EXPLORING FATIGUE MANAGEMENT OF HAUL TRUCK DRIVERS THROUGH A SOCIO-TECHNICAL PERSPECTIVE

by

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ABSTRACT

Fatigue management is becoming a more widely studied subject due to increased consideration of the "fitness for duty" of equipment operators at mines. This research aims to understand fatigue awareness, fatigue characteristics among haulage truck drivers in mines, the action taken against fatigue, and the social acceptance of fatigue monitoring technology. Multiple research studies account for the "tangible" factor of fatigue (e.g., cost, operation, or profitability). However, the "intangible" factors (e.g., culture, experience, or social acceptance) are under-researched. For the present study, a survey was developed that aligned with the results of focus groups; it was distributed to operators in four mine sites. The data received in response to the survey are analyzed through three dimensions: mine sites, job experience, and overall driving experience. A simple Analysis of Variance test (ANOVA) is performed, and the initial analysis shows an interaction between the dimensions and the responses. Through this research, we can understand fatigue monitoring (from the perspective of operators) and awareness. This can lead to a better understanding of fatigue management.

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CHAPTER 1

INTRODUCTION

Fatigue is a multifaceted issue; it has many origins and many repercussions for haul truck drivers (HTDs). It arises from an accumulation of outside-of-truck and inside-of-truck factors that combine to determine an HTD's "fitness for duty" and contribute to fatal accidents and injuries. For this reason, there is a need to investigate the impact and consequences of fatigue and fatigue management.

1.1 Problem Statement

Increasingly, mining companies worldwide are placing a higher value on fitness for duty. The term "fitness for duty" is defined as whether the worker has sufficient capacity before beginning to work. It takes into account sleep habits, intrusive monitoring of brain activation, and changes in muscle activation (Sedighi Maman et al., 2017). To have sufficient capacity, the worker must have enough rest for the work shift. There is a notable difference between sleepiness and fatigue. Sleepiness comes from the neurobiological need that induces an individual to sleep. Sleepiness accumulates as prolonged sleep debt increases. Fatigue is impairment in task performance and includes the psychological aspect of reluctance to continue a task. It is not limited to the need for immediate sleep (Yazdi and Sadeghniiat-Haghighi, 2015). Worker's fatigue is a new problem in the industry due to high demand, more extended shift periods, disruption of circadian rhythms, and accumulation of sleep debt. Fatigue affects HTDs regardless of their abilities. Haul truck driving has prolonged shift work and task performance that requires constant attention and concentration. Therefore, it is fitting to study fatigue management and how fatigue affects HTDs and their fitness for duty.

1.2 Research Objective

This research aims to understand fatigue awareness, characteristics of fatigue among HTDs, actions that have been taken against fatigue, and the social acceptance of technology that has been integrated to monitor fatigue. It examines the attitude of the mining workforce toward fatigue monitoring technologies and some of the reasons they accept or resist the technology.

We study the psychological, physiological, cognitive, and behavioral impacts of fatigue among HTDs, using a literature review and results from a survey. This survey was developed from focus groups. We then examine the attitude of the mining workforce toward fatigue monitoring technologies to explore human-factor engineering. We use these findings to understand why fatigue happens in the first place and how it affects HTDs during their shifts. Most importantly, we want to understand HTDs' fitness for duty.

In summary, these are the three areas that we want to focus on as our research objectives:

1. Improved understanding of perception and awareness of fatigue
2. Competent action against fatigue
3. Social acceptance of fatigue monitoring system

We believe that increasing our understanding of HTDs' personal and organizational fatigue management could lead to a better understanding of fatigue management in general, and of the "fitness for duty" of HTDs.

1.3 Background

Long-distance driving requires significant concentration and awareness. This can lead to drivers' fatigue. Fatigue impairs alertness, driving performance, and human efficiency. Such impairment can lead to accidents, equipment damage, loss of workdays, and loss of productivity (Patel et al., 2011). HTDs in mine sites struggle with identical situations and experiences. Since fatigued driving can contribute to mine accidents, we want to examine fatigue's contributing factors and consequences (T. Bauerle et al., 2018). We therefore need a better understanding of the "fitness for duty" of HTDs.

A typical shift cycle for HTD can be separated into two cycles: HTD out-of-the-truck time and HTD in-the-truck or working time. Figure 1.1 shows the interaction between the two cycles. The right-hand cycle (the yellow circle) is the work time cycle, and it comprises two sections: productive truck time and unproductive truck time. The productive truck time is when the HTD is in the haul truck, loading, hauling, and dumping materials. Fatigue is commonly monitored through technologies that deliver data to a central communication system or dispatch. These data could also be recorded and stored for research. The unproductive truck time is when the haul truck is not loading, hauling, or dumping material. It includes the down assignment of the haul truck, waiting, and exchanging of HTD. The left cycle (the light green circle) is the HTD's out-of-the-truck time cycle, including unproductive events and personal time. Usually, no fatigue events are recorded during the exchanges and personal time. However, some companies are using wellness programs to track sleep.

Generally, the cycle starts from personal time as the HTD arrives at the site. The HTD clocks in, lines up for the haul truck schedule, and prepares for transportation to the assigned haul truck. While the haul truck is waiting for the driver exchange, the haul truck is at down assignment (unproductive time). The HTD time cycle interacts with the working time cycle during the exchange of drivers. The haul truck is back to productive time once the HTD is seated and on the road; however, this does not include the HTD's lunch, fatigue, or bathroom breaks. When the shift ends, the driver is exchanged and transported back to the main area where the HTD clocks out. The HTD returns home, and the cycle starts again.

During the productive time, fatigue is monitored and reported by technologies or by HTDs' self-evaluations. We know, generally, when HTDs feel tired during their shift. Comparatively, the personal time is the opposite; we know very little of the lives of HTDs because of their differences. We wanted to understand how HTDs prepare for their shift, which directly affects their "fitness for duty." Therefore, personal time is significant for understanding how to manage HTD fatigue.

This research also studies the socio-technical acceptance by HTDs of fatigue and monitoring systems. Fatigue has a narrow interpretation as an unwanted by-product of work, both physical and mental. Work exhaustion is natural when humans interact with machines (Hockey, 2011). The negative associations of fatigue and energy depletion have led drivers to think that fatigue is "taboo" as vocabulary in the workplace. Filtness and Naweed led a focus group discussion among train drivers in Australia. They analyzed and identified fatigue's causes, consequences, and countermeasures. Participants expressed feeling stressed about the word “fatigue.” It was seen as taboo, and “a highly reactive organizational culture of fear had developed around [it].” The drivers were afraid to report a fatigue episode to managers. They most feared the mandatory medical assessment; it was perceived as a threat to their job security. The drivers would not talk about sleeping disorders as a reason for their fatigue.

Most importantly, they were willing to report that they dozed off to the investigator. The author suggested there was a “culture of not wanting to be seen as fatigued” and that not “mentioning the word for fear of its implication is a concern as it would likely lead to drivers not reporting genuine problems” (Filtness and Naweed, 2017). The negativity around fatigue could lead to a lack of support for, or willingness to adapt to, a fatigue monitoring system (FMS). With the growing use of FMSs, our research group is adamant about the acceptance of the FMS and its usefulness from the HTD perspective. We conducted focus groups to increase our understanding of FMSs in a closed-door, comfortable setting where HTDs could express their attitude toward FMSs. We also devised an anonymous survey on fatigue management and current FMS ratings. We wanted to avoid negative feelings toward fatigue or fear of punishment for speaking about fatigue.

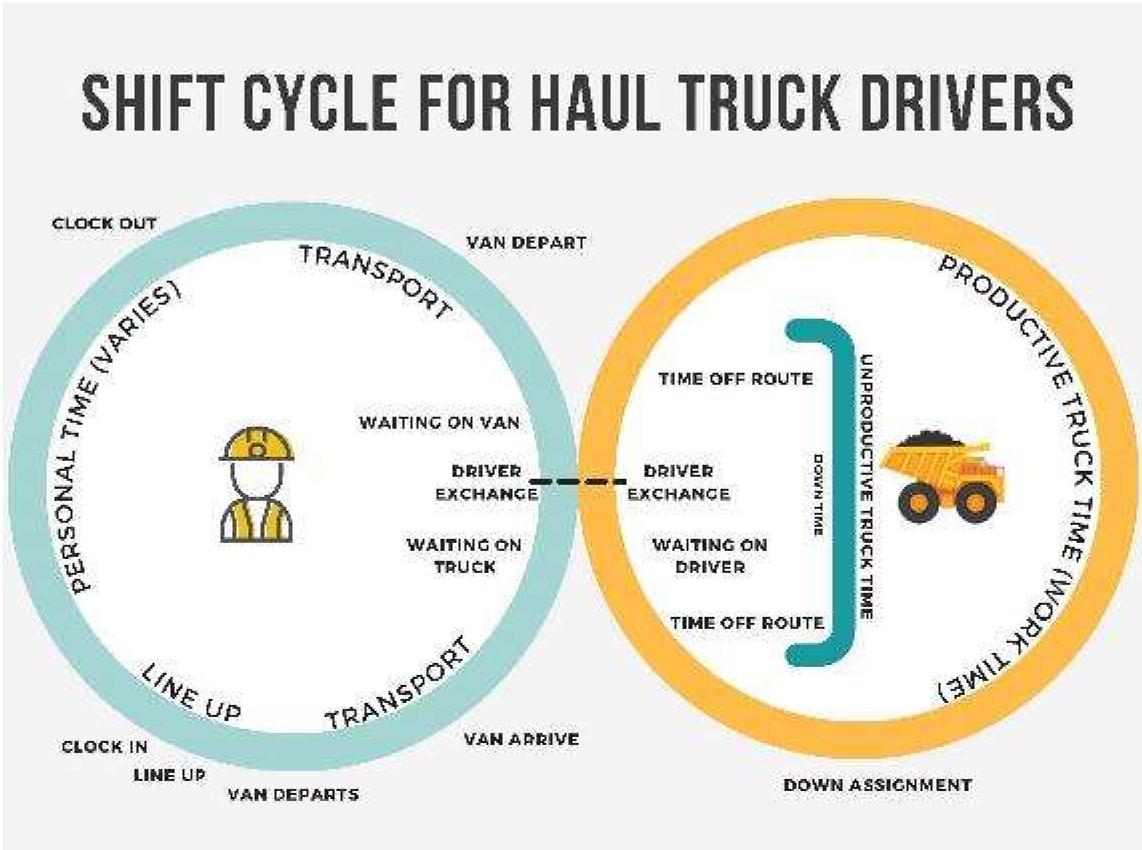

Figure 1.1 Shift cycle for haul truck drivers. Adapted by Freeport-McMoRan (2018).

CHAPTER 2

LITERATURE REVIEW

Fatigue management is becoming more widely studied due to increased consideration of equipment operators' "fitness for duty" at mines. However, there is limited research on fatigue management and monitoring systems in mining. This can be attributed partly to barriers between the manufacturers and the workforce. While mining suppliers and equipment manufacturers are at the forefront of innovations that improve the framework of mining—such as developing technological solutions, samples, and reports for mining companies—groups such as the workforce are underrepresented. These workers are users of the technology, so naturally, they are the best consultants on how the technology works (Gruenhagen and Parker, 2020). In this study, we wanted to understand how the workers perceive these fatigue monitoring technologies, and what their level of acceptance of them is. First, it is necessary to understand the basics of these monitoring systems. Sedighi Maman et al. (2017) explained that fatigue monitoring measurements "can capture *what* happened (through statistics and traditional surveillance) and a general overview of *how* it happened (video and observational data). The *why* it happened remains unclear" (Sedighi Maman et al., 2017). This literature review aims to answer *why* fatigue happens and explore the human factor, considering the social acceptance of the FMS.

The literature review is divided into six subsections. First, we address some health and safety management indicators and theories implemented in the mining industry, focusing on fatigue. A background understanding of fatigue, its contributing factors, and its impact and consequences are necessary to answer why fatigue episodes happen. The following section discusses the models of fatigue management. The last section discusses human factors and the social acceptance of fatigue management and monitoring systems.

2.1 Mining Health and Safety Management Systems

The mining industry is complex, and has many safety and health risks. It accounts for 8% of fatalities, with accidents continuing to occur at mine sites around the world (Tetzlaff et al., 2021). Mining companies implement occupational health and safety management system (HSMS) standards and comply with many health and safety regulations to reduce work-related fatalities and increase efficiency in achieving business goals (Haas and Yorio, 2016). HSMSs control risk and limit the hazard exposure of the workforce and capital assets. They are used with varying levels of success by companies around the world. HSMSs are used to prevent, investigate, and learn about incidents in a systematic way. Various HSMS methods are used to investigate and analyze accidents in the mines. One of the goals of HSMS investigation is to establish the origin and causation of each incident to prevent a reoccurrence (Chen and Zorigt, 2013; Tetzlaff et al., 2021). Robson et al. (2007) performed a systematic literature review on the effectiveness of HSMS as it is commonly understood. They found limitations across studies, a lack of consistency in HSMS techniques, and potential underreporting biases. First, HSMS measurement used within health and safety literature may employ different definitions. For example, injuries and illnesses require different types of measurement for accurate reporting in HSMSs. Second, the occupational standards given worldwide vary according to setting. These differences continue to make standards challenging to establish. HSMS standards remain highly complicated and difficult to homogenize (Yorio et al., 2015).

In a general sense, HSMSs take on multilevel and strategic management theories; for example, a top-down construct of organization. An HSMS is seen as a comprehensive system achieving occupational health and safety objectives (Makin and Winder, 2008; Yorio et al., 2015). These ideas are mentioned in the ANSI/AIHA Z-10:2005 HSMS consensus standards. ANSI (American National Standard Institute) approved the ANSI/AIHA Z-10:2005 standards for consensus on safety and health management systems. The ANSI Accredited Standards Committee (ASC) approved the AIHA (American Industrial Hygiene Association) (Fred A. Manuele, 2006). These standards cover top-management leadership and employee participation, planning, implementation and operation, evaluation and corrective action, and management review. These elements have the same objective of preventing occupational injuries and illnesses. For example, accident investigations require employee participation and an accountability system with correction (Yorio et al., 2015). Makin and Winder (2008) proposed that the building blocks of an HSMS should incorporate a "safe place," "safe people," and a "safe system." A safe place should eradicate hazardous substances, distractions, noise disturbances, and electrical hazards through proper maintenance and housekeeping. Safe people are workers that receive appropriate training and appropriate risk management through surveillance and appraisals. Finally, a safe system provides regular feedback and communication within a culture of trust, respect, and transparency for continuous improvement.

Besides the safe place, people, and system, Haas and Yorio (2016) identified safe practices to embed in HSMSs. These include several indicators of frameworks: proactive/reactive indicators, proactive activities, and outcomes. Proactive/reactive indicators can be separated into predictive and monitoring indicators that give information about activities. Predictive proactive are indicators that supply information that can reduce risk in the workplace. Monitoring proactive are indicators that observe variables before incidents occur, such as near misses, hazardous substances, safety inspections, safety audits and attitudes, and behavioral observation. An organization's activities, such as management goals or training, are proactive activities. The proactive outcome is the personnel knowledge that focuses on the result rather than the activities. These frameworks are applicable in the mining industry. From the fatigue management perspective, the indicators yield information about HTDs during their shifts. For example, FMSs fall under monitoring proactive. They provide physiological response observation when the HTD is fatigued, and alarm the dispatch and the driver before an accident occurs. These observations can also be analyzed and studied; they become a proactive outcome driving the proactive activities of tailoring fatigue management to HTDs' needs.

The terms lagging and leading have been adopted to identify and describe the types of indicators. A lagging indicator is information related to an incident; for example, injuries, illnesses, or property loss. Leading indicators are things such as proactive planning and checking of the management system cycle, or management of the organizational circumstances associated with health and safety (Haas and Yorio, 2016). Haas and Yorio (2016) also suggest that the most influential leading/lagging framework is established by determining the rank order of the magnitude leading indicator with correlation to the identified lagging indicator. However, the authors argue that the linkage is time-lagged and complex. It is difficult to make a strategic decision with an HSMS, and such a decision might take time to actualize. Second, the leading/lagging classification of indicators cannot capture the full complexity of HSMSs. For example, a lagging indicator usually influences the leading indicator. Both indicators articulate each other, which could cause confusion and inappropriate interpretations.

On the other hand, the authors suggest that an HSMS should comprise numerous interactions of management and leadership; organizational values should be unified within an HSMS. Organizational leadership plays a vital role in implementing an HSMS and avoiding inconsistencies. Yorio et al. (2015) developed a conceptual model (shown in Figure 2.1) to illustrate how leadership can strategically articulate and communicate within HSMS implementation. The organizational leadership values should be implemented in the HSMS as a normative cultural attribute. These attributes are understood by the work group leadership and should be reflected in the overall organizational values. The workers' perception and interpretation of the HSMS comes from their work group’s leadership and organizational values, and this can influence how they act during their work shift. If the HSMS is articulated in a way that impresses the workers, the safety policies, practices, and procedures are attentively enacted. Thus, the outcome of the HSMS will be a decrease in injuries, incidents, and illnesses.

As reflected in the HSMS conceptional model, leadership is fundamental to successful HSMS. Yorio et al., (2015) point out that leadership contingency is another characteristic that influences HSMS implementation. As shown in Figure 2.1, workers’ perception of an HSMS is shaped by the unique work group leader who is in place. For example, when a group leader assumes their role, the workers will look to them for cues on how to interpret the HSMS. Therefore, leadership should fully understand the importance of HSMS and ensure that their interpretations are unified in policies, practices, and procedures.

Addressing the need for unified policies, practices, and procedures, the US National Mining Association's Health and Safety Management System (CORESafety) designed a 20-element specific management practice for the mining industry. The CORESafety handbook was developed by mine safety professionals specifically for US mining and is consistent with the ANSI/AIHA Z-10 and OHSAS 18001 standards. It is designed to accommodate each company's unique operation and HSMS. Table 2.1 is the designed HSMS framework with its elements (CORESafety: Handbook | CORESafety, n.d.). The table is separated into five framework sections: plan, do (action), checking and corrective action, management review, and health and safety commitment.

The elements listed adjacent to the framework are the action plan that corresponds to the framework. The CORESafety was recently developed in collaboration with mining stakeholders throughout the US (Haas and Yorio, 2016). The elements suggest actions for the framework and could be applied to fatigue management. For example, a fatigue prevention plan helps reduce fatalities and injuries. The action plan could include training and communication, health and behavior optimization, and engineering methods. These plans of action could be checked by incident reporting and investigation. An HSMS could enable a review of corrective actions. It could then develop commitment and promote responsibility and accountability. We must understand how and why fatigue happens to develop a more elaborate HSMS framework and elements. In doing so, we can find the "fit" of fatigue management with a specific framework.

2.2 General Background on Fatigue

Fatigue is the response of the body to the "depletion of resources required to handle the immediate task at hand" (T. Bauerle et al., 2018). For haul truck drivers in mines, work shifts are generally 10 to 12 hours per shift. During this period, they must remain alert and avoid drowsy driving. Unlike transportation, mine haul truck driving includes complexity levels and fatigue mechanisms (Butlewski et al., 2015). Fatigue mechanisms include:

- Circadian rhythm
- Quality of rest
- Operational analysis of work cycle: monotonous driving
- Movement of vehicles and machinery

These mechanisms play a crucial role in operators' fatigue. The circadian rhythm prevents them from staying awake during night shifts. The quality of rest affects how tired they will be the next day. The monotonous driving leads to physical fatigue. The movement and vibration of the vehicle also increase operator fatigue. Finally, the mining environment is described as "…dim lighting, limited visual acuity, hot temperatures, loud noise, highly repetitive, sustained, …shift work, long work hours, early morning awakenings, and generally poor sleeping habits" (T. Bauerle et al., 2018). All of these mechanisms and characteristics make the mining industry unique (Drews et al., 2020). While there are several similarities between mine haul truck driving and long-distance truck driving, some aspects set them apart. For example, mine haul trucks move at a much lower speed and use the same route day and night. Thus, the operators are exposed to a high level of environmental monotony. Distance truck drivers, however, have a variety of environments, surroundings, and speeds (Drews et al., 2020). In summary, fatigue mechanisms play a crucial role in HTD fatigue management. We also sought to study other external contributing factors to fatigue.

2.3 Contributing Factors of Fatigue

Although fatigue is a widely studied topic because of its complexity and ambiguity, the involvement of different contributing factors makes it hard to control and analyze fatigue. Individual HTDs have different lifestyles, family situations, and socioeconomic factors contributing to fatigue; personalized fatigue management is complex. However, we can attempt to understand the contributors to fatigue to prevent it. Di Milia et al. (2011) compare the endogenous (internal) and exogenous (external) factors that impact the human body. Figure 2.2 shows endogenous and exogenous variables linked to fatigue (di Milia et al., 2011). We will explore each classification starting with endogenous.

Endogenous variables are contributing factors in bodily responses to fatigue. For example, the circadian rhythm, or our biological clock, is how our body regulates physical, behavioral, and mental changes during a twenty-four-hour period. Folkard (2008) reviewed workers' circadian adjustment to permanent night shifts by studying melatonin secretion. Melatonin is a hormone released by the pineal gland during the nighttime; it controls the sleep-wake or circadian cycles (Folkard, 2008). There is a generalization that maximizing circadian adjustment requires "permanent" or "fixed" night shifts. In contrast, a study by Folkard (2008) shows that only a tiny minority (<3%) of permanent night-shift workers show evidence of "complete" adjustment of their endogenous melatonin rhythm. Less than a quarter (21.1%) of permanent night-shift workers show evidence of adjustment substantial enough to derive any real benefit (Folkard, 2008). Few of them exhibit a "complete" adjustment for a whole night of work. There is a greater risk of falling asleep between 2 am and 6 am, which coincides with the standard circadian rhythm (di Milia et al., 2011). Legault et al. (2017) found a decline in cognitive performance during the night shift and the drive home. Legault suggested that operators' ability to adapt to changes in biological rhythm had decreased while working the night shift, and this could lead to circumstances where personal safety is compromised. Operator race and ethnicity are under-researched endogenous variables, and no differences have been found or characterized. Di Milia et al. (2011) also found that females appear more likely to "complain" of fatigue than males; they are more prone to recognize and acknowledge fatigue. The study also shows that females may experience more stress from their domestic burdens and social lives.

Exogenous variables contribute to fatigue "outside" of the body, such as medication, social status, family, shift schedule, and commute time. The various exogenous variables differ for each mine site and individual operator.

Some locations of mine sites are inaccessible and "out-of-the-way." Longer commute time increases the risk of falling asleep behind the wheel. Sometimes, the end of the shift coincides with the circadian clock (di Milia et al., 2011). For example, the HTD drives home between 2 a.m. and 6 a.m. This period within the circadian rhythm creates an even greater risk of falling asleep. A commute of one hour drastically extends the total amount of time to a 12-hour shift; this limits the remaining time for family, social, and personal events. Gradually, longer commute times disrupt sleeping time. When a commute time is greater than 35 minutes and is combined with less than 6 hours of sleep, this increases the driver's sleepiness (di Milia et al., 2011). The study by di Milia et al. (2011) found that long-distance drivers with these criteria have more extended periods of eye closure and increased accident frequency.

McCartt et al. (2000) identified six other endogenous variables that predicted fatigue during long-distance driving. These six variables were the hypothesized predictor variables for long-distance truck drivers (McCartt et al., 2000).

- High daytime sleepiness level
- Demanding work schedule (long working hours)
- Inadequate sleep
- Sleep disorder
- More experience
- Older age

The issue is that many of these variables can be both endogenous and exogenous factors. In the case of high daytime sleepiness and inadequate sleep levels, for example, the HTD could be a night person (endogenous) or their sleepiness could be a consequence of balancing life's activities (exogenous). The HTD does not control the work schedule; that is an exogenous variable. A sleep disorder could affect the HTD's quality of sleep before the shift, which could directly influence the HTD's work performance. An HTD with more experience has been driving more; therefore, they have had more encounters with the night shift. Thus, their body might experience more inadequate sleep and fatigue. Old age is an endogenous variable; a younger physical body might have more tolerance than an older physical body (di Milia et al., 2011). The following subsections discuss other endogenous and exogenous factors impacting HTDs' fatigue.

2.3.1 Personality Factors

Personality traits such as being a morning or a night person also contribute to fatigue levels at any given time. Di Milia et al. (2011) looked in depth at the difference between the two preferences. Morning people experience fatigue in the late afternoon and evening; they like the morning and feel well-rested from retiring early and rising early (di Milia and Bohle, 2009). These people generally show conscientiousness, high anxiety, high impulsivity, and greater life satisfaction. Night people grow more alert as the day and night evolve and retire to bed several hours later than a morning person. They show irregular sleep patterns, shorter sleep duration, and poorer chronotypes. These people tend to show extroverted behavior, lower self-control, procrastination, subclinical manic-type symptoms, and melancholy mood (Cavallera B et al., 2014). Of course, these are suggestive personality traits for morning or night people; the preference for morning or night is not causative of the listed personality traits. However, a morning person might prefer a morning shift to a night shift because they feel well-rested in the early morning and fatigued in the late afternoon. In contrast, a night person might prefer a night shift because they grow more alert as the night progresses.

2.3.2 Sleep Apnea

Murray and Thimgan (2016) point out that sleep apnea is one of the most common sleeping disorders and occurs when breathing interruptions or shallow breathing happen during sleep. These interruptions decrease blood oxygen saturation, lasting from seconds to minutes, and resulting in fragmented sleep. Sleep apnea is a chronic condition that repeats nightly. The apnea-hypopnea index (AHI) measures the severity of sleep apnea in apneas and hypopneas per hour. The severities of sleep apnea include:

1. 0-4 incidents per hour = no sleep apnea
2. 5-14 incidents per hour = mild sleep apnea
3. 15-29 incidents per hour = moderate sleep apnea
4. 30+ incidents per hour = severe sleep apnea

Sleep apnea can create a physical airway blockage, and blood oxygen saturation can drop below baseline level (Murray and Thimgan, 2016). The person would then have a brief awakening as throat muscles contract and open the airway. The person would then fall back asleep without realizing that they were awake. This involuntary awakening to open the airway creates a disruption to the sleep cycle and results in less of the more profound stage of sleep. Despite what seems like a whole night of sleep, the person feels tired and has not achieved full restful sleep. To illustrate the comparison of a healthy sleeper to a sleeper with apnea, Murray and Thimgan (2016) draw from a study by Brand and Kirov (2011). Figure 2.3 shows the hypnograms of a healthy sleeper, and Figure 2.4 shows a sleeper with sleep apnea. A healthy sleeper shows few to no arousal ticks at the top of the graph. This sleeper also achieves stage NREM 3/4 (non-rapid-eye movement, also known as quiescent sleep) throughout the night. However, an individual with sleep apnea shows ticks of multiple arousals at the top of the graph. These frequent arousal episodes lead to fragmented sleep. This individual achieves NREM 3/4 only a couple of times during the night, which can cause the individual to feel “not fully rested” and tired.

2.3.3 Chronic Fatigue Syndrome (CFS)

At least one million Americans have CFS (Maquet et al., 2006), with no differences in incidence among ethnic or racial groups. A report by the US Centers for Disease Control and Prevention (CDC) shows that CFS occurs most in the 40 to 59 age group and in the geriatric population (Griffith and Zarrouf, 2008). CFS displays symptoms of debilitating fatigue resulting in reduced occupational, personal, social, and educational capabilities. CFS should not be mistaken for depression. CFS is an illness characterized by limitations through fatigue for at least six months with numerous rheumatological, infectious, and neuropsychiatric symptoms (Afari and Buchwald, 2003). Patients suffering from CFS experience functional impairment; their perceptions, attributions, and coping skills may perpetuate the illness. Studies have shown that treatment for CFS includes pharmacology and behavioral strategies. Additional cognitive behavioral therapy with appropriate exercise can treat fatigue and associated symptoms.

2.3.4 Insomnia

Insomnia is a common symptom that has been widely studied. Patients with insomnia often report having nonrestorative sleep and the inability to fall or remain asleep. The characteristics of insomnia are summarized as follows (Murray and Thimgan, 2016):

- The difficulty of falling asleep
- Inability to maintain sleep for the entire duration
- Fragmented sleep

The duration of insomnia also has important implications in diagnosis. Transient insomnia often lasts only a few days and is temporary; it results from sudden acute stress, illness, jet lag, or medication. Insomnia longer than three weeks is considered chronic, and has different causes (Kupfer and Reynolds, 2009). In addition, chronic insomnia is characterized by a resultant sleepiness during the day that occurs three times a week for 1-3 months. Activation of the hypothalamic-pituitary-adrenal (HPA) axis, which plays a role in stress response, could be responsible for insomnia. In parts of the HPA axis, the levels of cortisol and catecholamines released are high among insomniacs; both hormones are known to be released during a stress response. Hence, patients with insomnia reported that they are hyper-aroused, which causes them to have difficulty falling asleep. The quality and efficiency of sleep are disrupted, and the patient feels tired during the day, affecting the quality of work.

People with insomnia are two to four times more likely to have workplace accidents (Murray and Thimgan, 2016). Insomniacs report fatigue or decreased energy during the daytime. This affects their attention span, concentration, and memory. Studies show that insomnia leads to medical conditions such as hypertension, cardiac events, diabetes, and neurodegenerative diseases. These are the endogenous effects that insomnia has on fatigue. The following subsections discuss the exogenous factors that lead to fatigue.

2.3.5 Life Events and Stressors

A stressor can be any environmental event or state that triggers our stress response system. Stressors directly disturb or threaten the homeostasis of our daily lives; they are perceived as unpredictable and uncontrollable (Hockey, 2011). Stress responses are usually associated with physiological and behavioral changes and have little meaning at the psychological level. Stressor events disturb stress response systems, leading to sleep restriction and fatigue. There are three types of sleep restrictions identified by Drews et al. (2020):

1. Transient fatigue: acute and extreme sleep restrictions within 1-2 days
2. Cumulative fatigue: repeated mild sleep restriction over a series of days, which is associated with long shift durations
3. Circadian fatigue: according to the body's circadian rhythm, particularly during the circadian low (WOCL) window between 2 am and 6 am.

2.3.6 Previous Shift/Shiftwork

Effective scheduling of shift work requires a balance of social, personal, psychological, medical, and safety concerns (Legault et al., 2017). Different mines implement shift work schedules to accommodate the mine production schedule as well as the workers. For example, a typical HTD shift is about 10-12 hours. With the long hours per shift, sleep deprivation and fatigue issues arise. Sleep issues do not seem to create problems for individuals while working the day shift; however, safety issues increase from sleep deprivation. Section 5.2 dives deeper into the case of shift work.

2.4 Impact and Consequence of Fatigue

Sleep deprivation causes physical and cognitive deficits. It may increase accidents and cause health issues. Accumulated sleep deprivation over consecutive days can impact cognitive and physical performance and increase the risk of errors (Ferguson et al., 2010). Because fatigue can affect operators psychologically, physiologically, cognitively, and behaviorally, it impacts their situational awareness while driving (T. Bauerle et al., 2018).

This is very dangerous for HTDs driving long hours during a shift in the mine. The changing nature of the mine site and exposure to environmental changes compound the risk. The lack of situational awareness can lead to slower reaction time, failure to correctly perceive environmental elements, and inadequate comprehension of the current situation. T. Bauerle et al. (2018) also listed the fatigue states and their corresponding impact on operators. Table 2.2 shows how fatigue could impact different states: psychologically, physiologically, cognitively, and behaviorally.

A conceptual model of fatigue was recently adapted by Drew et al. (2020). Figure 2.5 displays proximal factors and distal factors contributing to fatigue states. Distal factors are contributing factors that indirectly affect the health of an HTD; they are located on the left side of Figure 2.5. Sleep history is affected by sleep efficiency, clinical conditions, life events and stressors (transient), personality factors, and the previous shift. Proximal factors are contributing factors that directly affect the health of the HTD; they are located on the right side of Figure 2.5 (Drews et al., 2020). We have discussed the possible contributing factors to fatigue, and explained that fatigue is the impairment of task performance (Yazdi and Sadeghniiat-Haghighi, 2015). Sections 2.4.1 to 2.4.4 further discuss these impairments' specific impact on an individual.

2.4.1 Psychological Impact

Fatigue causes physical exhaustion, leading to a profound lack of motivation or to depression (Hockey, 2011). Motivation guides the direction of behavior and the factors that “make us do what we do.” It is the initial part of our information processing system that drives our behavior. If our processing system perceives a task as monotonous and dull, our behavior becomes exhausted and frustrated. Motivation is the "willpower" to perform work. The fatigue state can be summarized as having three areas: phenomenology, task performance, and effort and costs.

- Phenomenology: Individuals feel multiple layers of fatigue, including elements of effort, anxiety, discomfort, frustration, boredom, and lack of engagement.
- Task performance: Decrease of performance often includes (with imposed tasks) heavy workload or stress. However, if the goals or motivation are valued, performance might increase even under monotonous work conditions.
- Effort and costs: Effort increases if the task goal is considered achievable and worthwhile.

As mentioned previously, fatigue is the response to the "depletion of resources required to handle the immediate task" (T. Bauerle et al., 2018). The depletion of willpower through a lack of motivation is also a contributing factor to fatigue. Since motivation drives behavior, this psychological impact of fatigue affects an HTD's ability to drive safely. In a fatigued or willpower-depleted state, the individual has decreased mental resources and is less likely to attend to self-regulatory actions. This leads to poor decisions—this idea is linked to safety motivation. Neal and Griffin proposed that safety motivation mediates the relationship between safety climate and behavior (Neal and Griffin, 2006). The term itself refers to an individual's willingness to give effort to safety-related behaviors. Individuals are motivated to comply with safe working practices and participate in safety training if they feel their work has a favorable safety climate. Situation-based and indirect person-based factors influence motivation and knowledge of safety performance behaviors, and safety performance behaviors influence accidents and injuries. Thus, safety climate is affected by safety knowledge and motivation; safety performance is correlated with accidents and injuries (Christian et al., 2009).

2.4.2 Physiological Impact

Lenné et al. (2012) reviewed 263 mining incidents across Australia from 2007 to 2008; the review was then analyzed using the Human Factors Analysis and Classification System (HFACS). Organizational processes and skill-based errors are among the most frequent categories of accidents. These accidents could be linked to workers' physiological states (Lenné et al., 2012). The physiological impact of fatigue includes loss of strength and stamina and increased energy consumption (T. Bauerle et al., 2018). Multiple studies show that the body's physical reaction to fatigue is associated with work performance; for example, heart rate affects cognitive processing and behavioral response.

The haul truck's physical environment might contribute to HTDs' physiological fatigue. Various studies suggest that professional drivers are at risk of lower back pain and injuries from Whole-Body Vibration, chronic and prolonged sitting, and awkward postures (Lyons, 2002). This research dives into factors such as Static Postures and Whole-Body Vibrations (WBV) and the physiological impact (through heart rate) on an individual's overall fatigue state.

2.4.2.1 Heart Rate

Heart rate provides information about the efficiency and functioning of the body's cardiovascular system. The heart rate illustrates patterns of alert and fatigue states in a driving setting. Heart rate variability (HRV) is a standard measurement of cardiac autonomic modulation (Phan et al., 2015). It measures the variation in a heartbeat. The heart rate accelerates after inspiration and decelerates after expiration (Segerstrom and Nes, 2007). Phan et al. (2015) used HRV to quantify drowsiness. Previously, HRV has been applied to measure mental workload, stress, and driver fatigue. Increased HRV indicates a low mental workload, which frequently occurs during monotonous driving (Patel et al., 2011).

2.4.2.2 Sitting Posture

A typical HTD's shift ranges from 10 to 12 hours, during which the HTD remains in a static sitting posture. This posture leads to a biomechanical stressor in the lordotic curve of the spine's lumbar region. Figure 2.6 illustrates the effects on the lumbar region from sitting; on the right is the standing posture, and on the left is the sitting posture. The sitting posture flattens the lumbar spine angle by roughly 30 degrees, causing anterior compression and posterior tension (Chaffin et al., 2006). The flattening and compression of the lumbar region may cause musculoskeletal and back muscle fatigue.

Looking deeper into the sitting posture, Figure 2.7 illustrates the compression and tension of ligaments that stems from the flattening of lumbar spinal curvature. The lumbar region consists of the nucleus pulposus, apophyseal ligaments, and erector spinae. The sitting posture compresses the nucleus pulposus on the anterior side of the disc. The apophyseal ligament and erector spinae experience tension on the posterior side of the disc. This tension may result in tensile ischemia and hamper nutrition supply to the nerves. If the posture continues chronically, it may lead to neurological dysfunction, lesion, or prolapsed disc in the spinal canal (Yu and Keyserling, 1989). Both body mechanic figures show that sitting posture correlates with lower back pain (LBP). Chronic flattening of the lumbar region causes lower back muscle fatigue and limits the nerves' nutrition supply.

2.4.2.3 Whole Body Vibration (WBV)

One of the less-studied aspects of the environment inside the haul truck is the HTD's exposure to vibration. A vibration is a form of mechanical wave that travels through objects; it is an oscillation movement about a reference or fixed point (Mansfield, 2004). For example, the vibration of a haul truck can come from bumping a rock in the dirt road or simply the running of the truck's engine. Vibrations with a wide range of magnitudes, waveforms, and durations can travel from the haul truck through the HTD; the effect is called whole-body vibration (WBV). WBV occurs when the human body is in contact with a shaking surface, and the vibration affects different body parts. In the case of an HTD, the vehicle's vibration enters the body through the driver's seat and footrest (if provided in the haul truck) while the driver is in a sitting posture (Johnson and Nève, 2001). Once the vibration enters the body, different body parts transmit different resonant frequencies. Figure 2.8 shows the mechanical system of the human body subjected to vertical vibration; individual body parts show different resonant oscillation frequencies.

The muscle tissue and organs absorb energy when the vibration travels through the body. This causes involuntary and voluntary muscle contractions, leading to muscle fatigue. The vibration's mechanical energy depends on the body's posture and muscle contraction. Vibration transmission is measured by the relationship between input and output acceleration at a body point. Figure 2.9 shows acceleration verses frequency data of vibrations experienced in standing and sitting postures.

The standing position allows the ankle and knee to absorb the frequency. The sitting posture does not offer absorption; hence, the head and shoulders receive higher frequencies. The spike of the acceleration ratio could result in neck pain and might translate through the spine to create LBP (Lower Back Pain). However, there is limited literature on this subject. The influence of WBV on the central nervous system (CNS) is unknown, but some CNS processing is affected. Studies suggest that low-frequency vibration (1-3 Hz) with moderate intensity instigates sleep and decreases wakefulness (Chaffin et al., 2006).

The National Institute for Occupational Safety and Health (NIOSH) Pittsburg Mining Research Division (PMRD) performed a case study measuring the WBV and hand-arm-vibration (HAV) exposure of mine/quarry haul truck drivers. They focused on haul truck activities such as dumping, loading, and driving with and without a load (Mayton et al., 2018). They compared the results with the ISO/ANSI and European Directive 2022/44/EC standards and found that the measured values were generally below the health guidance caution zone (HGCZ). However, there were some instances where the Exposure Limit Value (ELV) exceeded 500-600% of that recommended by the standards. NIOSH researchers determined that excessive instances could occur when driving without a load while descending to the open pit loading area, when sliding on wet and slippery road surfaces during rainfall, or in cases of overwatering. Some WBV levels exceeded the ISO/ANSI EAV by 9-53% when driving without a load. HAV measurement was below the HGCZ standards when steering and shifting controls; the researchers concluded that HAV is not a significant issue for HTDs. Although WBV and HAV measurements are below the provided standards, studies have shown that WBV and HAV contribute to fatigue and affect job performance. In some cases, they may lead to musculoskeletal disorder (MSD), LBP, and other injuries (Mayton et al., 2018).

2.4.3 Cognitive Impact

When activities such as problem-solving and task completion are performed in a fatigued state, they require an elevated level of cognitive effort over an extended period (Hockey, 2011). Other cognitive impacts of fatigue include increased reaction time and forgetfulness (Drews et al., 2020). Cognitive thinking often requires the combining of adaptive problem-solving with emotional and behavioral coping skills in highly stressful situations (Killgore et al., 2008). Cognitive ability is impacted by passive and active fatigue. Active fatigue is associated with a high cognitive workload, while passive fatigue arises from tasks with low perceptual-motor requirements (May 2011). Passive fatigue can also consider an intense cognitive workload with limited physical activities; however, driving requires constant attention on the road. Research also suggests that fatigue during the night shift directly impacts cognitive thinking due to the inability to adapt to changes in biological function that arise from working outside of normal circadian rhythms (Legault et al., 2017). In the case of HTDs, the driving task requires quick reaction times and good memory performance, which are affected by fatigue.

2.4.3.1 Memory

There are two types of memory, declarative and procedural (Murray and Thimgan, 2016). Declarative memory is the ability to recall or state facts; for example, recalling that the capital of Peru is Lima. Procedural memory involves remembering how we do things, and is more impacted by fatigue. Research suggests that the more complex procedural memory is, the more it depends on REM sleep (Murray and Thimgan, 2016). While there is no existing evidence that clearly details the relationship between memory and sleep, there is evidence that fatigue has adverse effects on the ability to memorize complex information.

Despite a lack of understanding of what is happening to our brain while we sleep, research suggests that learning and memory are impaired by sleep deprivation. Fatigue can hamper our ability to learn new information. The learning hurdle could be a lack of focus, motivation, attention, or concentration. Fatigue increases the pressure to sleep. This could make it more difficult to acquire new information and recall it. Joyce et al. (1996) stated that patients with chronic fatigue syndrome complain about poor memory and concentration. On the other hand, sleep consolidates long-term and short-term memories. When we sleep, our brains process, store, and organize any information we have acquired; additional unused information is also stored (Murray and Thimgan, 2016).

2.4.3.2 Reaction Time

Reaction time is the time in which an individual responds to a stimulus. This is commonly studied in cognitive thinking research. Usually, a reaction time test includes alarm sounds or vibrations that signal the participants to push a button. Some tests require a choice reaction, which involves a thinking process rather than a single response. Kilgore et al. (2008) investigated reaction time in connection with sleep deprivation. Twenty-six participants completed the Bar-On Emotional Quotient Inventory (EQi) and the Constructive Thinking Inventory (CTI) tests. This test studies reaction time in monotonous tasks after one night of sleep deprivation. Participants were asked to monitor a computer screen for two hours and press a key each time a yellow dot appeared. The test was designed to monitor a task that requires attention but not a high level of focus. The study showed that reaction time performance was significantly slower with sleep deprivation. Reaction times were 20% slower in sleep-deprived participants. These participants were also three times more likely to miss the signal than an average person (Murray and Thimgan, 2016). The study concluded that sleep deprivation affects human judgment and decision-making.

Based on EQi testing, the Interpersonal composite scale shows a significant decline from the baseline after sleep deprivation. This also includes empathy and the Interpersonal Relationship scale (empathy toward others and quality of interpersonal relationships). The CTI testing results suggest unrealistically optimistic self-description and increased carelessness arising from sleep deprivation. Other constructive thinking scales, such as the Global Constructive Thinking scale, suggest a decrease in Behavioral Coping (positive thinking) and a significant increase in Esoteric Thinking (reliance on superstitions and magical thinking). The research concludes that sleep deprivation causes a decline in emotional intelligence traits and some aspects of coping abilities (Killgore et al., 2008).

2.4.3.3 Situational Awareness (SA)

Situational awareness (SA) is a cognitive decision process with a three-level hierarchical pattern: perception of environmental elements, comprehension of the situation, and projection of future status (Endsley, 1995). Figure 2.10 is a conceptual model for SA. The first step is perceiving the characteristics and qualities of elements in the environment.

For an HTD, an example of this would be perceiving obstacles on the road, or the truck's status. The second step involves comprehending and analyzing the situation—using the awareness of the present elements from the first step and making a decision based on that knowledge. For example, obstacles on the road could threaten truck safety. HTDs might deviate from expected decisions based on their different perspectives or their driving experience. The third step is to project future actions; this is achieved through the perception and comprehension of the situation (both the first and second steps). For example, in response to the obstacle on the road, the HTD can slow down or avoid it to prevent a potential collision (Endsley, 1995). The three-level hierarchical pattern indicates that SA is more than perceiving the environment; it plays a critical role in complex decision making. The theory of SA addresses the construct of human cognitive decision-making and performance.

Figure 2.10 also shows that a decision made after the three levels of SA is influenced by innate abilities, experience, and training. Other features that could affect SA include system capability, interface design, stress and workload, the complexity of the task, and automation. This is where fatigue could impair SA and affect decisions and performance. Fatigue can contribute to compromised or depleted cognitive abilities in SA decision-making; this could be one way that fatigue leads to injuries and accidents (T. Bauerle et al., 2018).

2.4.4 Behavioral Impact

During a focus group conducted by Drews et al. (2020), HTD participants mentioned mood changes as one symptom of fatigue. HTDs described themselves as "grumpy" or "irritable" as their fatigue increased. These risky behaviors support the positive relationship between risk-taking behavior and work injuries (Paul and Maiti, 2007). HTDs also mentioned slower reaction time directly affecting their driving precision and control. Some HTDs reported that when they are fatigued, they recognize closure of their eyelids, nodding off, microsleep, and loss of concentration (Drews et al., 2020).

Khan and Lee (2019) reviewed other studies and summarized a list of fatigue-related symptoms and behaviors in drivers:

- Frequent yawning
- Increased eye-blinking frequency
- Burning feeling in the eyes and hard to keep them open
- Lethargic or relaxed position of the hands on the steering wheel
- Delayed response time
- Vehicles wandering between and out of lanes
- Nodding off, or spontaneous head nod
- Shallow breathing
- Reduced head movement
- Frequent scratching legs, chin, head, and ears
- Turning head to relieve neck muscle tension
- Feeling irritated or depressed

Fatigued drivers' behavior is in response to physiological phenomena, but the innate responses of different drivers can display as different symptoms and behavior (Khan and Lee, 2019). These response behaviors can act as a distraction to the driver and increase risky behavior. Because drivers exhibit a broad range of fatigue behavior, detecting these behaviors is essential to fatigue monitoring. For example, as seen in the list above, multiple fatigue behaviors are associated with the eyes. PERCLOS (a camera-based monitoring system) captures the percentage of time that eyes are moving and detects in-situ fatigue (Khan and Lee, 2019). Section 2.5.1.1 further discusses the general mechanism of PERCLOS.

There are other specific driving behaviors that drivers display when fatigued; for example, low velocity of steering wheel movement, increased speed, and jerky motion (Khan and Lee, 2019). These driving behaviors are as crucial as for HTD in mine sites.

As we can see, fatigue impacts psychological, physiological, cognitive, and behavioral task performance. Understanding the impairment in task performance that fatigue causes, especially in the mining industry, is essential. We hope to mitigate the effects of fatigue by managing and modeling fatigue episodes.

2.5 Modeling and Managing Fatigue

Fatigue has been studied through changes in heart rate, blood pressure, hand strength, and actigraphy. It can also be assessed in objective performance on stimulating tasks, such as the Psychomotor Vigilance Test (PVT) and the logical reasoning numerical aptitude test (di Milia et al., 2011). These are fair assessments attempting to measure and manage fatigue. However, they still ignore individual differences (endogenous variables) in response to fatigue and assume that changes in one indicator are not due to other factors (exogenous variables). Endogenous and exogenous variables can be used to study the "fitness for duty" of HTDs outside of their shifts. In contrast, organizational approaches such as fatigue monitoring systems (FMSs) study HTD fatigue during the shift. FMSs can be separated into contact and contactless (Yan et al., 2016). Contact-type monitoring systems include those that measure heart rate or body temperature using direct contact, and measure bodily responses. These responses are part of fatigue's physiological impact and consequences. A standard contactless monitoring system monitors facial expressions or eyelid closure to detect fatigue indirectly, and analyzes fatigue responses. These responses are part of fatigue's behavioral impact and consequences. One example of contactless monitoring is the camera-based monitoring system PERCLOS, developed by Hexagon. However, contactless monitoring systems have limitations, such as requiring visible light to achieve face detection. The system needs an additional facial recognition algorithm for the HTD's face and eye region to analyze fatigue responses in grayscale images.

2.5.1 Fatigue Monitoring System (FMS)

Monitoring physiological fatigue signals has become a way of measuring an HTD's "fitness-for-duty." Some larger-scale mine sites incorporate FMSs for HTDs; many FMSs have been developed.

Table 2.3 provides the types of technology and their descriptions. Fatigue monitoring technology uses a range of physiological, cognitive, and behavioral factors to measure fatigue and/or raise alarms. The focus group mentioned FMSs such as camera-based measurement of eyelid closure and electroencephalogram (EEG), also known as cap/helmet. A camera-based system, such as PERCLOS, uses facial and eye recognition software to identify facial behavior associated with fatigue. It recognizes fatigue by making behavioral observations (rapid eyelid closure and yawning) and commenting on changes such as eyelid closure that lasts longer than a specific time. The cap/helmet detects fatigue events by integrating EEG electrodes to measure EEG. Most of the models for EEG have implemented wearable watches or headbands. The cap uses brainwave measurement to predict fatigue. Unlike the camera-based method, it proactively monitors the initial stages of exhaustion before the HTD shows signs of fatigue (Drews et al., 2020).

2.5.1.1 PERCLOS

PERCLOS is a camera-based FMS that utilizes facial detection to analyze eye closure; PERCLOS stands for PERcentage of eyelid CLOSure (Darshana et al., 2015). It calculates the percentage of time the eyelid covers 80% of the pupil area; thus, PERCLOS analyzes intervals of prolonged eyelid closure. A typical eye closure interval is between 1 to 5 minutes (Sommer and Golz, 2010). PERCLOS determines the degree of an HTD's fatigue by looking at prolonged eye closure periods. PERCLOS had three fatigue metrics:

1. P70: the proportion of time of eyelids closure for at least 70%
2. P80: the proportion of time of eyelids closure for at least 80%
3. EYEMEAS (EM): the mean square percentage of eyelid closure rating

Of the three metrics, P80 has the optimal relationship with fatigue. PERCLOS determines eyelid closure without being affecting by the distance of the eyes from the camera. Eyelid closure can be expressed by the eye's length and height ratio. Further, the PERCLOS value is determined by the balance between the number of occurrences of eyelids open and closed at 20% (P80) and the frames of the eye open at 20% and 80%; A PERCLOS value greater than 0.15 is an indicator of fatigue (Xie et al., 2012).

2.5.1.2 Electroencephalogram (EEG)

The electroencephalogram (EEG), wearable sensor, or cap/helmet, records electrical signals from the brain based on standard neural responses. Figure 2.11 shows an alert brain's EEG topography image; it indicates the delta, theta, alpha, and beta rhythm activities. High brain activity is shown in red, while low activity is shown in blue. For example, the alpha rhythm (8 to 13 Hz) usually indicates that the driver is in a state of wakeful relaxation with eyes closed (von Rosenberg et al., 2016). When the driver's wakefulness and activities increase, the alpha rhythm decreases. The delta rhythm (±0 to 4 Hz) is high during sleep, and the theta rhythm (4 to 8 Hz) increases in the early stages of fatigue. However, the beta rhythm (13 to 20 Hz) decreases during fatigue and increases with alertness. The different states of these frequencies are obtained by EEG and thus the device can detect the current state of the driver (Jap et al., 2009).

The electrodes for measuring brain activity are usually attached in a helmet form to have the closest access to the head and neck area. Figure 2.12 shows the location of the signal electrodes in the helmet, along with an optional respiration belt and chest EEG for reference.

2.5.1.3 Smartwatches

Smartwatches provide a flexible, bidirectional, and real-time communication control between the wearer and a server (Kheirkhahan et al., 2019). They are ideal for monitoring activities for extended periods and investigating physical activities at various times. Smartwatches are popular among users and exhibit high acceptability; they are a nonintrusive monitoring system that collects and analyzes data in real time (Kheirkhahan et al., 2019). The purpose of smartwatches in fatigue monitoring is to synchronize data with reports of possible physical reactions to fatigue. A common physiological response that the smartwatches monitor is heart rate. Smartwatches use photoplethysmography (PPG) to monitor cardiovascular activities by exposing the skin to a light source. Since blood is red, it reflects red light and absorbs green light. More blood flows through the wrist when the heart beats, meaning more green absorption. Conversely, less blood means less green absorption. The PPG directly collects reflected light using photodetectors at the wrist to convey data (Morresi et al., 2020).

2.5.1.4 Speech Recognition

Speech is one of the most complex motor behaviors and requires substantial temporal and computation effort (Vollrath, 1994). Scherer (1989) studied the correlation of vocals with emotional arousal and affective disturbance. Scherer proposed that "vocalization can be considered the most direct correlate, and consequently one of the most powerful indicators, of motivational and emotional processes" (Scherer, 1989). Therefore, vocalization can reflect motor coordination in speech, and shows the activation of emotional processes which influence motor processes (Vollrath, 1994). Additional research shows that voice is an indicator of an individual's psychological, physical, and emotional state.

Consequently, examining voice recordings could determine the effects of fatigue on simple voice characteristics (Whitmore and Fisher, 1996). Greeley et al. (2006) illustrate a strong relationship between voice and performance on standardized tests such as the Sleep Onset Latency test, and the Sleep, Activity, Fatigue, and Task Effectiveness test.

Changes in voiced articulation indicate changes in the body's voice mechanism that may stem from fatigue. For example, the Mel Frequency Cepstral Coefficients (MFCC) feature vector changes as a function of the level of fatigue; the MFCC determines different phonemes and shows their variation due to fatigue. For example, the MFCC shows distinct changes in vector for the sound "t" due to fatigue (Greeley et al., 2006).

WOMBATT-VOZ is a fatigue prediction system that uses voice analysis; it was developed for the European Space Agency to detect astronauts' fatigue. Recently, this technology has been implemented in the mining industry. WOMBATT-VOZ uses iVOICE fatigue detection technology through mobile phones or tablets. The artificial intelligence from iVOICE analyzes an 8-second voice recording and then uses another 5 seconds to predict the fatigue level. The AI also analyzes multiple voice muscles, and the algorithm also learns the individual's voice characteristics (*WOMBATT-VOZ*, n.d.).

2.6 Human Factor and Adapting Fatigue Monitoring

In this case, the mining industry adapts FMSs to better monitor HTDs for fatigue. Although the goal of these systems is to predict fatigue, most of them can only measure fatigue at the point it occurs (Drews et al., 2020). Overall, they measure physiological and behavioral responses from the HTD and assess fatigue. Because the monitoring systems measure human body response, they rely on ergonomics and human-factors engineering. Ergonomics can be defined as a user-centered approach to designing equipment, processes, and the environment so that a required task is within human limitations and maximizes human capabilities. Ergonomics is an applied science that aims to promote workers' health, efficiency, and well-being (McPhee, 2004). Under the study of ergonomics, human factors science is the science of the relationship between psychology and engineering. It focuses on work system designs that support human performance and safety (Human Factors and Engineering Psychology, 2014). Successful engineering design is infused with human factors to promote efficiency, safety, and effectiveness (Russ et al., 2013). Human factors include operator acceptance, user-centered design, human-system integration, and overall trust in the system. The mining industry's adoption of a human-centered approach is limited; it is unlikely that the equipment and technologies fulfill the operators' needs, support the appropriate interaction between users and machines, or have improved design for a "fit" between users. Other human factors issues could be addressed and likely significantly impact workers.

Table 2.4 summarizes the human factors issues with possible suggestions and explanations (Horberry and Lynas, 2012).

One suggestion is a barrier between a technology company and the user due to finding/recruiting specialists in the workforce (Gruenhagen and Parker, 2020). Therefore, it is crucial to understand how human factors contribute to fatigue monitoring in the mining industry and the impact of automation on humans to increase effectiveness (Rogers et al., 2019).

2.6.1 Adapting FMS

The use of fatigue monitoring technologies increases productivity, efficiency, and health and safety in the mining environment. However, technologies also have limitations as they can fail to effectively implement human factors. Gruenhagen and Parker (2020) argued that mining suppliers and equipment manufacturers are at the forefront of mining innovation, developing new technological solutions to increase productivity. They listed these variables as tangible factors. Meanwhile, intangible factors such as the workforce, communities, and safety culture are underrepresented; naturally, these groups would be the best “consultants” for how well the technologies perform and how effective they are. A fear of monitoring causes workforce resistance to fatigue monitoring technologies (Gruenhagen and Parker, 2020). Understanding how well these monitoring systems perform could help validate the concept of machines and technologies with human interaction. FMSs should meet human factor engineering objectives. Monitoring systems should enhance the effectiveness and efficiency of HTDs by recognizing fatigue and mitigating haul truck accidents. They should also enhance specific human values, including safety, reduced fatigue and stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life. The design of monitoring systems influences human behavior and overall well-being. Although FMSs do not require humans to work with the machine, the system is supposed to work for humans by monitoring them in the most non-intrusive way possible.

2.6.2 Information Transparency

A typical firm traditionally protects its innovation advantages with intellectual property rights (IPRs), trademarks, copyrights, or other protections. A study by Ritala et al. (2015) found potential negative concerns from the employees to the administrative level; this survey was conducted among 150 Finnish technology-intensive firms to understand the general acceptance of knowledge sharing. The results show that external knowledge sharing has positive effects on innovation performance (Ritala et al., 2015). On the other hand, accidental and intentional knowledge leakage harms the relationship between employer and employees. Knowledge leakage is different from knowledge sharing; knowledge leakage negatively affects firms, while knowledge sharing positively affects the employer-employee relationship. Knowledge leakage is the accidental or intentional sharing by the employees of knowledge that might damage the firm's reputation; this could lead to loss of trust, loss of revenue, and recovery costs (Ahmad et al., 2014). Knowledge sharing between moderators and employees shows trust and acceptance between partners, and the information is controlled (Ritala et al., 2015). In other words, the company benefits from external knowledge sharing. This is a vital issue for reaching innovation and acceptance outcomes. Managerial and employee judgment is needed on what knowledge is shared, when it is shared, and why it is shared.

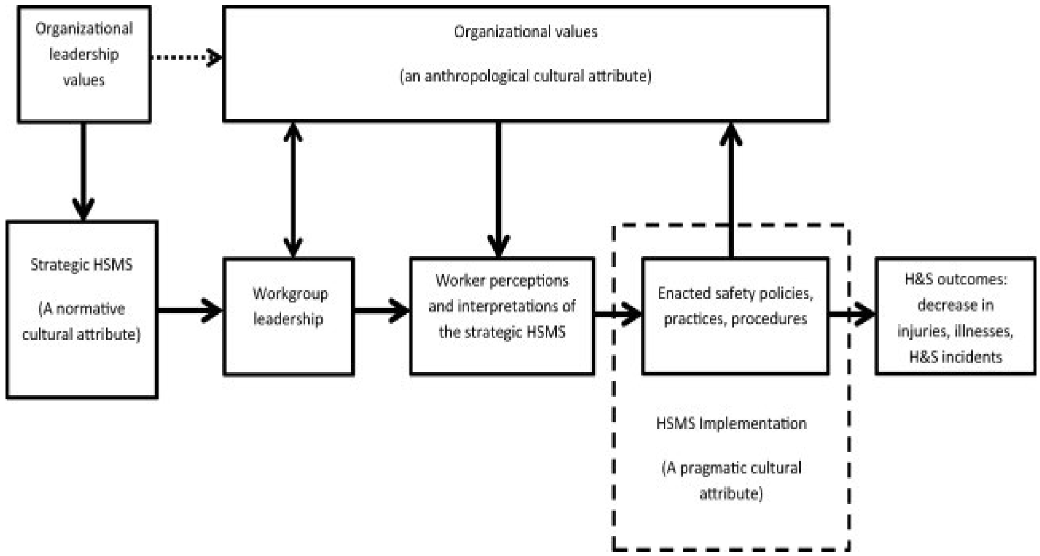

Figure 2.1 HSMS conceptual model. Adapted from Yorio et al. (2015).

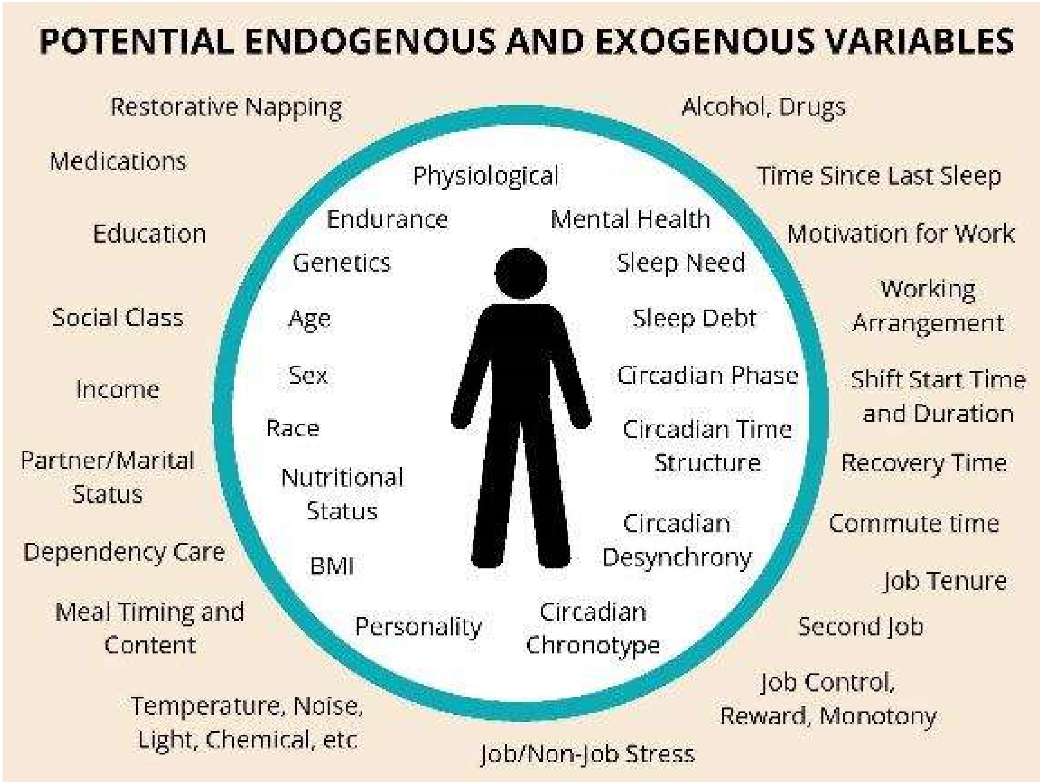

Figure 2.2 Potential endogenous and exogenous variables. Adapted and redesigned from di Milia et al. (2009).

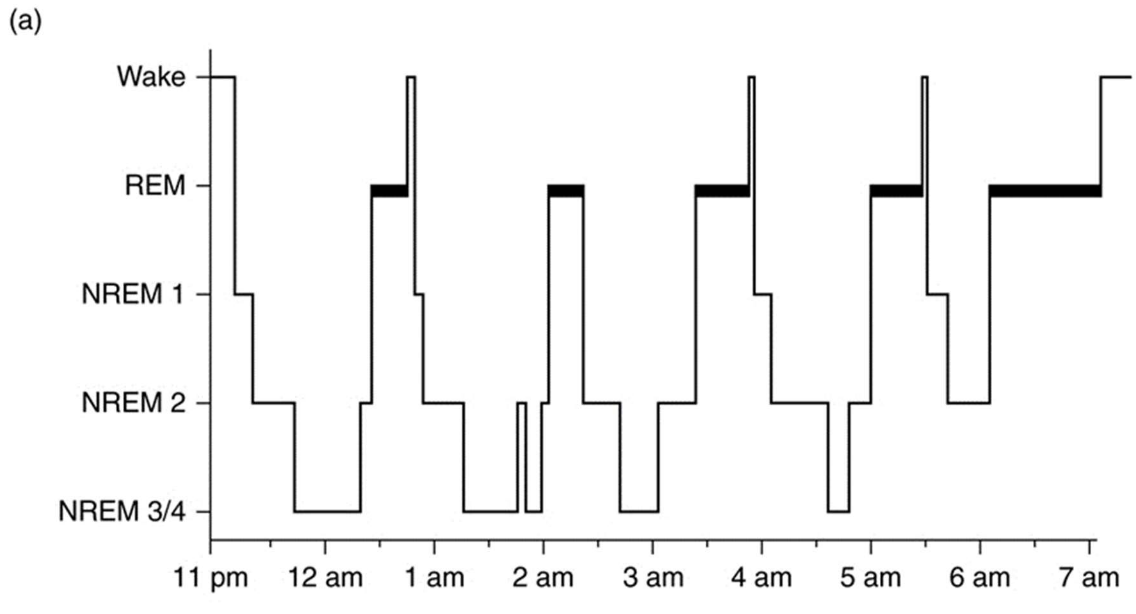

Figure 2.3 Hypnogram from a healthy sleeper. Adapted from Murray and Thimgan (2016).

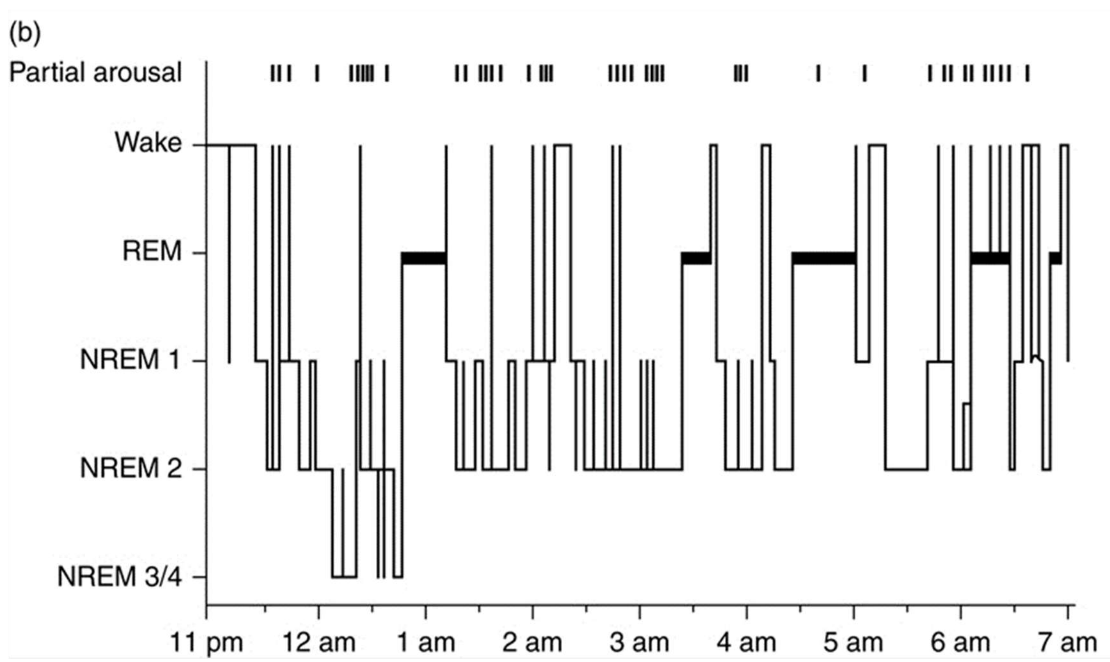

Figure 2.4 Hypnogram from an individual with sleep apnea. Adapted from Murray and Thimgan (2016).

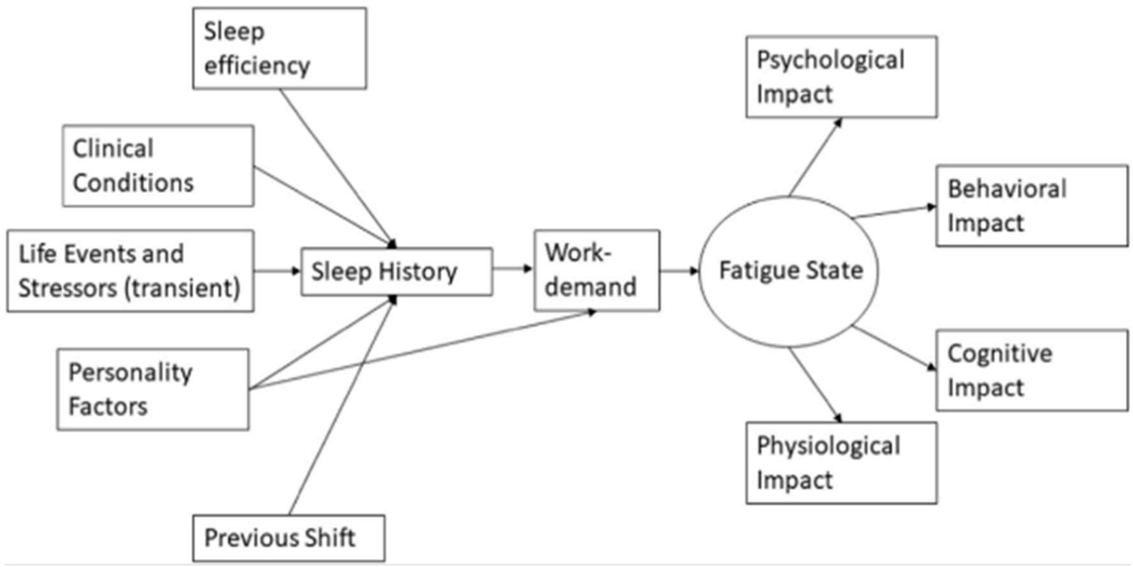

Figure 2.5 Fatigue state impact. Adapted from Drew et al. (2020).

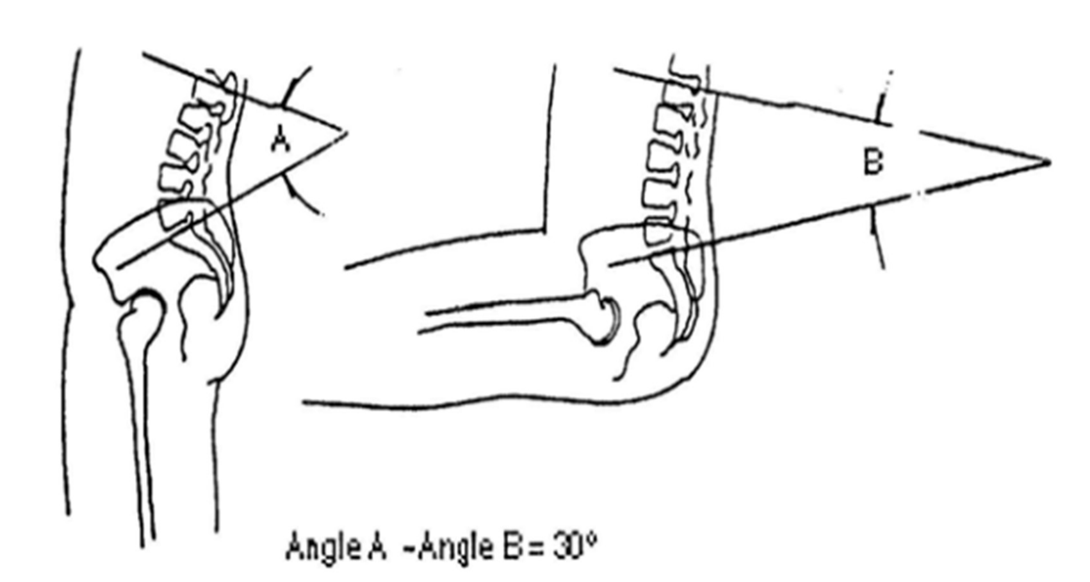

Figure 2.6 Reduction in the lordotic curve from standing to sitting. Adapted from Chaffin et al. (1999).

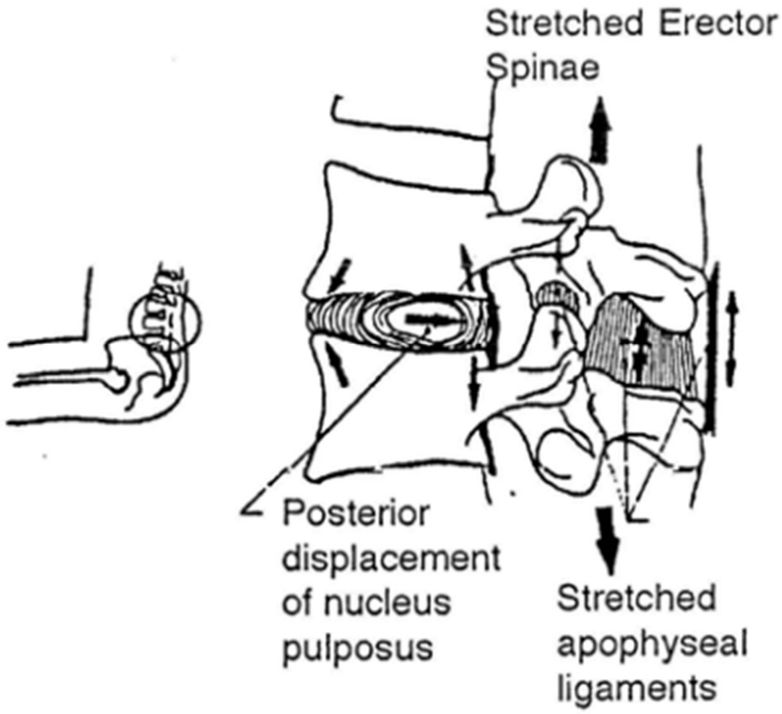

Figure 2.7 Flattening of the spine's lumbar region. Adapted from Yu et al. (1989).

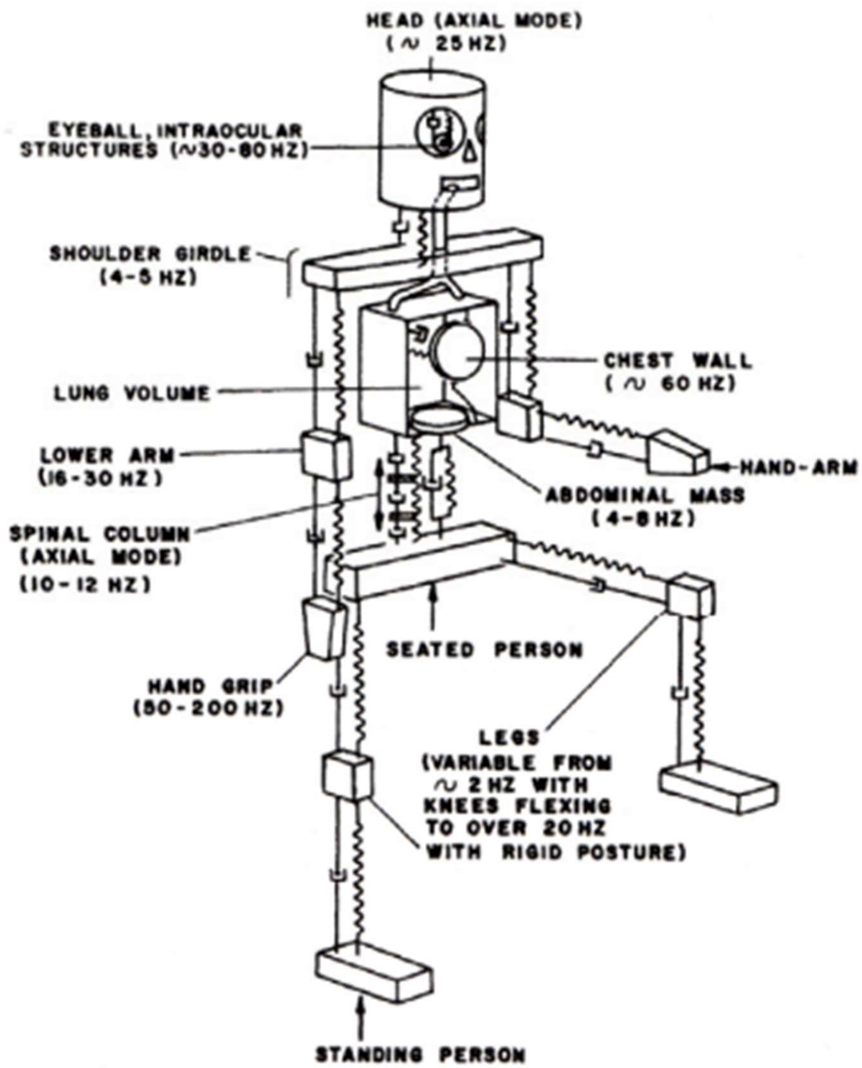

Figure 2.8 Mechanical system of the human body. Adapted from Chaffin et al. (2006), Rasmussen (1982) and von Gierke et al. (1975).

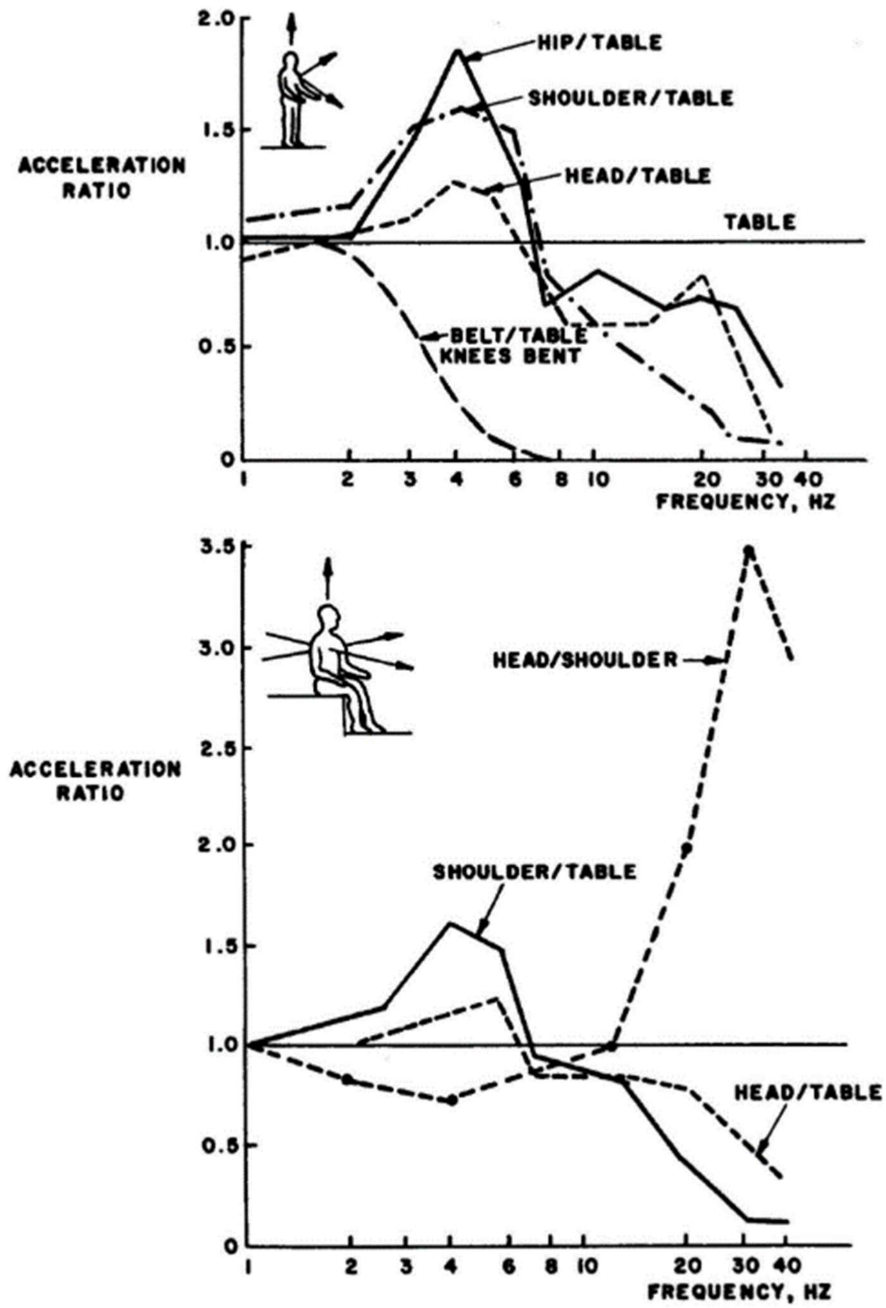

Figure 2.9 Transmissibility of vertical vibration of the body of standing and sitting postures. Adapted from Chaffin et al. (2006) and Rasmussen (1982).

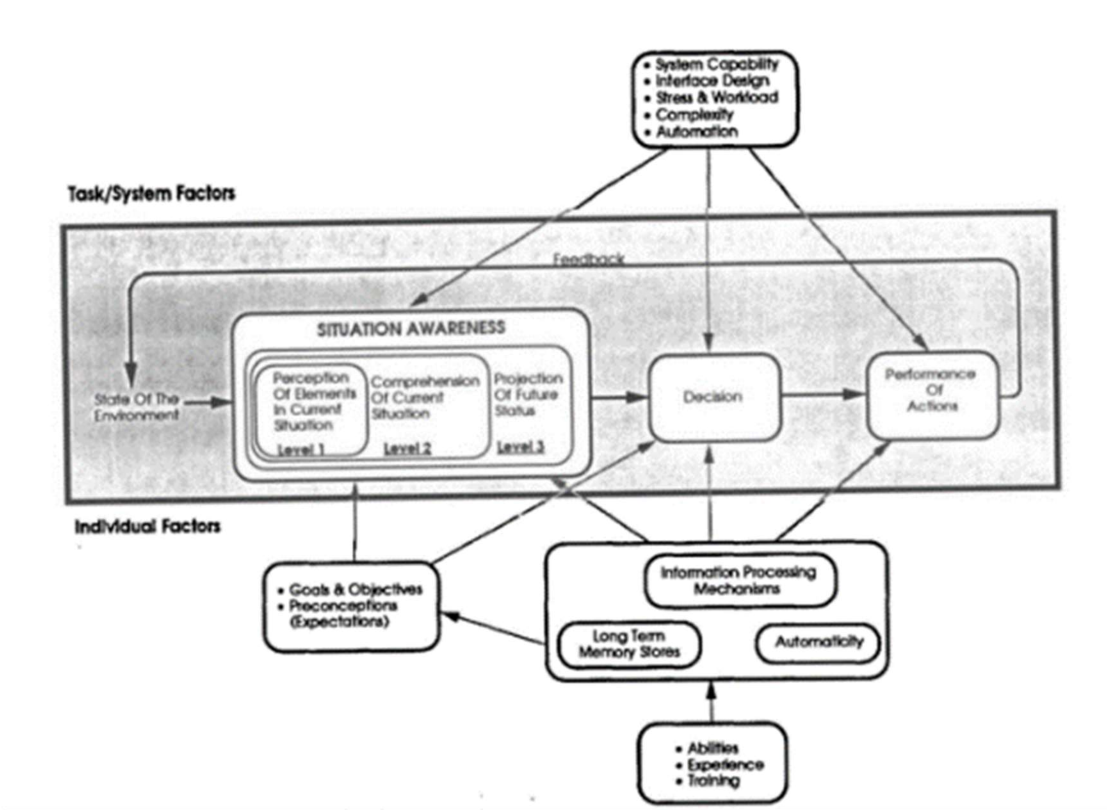

Figure 2.10 Conceptual model of SA. Adapted from Endsley (1995).

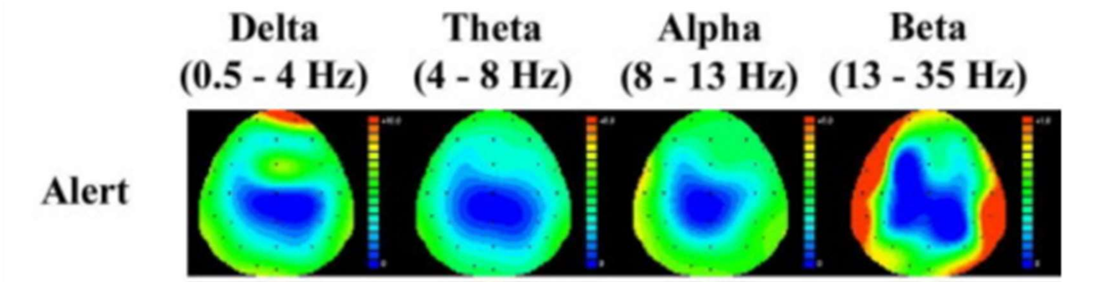

Figure 2.11 Brain topography at alert state. Adapted from Jap et al. (2009).

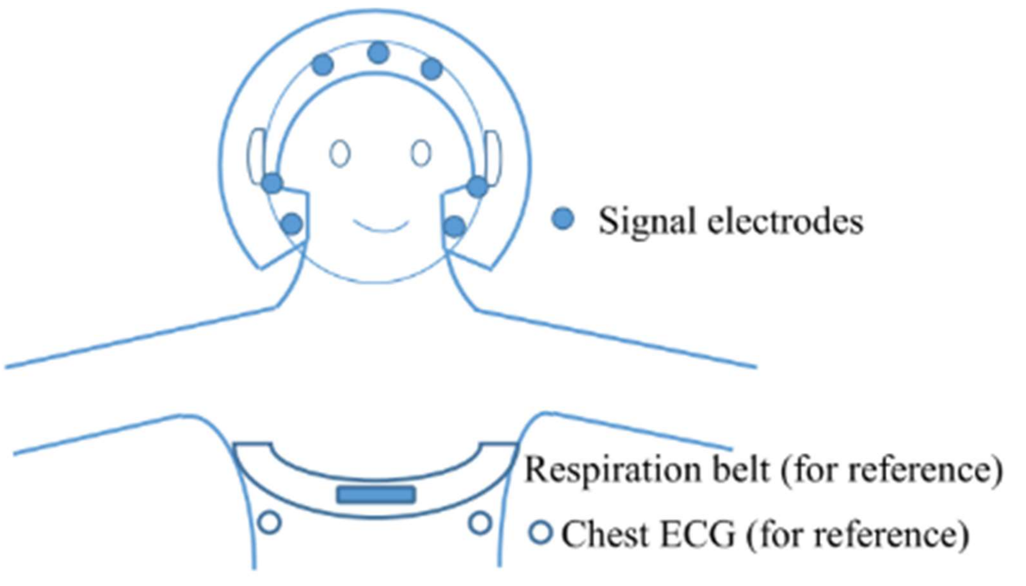

Figure 2.12 Simplify the location of the electrodes helmet. Adapted from von Rosenberg et al. (2016).

Table 2.1 Health and safety management system framework

Framework	Elements
Plan	Fatality prevention and risk management
Do	Training and competence
	Change management
	Contractor management
	Emergency management
	Collaboration and communication
	Reinforcement and recognition
	Work procedures and permits
	Health optimization
	Culture enforcement
	HR and labor relations
	Behavior optimization
	Engineering and construction
	Documentation control
	Compliance and assurance
Checking and corrective action	Fatality prevention and risk management
	Incident reporting and investigation
Management review	Safety and health management assurance
HandS commitment	Leadership development
	Responsibility and accountability
	Management system coordination

Source: Adapted from Haas and Yorio (2016).

Table 2.2 Fatigue state and its impact

Fatigue state	Impact
Psychological	Weariness, lack of motivation, stress-induced actions
Physiological	Loss of strength and stamina, energy consumption
Cognitive	Slowed reaction time, forgetfulness
Behavioral	Eyelid closure, head nods, slower speech, decreased productivity

Source: Adapted from Bauerle et al. (2018).

Table 2.3 Fatigue monitoring systems

Type of Technology	Description
Cognitive test	An employee's past 14-day work schedule and sleep history are used to evaluate a job risk profile. Other selected factors are included to build a comprehensive fatigue and alertness profile. Finally, the system will run a 60-s impairment test to confirm its findings and predict fatigue and alert employees and supervisors of upcoming fatigue [20].
Sleep pattern analysis using the smartwatch	Fatigue is predicted based on a biomathematical fatigue model and actigraphy-based sleep data [21].
Anti-drowsy alarm	This system raises driver awareness of momentary lapses caused by sleepiness. A device worn behind the driver's ear detects nodding movements and after crossing a threshold of the movement, it emits an alarm sound [22, 23].
Eyelid movement detection with infrared reflectance	Drowsiness or wakefulness is measured by a system that assesses infrared reflectance of the eye. Based on the reflectance data, eyelid movement is detected and used to assess eyelid closure. Other measures involve electro-oculography or video [24].
EEG cap/helmet	This system uses a cap that has EEG electrodes integrated to measure EEG. These measurements are used to recognize fatigue events [25].
Camera-based system	The system uses facial and eye recognition software to identify operator fatigue and to alert the driver if an instance of closed eyes for longer than a specific time was detected [26].
Fatigue warning kit	This system randomly emits a visual warning to which the operator has to respond by acknowledging the warning. Omission to do so activates a fatigue alarm [27].
Predictive and non-invasive monitoring	This approach uses a combination of two systems, one that is "knowledge-based" and provides an electronic template predicting hourly the likelihood of the driver falling asleep (circadian rhythm based), and the second using steering sensors to detect monotonous driving and steering movement characteristics to identify fatigued driving [22, 28].
Pupillometer	This system uses a light that flashes through the viewer's eyes and assesses the pupil response to this stimulus (constriction and dilation). The pupil response time is used to assess driver impairment such as lack of sleep [22, 29].

Source: Adapted from Drews et al. (2020).

Table 2.4 Other human factors issue

Human Factors Issues	Possible Explanation
Lack of acceptance	Fear of monitoring, lack of interaction between human and machine, and possible false alarm creates a lack of trust
Problems with the integration of warnings and alarms	Limited research in this area, particularly in the mining industry
Lack of technology standardization	Challenging for the user to use; different companies develop different products in the same area
Inadequate operator and maintainer training and support	Lack of training time and materials
Over-reliance on the technology	Technology provides data that involves human behavior and could be unpredictable
Organizational issue	Administrative barrier; new technology can change the nature of the task
Outside of the system control	Operators feel they are not in control; lack trust
Behavioral adaption/ risk homeostasis	The introduction of new technologies results in more risky behavior

Source: Adapted and analyzed from Horberry and Lynas (2012).

CHAPTER 3

METHODOLOGY

As mentioned, this research aims to understand fatigue awareness, characteristics of fatigue, actions that have been taken against fatigue, and the social acceptance of technology that has been integrated to monitor fatigue. We proposed a mixed method of traditional quantitative and qualitative approaches to reach our objective. The hybrid process helps identify different layers and explanations tailored to a research study (Brannen and Moss, 2012). The majority of the quantitative research section is statistical survey results. The qualitative section of this research includes the literature review, focus groups, survey, and discussion interpretation. This method often contains in-person focus groups and data to analyze respondents. We also wanted to study the general background of fatigue, the impact and consequences of fatigue, and human factors so that we could generate ideas to use in analysis of the focus groups, survey, and data interpretation. The mixed methods (the summary from the literature review and the results of the focus group and surveys) are compared, with interpretations.

3.1 Literature Review—Key Concepts

The literature review in Chapter 2 includes a general overview of health and safety management implemented in the mining industry, fatigue impact and consequences, current FMSs, and the human factors of adopting FMSs. The literature review is divided into six sections listed below: (refer to Chapter 2 for elaboration)

1. Mining health and safety management
2. General background on fatigue and impact
3. Contributing factors of fatigue
4. Impact/consequence of fatigue
5. Modeling and managing fatigue
6. Human factor and adopting fatigue monitoring

As mentioned in Chapter 2, fatigue management is becoming popular due to increased consideration of HTDs' fitness for duty during their shift. In this research, we learn to understand fatigue and perform an analysis through literature review. In Chapter 2, we explored endogenous and exogenous variables and their contributions to fatigue. Our bodies respond to both types of variables in exhibiting fatigue behavior. Commute time and shift schedule are exogenous variables that can influence endogenous variables. Because of lost sleep time, an HTD may suffer the internal physiological impacts and consequences of fatigue. To monitor and predict fatigue, FMSs monitor physiological fatigue signals to better understand operators' fitness for duty. Considering the increase in FMS usage, we need to understand the interactions between humans and machines to promote a user-centered acceptance of monitoring systems.

3.2 Data Collection

The data collection for this research is from focus groups and surveys. The focus groups' conversations were recorded and transcribed. The transcription was then analyzed to develop larger-scale survey questions. The data collection aims to identify HTDs' preferences regarding fatigue management, and their perception of FMSs.

3.2.1 Focus Groups

An oversight focus group with several HTDs discussed the research topic as another way to explore fatigue management in mines. This part of the research is based on the study by Drews et al. (2020). The focus groups were conducted in 2019 at mine sites in the western US. Each focus group consisted of 5 to 7 participants, with a total of eight focus groups. The participants volunteered to participate in the University of Utah Institutional Review Board-approved study. All participants were HTDs at the time of the focus groups.

A focus group is a form of qualitative statistical approach. Qualitative data are contextual analysis, providing information and understanding of the subject (Ritchie et al., 2013). In this case, the information is from the participant's perspective. Qualitative research remains open-ended and the data are used to develop themes. This research method focuses on exploration and discovery of data through participation in a natural, interactive setting (Campbell, 2014). The goal of a focus group is to give participants a voice to share their experiences and thoughts. Those conducting the groups encouraged participants to share without feeling constrained or wronged. Each focus group lasted about 45-60 minutes with questions and answers relating to the topic. Recordings and the names of participants remain confidential so that participants would feel safe to share their thoughts.

While drafting the questions to ask the focus group, we identify five focal points of HTD fatigue management (Figure 3.1):

1. Recognition
2. Precursors
3. Time course
4. Strategies
5. Company Approach

3.2.1.1 Recognition

We wanted to understand how HTDs recognize fatigue episodes. There might be body reactions and signs that alert the HTD to fatigue, such as yawning, watery eyes, rubbing eyes, or head nodding. Also, we wanted to know which characteristics were more severe than others; for example, eyelids drooping can cause the HTD to stop looking at the road and swerve. We further asked, how is their driving affected when they are fatigued? Do they recognize the risks and dangers of drowsy driving?

3.2.1.2 Precursor

The precursor questions focus on understanding the contributors to fatigue (during or outside work) and how those affect HTDs' fitness for duty. We wanted to understand the contributing factors to HTDs' fatigue. Every HTD varies in how they come to work and what they do in their own time. A good night's sleep verses a lousy night's sleep can significantly impact driving ability the next day. There are also elements of the HTDs' working environment that might cause them to feel fatigued, such as the monotony of driving uphill loaded or the temperature of the cab. Some factors might have a more significant effect than others.

3.2.1.3 Time Course

The time course questions dive deeper into the timing of fatigue episodes. We wanted to apprehend the course of fatigue between day and night shifts. For example, how long into the shift do they notice fatigue becoming a problem? Are there differences between day and night shifts? If they feel tired, how long do these fatigue episodes last? And how long does it take for HTDs to realize that they need to take a break or stop?

3.2.1.4 Strategies

HTDs cannot escape feeling fatigued during their 12-hour shift; it is essential to understand what they do to combat and manage fatigue. We wanted to determine the personal approach each HTD uses when in the cab. Because fatigue could influence them physically, cognitively, behaviorally, and psychologically, there might be a practical solution that HTDs are currently employing. We wanted to understand the effectiveness of their personal fatigue management.

3.2.1.5 Company Approach

After understanding HTDs' approaches toward fatigue, we want to know the company's approach. There are many approaches that companies put in place to assist and monitor fatigue; for example, shift schedules, policies, and FMSs. We wanted to focus on general acceptance or resistance toward these approaches. It is also essential to know if HTDs would accept other FMSs.

<u>3.2.1.6 Core Organization</u>

The focus group discussion and results are based on Drews et al. (2020). After identifying the five cores of fatigue, the focus group discussion questions covered the following topics:

- What factors affect the frequency and severity of fatigue episodes experienced by operators?
- What are the best practices operators used to reduce the number of fatigue episodes?
- What are effective strategies to address fatigue?
- What are the operators' understanding of mine specific in use fatigue monitoring technology?

These topics covered the factors that lead to fatigue episodes, practices and strategies to combat fatigue, and the HTDs' understanding of fatigue monitoring technology. We believe these questions examine how HTDs recognize and combat fatigue and their perspective on FMSs. The discussions were recorded for analysis purposes. Field notes were also taken to complement the audio. The meetings were held in a closed-door setting for privacy. Participants were encouraged to voice their opinions without pressure. The researchers share the discussion contents only; the results and analysis are later discussed.

3.2.2 Survey

The survey was developed from the focus group summaries and results. The survey questions aligned with the focus group findings and research. While interpreting the focus group discussion results, we strove to be as objective and neutral as possible with the qualitative data. The survey dives into associated topics from the discussion and asks participants to rank current FMSs based on mine sites' usage and preference. In terms of monitoring systems, the list that was ranked included SmartCap, Guardvant, Fitbit, other systems, and no monitoring system. This ranking section was designed to gain understanding of HTDs' acceptance of FMSs. Participants who preferred no monitoring system were asked about their fatigue management approach. The survey aimed to find HTD preferences for minimizing fatigue during shifts.

The survey was distributed to a larger pool of participants at four mine sites throughout 2019. It consists of 302 participants (n=302), and all were HTDs during the survey. Table 3.1 shows the survey's distribution with the number of participants from each mine site.

The first part of the survey asked participants to rank fatigue factors from least to most challenging to minimize, based on the effectiveness of their personal fatigue management: shift work, rapid day-to-night shift rotation, social activities, family demands, long commute, and financial concerns/working another job. HTDs were asked to rank the level of each challenge from extremely challenging (1) to not challenging at all (5).

The next part asked participants to assess the effectiveness of their personal approaches to minimizing fatigue at home and at the mine. The focus group commented on various approaches used during work: drinking coffee and energy drinks, taking stimulants or medications, talking over the radio, listening to the radio/music, changing cab temperature, taking a quick break to move around, and taking a short nap. For approaches in the home, they listed: taking sleeping aids, getting full rest before work, exercising regularly, eating healthy food, and setting up a blackout room. The HTDs were asked to rank the level of effectiveness from extremely effective (1) to not effective at all (5).

Then, the survey asked the HTDs to rank the mines' organizational approaches to fatigue management. First, they were asked about their companies' approaches to minimizing fatigue: educational materials and activities, safety training, work scheduling, fatigue monitoring technology, supervisor check-ins during a shift, and frequent radio contact. Then they were asked to rate the effectiveness of companies' approaches to fatigue management: more but shorter breaks, adding a long (30 minutes) break, permitting a long break upon request (when exceptionally tired), allowing more flexibility in breaks, and making lunch breaks social. For each approach, the HTDs were asked to rank the level of effectiveness. Next, they were asked how their employer could improve breaks during night shifts; the approaches were similar to those given for the last question. For each activity, the HTDs were asked to rank the level of desirability of their employer making each change from strongly agree (1) to strongly disagree (7). The survey results were presented as numbers and entered to an Excel file.

Finally, we wanted to know about HTDs' perceptions of fatigue monitoring technology. We learned from the focus groups that multiple monitoring systems are used in the mines. The HTDs were asked to rank their preferences for fatigue monitoring technologies in the survey. The listed technologies were: Cap/hat for measuring brainwaves (e.g., SmartCap), camera-based systems (e.g., Hexagon, Guardvant, Caterpillar), wrist-based sleep tracking systems (e.g., Fitbit, Readiband), a combination of systems, and no monitoring system. Participants ranked the technology from most preferred (1) to least preferred (5).

The survey also provided a comment section where HTDs could add any suggestions that we failed to mention in the survey.

Due to COVID-19 travel restrictions, we depended on the mine sites to deliver and issue the survey. The survey was distributed by safety and health personnel, continuous improvement groups, and front-line supervisors, and was collected in 2020. The survey was kept anonymous.

The data presented in the survey are expressed in numbers rather than in language (quantitative data). This presents a numerical value that describes the information without being measured or counted. Section 4.1 explains how the quantitative data were analyzed through statistical analysis.

3.3 Data Analysis

The survey's results were returned as numeric measurements and ratings. These measurements underwent statistical analysis to draw observations and inferences. Three variables were used to define one individual member of the HTD population in relation to another (Ali and Bhaskar, 2016). We wanted to examine the responses from different mine sites. There are differences in preferences for personal, organizational, and technological approaches among the mine sites. Next, we were curious about how the perspective of HTDs changes with their driving experience. With these differences, we proposed the mine sites, current job driving experience, and overall professional driving experience as our variables to use in comparing responses.

3.3.1 Variables

The interaction and statistical differences among the variables and the survey responses produce different perspectives for fatigue management. The variables were compared with the survey results through an ANOVA test (Analysis of Variance) to see if the results are significant. The independent variables (IV) of this research are the mine site where an HTD works, their driving experience at their current job, and their overall professional driving experience (Table 3.2). The dependent variables (DV) are the responses affected by the IV. The statistical significance determines if the result and variables are meaningful and interact with each other (Tabachnick and Fidell, 2007).

3.3.1.1 Mine Sites

Four mines provided access to their employees for this study; these mine sites are located in the western US. Each mine is located in a different part of the city, with various demographics unique to each mine site. For example, one mine is located close to an urban area with a large metropolitan center, while the other three are in more remote, rural areas.

3.3.1.2 Current Driving/ Professional Driving Experience

The initial part of the survey also asks for the participant's demographic information, including their current job experience (CJE), total professional driving experience (PDE), and sex. We believe that the driving experience of an HTD influences how they replied to the survey on fatigue management. We also believe that HTDs likely change or improve their tactics against fatigue as their driving experience increases.

This research provides two types of statistical analysis:

- Descriptive Statistics
- Inferential Statistics

We are confident that these statistical methods can draw meaningful interpretations from the reported survey findings.

3.3.2 Descriptive Statistics

Descriptive analysis summarizes and describes data to help readers understand a specific aspect of the data; the analysis provides observations and summaries of the sample, which can help identify patterns in the responses. We focused on response patterns and described the essential characteristics of survey responses that supported the topic of interest. Then, we drew a simple conclusion and case study from the sample (Conner and Johnson, 2017; Pérez-Vicente and Expósito Ruiz, 2009).

3.3.3 Inferential Statistics

In contrast to descriptive statistics, inferential statistics study whether there are differences between groups (IV and DV) and determine if the differences are unique to the sample (Allua and Thompson, 2009). Further, inferential statistics are grounded on probability theory and verify hypothesis testing. Two statistical tests were used on the survey responses to test the differences between the variables for this research: ANOVA (Analysis of Variance) and Chi-square.

3.3.3.1 Analysis of Variance (ANOVA)

ANOVA tests whether the effect of the variables is statistically significant. This tests the reliability of any association or relationship between the IV and DV (Tabachnick and Fidell, 2007). For this research, statistical significance was calculated using Excel. The p-value for this research is less than 0.05 ($\mu<0.05$). The p-value is a probability value expressing how likely it is that the data occurs by random chance. The dependent variable is null if the calculated value of the IV and DVs is greater than 0.05 ($\mu>0.05$). If the value is below 0.05, the observed difference is statistically significant. Also, it signifies a less than 5% probability that the null hypothesis is correct; the result is not random, and there is a relationship between the IV and DV (McLeod, 2019). We investigate the relationship between a contributing factor and a specific response.

3.3.3.2 Chi-Square

The chi-square test examines the independence of categorical variables and how well the sample fits the distribution (the goodness of fit) (Franke et al., 2011). The test calculates and compares the expected and observed values to establish hypotheses, make interpretations, and reject the null hypothesis. The formula for chi-square statistical analysis is shown in EQ 3.1; the observed value is O, and the expected value is E. The n is the number of cells in the table. The obtained statistical value is compared with a critical value calculated from degrees of freedom (df) for the chi-square, shown in EQ3.2. The r is the number of rows, and c is the number of columns. Like the ANOVA analysis, the p-value for this research is less than 0.05 ($\mu<0.05$). The critical value is found using the p-value and the calculated df on the chi-square distribution table. If the chi-square calculated value (from EQ 3.1) is less than the critical, we accept the null hypothesis; there is no statistical significance to differences in FMS preference. However, if the chi-square value is greater than the critical value, we reject the null hypothesis; the differences in preference are statistically significant. The variables influence each other and are not independent.

The statistical data from the survey are analyzed through RStudio™ and Excel for visualization. The results are evaluated and analyzed to further understand HTDs' recognition of fatigue and fatigue management. The social acceptance of FMSs was also questioned in the ranking section of the survey.

$$\chi^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E} \qquad (EQ\ 3.1)$$

$$df = (r - 1)(c - 1) \qquad (EQ\ 3.2)$$

<u>3.3.3.3 RStudio™</u>

This research's statistical platform is the RStudio™ Integrated Development Environment (IDE). RStudio™ or R is an open software for statistical analysis and graphics; it is similar to other programming languages with extended user-written functions (Vernazi, 2011). R does not have a parallel programming language like Java; it was not developed by software engineers but by statisticians for interactive data analysis (Irizarry, 2020). Figure 3.2 is an example of R's startup panel. The left side is the console for a programming language; the top-right side is the workspace and files. The bottom-right is the R package library. For this research, the R platform is used to develop a Likert scale to illustrate the ranked preferences of participants.

3.3.3.4 Likert Scale

The survey specifically asked the participants to rank their preference for FMSs. A Likert scale was developed to illustrate the results of this feedback. The Likert scale was created in 1932 by Rensis Likert to measure attitudes; respondents are asked to rate the degree to which they agree or disagree with a question or statement. The responses are usually ranked on an ordinal scale, but the distance between these responses is not measurable. For example, “always,” “often,” and “sometimes” are not measurable. The Likert scale is often recommended for attempts to measure less concrete concepts (Sullivan and Artino, 2013). The Likert scale is used for observations and initial understanding of the survey responses.

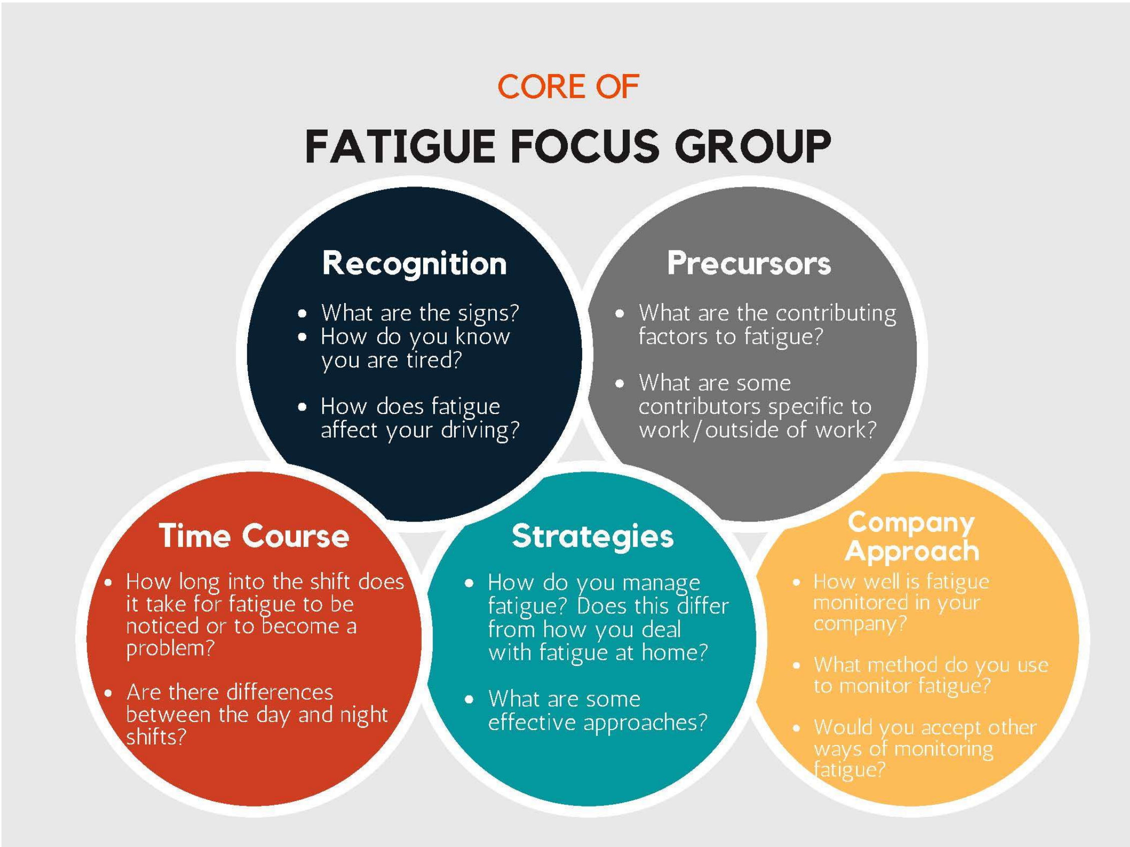

Figure 3.1 Core discussion of the fatigue focus group.

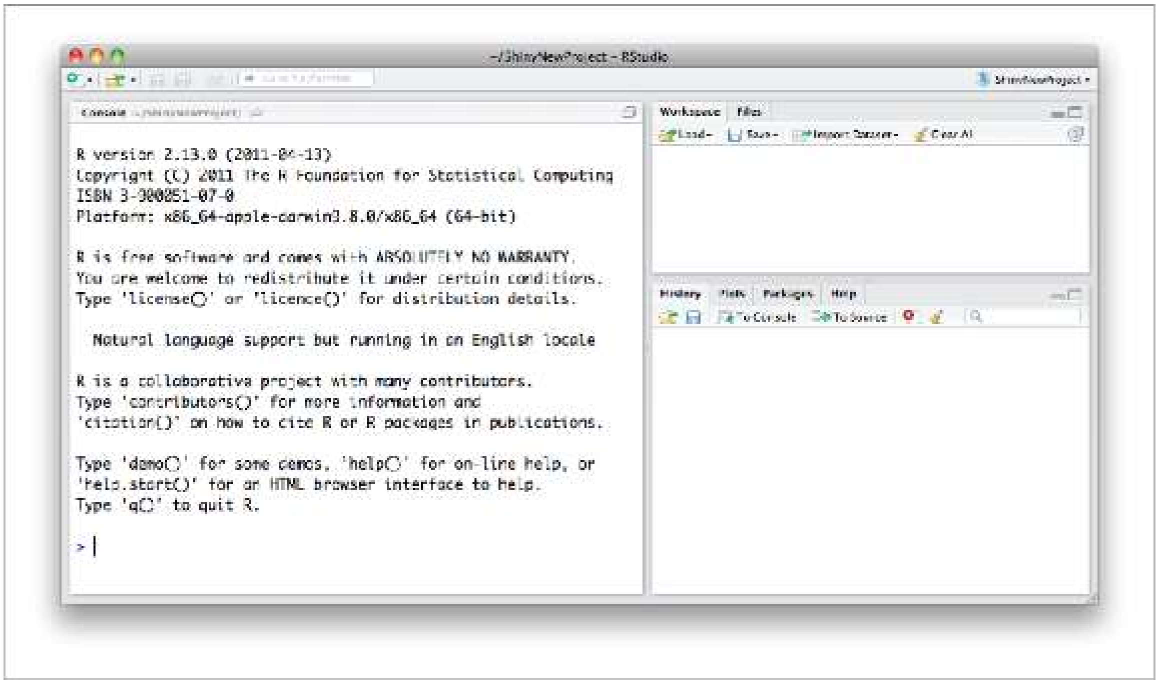

Figure 3.2 R startup panels example. Adapted from Vernazi (2011).

Table 3.1 Mine sites participants

Site	Number of Survey Respondents
Mine site 1	5
Mine site 2	13
Mine site 3	233
Mine site 4	51
TOTAL	302

Table 3.2 Independent variables in the survey

Independent Variable (IV)
Mine sites
Current job experience (CJE)
Professional driving experience (PDE)

CHAPTER 4

RESULTS

4.1 Qualitative Research

As mentioned in Section 3.2.1, the focus group is the form of qualitative research in this study, and the focus group design is based on Drews et al. (2020).

During the focus groups, participants expressed proximal symptoms they would experience during a fatigue episode, such as yawning, rubbing their eyes, microsleep, and feeling weak with no energy. Some HTDs even experience phenomena where they "imagine" things at night. Because of these distractions, HTDs lose their concentration; they feel like they are on auto-pilot. The lack of attention could be associated with cognitive impact from fatigue. Passive fatigue results from an intense cognitive workload with limited physical requirements, such as constant concentration in driving. Section 2.4.3 further discusses the impact fatigue has on cognitive activities. HTDs also noticed their mood and behavior changed when fatigued. For example, their reaction time was slower, they lacked driving precision, and they experienced forgetfulness. As their fatigue increased, they became increasingly "grumpy" or "irritable" and their behavior changed. Section 2.4.4 further discusses the impact fatigue has on behavior.

Besides proximal symptoms, HTDs also mentioned distal factors contributing to fatigue. They emphasized diet practices and how a good diet could help in avoiding fatigue.

Some HTDs listed vegetable snacks, protein bars, and drinks. They pointed out that they avoid junk food, high sugar, or carbohydrates. Another distal factor identified by HTDs is shift schedule. Mandatory overtime shifts limit HTDs' ability to recover from previous sleep debt. Also, the frequent rotation of night and day shifts causes an accumulation of lost rest time. HTDs suggest that a more consistent schedule would avoid the "flip-flop" of day and night shifts. Commute time was also a contributing factor to fatigue. Shift and commute time take up to 16 hours daily, leaving little time for rest and social activities.

After discussing the impact of fatigue, we examined strategies that HTDs use to combat fatigue. They listed cognitive, physical, and social strategies. HTDs suggested listening to podcasts, radio, or music to help them stay cognitively alert. Some proposed practicing mindfulness exercises to combat fatigue. Physical activities mentioned included moving around in the cab, leaving the cab to stretch, or changing the temperature of the cab by opening the window. Lastly, HTDs use social interaction as another strategy to combat fatigue.

In addition to personal fatigue management, we also discussed organizational support. There were mentions of additional break time or vending machines. Most HTD answers are FMSs: Cap/hat (EEG) and camera-based monitoring system (PERCLOS). The feedback on both FMSs was skeptical and low-acceptance. The unintended consequence of false alarms and incorrect measurements is distraction. Others mentioned that they felt they were being "spied on," which creates an invasive environment.

Overall, we learned that HTDs are aware of their fatigue and demonstrate substantial knowledge of fatigue management. Further, HTDs understand the impact of fatigue (cognitive, physiological, behavioral, and psychological) and how it could affect their “fitness for duty.” They also expressed concern about the effectiveness of FMSs; they would prefer less invasive approaches to fatigue monitoring.

We recognize the limitations that we encountered with the focus groups. The results of the focus groups provide details about fatigue management among HTDs. However, the collected data might be biased due to overrepresentation of one type of individual in the focus group. This could limit the generalizability of the results and the represented perspectives of HTDs.

4.2 Descriptive Statistical Analysis

This section studies each survey question using the descriptive statistical analysis method (see Section 3.3.2). The responses are imported into RStudio™ for visualization; then, the initial analysis is studied through the Likert scale. The IV (mine sites, current driving experience, and overall professional driving experience) are compared with the DV (survey responses). Table 4.1 shows the corresponding response choices. The y-axis is the IV, while the x-axis is the responses. The tan colors represent lower number rankings ; the green colors represent higher number rankings. The middle rankings are in grey.

The original survey is located in the Appendix (refer to the fatigue survey document in the Appendix). For example, the Likert scale for challenging factors to minimize fatigue is shown at the end of the chapter (Figure 4.1 - Figure 4.3). Other questions are located in the Appendix.

The first section of the survey focuses on how HTDs personally manage fatigue. The first question asks how fatigue impacts HTDs’ job performance and safety (refer to Appendix). The responses are from no impact (dark tan) to significant impact (dark green).

The IV doesn’t show an extreme distribution. Mine sites 1 and 2 suggest that fatigue has minimal impact on their safety performance; 88% and 77% of participants, respectively, agree that it has minimal or no impact. Distributions based on both current and professional driving experience show approximately half each between no/minimal impact and significant impact.

The next question discusses which fatigue factors are challenging to minimize (Figure 4.1 - Figure 4.3). The ranking order is as follows: extremely challenging (1), very challenging (2), moderately challenging (3), slightly challenging (4), and not challenging at all (5); the color order is dark tan (1), light brown (2), grey (3), light green (4), and dark green (5). Overall, current and professional driving experience show similarities in the ranking of which fatigue factors were challenging to minimize. However, different mine sites show differences in HTDs’ responses. The most challenging factors that HTDs face are long commutes and rapid shift rotation, especially at mine site 3. As HTDs’ driving experience progresses, a long commute becomes a more challenging fatigue factor; 25% of HTDs with less than one year of experience driving professionally and 47% of those with more than 15 years of driving experience suggest that a long commute is challenging; the number nearly doubled. As current and overall driving experience progresses, we observed that the long commute has a greater impact on fatigue; this phenomenon also applies to rapid shift rotation, shift work, and social activities.

The next question asks about the listed personal approaches' effectiveness in minimizing fatigue during a shift. The same color combination and rankings are used (see Appendix). This question shows a similar response pattern across three variables; neither mine site location nor levels of driving experience alter the HTDs’ responses regarding personal approaches. Across all three variables, respondents agree that stimulant medications and talking over the radio are ineffective personal approaches to combating fatigue. Changing the cab temperature and coffee/energy drinks show in the grey area; HTDs feel that these two factors have moderate effects on fatigue. Comparatively, listening to radio music, a quick break to move around, and a short nap are considered the most effective personal approaches to minimizing fatigue.

The next question asked about HTDs' approaches to preparing their shift. The color combinations and effectiveness rankings are similar to the previous questions (see Appendix). We see a similar response pattern across the variables; mine site location and driving experience do not alter the HTDs' responses regarding personal approaches before a shift. We observed that respondents across all three variables agree that sleep aids (such as melatonin) are ineffective for fatigue reduction. As in the previous question, HTDs do not feel that medication (for arousal or as sleep aid) is a practical approach to fatigue reduction. Comparatively, the approach they feel is most effective in preparing for their shift is to get a complete rest before work. As in the previous question, HTDs feel that taking a short nap is a practical approach to reducing fatigue. In other words, resting, taking naps, or sleep are effective fatigue management. Moreover, HTDs seem to agree that blackout rooms, a healthy diet, and regular exercise are practical fatigue reduction approaches before their shift.

The second part of this survey asked how HTDs' employers manage their work fatigue. We wanted to understand how practical the organizational activities are in minimizing fatigue, according to the HTDs. These activities include educational materials and activities, safety training, shift schedule changes, fatigue monitoring technology, supervisor checks during the shift, and frequent radio contact with dispatch (see Appendix). The pattern across the three variables is similar; however, there are some differences in the fatigue monitoring technology category. Different mine sites have different FMSs, affecting the survey result. Mine sites 1 and 2 have no FMS; mine site 3 uses PERCLOS, developed by Hexagon, to detect fatigue through facial behavior. Mine site 4 uses a cap/helmet, utilizing EEG technology to detect fatigue through brainwave activity (see Section 2.5.1.2). About 80% of Mine site 1 HTDs suggested that including new FMSs would not effectively minimize fatigue. This could imply either that mine site 1 does not acknowledge the effectiveness of any technologies or that PERCLOS is sufficient for monitoring fatigue. Mine sites 2 and 3 do not have any FMSs; however, more than half of their HTDs do not believe installing FMSs would be effective. 51% of HTDs in mine site 4 recognize that new FMSs would be moderately effective; 20% of HTDs believe new FMSs would be better than EEG, and 29% favor no technologies. In contrast, at mine site 3, only 9% of HTDs felt that new FMSs would be effective; this could reflect how mine site 3 HTDs view PERCLOS; 69% of HTDs believe new FMSs would have no effect at all.

The next question asked how desirable the listed organizational approaches are in helping to manage fatigue (see Appendix). These approaches include frequent shorter breaks, adding longer breaks, permitting long breaks upon request (for the exceptionally tired), allowing flexibility in break timing, and making lunch break social (enabling hanging out with others). This question asks about HTDs' breaks and shift scheduling and how desirable these factors would be. 96% of HTDs in mine site 4 agree that permitting long breaks upon request is desirable to improve fatigue. On the other hand, 60% of HTDs in mine site 3 find frequent shorter breaks are more desirable than longer breaks. Looking at

CJE as a variable, those with job experience of less than one year do not find longer breaks as desirable as those with more than one year of job experience do.

The next question asked HTDs to rank the current FMS based on their preference or experience. The figures for this section are not in the Appendix but in Section 5.3 . The listed options included cap/hat measuring brainwaves (e.g., SmartCap), camera-based systems (e.g., Hexagon, Guardvant, Caterpillar), wrist-based sleep-tracking systems (e.g., Fitbit, Readiband), a combination of systems, and no monitoring system. Across the three variables, HTDs prefer no monitoring system while driving. Further, as driving experience progresses, more HTDs prefer no monitoring systems; this could suggest that as their experience grows, HTDs develop fatigue management strategies and feel that they do not want to rely on FMSs. Also, FMSs can take the form of intrusive monitoring that gives HTDs an uncomfortable feeling of being “watched-over” by their employer. Surprisingly, 90% of HTDs from mine site 4 feel comfortable with a wristband tracking system. A wristband is a contact monitoring system; it directly measures heart rate and gathers data about fatigue patterns. A wristband is considered noninvasive enough that HTDs can go on with their daily lives without feeling “watched-over,” studied, or analyzed, as long as their information remains private.

The survey’s final question asks how the HTD’s employer could improve their breaks to minimize fatigue during the night shift. The given approaches in this question are the same as in question 10 (see Appendix). However, this question focuses on improving breaks during the night shift. The survey results for this question were relatively similar to the previous question. We understand that HTDs feel indifferent about breaks between the day and night shifts.

4.3 Inferential Statistical Analysis

The following sections describe the inferential statistical analysis implemented in analyzing the survey results.

4.3.1 ANOVA (Analysis of Variance) Test

As explained in Section 3.3.3.1, an ANOVA test is performed for each factor with all three variables (mine sites, CJE, and PDE) and the responses; that way, we can understand the relationship between the IV and DV. The test is performed and calculated using Excel software. After the ANOVA test, p-values less than 0.05 ($\mu<0.05$) are documented (Table 4.2 - Table 4.4). Other DVs display a p-value less than 0.05; however, in this research, we focus on repeated variables among the IV. Long commute, shift work, and new fatigue monitoring technologies are the variables that are repeated among the IV. These variables are further discussed in Sections 5.1 to 5.3 .

4.3.2 Chi-Square

The chi-square method is used on question 11, asking HTDs to rank FMSs based on their preference. As mentioned previously, the chi-square test examines the independence of the categorical variable (Franke et al., 2011) and compares the expected and observed values to establish hypotheses, interpret data, and reject the null hypothesis (see Section 3.3.3.2).

We counted the number of each preference ranking for each listed FMS category (1: most preferred; 5: the least preferred). For example, we counted ten 1's in the Cap/Hat category. Table 4.5 shows the aggregated data for the chi-square calculations. The steps were repeated for each category and preference; these are the observed values. We calculated the expected value using the summation of the column and row values. As expected, the sum of the expected values is 0.2 (20%). Since there are five categories, the chi-square theory proved that the expected value from each category would be 20% (Table 4.6). The df is calculated with EQ 3.2, which is 16. Using the df, we looked up the critical value on the chi-square table and found 26.3. Then using the value from Table 4.7, the sum of the chi-square value (EQ 3.1) and the final chi-square value is 576.47. We reject the null hypothesis since the chi-square value is greater than the critical value. The variables might influence each other; they are not independent.

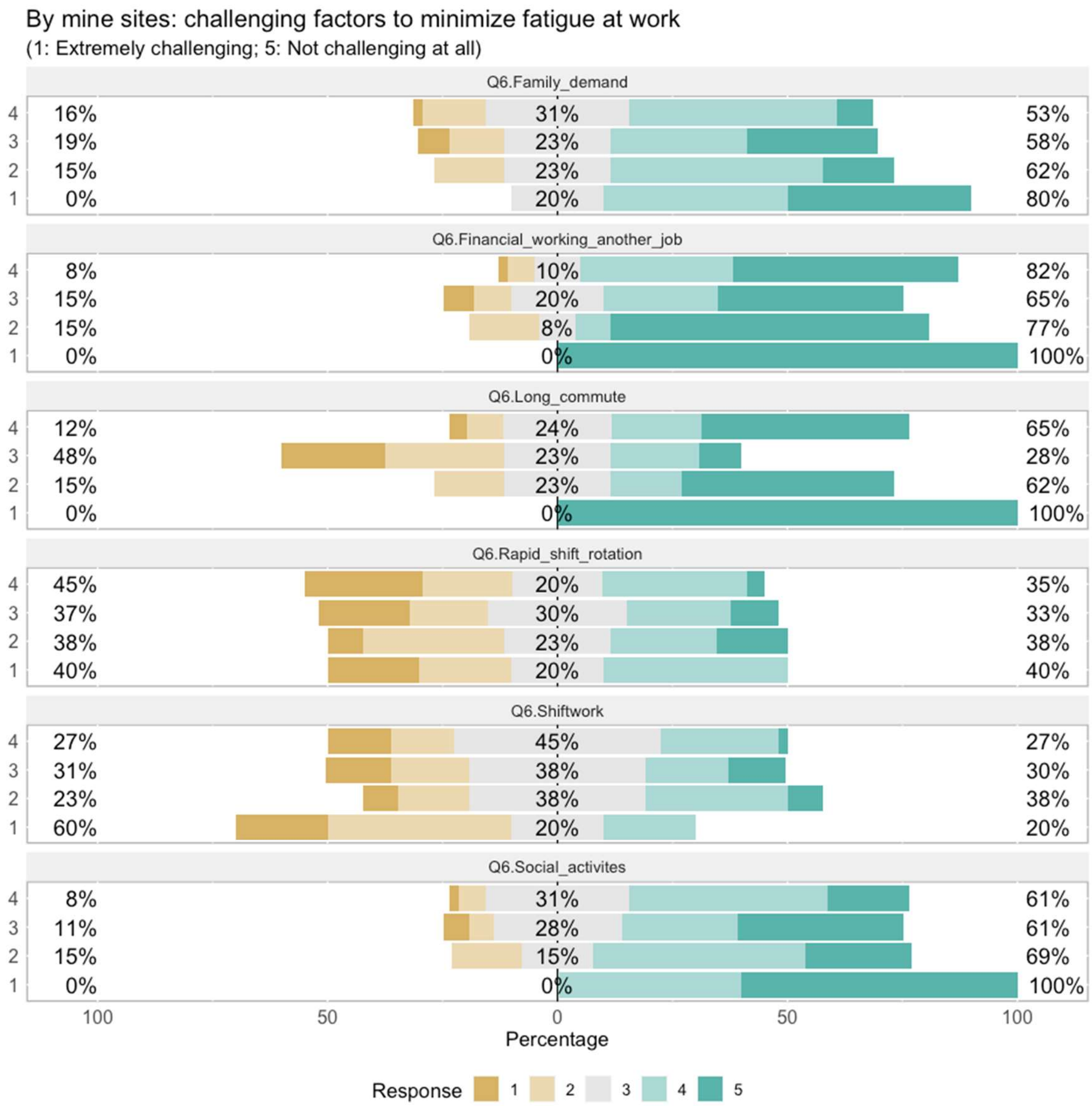

Figure 4.1 Challenging factor for minimizing fatigue at work by mine sites.

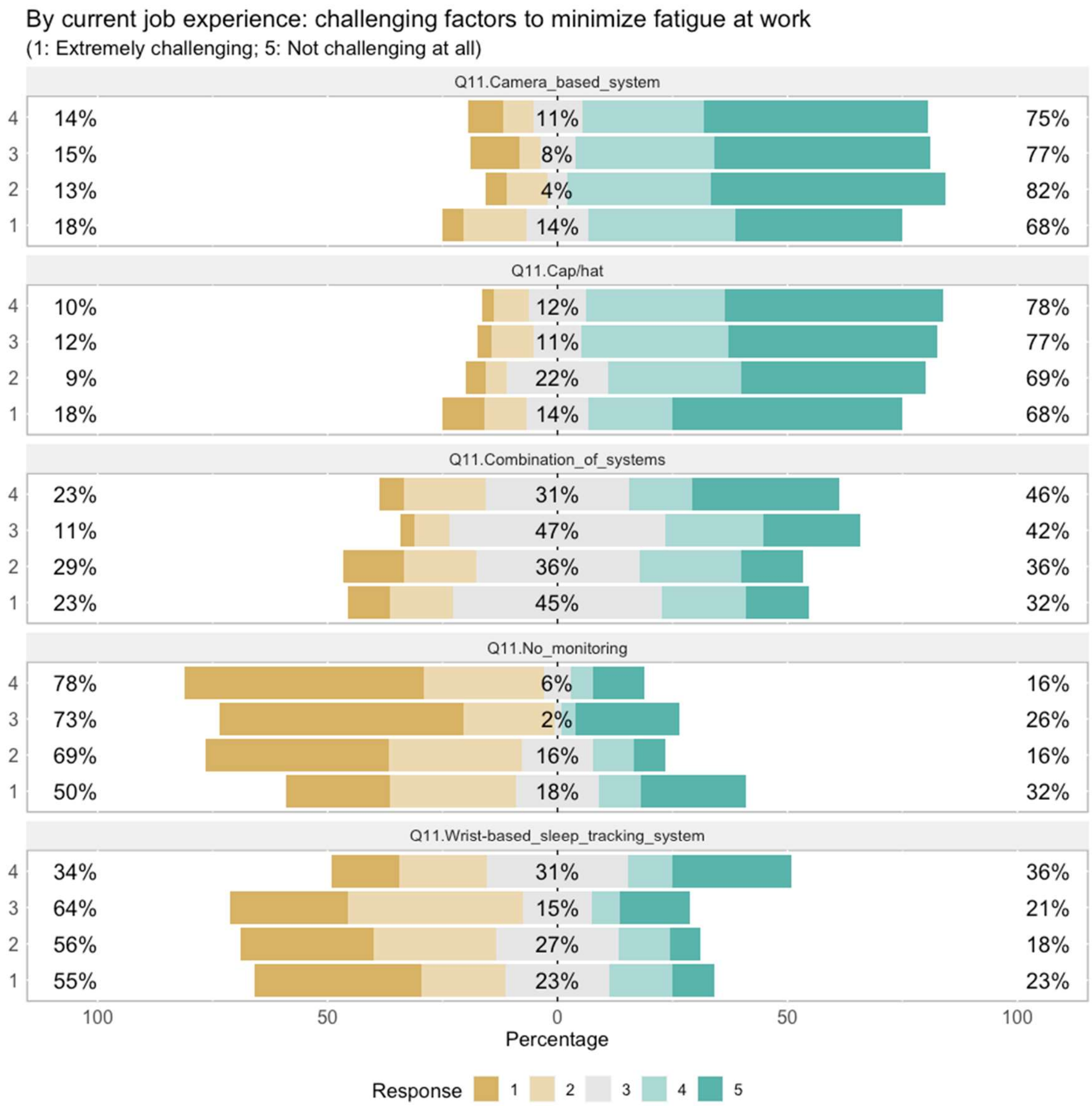

Figure 4.2 Challenging factor for minimizing fatigue at work by CJE.

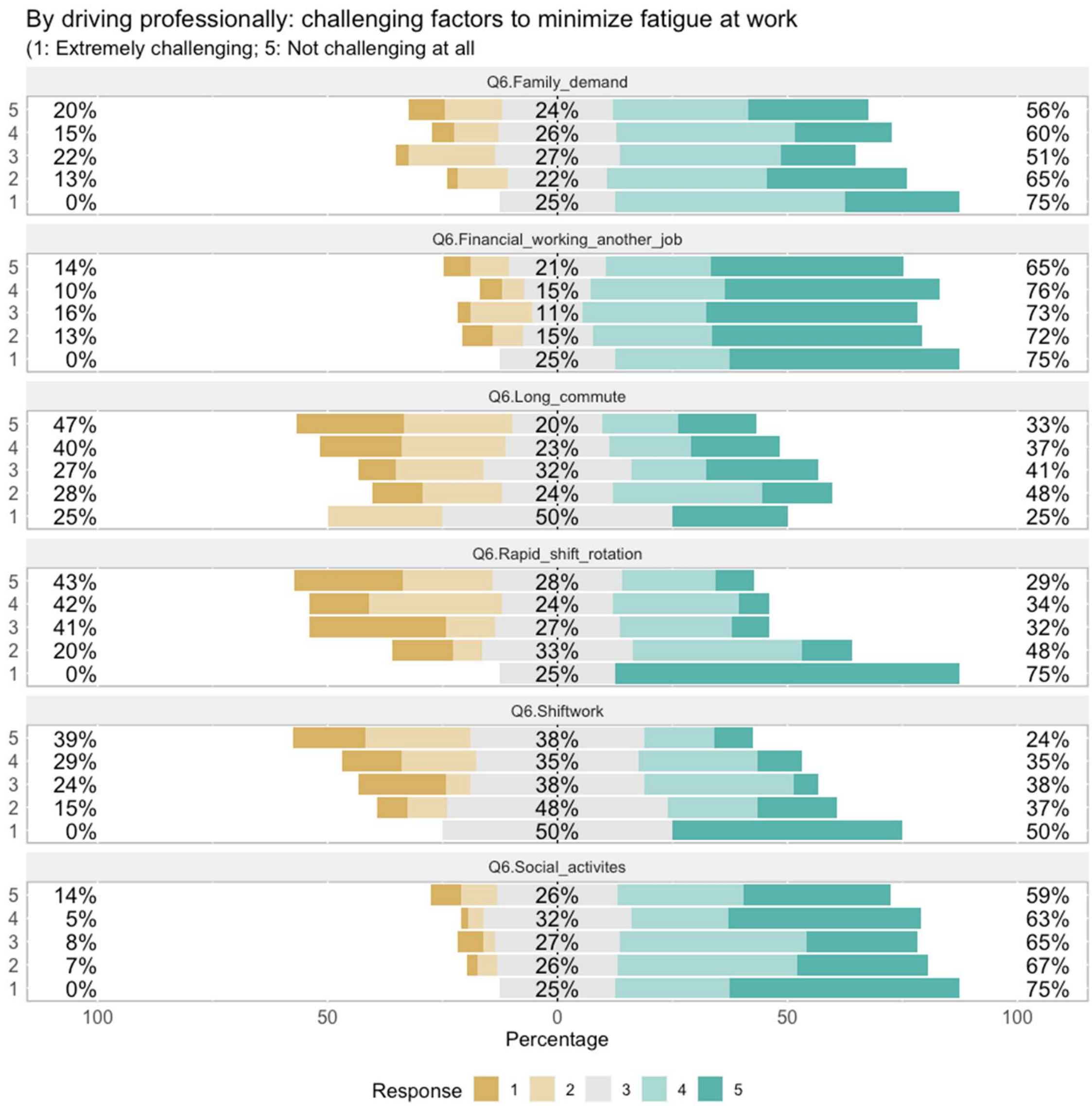

Figure 4.3 Challenging factors for minimizing fatigue by PDE.

Table 4.1 Independent variables with their corresponding explanations

Ratings	Independent Variable (IV)		
	Mine site	Current job experience	Professional driving experience
1	1	Less than one year	Less than one year
2	2	1-2 years	1-5 years
3	3	3-4 years	6-10 years
4	4	Five or more years	11-15 years
5	N/A	N/A	More than 15 years

Table 4.2 Mne site as variable

Factor	ANOVA P-Value ($\mu<0.05$)
Long commute	3.13E-13
Financial: working another job	0.0161
Full rest prior to work	0.0199
Eat healthily	0.0289
New fatigue monitoring technology	3.95E-07
Frequent radio contact with dispatch	0.00336
More shorter breaks	7.69E-06
Permit long break upon request	8.81E-05
Making lunch social	0.000142
Organizational: more shorter breaks	2.15E-07
Organizational: permit long break upon request	0.000745
Organizational: making lunch social	0.000366

Table 4.3 Current job experience as variable

Factor	ANOVA P-Value (μ<0.05)
Shiftwork	0.00831
Rapid shift rotation	0.0482
Long commute	0.0351
Short nap	0.0247
Educational material activities	0.000596
Safety training	0.000403
New fatigue monitoring technology	0.00234
Supervisor check during shift	0.0295
Permit long break upon request	0.0364

Table 4.4 Driving experience as variable

Factor	ANOVA P-Value (μ<0.05)
Shiftwork	0.0170
Rapid shift rotation	0.00596
Listen to radio music	0.0293
Changing cab temperature	0.000677
Quick break to move around	0.00662
Sleep aids	0.0215
Eat healthily	0.00460
Blackout room	0.0184
New fatigue monitoring technology	0.0257
Supervisor check during shift	0.00899

Table 4.5 Observed value for FMS preference

Ratings	Cap/Hat	Camera-based system	Wrist-based sleep-tracking system	A combination of systems	No monitoring system	Total
1	10	23	63	19	146	261
2	23	21	73	45	76	238
3	41	28	79	110	22	280
4	89	86	28	51	16	270
5	139	144	59	77	42	461
TOTAL	302	302	302	302	302	1510

Table 4.6 Expected value for FMS preference

Ratings	Cap/Hat	Camera-based system	Wrist-based sleep-tracking system	A combination of systems	No monitoring system
1	0.0346	0.0346	0.0346	0.0346	0.0346
2	0.0315	0.0315	0.0315	0.0315	0.0315
3	0.0371	0.0371	0.0371	0.0371	0.0371
4	0.0358	0.0358	0.0358	0.0358	0.0358
5	0.0611	0.0611	0.0611	0.0611	0.0611
TOTAL	0.2	0.2	0.2	0.2	0.2

Table 4.7 Calculated chi-square value for FMS preference

Ratings	Cap/Hat	Camera-based system	Wrist-based sleep-tracking system	A combination of systems	No monitoring system
1	34.1	16.3	2.2	21.1	168.6
2	12.7	14.9	13.6	0.1	16.9
3	4.0	14.0	9.4	52.1	20.6
4	22.7	19.0	12.5	0.2	26.7
5	23.8	29.1	12.0	2.5	27.3

CHAPTER 5

DISCUSSION

In this section, we further study these DVs (long commute, shift work, and FMS) with the IV and the background of the mine sites. The specific rating and explanations are shown in Table 4.1. The selected dependent factors are those that repeated across the ANOVA test with the given IV with a statistically significant value of less than 0.05 ($\mu<0.05$). Table 4.2 - Table 4.4 show the p-value of each factor with the IV. Between mine sites and CJE, the repeated factor is the long commute. Between CJE and professional driving experience, the repeated factor is shift work and other shift-schedule-related factors; we consider both factors as shift work. New fatigue monitoring technology has a p-value less than 0.05 and is repeated across the three IV. We will not further discuss this factor; however, we study the FMS preference to understand why new fatigue monitoring technology is repeated.

We also drew conclusions by considering the selected factors; we believe the background of the mine sites prompts the survey results. For example, in understanding the long commute, we consider travel time based on the distance between the HTD's home (a residential area) and the mine site; and, therefore, we conclude how commute time could impact HTD's fatigue. Shift work is complex and differs across mine sites. To simplify, we assumed that all four mine sites have a 10-12 hour day-night shift. Different mine sites and driving experiences would result in different perspectives on how shift work could impact fatigue. And finally, we sought to understand the socio-technical perspective of FMSs based on the FMS preference rating section of the survey; therefore, we considered which mine sites used which FMSs and compared the rating results. Table 5.1 summarizes the backgrounds and considerations of the mine sites.

During the summer of 2021, I had an opportunity to intern in one of the large-scale mining companies in the western US. I shadowed a haul truck driver and had a chance to ride inside the haul truck. This company uses a camera-based FMS to capture eye movement (see Section 2.5.1.1). The driver had six months of driving experience on the site and six months of training (at that time). He revealed that he eats snacks to stay awake. If circumstances call for it, he calls in for a quick break or a short nap. Unlike the HTDs with whom I had conversed in the focus groups, he indicated that he did not mind the current fatigue technology the company was using. The idea of a camera in the cap is somewhat awkward; however, he does not feel that the FMS is intrusive as long as it does its job. He also expressed that he is a night person and feels that the shift work is working for him. After conversing with him, I perceived that he was optimistic about being an HTD; he seldom complained about FMSs, shift work, or the commute time. In comparing our research data, we find that HTDs with less driving experience have expressed that fatigue factors are less challenging. For example, regarding which fatigue factors are most challenging to minimize (Figure 4.3), only 25% of HTDs with less than one year of driving experience indicated that a long commute was very challenging. Meanwhile, 47% of HTDs with more than 15 years of experience indicated that a long commute was an extremely/very challenging factor. The percentage nearly doubled.

A similar pattern emerged for shift work. HTDs with less than one year of driving experience did not feel that shift work was a challenging factor; in fact, 50% considered shift work not challenging at all. However, as driving experience increased, shift work came to be considered more challenging. 39% of HTDs with more than 15 years of experience indicated that shift work was a challenging factor. The survey suggested that HTDs with more experience tend to recognize what challenging factors are affecting their fatigue at work.

5.1 Long Commute

Depending on the ore depository, some mine site locations are far from urban and residential areas, impacting commute times for mine workers. The long commute can lead to cognitive fatigue and drowsiness, increasing the risk of driving accidents during work shifts and when traveling back home. On average, workers in the mining industry have the longest commutes of any industry (T. J. Bauerle et al., 2021). In a 2018 analysis of five fatalities involving haul trucks in Indonesian coal mines, the root causes for these accidents were found to be cell phone usage due to boredom, monotony or cognitive fatigue, drowsiness due to long commute times, and shift schedules (T. J. Bauerle et al., 2021; Sudiyanto et al., 2018).

Section 2.3 discussed the impact of long commute time on HTDs' fatigue; commute time is an exogenous variable, meaning its impact is on the outside of the body. Di Milia et al. (2011) suggested that a longer commute disrupts sleeping time, leading to HTD fatigue. During our focus groups, HTDs recognized that commute time contributed to fatigue (Drews et al., 2020). Depending on the location of their home in relation to the mine site, HTDs must plan their departure and arrival times according to their commute; therefore, some HTDs lose rest and other personal time.

The HTDs surveyed also responded that a long commute is a challenging fatigue factor to minimize, which supports the impact of a long commute mentioned previously (Section 4.2 and Figure 4.1) We observed that HTDs at different mine sites have different responses to long commutes. As their current driving experience progresses, HTDs increasingly feel that a long commute impacts fatigue. Also, the ANOVA test shows that a long commute has a statistically significant relationship with mine site and CJE (μ = 3.13E-13 and μ = 0.0351, respectively) (Table 4.2 and Table 4.3). We decided to study the location of the actual mine site in the nearest urban area: mine sites 1 and 2 are located moderately close to an urban city. Mine site 3 is located in a remote area; mine site 4 is very close to a city (Table 5.1). Table 5.2 contains the travel time between mine sites and residential areas. Mine site 4 is very close to an urban area even though it has more travel time; there are residential areas along the commute. We also assume the average number of HTDs who travel to a more extensive residential area. The survey result shows correlations between the different mine site locations and difficulty minimizing fatigue during work (Figure 4.1).

Examining the figure, the far-left numbers represent the mine sites, and the responses are color-coded according to the corresponding rating of how challenging a factor is (see Section 4.2 for descriptive analysis). HTDs from mine sites 1, 2, and 4 did not find commute time to be as challenging as those from mine site 3 did. Only 15% of mine site 2 HTDs and 12% of mine site 4 HTDs felt that a long commute was a challenging factor. Since mine site 3 is remote, nearly half (48%) of HTDs felt that a long commute was a challenging factor. This supports the argument that HTDs lose rest and personal time due to long travel time. HTDs must find ways to compensate for their lost time. The lost rest or sleep time increases sleep deprivation.

On the other hand, considering PDE as a variable, there is a slight increase in HTDs' feeling that a long commute is a challenging factor as their experience increases (Figure 4.3). Only 32% of HTDs with less than one year of experience feel that a long commute is a challenging fatigue factor to minimize; 46% of HTDs with more than 15 years of experience feel that a long commute is challenging. The other details of this variable and responses are shown in Figure 4.3; this suggests that the more experienced the HTD is, the more they feel that a long commute is a challenging fatigue factor to minimize.

5.2 Shiftwork

In the mining industry, shift work is common in workers' schedules due to the mine's 24-hour operation. Shift work includes work outside of regular daylight hours (e.g., 7 am to 6 pm) to compensate for the mine's operation hours (Murray and Thimgan, 2016). An HTD is considered a shift worker due to their 10-12-hour shift. Individuals with shift work have challenges balancing life activities such as family and social needs, other work opportunities, and leisure or rest time; these activities rarely coincide with time away from work (Ferguson et al., 2010). Other shift-related contributing factors include mandatory overtime shifts that limit the worker's ability to recover from sleep deprivation (Drews et al., 2020). In addition, Ferguson et al. (2010) suggested that shift work imposes physiological challenges such as sleep deprivation and circadian rhythm disruption (see Section 2.4). Studies also suggest that to maintain positive work performance, workers should receive more than 6 hours of sleep consecutively (Ferguson et al., 2010). During our focus group, a common topic was the frequent rotation of shift work between night and day and the “flip-flop” of days to nights. Many expressed that they would prefer a consistent shift schedule with fewer changes. To compensate for the loss of sleep from the night shift, HTDs set up black-out rooms in their homes. For example, these rooms have black-out window shades, low temperatures, and noise-canceling earplugs (Drews et al., 2020).

Further, we observed a correlation between long commutes and shift work time. HTDs objected that shift schedule time, with the addition of the commute, results in 16 hours of work plus traveling. This leads to fewer hours for family, social, and sleep time (Drews et al., 2020). Thus, shift work with inadequate sleep from unbalanced life activities leads to fatigue-related episodes. Also, the accumulated sleep debt can impact cognitive and physical performance and increase the risk of errors and accidents in the workplace and on the road. This then can raise questions of the HTD's fitness for duty.

After observing the ANOVA result, we found that shift work does not show statistical significance with mine site as IV ($\mu < 0.05$). We assume the same shift schedule across mine sites (10-12 hours per shift). However, shift work shows statistical significance with CJE and PDE ($\mu = 0.00831$ and $\mu = 0.0170$, respectively) (Table 4.3 and Table 4.4). We decided to study the Likert scale among the CJE and PDE variable results. Only 18% of HTDs with less than one year of CJE find shift work to be a challenging fatigue factor to minimize. Approximately 41% of HTDs with five or more years of CJE feel that shift work is challenging. We also observe a similar pattern under PDE as a variable. 0% of HTDs with less than one year of PDE feel that shift work is challenging, while 39% of

HTDs with more than 15 years of experience feel that shift work is challenging. The result is in accord with a conversation I had with an HTD with only six months of driving experience; this particular HTD did not feel that shift work significantly impacted his fatigue. He was optimistic about his schedule and was growing to accept his new lifestyle. As the HTD's driving experience progress, shift work becomes a more challenging cause of fatigue to minimize. Also, during the focus group, experienced HTDs shared that the shift schedule is a challenging factor; they expressed that they have a hard time driving at night.

On the other hand, HTDs with less experience driving shared that they are neutral about the shift schedule. They revealed that breaks, snacks, or entertainment could resolve fatigue issues. An HTD's driving experience can be an endogenous and exogenous variable that affects the HTD. The shift schedule is an exogenous variable; it affects the outside of the HTD's body. As mentioned, most HTDs would identify as either a night person or morning person, which is an endogenous factor. A night person would be more amenable to a night shift than a morning person, so their sleep quality would be different. Another explanation for the difference in attitudes between those with more experience and those with less experience might be that those with more driving experience have encountered more night shifts. Therefore their bodies have experienced more inadequate sleep and fatigue. Increased driving experience also indicates older age, which is an endogenous variable; a younger body (or less driving experience) might have more tolerance toward an inadequate sleeping schedule (see Section 2.3).

5.3 Fatigue Monitoring System (FMS) Preference

In Section 2.5, we discussed ways that mining companies manage fatigue and determine the "fitness for duty" of their HTDs. There are a fair number of standardized tests and self-evaluations used in regulating fatigue. Monitoring physiological responses has become a way of measuring fatigue; some larger-scale mine sites incorporate FMSs for better surveillance and evaluation of "fitness for duty." The types of monitoring technologies are discussed in Section 2.5.1. Drew et al. (2020) discussed FMSs in a focus group setting. Participants (HTDs) argued that the EEG (or caps) and camera systems give false alarms; when they are awake, it alarms them, and when they are asleep, it does nothing. The alarms would try to "wake up" the HTD by vibrating the seat and initiating auditory alarms. Because of the false alarms, HTDs are skeptical toward caps. Some HTDs expressed that fatigue technology is still limited and lacks predictive capabilities that it claimed to have with delayed alarms. Other false alarms the participants mentioned occur when an HTD turns to look at the side-view mirror or inside the cab, with their eyes and head averted away from the camera, or when the cap cannot detect brainwaves. Because of false alarms, participants worried that the monitoring system has the potential to become a distraction (see Section 2.5).

As mentioned in Section 2.6, human factor engineering should increase safety, reduce fatigue and stress, increase comfort, increase user acceptance, increase job satisfaction, and improve quality of life. The focus groups and surveys give insight into whether the current fatigue monitoring technologies are meeting these requirements according to HTDs' perspective.

The results of the survey's FMS ratings are shown on a Likert scale. Before analyzing the results, we must understand the background of the different mine sites. Mine sites 1 and 2 do not have FMSs. Mine site 3 uses PERCLOS (see Section 2.5.1.1), developed by Hexagon, as their primary FMS. Mine site 4 uses EEG technology to monitor fatigue (see Section 2.5.1.2) (Table 5.1). The FMSs listed in the survey include a camera-based system (PERCLOS), a cap/hat (EEG), a combination of systems, a wrist-based sleep tracking system (smartwatches), and no monitoring. A combination of systems might, for example, combine EEG with smartwatches. Figure 5.1 shows HTDs' FMS preferences by mine site. HTDs from mine site 1 did not prefer any FMS; they preferred no monitoring during their shift. 92 % of HTDs from mine site 2 preferred no monitoring system at all. Similarly, 73% and 69% of HTDs from mine sites 3 and 4 do not want any monitoring system.

On the other hand, 38% of HTDs from mine site 3 preferred a wrist-based sleep tracking system. Also, 90% of HTDs from mine site 4 accept wrist band tracking systems. Looking at the results by mine site, we conclude that HTDs generally preferred no monitoring system at all; however, mine sites 3 and 4 show a preference for a wrist-based tracking system or smartwatches. Observing the preference results, most HTDs prefer no monitoring system. During the focus group, the acceptance of EEG and PERCLOS were low. Participants expressed that FMSs provide false alarms or incorrect measurements. Because of false alarms, they create unintended distraction (Drews et al., 2020). The distraction creates discomfort, leading to low preference for, and low trust in, FMSs. Also, HTDs from mine site 4 show a high preference for smartwatches. As explained in Section 4.2, a smartwatch is a contact type of monitoring system. It directly measures physiological response without the HTD feeling “watched over.” The direct-contact measurement provides less unintended distraction; it is popular among users because it is unintrusive and collects data in real time (Section 2.5.1.3).

Figure 5.2 shows the preference of FMS by CJE. Under 20% of HTDs at all CJE levels prefer a camera-based system and cap/hat. Interestingly, there is a slight increase in preference for a combination of systems. More than 50% of HTDs with less than 1 to 2 years of CJE prefer a wrist-based tracking system. 64% of HTDs with 3-4 years of experience also prefer wristbands. However, only 34% of HTDs with five or more years of CJE would prefer smartwatches. Finally, more than 50% of HTDs at all levels of CJE prefer no FMS. The more CJE they gain, the more HTDs prefer no monitoring system.

The Likert results for PDE have a similar pattern to those for CJE; there is a low preference for camera-based systems, cap/hat, and combinations of systems (Figure 5.3). However, only 25% of HTDs with less than one year of PDE prefer smartwatches. 38% of HTDs with more than 15 years of PDE prefer smartwatches. The rest of the HTDs (PDE from 1 to 15 years) have a high preference for smartwatches; more than 50% of HTD do not mind the wrist-based tracking system. Lastly, no monitoring is still the most preferred method for minimizing fatigue among HTDs at all levels of PDE. 79% of HTDs with more than 15 years of PDE prefer no monitoring. Only 25% of HTDs with less than one year of PDE prefer no monitoring. As PDE progresses, HTDs increasingly prefer no monitoring system.

5.4 Implications for Health and Safety Management Systems

In Section 2.1, we discussed the complexity of HSMSs and how organizational leadership plays a crucial role in HSMS implementation (Yorio et al., 2015). The HSMS conceptual model also reflects that leadership influences HSMS implementation. Since fitness for duty is a vital element of a mine worker's health, it is crucial to understand how HSMS interacts with fatigue management. The HSMS framework (shown in Table 2.1) from CORESafety lists elements that fit the framework.

After studying the three variables, it is essential to incorporate the survey results and summary into the HSMS framework. In Section 5.1, we discussed the long commute as a challenging fatigue factor to minimize. The survey found that the more remote the mine site is, the more challenging it becomes for the HTD. The longer the commute time, the more sleep debt they accumulate. Also, more experienced HTDs suggest that the long commute is an increasingly challenging factor. Following Table 2.1, the planning elements include fatality prevention and risk management. Mitigating long commutes by shortening the HTDs' driving time could prevent a fatality or injury from fatigue. For example, in the survey's comment section, many HTDs said they wanted the return of buses. They commented that they favored buses because they could sleep during the ride. As for the action plan, leadership could implement the creation of a new transportation department that focuses on traveling to and from mine sites. The risk management program should track the transportation system's usage. A record of the demographics of the riders would also help plan the bus routes. There should be continued safety and health management communication between leadership and workers.

In Section 5.2, we discussed shift work as a challenging factor in minimizing fatigue. The survey result shows that as HTDs' experience increases, shift work becomes more challenging; the result agrees with the focus group responses and the private conversation I had with an HTD. The framework for action could include collaboration between the leadership and workers about optimizing the shift schedule. There could be another study documenting fatigue management and its impact on HTDs. That way, we could optimize shift work to benefit both the leadership and the worker. Another way is to update scheduling policies and protocols. We understand that each mine site has its production schedule; however, through labor relations and compliance, it would be possible to achieve a desirable schedule for both leadership levels and workers; this requires HSMS commitment, responsibility, and accountability.

Finally, we asked the HTDs about their FMS preference in Section 5.3. The majority of the HTDs in the survey have no preference for FMS. However, they are lenient toward wristbands or smartwatch monitoring systems. In implementing a HSMS framework for an FMS, there should be a broader understanding of how the FMS works. For example, training on how to mitigate false alarms. Companies should also understand why HTDs resist FMSs in order to optimize behavior toward FMSs; this could improve compliance and assurance between the two groups. Management should continue checking the interactions between HTDs and FMSs and investigate the effectiveness of FMSs. HSMS administrators should commit to continuously improving FMSs for a better fit of fatigue management, human factors, and FMS adaptations

In summary, the above are suggestions and considerations for the HSMS framework. There are many ways that individual companies could implement the

CORESafety guidelines and framework. Developers of HSMSs should consider the findings of this study. However, we recognize that each individual mine site has different policies, protocol, and demographics. We suggest that mine sites update their training protocol, procedures, and practices to create a safe environment for prolonged shift work among HTDs. We aim to find the fitness for duty of HTDs as we study fatigue management.

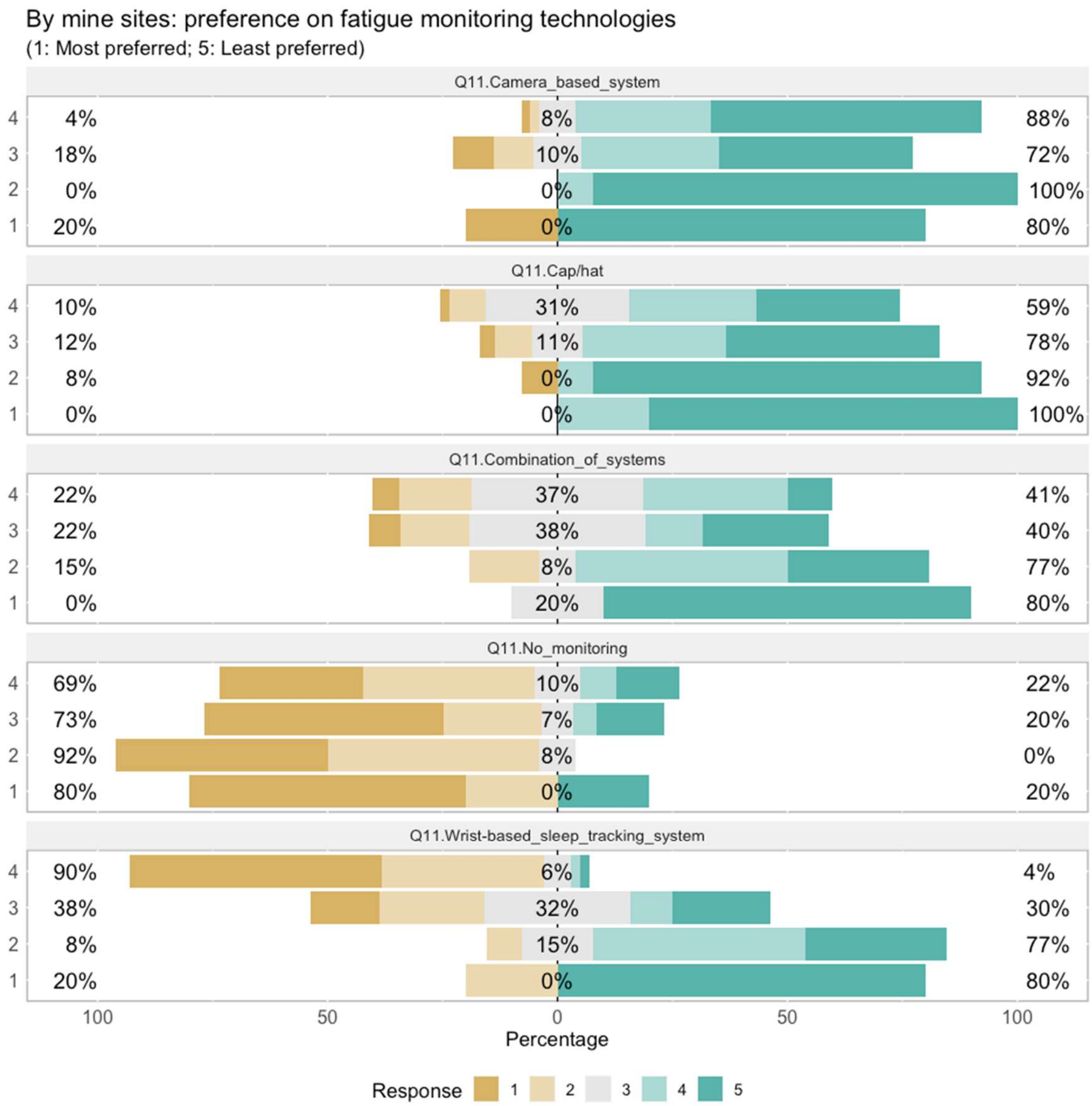

Figure 5.1 FMS preference by mine sites.

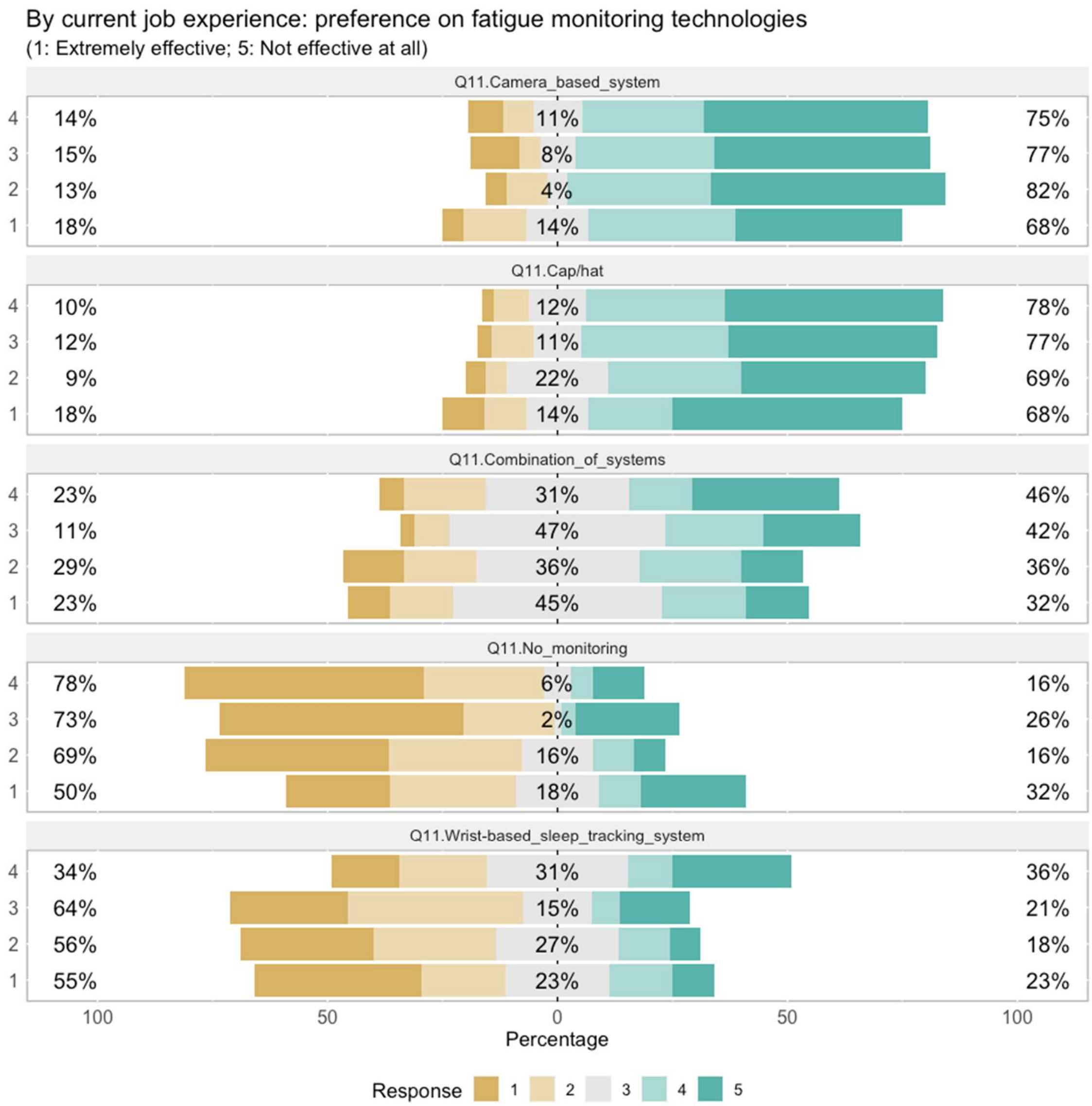

Figure 5.2 FMS preference by CJE.

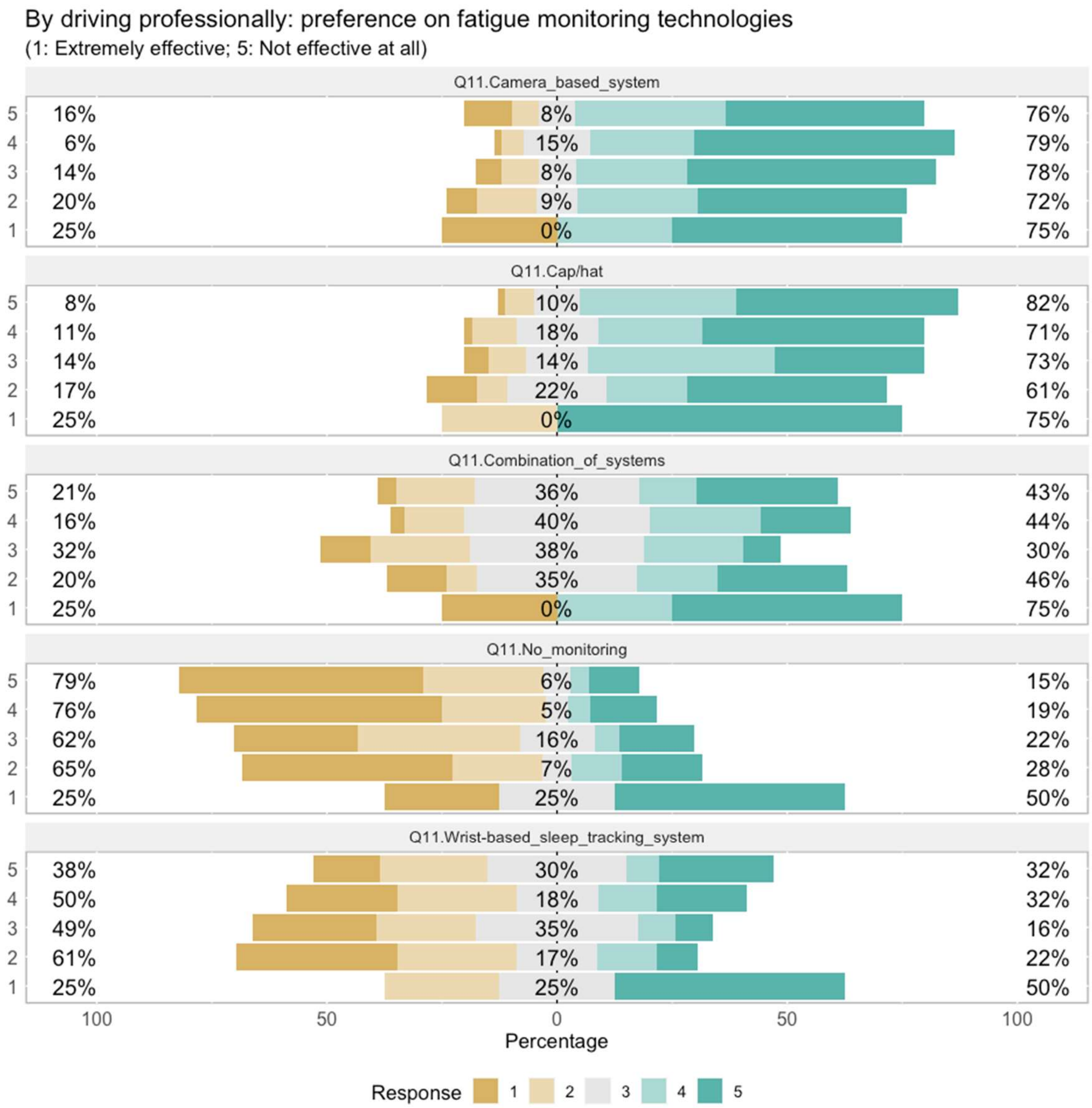

Figure 5.3 FMS preference by PDE.

Table 5.1 Summary of mine sites' considerations with variables

	Variables		
Mine site	Distance to urban area	Shiftwork (Hours)	FMS
1	Moderately close	10-12	None
2	Moderately close	10-12	None
3	Remote area	10-12	PERCLOSE
4	Very close	10-12	EEG

Table 5.2 More mine sites' travel time information

Mine site	Travel time (minutes)
1	15
2	20
3	90
4	35

CHAPTER 6

CONCLUSION

This study aimed to examine fatigue management in the mining industry and consider "fitness for duty" among HTDs. We studied the impact and consequences of fatigue that could affect HTDs' driving performance.

In summary, the literature review shows that fatigue can impair task performance (psychologically, physiologically, cognitively, and behaviorally), influencing HTDs' decision-making and motor skills. The survey indicated that long commute times and shift schedules are the most challenging factors in minimizing fatigue. Both exogenous variables result in more accumulated sleep debt as an HTD's experience increases. Finally, there is a low acceptance of FMSs. HTDs concluded that FMSs are distracting and invasive. They prefer monitoring systems that they consider less invasive, such as smartwatches.

6.1 Research Objectives Conclusion

The conclusion of this research also reviews the research objectives (Section 1.2) in connection with the results and discussion. The restatement of the research objectives as follows:

1. Improved understanding of perception and awareness of fatigue
2. Competent action against fatigue

3. Social acceptance of fatigue monitoring system

To understand perceptions and awareness of fatigue, we studied the endogenous and exogenous variables that impact fatigue. Specifically, we examined the following research questions:

- What factors affect the frequency and severity of fatigue episodes experienced by operators?
- What are the best practices operators used to reduce the number of fatigue episodes?
- What are effective strategies to address fatigue?
- What are the operators' understanding of mine specific fatigue monitoring technologies currently in use?

Drews et al. (2020) conducted a focus group as a form of qualitative statistical approach. The discussion questions were designed to explore fatigue management among HTDs. The focus group allowed HTDs to provide their perspective on how they and their company minimize fatigue. The results of the focus groups showed that HTDs demonstrated substantial knowledge of fatigue awareness and management. They understand that fatigue could affect their ability to operate equipment and make decisions. During the discussion, HTDs emphasized an interest in playing an active role in fatigue management. They recognized the severity of fatigued driving and would try to mitigate fatigue. Because of these acknowledgments, the survey asked about challenging factors and their effect on fatigue.

Similarly, they also know what contributes to their fatigue and how to minimize it. Regarding technological approaches, HTDs expressed that these approaches are distracting and often provide false alarms; they conclude that FMSs lack validity. Although the HTDs conveyed concerns about FMSs invading their privacy, they expressed that they would support less invasive technologies.

Based on the results and summaries of the focus groups, a survey was developed to increase the participant pool. The survey served as the objective qualitative data research. We surveyed four mine sites across the western US with 302 participants (n=302). The survey aimed to understand fatigue management practices among the HTDs and their preferences regarding FMSs. In summary, the HTDs considered long commutes and shift work to be exogenous variables that contribute to fatigue. HTDs from a remote mine site (mine site 3, with an average of 90 minutes of travel time) feel that a long commute is a challenging factor, supporting the argument that HTDs should be compensated for their travel time with rest time. We also found that as an HTD's experience progresses, shift work becomes more of a challenging factor. Accumulated sleep debt due to shift work can impact cognitive and physical performance, affecting the "fitness for duty" of an HTD. As we can see, the exogenous variables (commute and shift work) lead to endogenous variables (sleep quality and sleep debt). However, endogenous variables could also lead to exogenous variables. As the age and experience of an HTD progress, commute and shift work become more challenging.

The second point of the research objective is competent action against fatigue. We found that HTDs prefer their own methods of fatigue management. These methods vary among HTDs according to their personality, diet, preference, and schedule. Because HTDs prefer to manage their own fatigue, there is a general reluctance toward organizational fatigue management. The shift work schedules "flip-flop" from day to day, which affects sleep quality. Break time, transportation to the mine site, and improvements to avoid "faulty" FMSs are among the improvements desired by HTDs.

Studying the socio-technical perspective of FMSs, HTDs found that FMSs give them the feeling of being "spied on." They are also distracted by false alarms and invasiveness. HTDs prefer no monitoring system; they prefer personal approaches to combating fatigue. These personal approaches generate a more personalized fatigue management. On the other hand, a surprising number of HTDs prefer smartwatches as FMSs; smartwatches might serve as physiological monitoring system that feels non-invasive. They can also provide data for on-site and off-site physiological data.

These findings are important because we found some challenging factors that impact HTDs in minimizing fatigue and affect their socio-technical perspective on FMS. By understanding the impact and consequences of fatigue, we were able to interpret the focus group and survey results to gain a better understanding of fatigue management and the "fitness for duty" of HTDs.

6.2 HSMS Implementation

As mentioned in Section 5.4, we strive to understand the fitness of duty for HTDs as we study fatigue management and its impact on HTDs. We agree that the CORESafety HSMS framework should be considered in connection with the findings of this study. These frameworks and elements contain both general and specific ideas that can be tailored to a company's needs when fatigue management is understood and communicated.

This research has multiple implications regarding HSMS implementations that would benefit HTD fatigue management. Fatigue training could be more demographic-focused around the HTD. For example, the DV variable shows that the experience of the HTD plays a vital role in influencing their survey responses. As the experience of an HTD increases, shift work becomes more of a challenge to manage. Also, the location of the mine site in relation to residential areas determines the commute time. These demographic data of the HTDs should be considered when delivering fatigue training. The unique experience and location of the HTDs suggest a need for different personalized fatigue management approaches. Therefore, HSMS training should be more tailored to the HTD. Besides individual fatigue training, there is a lack of deployment of FMSs. As I shadowed one of the HTDs, he did not show a comprehensive knowledge of the FMS that his company was using. As discussed in Section 2.6.2, information transparency influences operators' perspectives on the company, and in this case, the FMS. Operators should be educated on how the systems work and how they monitor the operators. We believe that doing so would widen the dimension of acceptance toward FMS.

Another part of the survey asked HTDs to add comments about anything that the survey did not cover. Many respondents commented that they would like buses to be brought back, or other transportation between the mine site and home. This is an example of an action that the company can accomplish to mitigate the fatigue of HTDs and improve their fitness for duty.

Finally, a critical component of a successful HSMS is collaboration between leadership and operators (Section 2.1) in management review. Since several HTDs recognized that shift work is a challenging factor in fatigue management, there should be a collaboration to optimize the shift work schedule and also transportations that work with the schedule. Fatigue training and management should be refurbished to be more personalized. Investigation and accident reports are a vital part of continued collaboration between leadership and operators to reduce shift fatigue. Better collaboration could improve the fatigue culture among HTDs. As mentioned previously, some HTDs see fatigue as “taboo” vocabulary (Section 1.3). Increasing the transparency and communication about fatigue and culture could improve perspectives on fatigue management and raise awareness of fatigue.

6.3 Research Next Steps

Measuring fatigue is sometimes difficult, but there are ways to determine fatigue by measuring bodily functions, such as reaction time. Reaction time is the amount of time it takes to respond to a stimulus. Simple reaction time would be a predefined response to specific stimulation, such as pushing a button when a light is turned on (Murray and Thimgan, 2016). Our focus groups and survey found that HTDs are more tolerant toward smartwatches than other FMSs (see Section 5.3). For this reason, our research group developed a timed fatigue questionnaire and reaction time test as an application for smartwatches. Further study of this from a socio-technical perspective would be helpful.

This subsequent research step aims to dive further into ergonomics and improve the "fit" between the capabilities and expectations of the worker and the job requirements. Using fatigue surveys and Fitbit reaction times, we understood better how and when fatigue occurs during an HTD’s shift. External factors specific to the individual are largely out of our control, for example, the HTD’s personal life. For this, more significant potential for change is in the hands of the administration, as they can form programs that promote healthier lifestyles and educate workers on fatigue risk and management. As fatigue monitoring becomes a form of measurement, more opportunities for automated fatigue management arise. This could also allow more opportunities for humans to interact with systems and enable monitoring of automated tasks. Proper fatigue measurement could mitigate fatigue during shift. Fatigue can be accurately predicted before it happens. However, fatigue's impact and consequences continue. Other areas for further research include increased study of the human factor, how humans and FMSs interact, and user acceptance. There is still a limitation on FMS's adoption of a human-centered approach or a design to "fit" with users.

APPENDIX

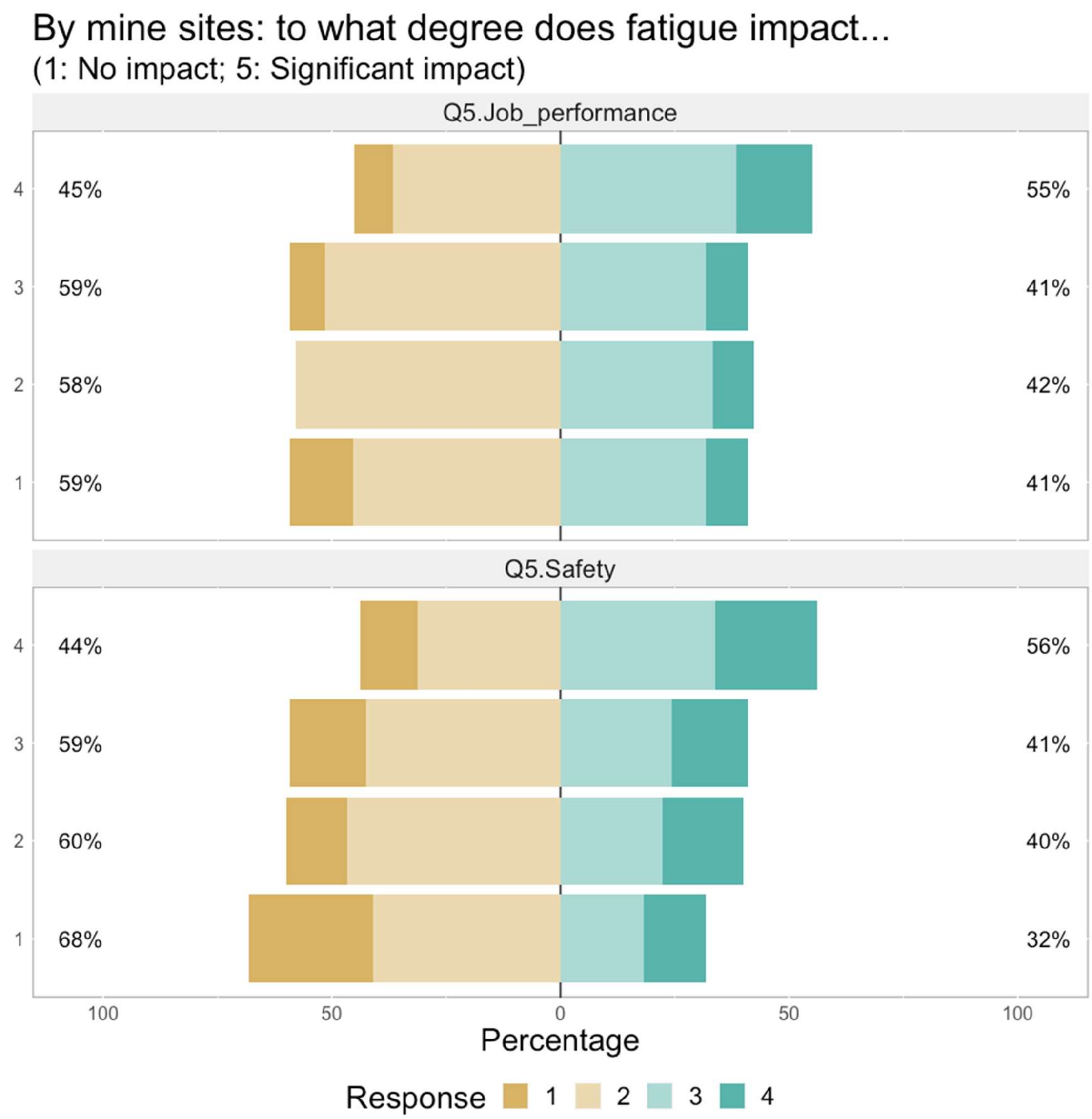

Figure A.1 Faitgue impact by mine sites.

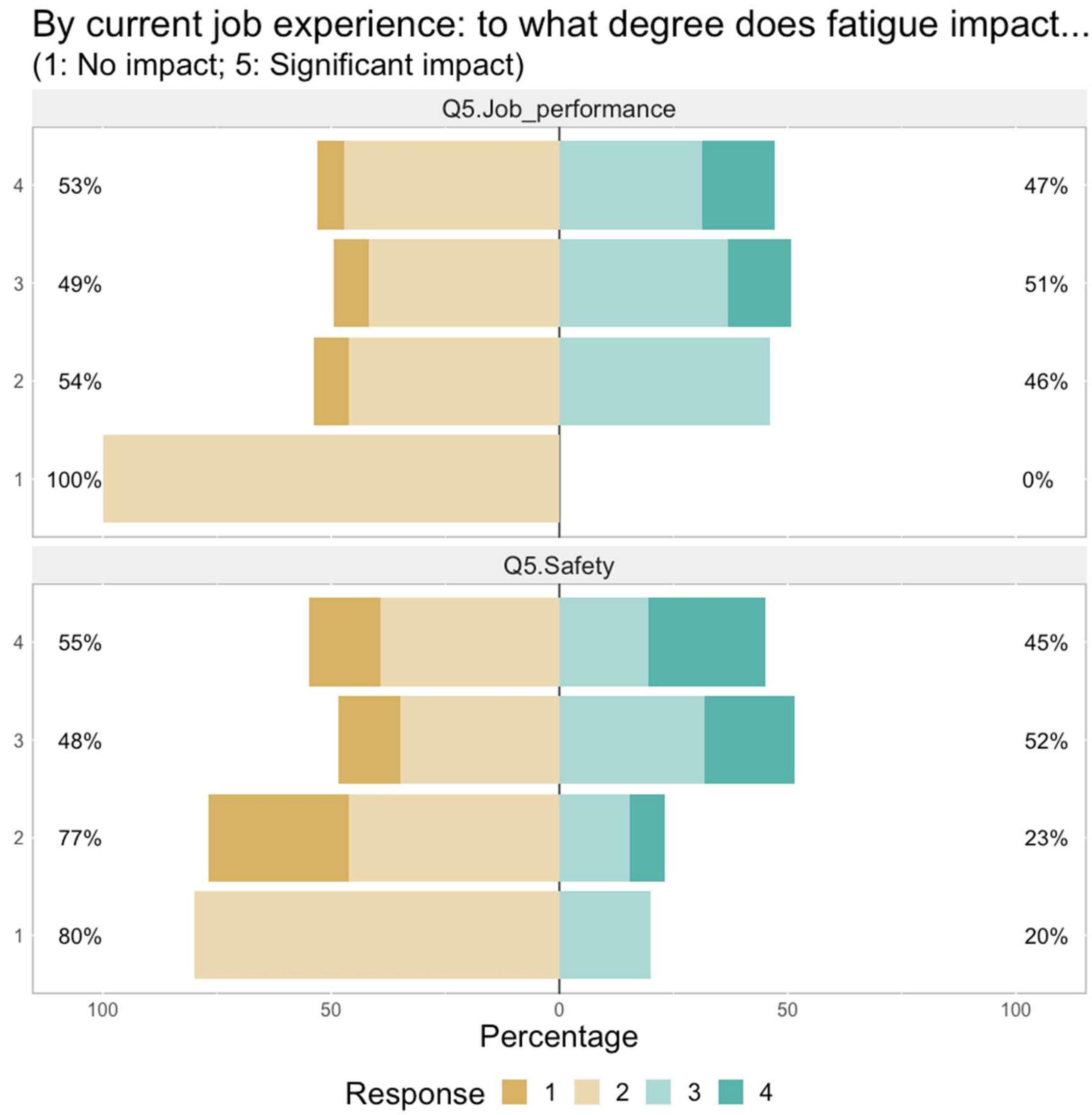

Figure A.2 Fatigue impact by CJE.

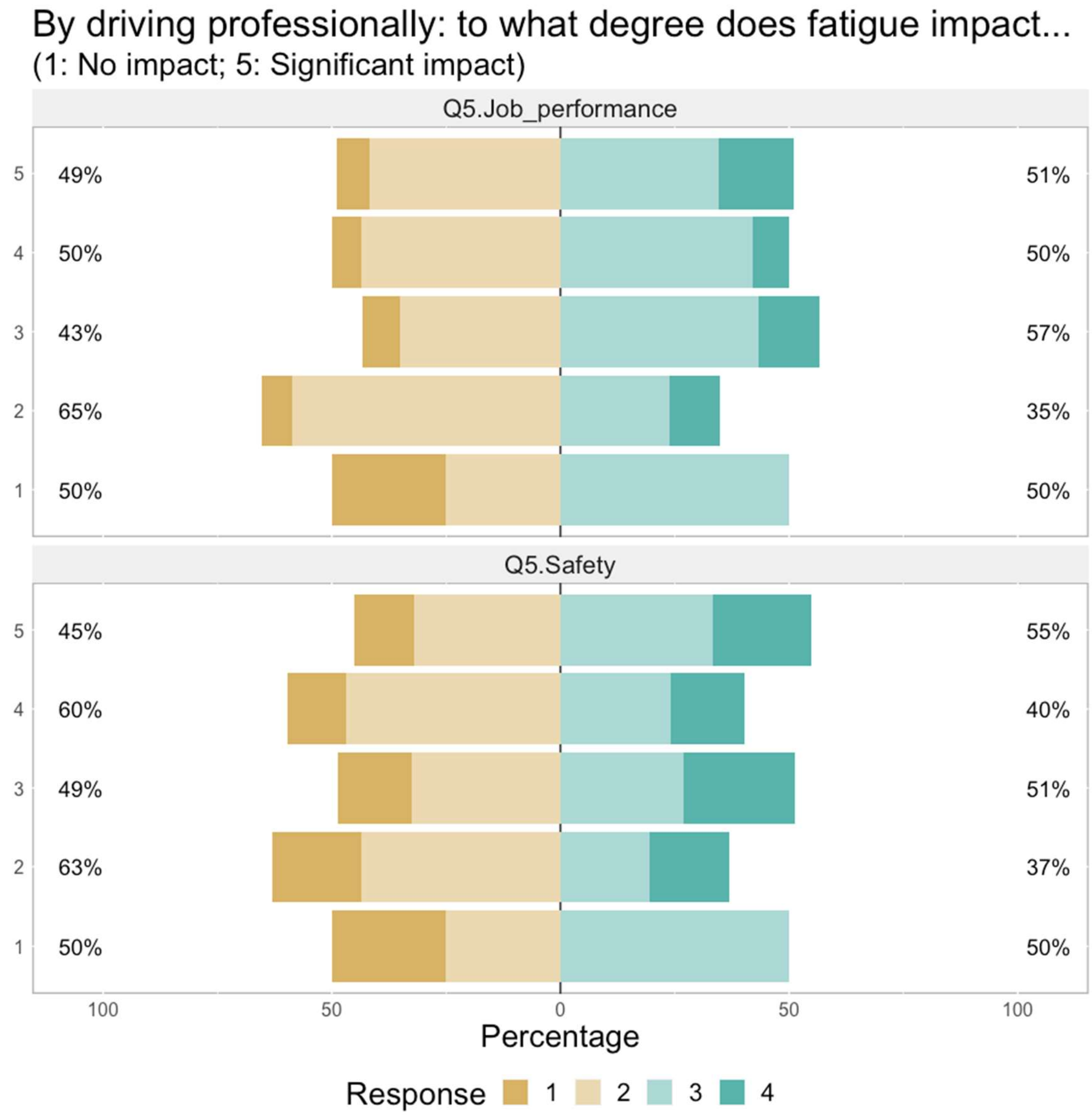

Figure A.3 Fatigue impact by PDE.

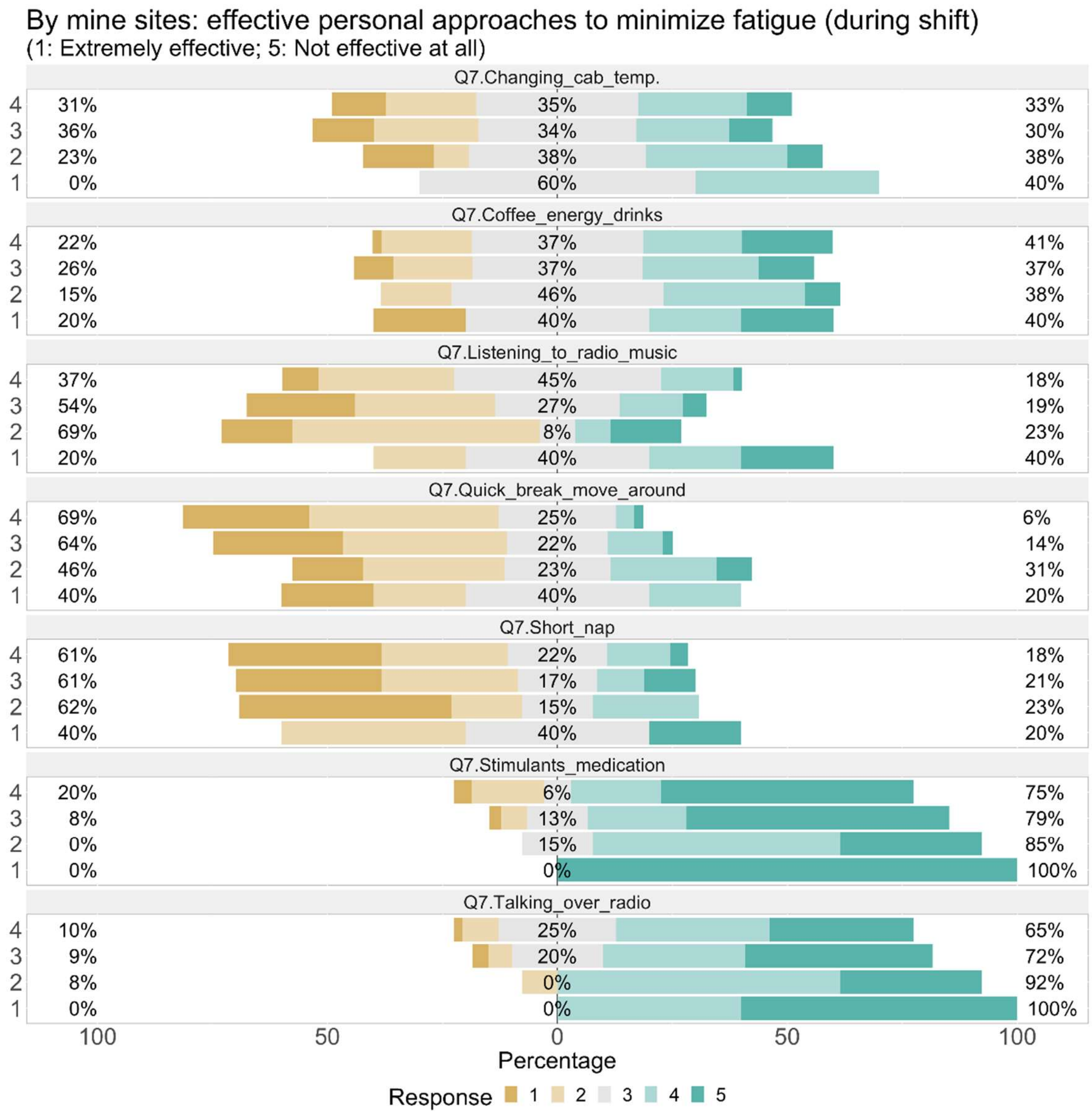

Figure A.4 Effective personal approaches by mine sites.

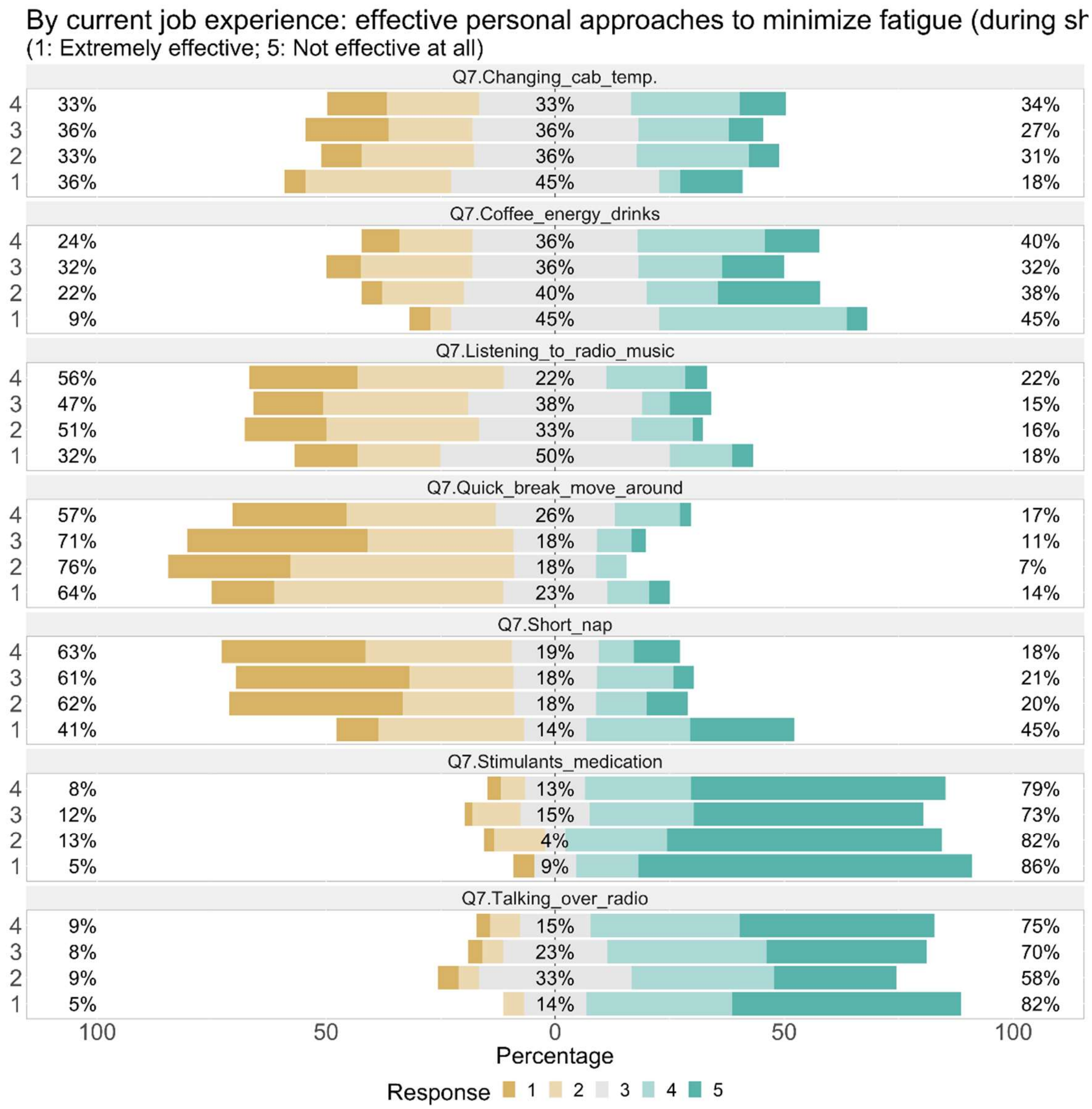

Figure A.5 Effective personal approaches by CJE.

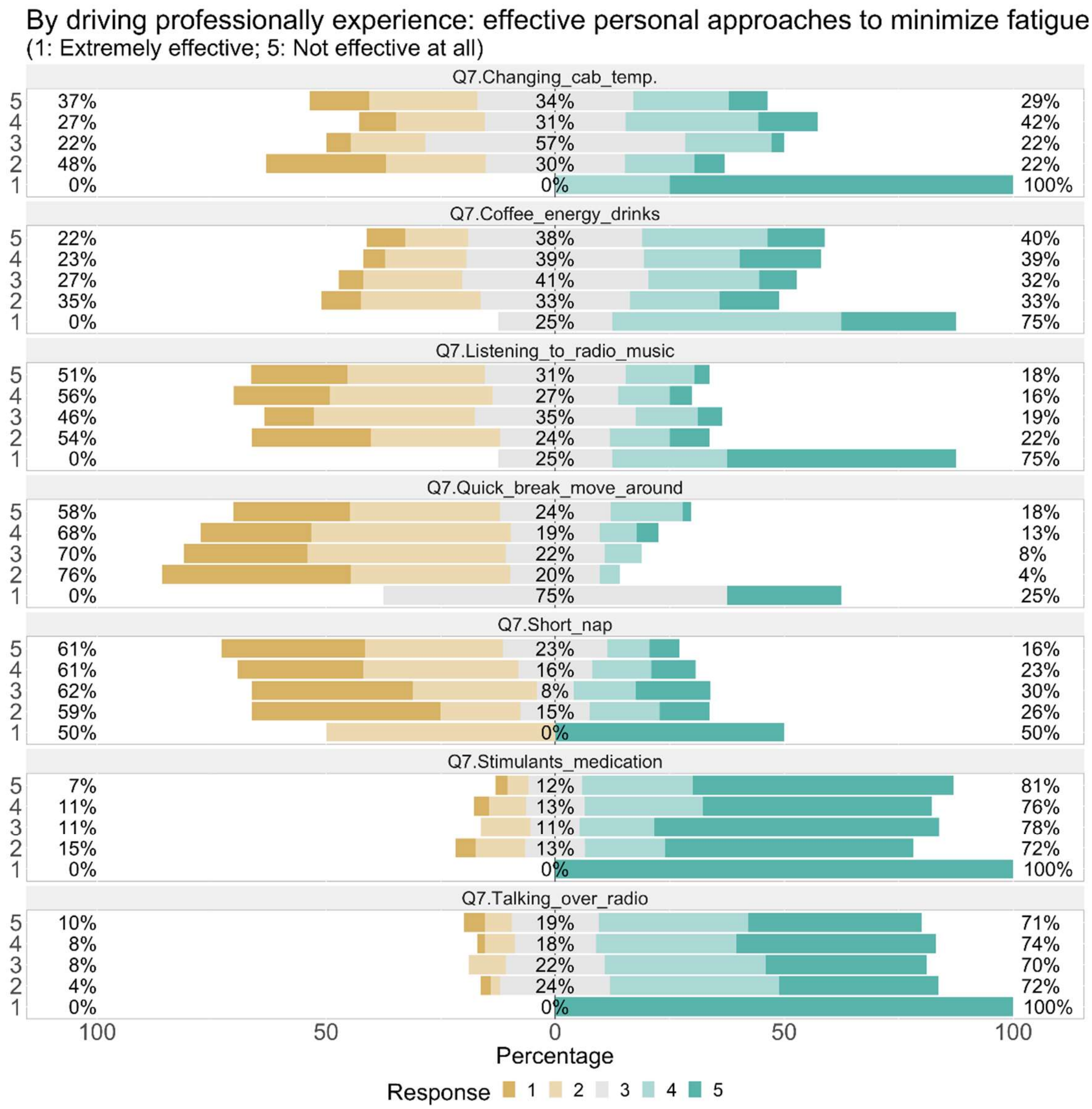

Figure A.6 Effective personal approaches by PDE.

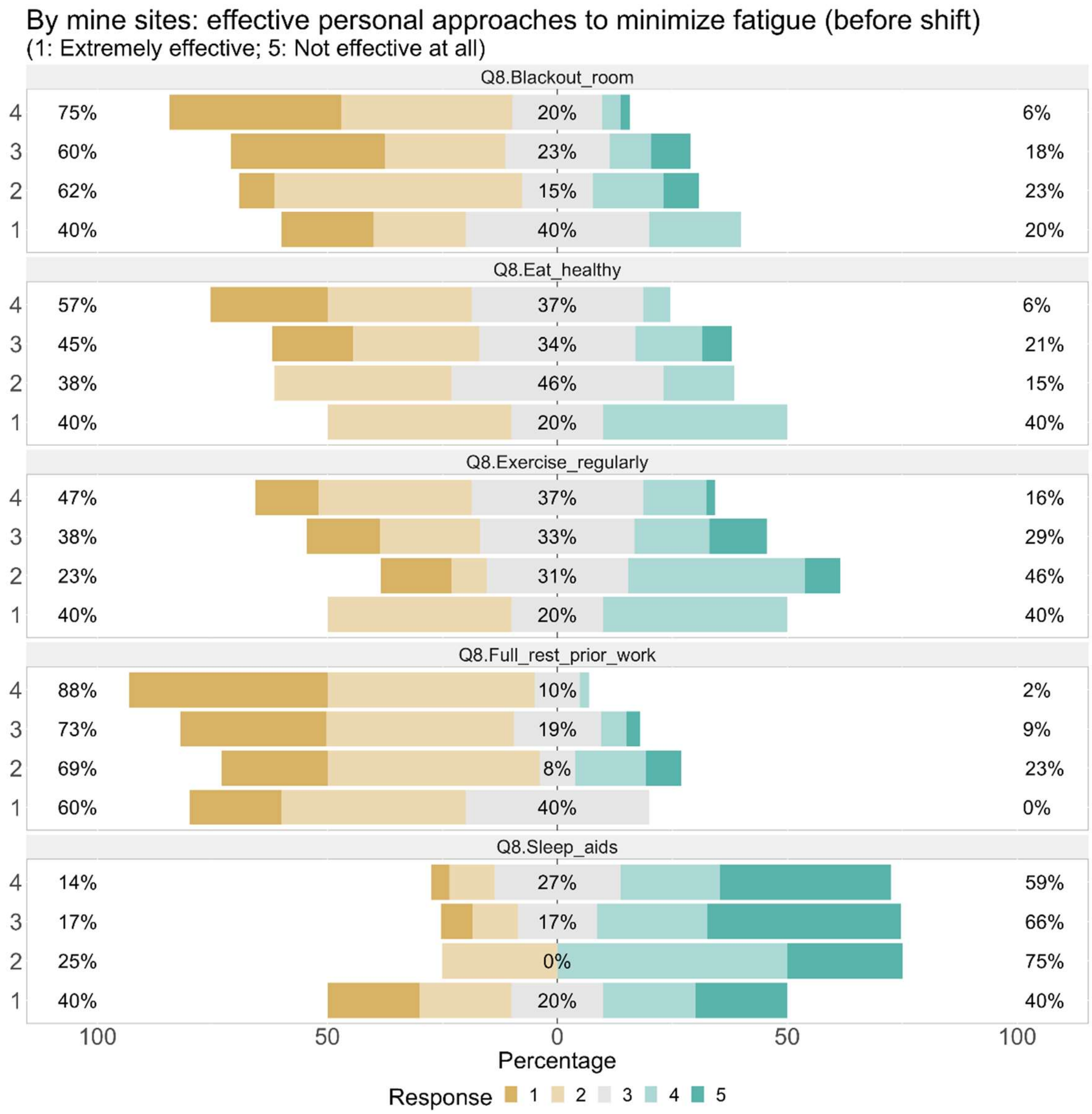

Figure A.7 Effective personal approaches before shifts by mine sites.

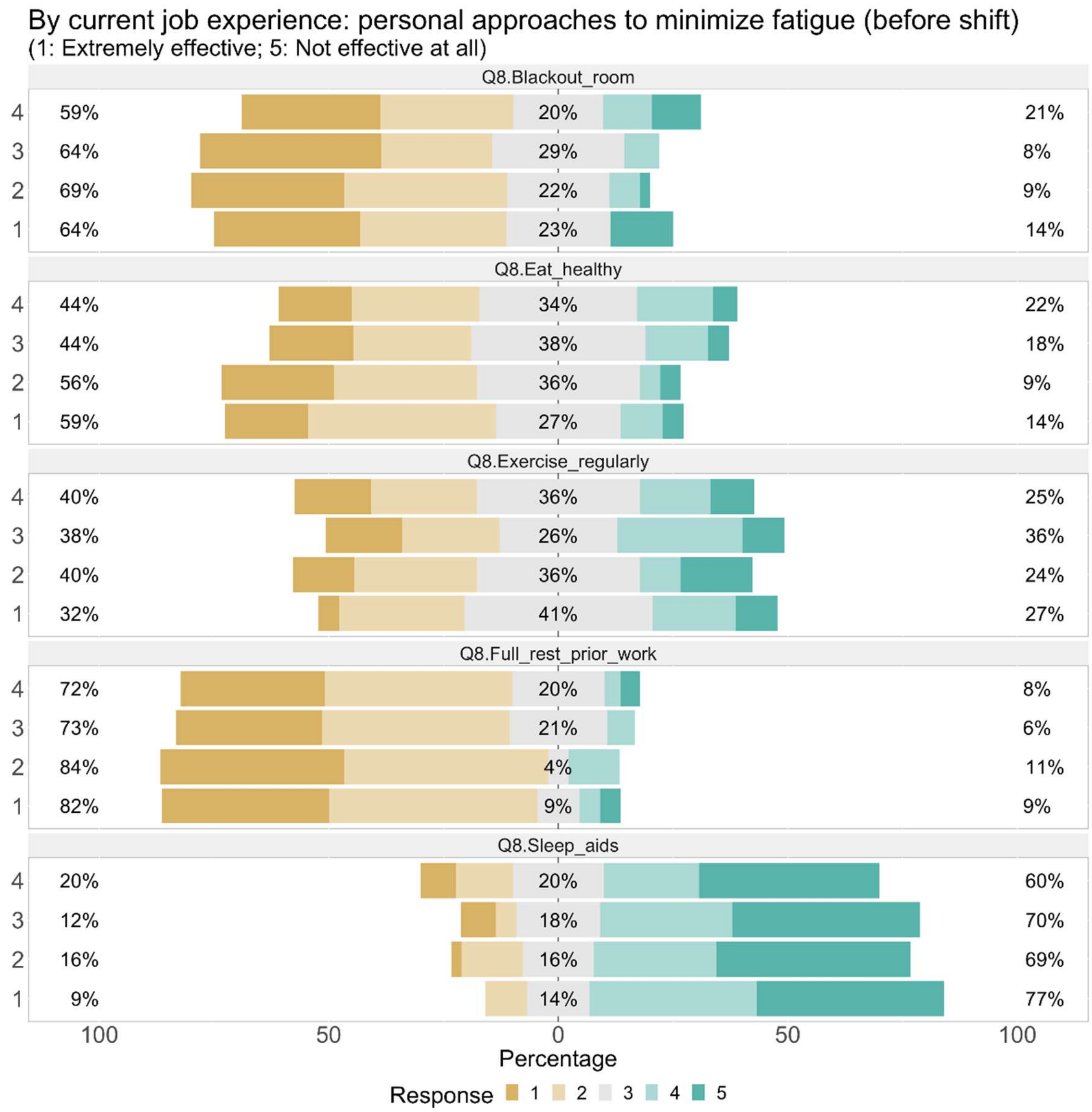

Figure A.8 Effective personal approaches before shifts by CJE.

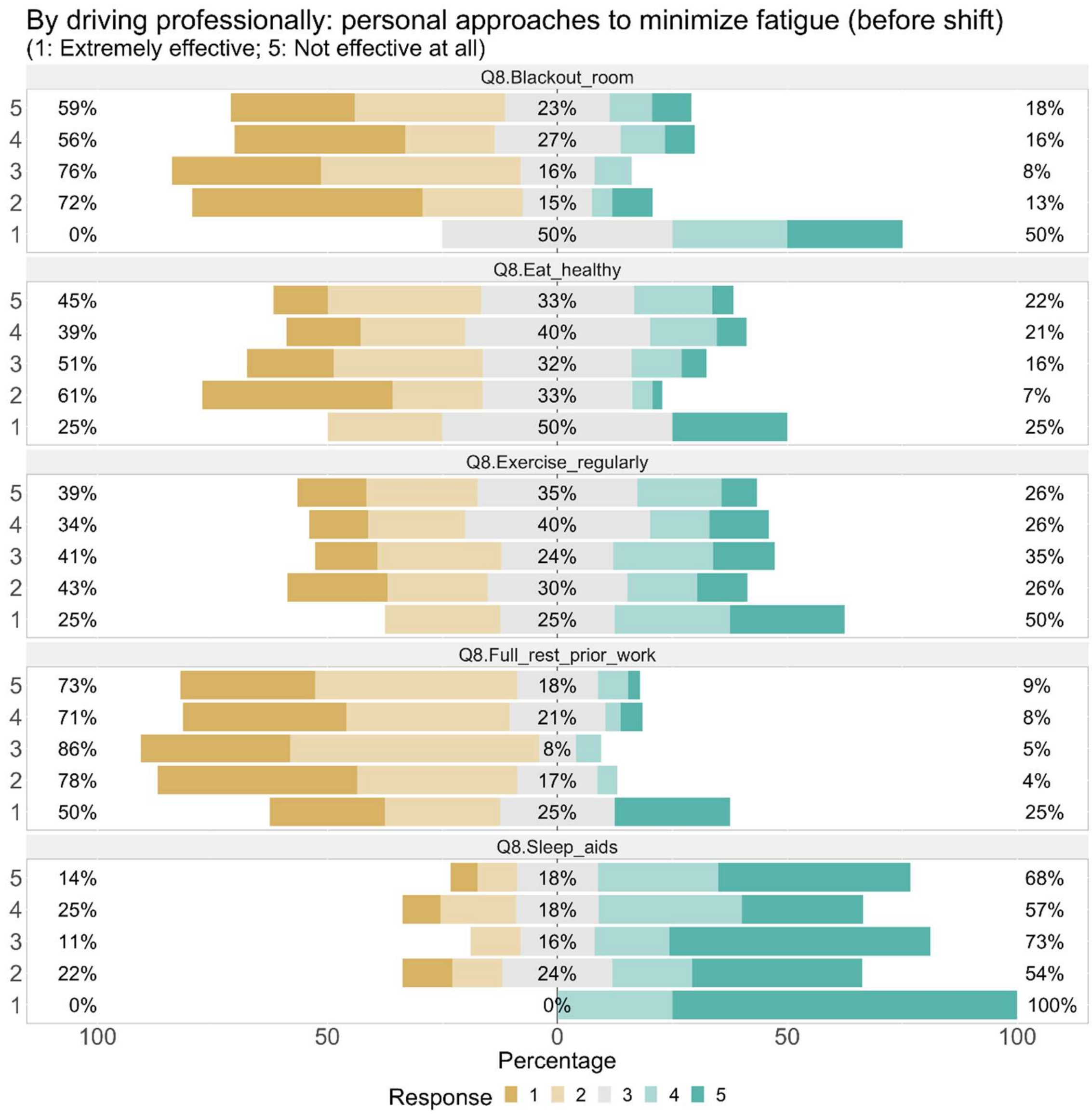

Figure A.9 Effective personal approaches before shift by PDE.

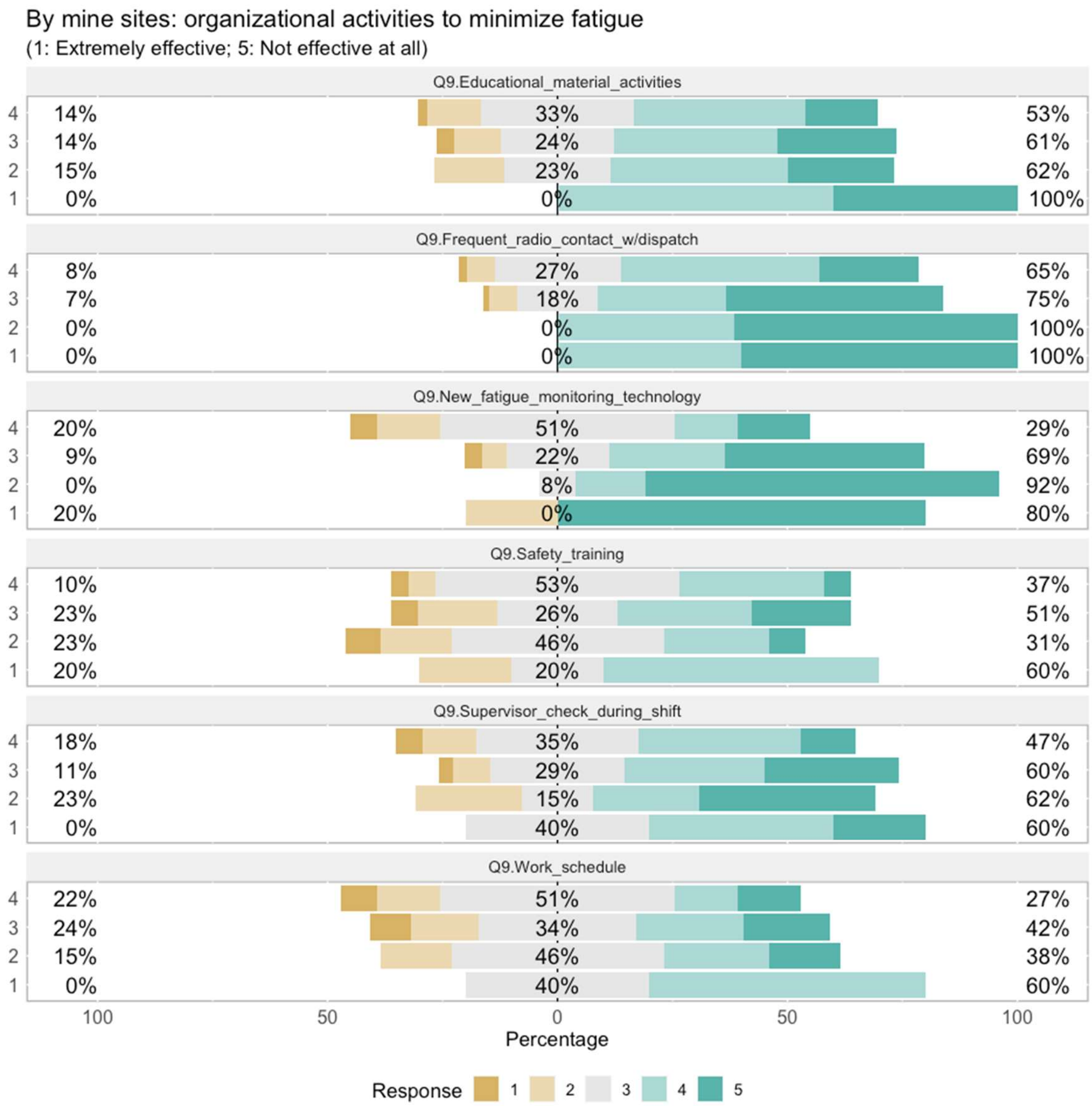

Figure A.10 Effective organizational activities by mine sites.

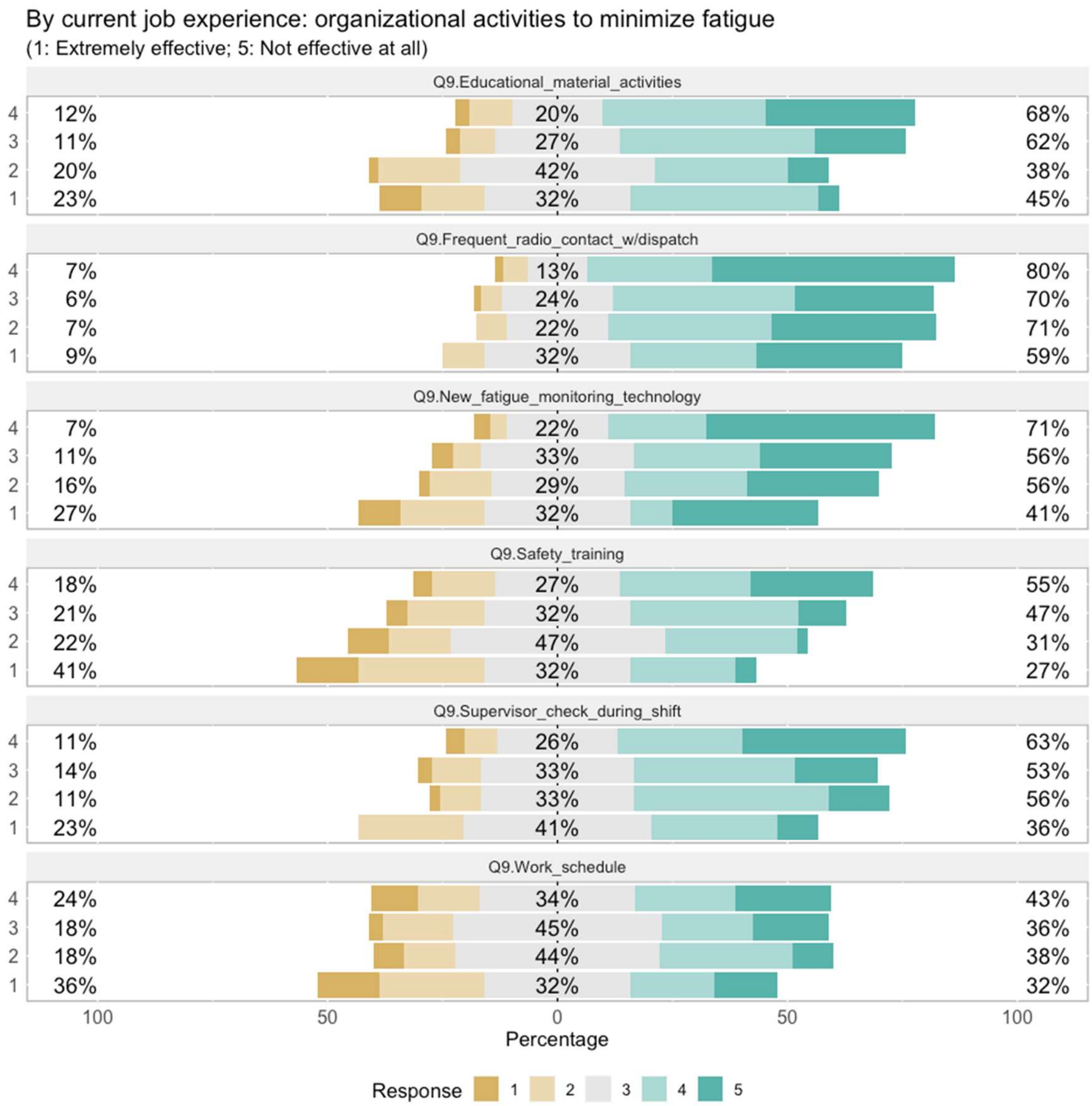

Figure A.11 Effective organizational activities by CJE.

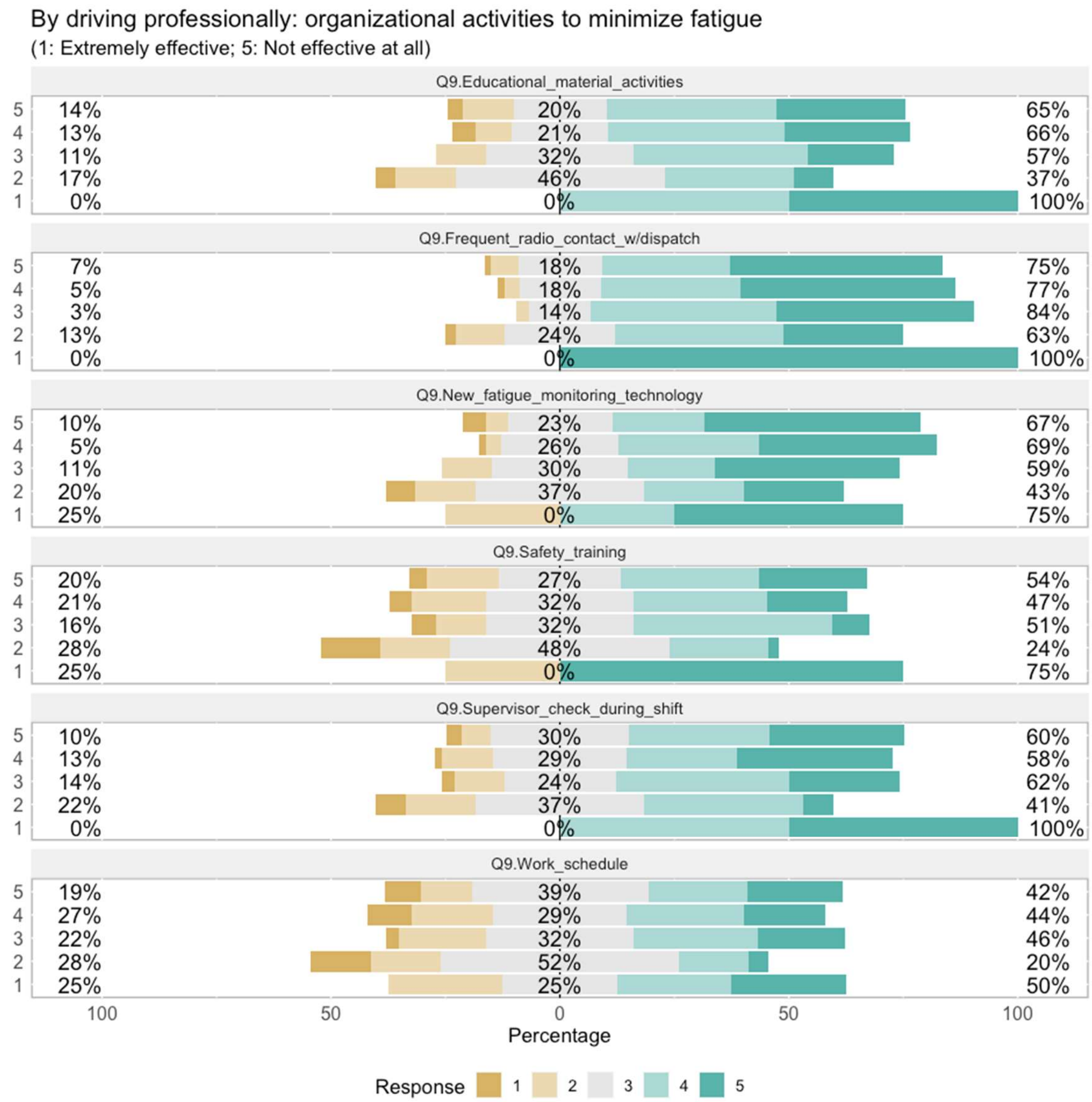

Figure A.12 Effective organizational activities by PDE.

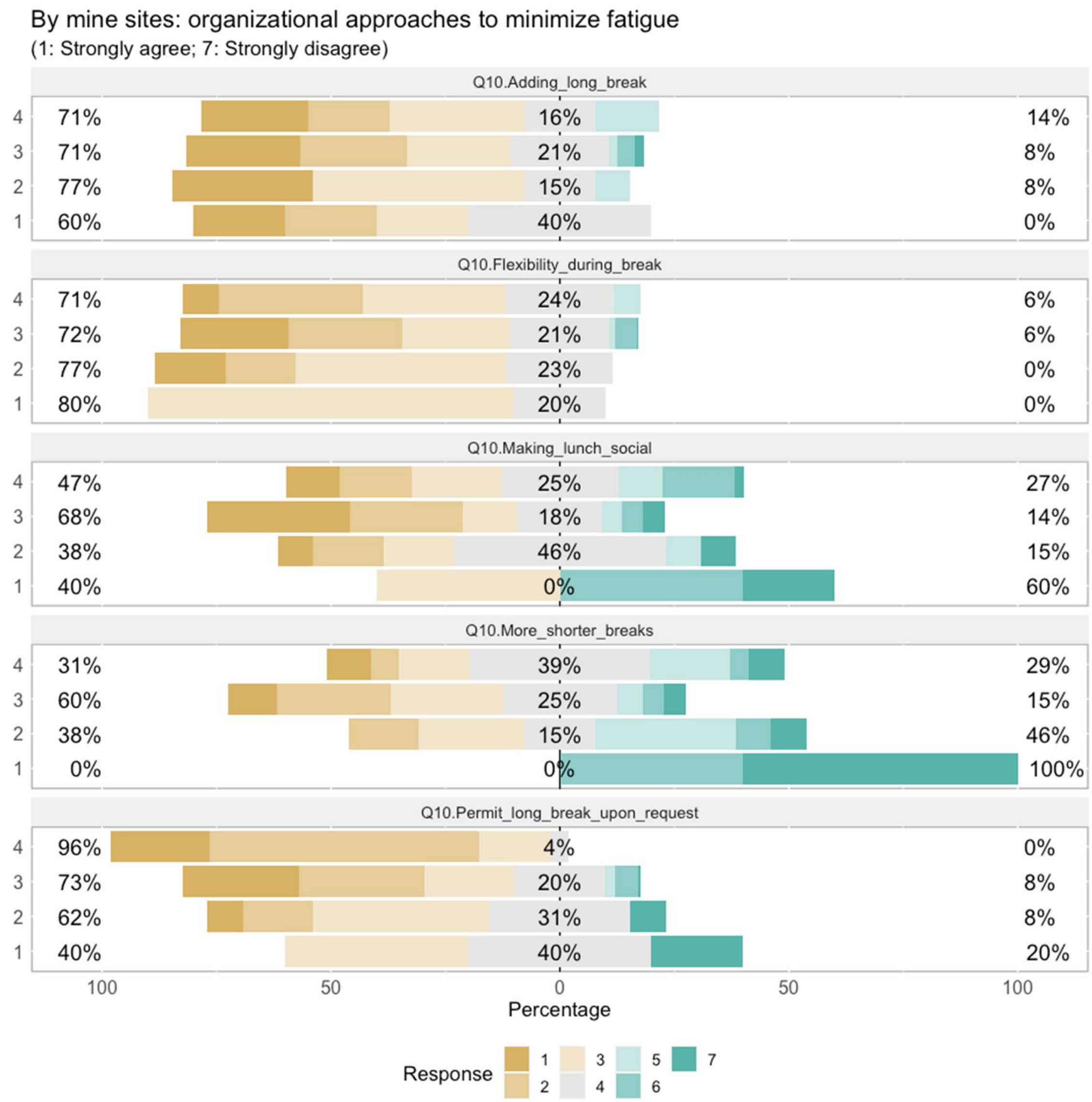

Figure A.13 Desirable organizational approaches by mine sites.

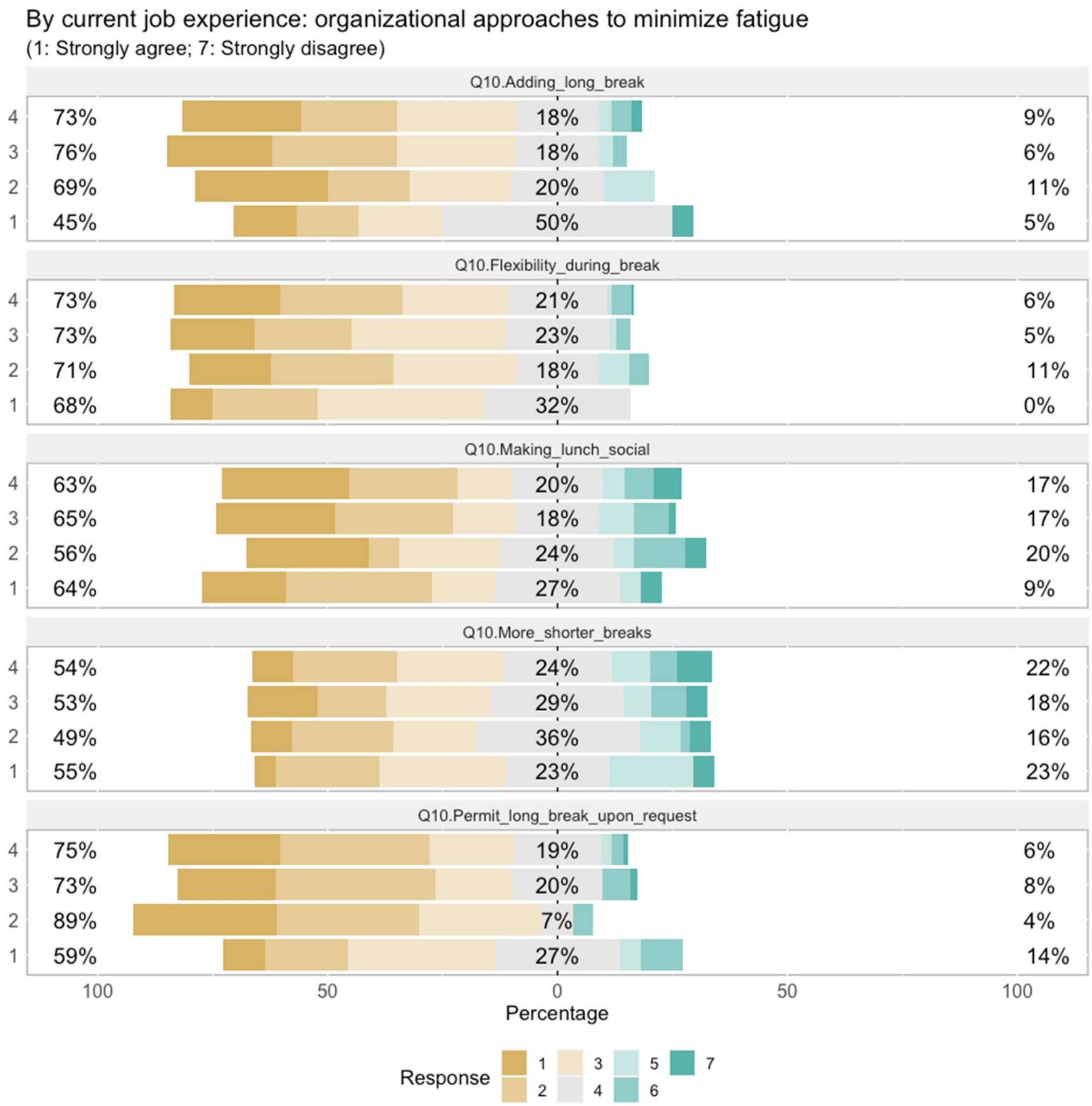

Figure A.14 Desirable organizational approaches by CJE.

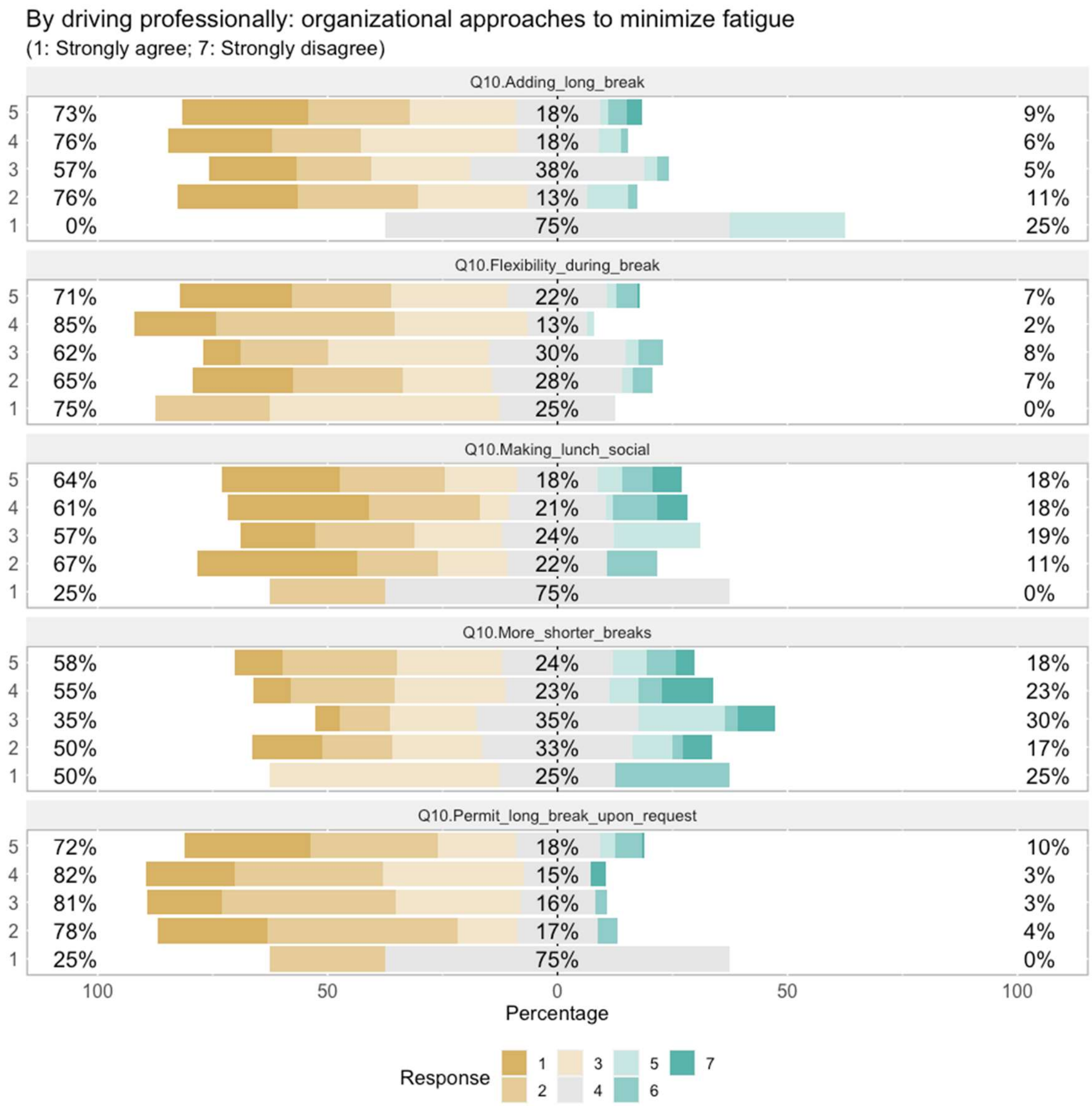

Figure A.15 Desirable organizational approaches by PDE.

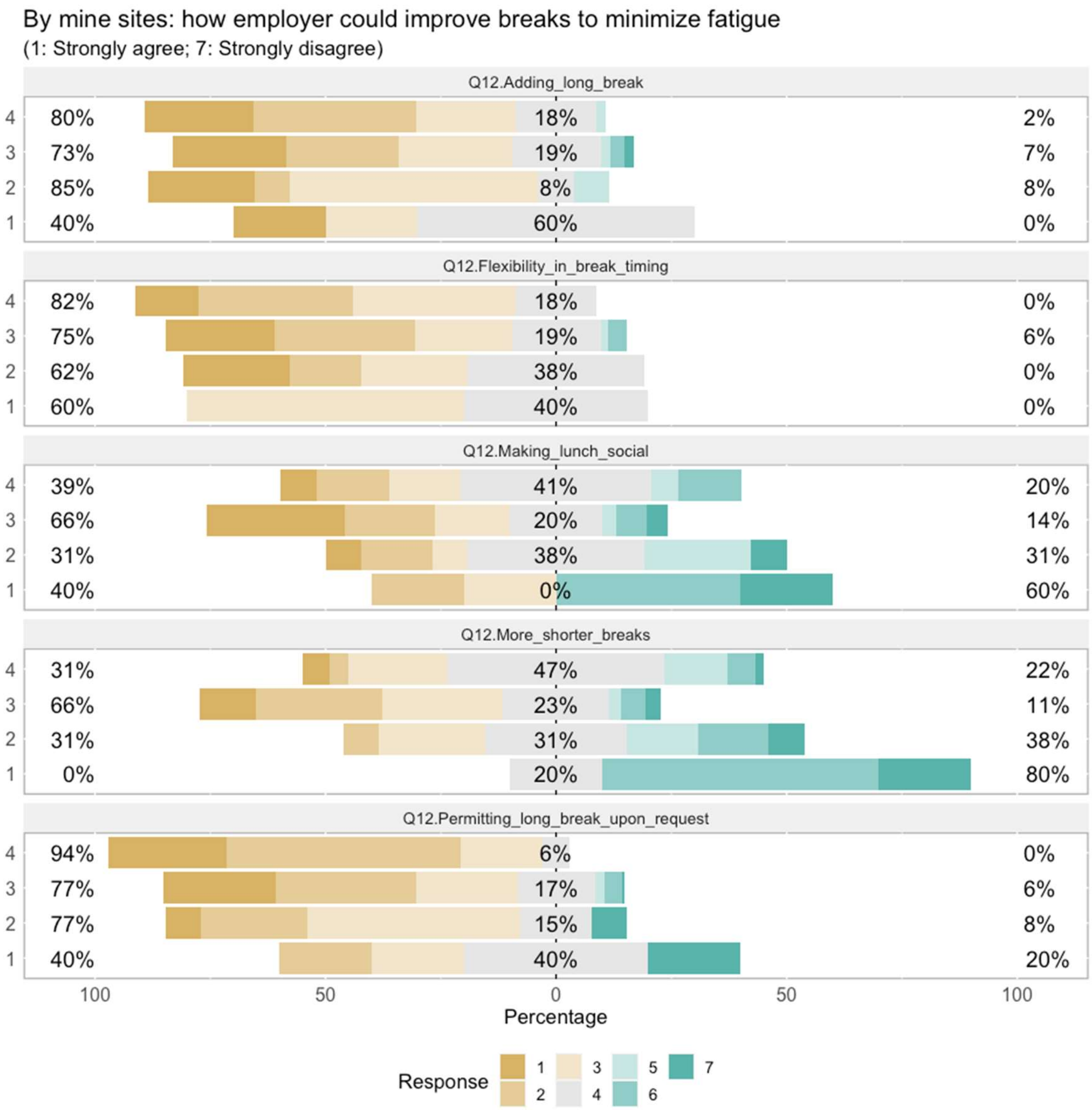

Figure A.16 Improve breaks by mine sites.

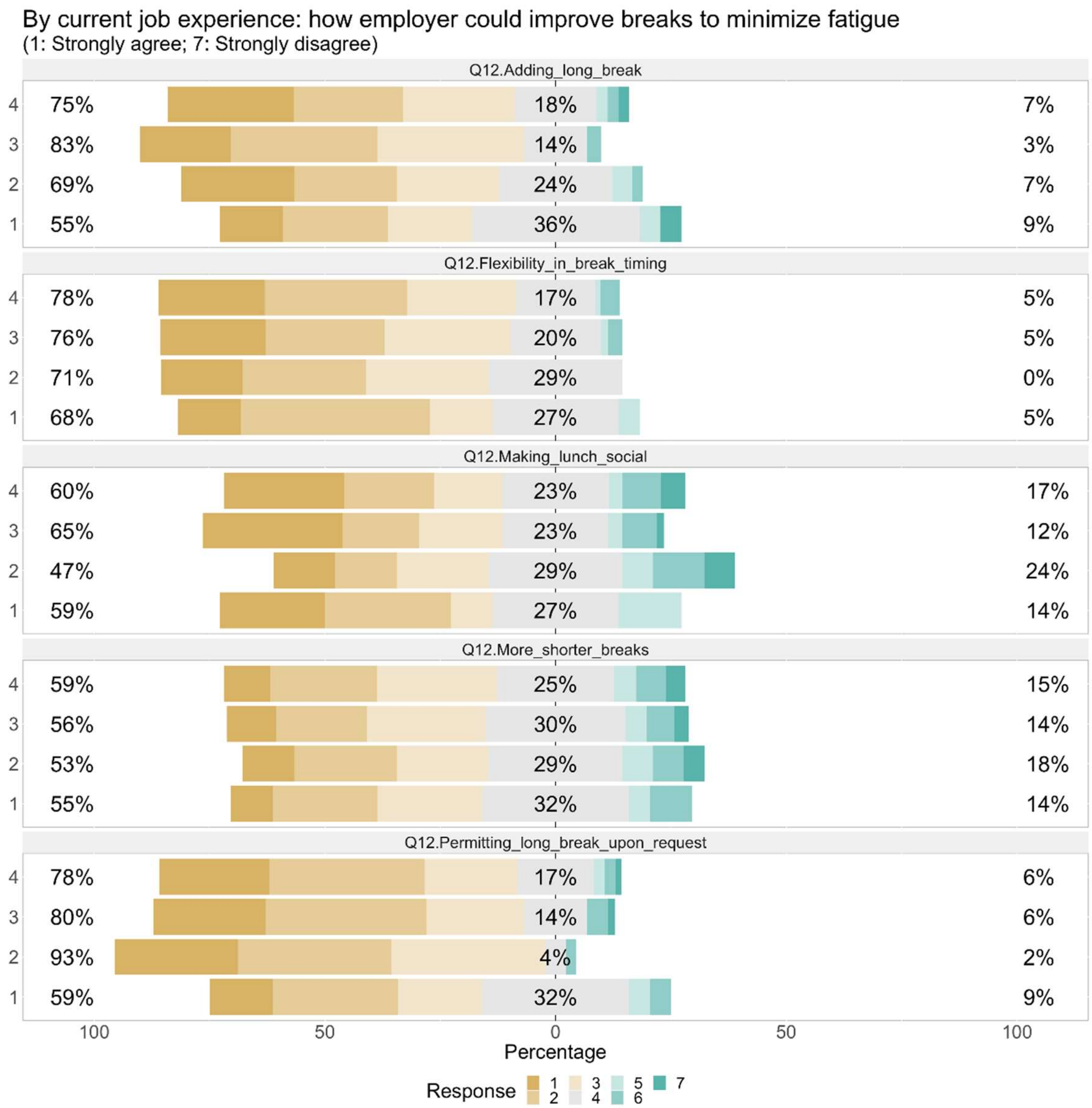

Figure A.17 Improve breaks by CJE.

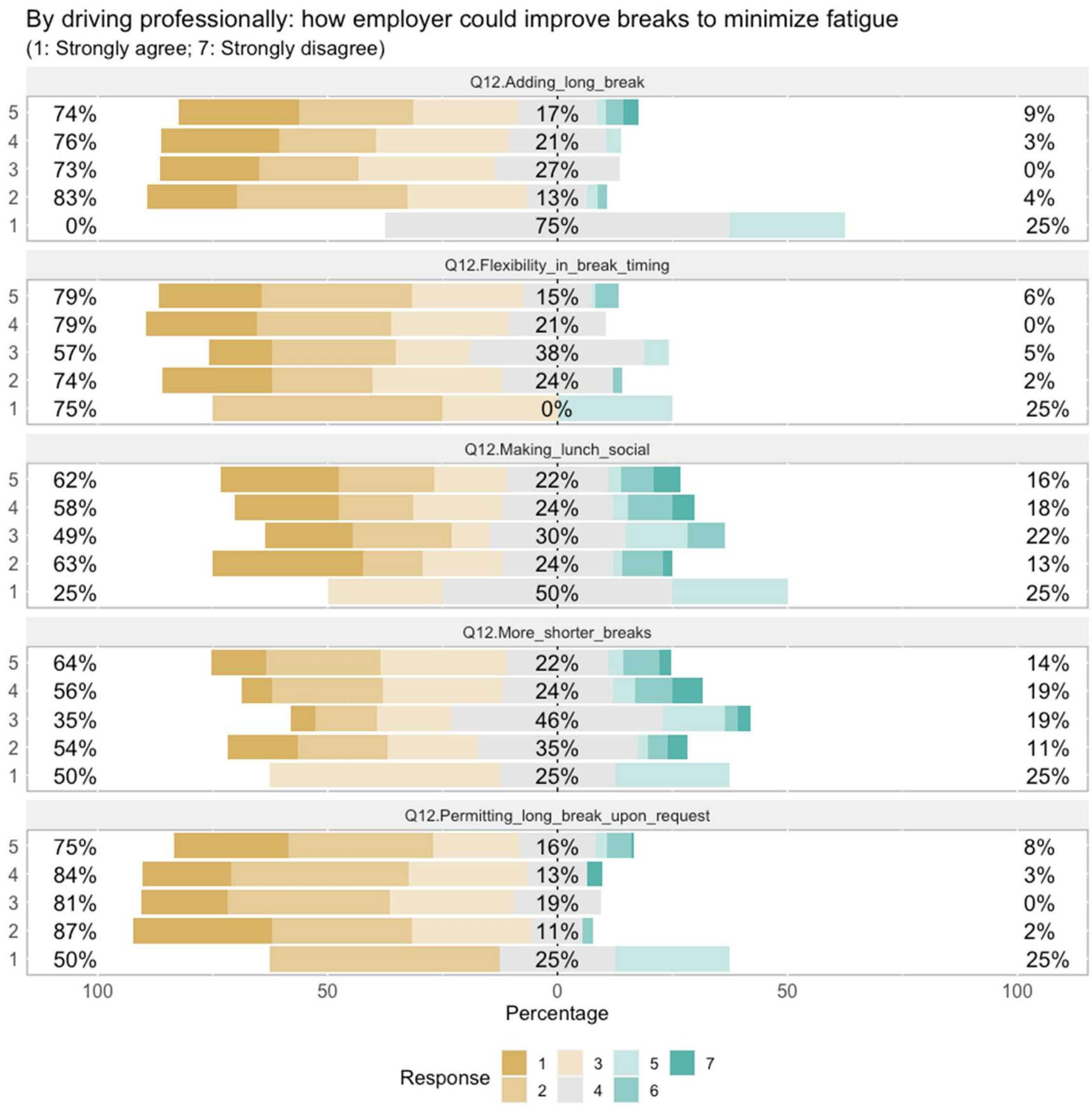

Figure A.18 Improve breaks by PDE.

THE UNIVERSITY OF UTAH

Fatigue Management Survey

Thank you for participating in this fatigue survey. Your answers will be helpful to understand better what issues and challenges you are facing in managing fatigue better at your workplace. Your answers will be recorded but all of the data are collected anonymously. This means we will not be able to know what your specific answers were. The results of this survey will be compiled and only the aggregates and summarized information will be provided to your employer. Answering the questions in this survey should not take longer than 10 minutes of your time.

For an electronic version of the survey, copy or type one of following links into your web browser:
https://csbsutah.co1.qualtrics.com/jfe/form/SV_204I0HNNsMW94oJ
https://tinyurl.com/yae25htj

Or use this QR code by scanning it with your smart phone

By answering the questionnaire, you are consenting to participate.

Figure A.19 Fatigue survey pg. 1.

1. Please enter your personal study ID (date of birth: DDMMYY + first and last name initials, for example: 070759JG): ____________________________

2. What is your gender?

- ○ Male
- ○ Female
- ○ Prefer not to answer

3. How long have you been working in your current job?

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-4 years
- ○ 5 or more years

4. How long have you been operating vehicles professionally?

- ○ Less than 1 year
- ○ 1-5 years
- ○ 6-10 years
- ○ 11-15 years
- ○ More than 15 years

Below is a number of questions that focus on how you personally manage fatigue.

5. To what degree does fatigue impact...

	No impact	Minimal impact	Moderate impact	Significant impact
Your job performance	○	○	○	○
Safety	○	○	○	○

6. How challenging do the following factors make it for you to minimize fatigue at work.

	Extremely challenging	Very challenging	Moderately challenging	Slightly challenging	Not challenging at all
Shift work	○	○	○	○	○
Rapid day to night shift rotation	○	○	○	○	○
Social activities	○	○	○	○	○
Family demands	○	○	○	○	○
Long commute	○	○	○	○	○
Financial concerns/working another job	○	○	○	○	○

Page 2 of 5

Figure A.20 Fatigue survey pg. 2.

7. How effective are the following personal approaches to minimize fatigue when tired?

	Extremely effective	Very effective	Moderately effective	Slightly effective	Not effective at all
Drinking coffee, energy drinks	○	○	○	○	○
Taking stimulants (medication)	○	○	○	○	○
Talking over the radio	○	○	○	○	○
Listening to radio/music	○	○	○	○	○
Changing cab temperature	○	○	○	○	○
Taking quick break to move around	○	○	○	○	○
Taking a short nap	○	○	○	○	○

8. How effective are these personal approaches to fatigue reduction?

	Extremely effective	Very effective	Moderately effective	Slightly effective	Not effective at all
Taking sleeping aids	○	○	○	○	○
Getting full rest prior to work	○	○	○	○	○
Exercising regularly to improve fitness	○	○	○	○	○
Eating healthy foods at work / home	○	○	○	○	○
Using a set-up (blackout room) to better sleep during day	○	○	○	○	○

Page 3 of 5

Figure A.21 Fatigue survey pg. 3.

The next questions/statements focus on how your <u>employer</u> manages employee work fatigue.

9. How effective are the following organizational activities in minimizing operator fatigue?

	Extremely effective	Very effective	Moderately effective	Slightly effective	Not effective at all
Educational materials and activities	○	○	○	○	○
Conducting safety training	○	○	○	○	○
Work scheduling to minimize fatigue	○	○	○	○	○
Use of new fatigue monitoring technology	○	○	○	○	○
Supervisor checking in during shift	○	○	○	○	○
Frequent radio contact with dispatch	○	○	○	○	○

10. How desirable are the following organizational approaches to help manage fatigue?

	Strongly agree	Agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly disagree
More, but shorter breaks	○	○	○	○	○	○	○
Adding a long (30 min) break	○	○	○	○	○	○	○
Permitting a long break upon request (when exceptionally tired)	○	○	○	○	○	○	○
Allowing more flexibility in break timing	○	○	○	○	○	○	○
Making lunch break social (hanging out with others)	○	○	○	○	○	○	○

11. Listed below are some current fatigue monitoring technologies. Please rank them based on your preference (1 most preferred; 5 the least preferred). Use each rank only once.

______ Cap / hat measuring brainwaves (e.g., Smartcap)
______ Camera-based systems (e.g., Hexagon, Guardvant, Caterpillar)
______ Wrist-based sleep-tracking systems (fitbit, readiband)
______ A combination of systems
______ No monitoring system

Page 4 of 5

Figure A.22 Fatigue survey pg. 4.

12. How could your employer improve breaks to minimize fatigue during night shifts?

	Strongly agree	Agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly disagree
More, but shorter breaks	○	○	○	○	○	○	○
Adding a long (30 min) break	○	○	○	○	○	○	○
Permitting a long break upon request (when exceptionally tired)	○	○	○	○	○	○	○
Allowing more flexibility in break timing	○	○	○	○	○	○	○
Making lunch break social (hanging out with others)	○	○	○	○	○	○	○

13. Please share with us any comments or suggestions you have.

____

____

____

____

____

Please return the completed survey to your supervisor.

Thank you for your participation!!

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Figure A.23 Fatigue survey pg. 5.

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