resources (JD-R) framework (Bakker & Demerouti, 2007), work demand may function as a mediating mechanism linking work schedule, work activities, and personal factors to fatigue. Production targets, time pressure, and physical and mental workload intensify perceived job demands, thereby accelerating fatigue accumulation. However, empirical evidence explaining this mediation mechanism remains limited, particularly in coal mining contexts characterized by high physical and cognitive demands (Goh et al., 2016; Williamson et al., 2011).

Furthermore, existing research often examines either job-related factors or individual factors separately, without incorporating living condition as a contextual variable that may influence recovery quality. In remote mining environments, inadequate accommodation, social isolation, extreme environmental exposure, and distance from family may impair physical and psychological recovery processes (Alcock et al., 2017; Hall et al., 2019). Empirical studies suggest that supportive living environments improve recovery and well-being (Friedman et al., 2014; Virtanen et al., 2019), yet mining research rarely positions living condition as a moderating variable (Talebi et al., 2021).

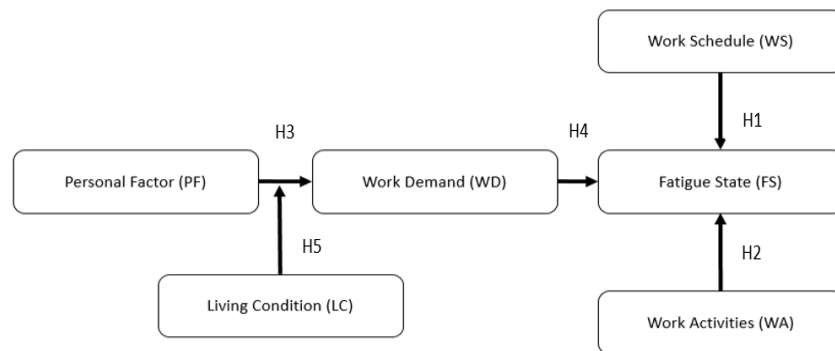
Research on work fatigue indicates that fatigue is a multidimensional phenomenon influenced by a combination of operational, individual, and environmental factors (E. Talebi et al., 2022), however, the majority of studies still analyze these variables partially and have not yet integrated them into a single comprehensive model. A study by Inayah et al. (2023) confirms that work schedule (work shifts) has a significant influence on the fatigue of heavy equipment operators, while other studies show that individual factors such as sleep quality and personal characteristics also contribute to fatigue (Hidayanti & Sumaryono, 2021; Maisey et al., 2021). In addition, work-related factors such as workload, work activities, and operational pressure have been proven to increase the risk of fatigue and workplace accidents in the mining sector (Duarte et al., 2021). Nevertheless, most previous studies have focused more on direct relationships between variables without considering indirect mechanisms, such as the role of work demand as a mediator, even though actual work demands represent the primary manifestation of work pressure in the mining industry (Prasetyaningtyas et al., 2025). On the other hand, environmental factors such as the living conditions of workers in remote mining areas have also begun to be identified as important determinants in fatigue recovery, yet they are rarely tested as a moderating variable in empirical models (Susilowati et al., 2013). Other research also highlights that fatigue among heavy equipment operators is associated with a combination of work and non-work factors such as the work environment, rest periods, and social conditions, but these have not yet been analyzed simultaneously within a single structural framework (Safitri & Susilowati, 2023). Furthermore, the majority of studies employ cross-sectional designs with simple analyses, and thus have not been able to capture the complex relationships among these variables. Therefore, a clear research gap exists in the development of a research model that integrates work schedule, work activities, and personal factors in relation to fatigue by incorporating work demand as a mediator and living conditions as a moderator, particularly among heavy equipment operators in the mining industry, which is characterized by high risk levels and unique working conditions.

In the Indonesian mining context, empirical studies integrating work schedule, work activities, personal factors, work demand, and living condition into a comprehensive analytical framework remain scarce. This gap limits the development of evidence-based fatigue management strategies tailored to operational realities in remote coal mining settings.

This study aims to explicitly examine the influence of work schedule, work activities, and personal factors on fatigue among heavy equipment operators. In addition, this study also investigates the mediating role of work demand

in explaining the relationship between these variables and fatigue, as well as the moderating role of living conditions in influencing the relationship between personal factors and work demand. Through the integration of these variables into a comprehensive analytical framework, this study seeks to provide a more robust empirical understanding of the mechanisms of fatigue in the mining industry.

In light of the identified issues and research gaps, the present study seeks to investigate the impact of work schedule, work activities, and personal factors on fatigue among heavy equipment operators, with particular attention to the mediating function of work demand and the moderating influence of living condition. More precisely, this research explores both the direct and indirect associations among variables within a cohesive analytical framework, aiming to achieve a deeper insight into the mechanisms underlying fatigue in isolated mining operational contexts. The findings are anticipated not only to advance theoretical understanding in the field of occupational fatigue research within the mining sector, but also to yield actionable policy recommendations for PT Pampersada Nusantara aimed at mitigating the incidence of work-related accidents stemming from fatigue.



**Figure 1. Theoretical Framework**

Source: Author's compilation

## METHODS

This study employs explanatory research with a quantitative approach to examine the causal relationships between work schedule, work activities, and personal factors on heavy equipment operator fatigue, with work demand as a mediating variable and living conditions as a moderating variable. The study was conducted on operators of PT Pampersada Nusantara (PAMA) selected using purposive and proportional quota sampling techniques, with a target sample of 400 respondents from a total population of 12,495 operators. The data used are primary data collected through an online questionnaire based on a five-point Likert scale, which had previously undergone a pre-test stage to ensure the clarity, relevance, and validity of the instrument. This investigation employs a cross-sectional design and was conducted from October to November 2025 across multiple mining operation sites in Indonesia. The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4 software, encompassing both the evaluation of the measurement model assessed through convergent validity, discriminant validity, and reliability and the structural model, which includes path coefficients,  $R^2$  values, and effect sizes. Hypotheses were tested via bootstrapping procedures to examine direct effects, indirect (mediation) effects, and interaction (moderation) effects. The analysis process was also preceded by data screening and descriptive analysis to ensure data quality and provide an initial overview of respondent characteristics. This approach enables the simultaneous testing of complex models and produces a comprehensive understanding of the factors influencing heavy equipment operator fatigue in the mining sector.

## RESULTS AND DISCUSSION

### Respondent Description

A total of 548 respondents participated in this study, consisting of 133 pre-test stage respondents and 415 valid respondents analyzed after the data cleaning process. The sample was selected purposively with the criterion that respondents must be heavy equipment operators with a minimum of one year of work experience. All respondents were male, with the majority falling within the productive age group, particularly the 19–24 age range. Most respondents held a senior high school or vocational high school (SMA/SMK) educational background and had work experience in the range of 1–5 years. In terms of occupational characteristics, respondents were predominantly in the TP position, working under a two-shift system, with the majority residing in company-provided dormitories. Overall, these characteristics indicate that the sample sufficiently represents the population, thereby supporting further analysis.

### Outer Model

#### Convergent Validity

As shown in Table 1, all constructs demonstrated AVE values ranging from 0.553 to 0.665. The highest AVE was observed for Living Condition (0.665), indicating that 66.5% of the variance in its indicators is explained by the construct. The lowest AVE was for Work Schedule (0.553), which still exceeds the minimum threshold, confirming adequate convergent validity.

**Table 1. Outer Loading Second-order Construct**

Variable	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Fatigue State	0.863	0.866	0.901	0.646
Living Condition	0.958	0.960	0.963	0.665
Personal Factor	0.879	0.882	0.906	0.580
Work Activities	0.739	0.746	0.835	0.560
Work Demand	0.913	0.915	0.928	0.590
Work Schedule	0.867	0.882	0.896	0.553

Source: SmartPLS Output, processed (2025)

#### Discriminant Validity

Discriminant validity was evaluated using the HTMT criterion. All construct pairs showed HTMT values below the conservative threshold of 0.90, indicating adequate distinction between constructs. The closest conceptual pair, Personal Factor and Work Demand, remained under 0.90. The interaction construct (Fatigue State × Work Schedule) had low correlations with other constructs (0.247), confirming no measurement overlap. Thus, discriminant validity of the second-order construct model is satisfied, supporting its suitability for inner model analysis.

**Table 2. Discriminant Validity (HTMT) Second-order Construct**

Variable	Fatigue State	Living Condition	Personal Factor	Work Activities	Work Demand	Work Schedule	Living Condition x Personal Factor
Fatigue State							
Living Condition	0.284						
Personal Factor	0.525	0.559					
Work Activities	0.502	0.306	0.750				
Work Demand	0.580	0.433	0.862	0.818			

Work Schedule	0.247	0.553	0.342	0.329	0.347	
Living Condition x Personal Factor	0.061	0.347	0.146	0.136	0.153	0.303

Source: SmartPLS Output, processed (2025)

These findings indicate that each construct in the model explains its own variables more effectively than other constructs. This confirms that discriminant validity is well-established, with no conceptual or measurement overlap between constructs.

**Construct Reliability**

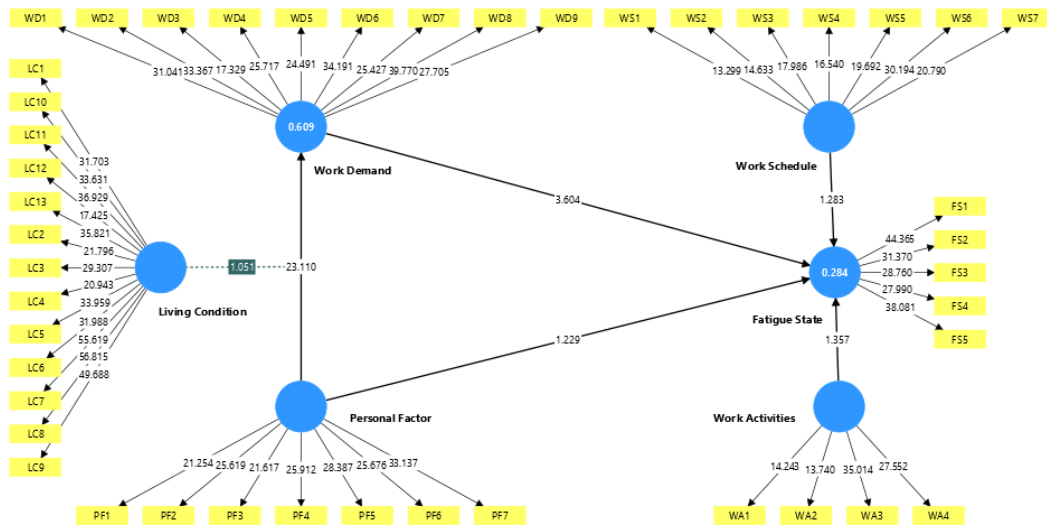
The reliability test for the second-order construct model (Table 3) indicates that all constructs meet the criteria for good reliability. Cronbach’s Alpha and Composite Reliability (CR) values exceed the minimum threshold of 0.70. The highest reliability is observed for Living Condition (CA = 0.958; CR = 0.963), followed by Work Demand (CA = 0.913; CR = 0.928) and Personal Factor (CA = 0.879; CR = 0.906). Work Activities has the lowest reliability, yet remains acceptable (CA = 0.739; CR = 0.835). All constructs also show Average Variance Extracted (AVE) values above 0.50, indicating adequate convergent validity. Overall, the second-order constructs are reliable and suitable for further structural model analysis, demonstrating strong internal consistency and measurement stability.

**Table 3. Construct Validity and Reliability Second-order Construct**

Variable	Cronbach’s alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Fatigue State	0.863	0.866	0.901	0.646
Living Condition	0.958	0.960	0.963	0.665
Personal Factor	0.879	0.882	0.906	0.580
Work Activities	0.739	0.746	0.835	0.560
Work Demand	0.913	0.915	0.928	0.590
Work Schedule	0.867	0.882	0.896	0.553

Source: SmartPLS Output, processed (2025)

**Path Coefficient Test Results**



**Figure 2. Path Analysis**

Source: SmartPLS Output, processed (2025)

Path coefficients for the main model (H1–H5) were obtained via SmartPLS bootstrapping (see Figure 2 and Table 4). Significance was evaluated using t-statistics and p-values at a 95% confidence level ( $p < 0.05$ ). A summary of the path coefficients is presented in Table 4.

**Table 4. Path Coefficient**

Variable	Original Sample (O)	Sample Mean (M)	STDEV	T Statistics	P Values
Living Condition -> Work Demand	-0.001	-0.003	0.044	0.017	0.987
Personal Factor -> Work Demand	0.038	0.043	0.037	1.051	0.293
Personal Factor -> Fatigue Stage	0.109	0.107	0.089	1.229	0.219
Personal Factor -> Work Demand	0.772	0.770	0.033	23.110	0.000
Work Activities -> Fatigue Stage	0.092	0.095	0.067	1.357	0.175
Work Demand -> Fatigue Stage	0.357	0.356	0.099	3.604	0.000
Work Schedule -> Fatigue Stage	-0.050	-0.058	0.039	1.283	0.200

Source: SmartPLS Output, processed (2025)

Table 4 shows that the strongest path was between Personal Factor and Work Demand ( $\beta = 0.772$ ,  $p = 0.000$ ), indicating that personal factors are the dominant determinant of perceived work demands. The path from Work Demand to Fatigue State was also significant ( $\beta = 0.428$ ,  $p = 0.000$ ), suggesting that higher perceived work demands increase fatigue levels. In contrast, the paths from Work Activities ( $p = 0.116$ ) and Work Schedule ( $p = 0.149$ ) to Fatigue State were not significant, indicating that these variables do not directly explain fatigue variation at the 95% confidence level. Similarly, Living Condition showed no significant direct effect on Work Demand ( $p = 0.959$ ) nor a moderating effect on the Personal Factor Work Demand relationship ( $p = 0.312$ ), implying that respondents' living conditions neither influence work demand formation nor strengthen or weaken the impact of personal factors in this model.

**Coefficient of Determination (R<sup>2</sup> and Adjusted R<sup>2</sup>)**

The assessment of the model was carried out by examining the R<sup>2</sup> and Adjusted R<sup>2</sup> values associated with the endogenous constructs. R<sup>2</sup> reflects the extent to which the variance in a dependent variable can be attributed to its predictor variables, whereas Adjusted R<sup>2</sup> adjusts for the number of predictors included, offering a more cautious and refined estimation. PLS-SEM results showed an R<sup>2</sup> of 0.609 for Work Demand (Adjusted R<sup>2</sup> = 0.606), meaning 60.9% of its variance is explained by Living Condition, Personal Factor, and their interaction, indicating strong explanatory power. In contrast, Fatigue State had an R<sup>2</sup> of 0.280 (Adjusted R<sup>2</sup> = 0.275), with 28.0% of variance explained by Work Demand, Work Activities, and Work Schedule. This moderate value reflects the complexity of fatigue as a psychophysiological response influenced by multiple external and internal factors. The difference highlights that Work Demand is more structurally predictable, whereas Fatigue State is multidimensional, resulting in lower explanatory power.

**Effect Size (f<sup>2</sup>)**

The substantive contribution of each predictor to the endogenous constructs was assessed using effect size (f<sup>2</sup>), indicating how R<sup>2</sup> changes if a predictor is removed. According to Cohen's criteria, f<sup>2</sup> values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively. Personal Factor had a very large effect on Work Demand (f<sup>2</sup> = 1.124), making it the dominant predictor, while Living Condition (f<sup>2</sup> = 0.000009) and its interaction with Personal Factor (f<sup>2</sup> = 0.004) had negligible contributions. For Fatigue State, Work Demand showed a small-to-medium effect

( $f^2 = 0.132$ ), whereas Work Activities ( $f^2 = 0.009$ ) and Work Schedule ( $f^2 = 0.004$ ) were minor predictors, consistent with non-significant path results.

#### **Predictive Relevance ( $Q^2_{\text{predict}}$ )**

PLSpredict analysis in SmartPLS 4 assessed the model's out-of-sample predictive relevance using  $Q^2_{\text{predict}}$ . Values for Work Demand ( $Q^2_{\text{predict}} = 0.596$ ) and Fatigue State ( $Q^2_{\text{predict}} = 0.220$ ) were both above zero, indicating good predictive relevance. Higher predictive power for Work Demand aligns with its stronger explanatory power ( $R^2$ ), whereas Fatigue State, being more complex, is less predictable. Comparison with a Linear Model benchmark confirmed the competitive predictive performance of PLS-SEM, particularly for harder-to-predict Fatigue State indicators.

## **DISCUSSION**

The results of this study indicate that Fatigue State in heavy equipment operators is predominantly influenced by Work Demand, which in this context serves as the primary mechanism linking various causative factors to fatigue. This finding is consistent with the Job Demands–Resources (JD-R) framework, which emphasizes that job demands are the primary determinant of the emergence of fatigue and performance decline, particularly when those demands exceed the individual's capacity to cope with them (Bakker & Demerouti, 2007, 2017; Demerouti et al., 2001). In the context of mining operations, high work demand can stem from production targets, time pressure, and task complexity requiring high concentration and physical endurance, which has been empirically proven to correlate strongly with operator fatigue (E. Talebi et al., 2021; Zhao et al., 2022). These findings suggest that operator fatigue is not solely caused by objective work characteristics, but is more significantly influenced by the accumulation of continuously perceived work pressure. Such conditions can lead to a gradual decline in cognitive and physical capacity, thereby accelerating the onset of fatigue in operational activities.

The non-significant direct effect of Work Schedule and Work Activities on fatigue indicates that in a standardized work environment, the variability of both factors becomes relatively low, so their contribution to fatigue is not dominant. This can be explained by operational practices in the mining industry, which have generally implemented structured shift systems, standard operating procedures, and strict operational controls. Previous studies have indeed shown that work shifts and long working hours have the potential to increase fatigue (Akerstedt, 2003; Arlinghaus et al., 2022; Caruso, 2014), however in conditions where such systems have been well optimized and controlled, their impact can be minimized. In other words, work schedule and work activity factors serve more as baseline conditions rather than as the primary determinants of fatigue variation in a homogeneous population. This finding is also consistent with research in the mining sector showing that operational standards and fatigue risk management are capable of reducing the variability of shift impacts on fatigue (Bauerle et al., 2021; Drews et al., 2020). These results are indeed consistent with several studies indicating that a standardized work system is capable of reducing the variability of shift impacts on fatigue. However, these findings also differ from previous studies that assert work schedule and work duration have a significant influence on fatigue. This discrepancy is likely attributable to the higher level of operational standardization and the more optimal implementation of fatigue risk management within the context of this study.

In contrast, Personal Factor emerges as the strongest predictor of Work Demand, indicating that the perception of work demands is largely determined by individual capacity, both physically, psychologically, and in terms of recovery ability. This is consistent with the work psychology perspective stating that workload is subjective and influenced by the interaction between task demands and individual resources (Karasek, 1979; Meijman & Mulder, 1998). Individuals with suboptimal physical condition, poor sleep quality, or low coping capacity tend to perceive work as more burdensome, thereby increasing the perceived work demand (Pramesti & Ernawati, 2025). Previous

research has also confirmed that individual factors such as sleep quality, health condition, and age are important predictors of fatigue in mine operators (Dawson & McCulloch, 2005; K. Talebi et al., 2022). Furthermore, insufficient recovery after work can lead to the accumulation of chronic fatigue, which further reinforces the perception of high work demands (Geurts & Sonnentag, 2006; Sonnentag & Fritz, 2007). This indicates that the perception of workload is highly subjective and is influenced by an individual's capacity to cope with work demands. Consequently, individuals with suboptimal physical and psychological conditions tend to experience an elevated perception of workload, which ultimately increases the risk of fatigue.

The mediation analysis in this study provides an important theoretical contribution by demonstrating that Work Demand fully mediates the relationship between Personal Factor and Fatigue State. This means that individual characteristics do not directly cause fatigue, but operate through an increase in the perception of work demands. This mechanism is consistent with the JD-R model, which positions job demands as the primary pathway to fatigue, while personal resources influence how individuals respond to those demands (Bakker et al., 2014; Schaufeli & Taris, 2014). This finding is also supported by empirical research showing that the effects of individual factors on fatigue are often indirect, operating through workload or job strain (De Croon et al., 2004). Consequently, interventions that focus solely on the individual without managing work demand are potentially less effective in reducing fatigue. These findings confirm that the mechanism underlying the occurrence of fatigue is indirect, whereby individual factors first influence the perception of work demands before ultimately having an impact on fatigue. In other words, work demand serves as the primary pathway through which the influence of individual factors is transmitted to fatigue.

Meanwhile, Living Condition shows no significant effect either directly on work demand or as a moderator. This indicates that in the research context, living conditions are relatively homogeneous or have been well facilitated by the company, so they do not constitute a significant differentiating factor. Although the literature shows that living conditions in remote mining areas can affect sleep quality, recovery, and work stress (Alcock et al., 2017; Ferguson et al., 2025; Hall et al., 2019), the impact is highly dependent on the variation in those conditions. When accommodation facilities, lifestyle patterns, and the social environment are relatively uniform, the contribution of living condition to fatigue becomes minimal compared to operational and individual factors. This also reinforces the argument that work-related factors tend to have a more direct and stronger influence on fatigue than external non-work factors (García-Herrero et al., 2021). Nevertheless, these results differ from several studies that found living conditions to have an influence on rest quality and fatigue levels. This discrepancy is likely attributable to the homogeneity of facilities and living environments in this study, resulting in relatively small and insignificant variation in their effects.

Theoretically, this study contributes to strengthening and extending the Job Demands–Resources (JD-R) framework. The findings indicate that work demand serves as the primary mechanism bridging the influence of various factors on fatigue, even acting as a full mediator between personal factors and fatigue. These findings clarify that in the context of highly standardized industries such as mining, objective job characteristics become less dominant, while the perception of work demands becomes the key factor in explaining the occurrence of fatigue. Accordingly, this study not only confirms the relevance of the JD-R model, but also enriches the understanding of the central role of work demand as the primary pathway in the formation of fatigue.

Overall, the results of this study reinforce the validity of the JD-R model in explaining the mechanism of fatigue occurrence in heavy equipment operators, particularly in the context of the mining industry. Fatigue is not solely determined by the objective characteristics of the job, but by how those demands are perceived and internalized by the individual. Therefore, fatigue control strategies need to focus on two main aspects, namely: (1) work demand management through a more balanced distribution of workload, adjustment of production targets, and adequate operational support; and (2) strengthening personal resources through improvements in sleep quality, fitness programs, stress management, and work placement based on individual capacity. This approach is consistent with modern fatigue

risk management practices that emphasize the integration of organizational and individual factors in reducing the risk of fatigue and work accidents (Dawson et al., 2012; Phillips, 2015; Williamson et al., 2011).

## CONCLUSION

This study analyzes the influence of Personal Factor, Work Schedule, and Work Activities on Fatigue State with Work Demand as a mediating variable and Living Condition as a moderating variable among heavy equipment operators at PT Pamapersada Nusantara. The findings indicate that Work Demand is the primary factor influencing Fatigue State. Personal Factor is proven to have a significant effect on Work Demand, meaning that an individual's physical capacity, psychological readiness, and recovery quality determine the level of work demands perceived. In contrast, Work Schedule and Work Activities do not have a significant direct effect on Fatigue State. Mediation analysis reveals that Work Demand fully mediates the relationship between Personal Factor and Fatigue State. Meanwhile, Living Condition is not proven to serve as a moderator nor to have a direct influence, indicating low variation in respondents' living conditions.

In practical terms, these findings emphasize that the management of operator fatigue needs to be focused on controlling Work Demand and strengthening Personal Factor. Companies are advised to integrate the measurement of workload perception into occupational safety management systems, not solely based on objective aspects such as working hours. In addition, enhancing the physical capacity and mental readiness of operators should be carried out through structured training programs. Interventions also need to be directed at regulating the distribution of workload and operational targets to ensure they remain aligned with individual capacity. Although not significant, the quality of Living Condition still needs to be maintained to support the recovery process and the overall well-being of operators.

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