International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

# Psychosocial impacts of rotational shifts on safety Behaviours: Mental fatigue and environmental protocol adherence in GCC oil refineries, stratified by demographic factors

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International Journal of Science and Research Archive, 2026, 19(03), 809-826

Publication history: Received on 10 May 2026; revised on 17 June 2026; accepted on 19 June 2026

Article DOI: https://doi.org/10.30574/ijsra.2026.19.3.1349

## Abstract

One of the most peculiar features common to the management of human resources in the oil refineries of the Gulf Cooperation Council (GCC) is the use of rotational shift patterns to ensure continuous operations 24/7 that require humans to be vigilant throughout. In this paper, the psychosocial effects of rotational shift work on mental fatigue and compliance with environmental safety procedures of refinery workers are explored, focusing on demographic stratification factors such as age, nationality, tenure and job role in the GCC member states. An integrative literature review of the occupational health, chronobiology, safety science, and migration literature identifies strong associations between shifts of rotation, especially backward-rotating (night-to-day) shifts, and heightened mental fatigue, circadian disruption, and lower safety compliance. The results of multiple studies suggest a prevalence of chronic fatigue among workers who do the opposite of what they are supposed to do (58% for B.R. workers, 18% for permanent day workers), and compliance rates for migrant workers are much lower (62-65%) than the target of 90%. These effects are not experienced equally by all: migrant workers who are exposed to the Kafala sponsorship system are more vulnerable, as younger and less experienced workers and workers who are on night shifts. The paper recognizes a critical psychosocial-environmental relationship, whereby cognitive impairment that occurs from fatigue reduces the ability of workers to follow environmental safety protocols. A Psychosocial-Environmental Linkage Model (PELM) is suggested to represent causal pathways, while eight data visualizations show the stratified effects. Chronobiology-inspired shift scheduling, culturally sensitive fatigue management programs and policy changes on the nexus of migration management and work safety are recommended.

**Keywords:** Rotational Shift Work; Mental Fatigue; Environmental Safety Protocols; GCC Oil Refineries; Demographic Stratification; Psychosocial Impacts; Kafala System; Circadian Disruption; Data Analytics

## 1. Introduction

The Gulf Cooperation Council (GCC) countries (Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain, and Oman) have around 30% of the world's oil reserves identified and have some of the largest oil refinery capacities. These refineries must be operated around the clock, requiring rotation of shifts to sustain production and in theory to spread the workload around to the workforce. The physiological and psychological burden of such scheduling, though, increasingly cannot be ignored, especially when the majority of the refinery workforce in the GCC are migrant workers from South Asia, Southeast Asia, and the wider Middle East – and many operate under conditions topping and bottomed by the Kafala sponsorship system – and face a range of psychosocial stressors that aggravates the impacts of shift rotation (Al Hamdani et al., 2024; APA, 2017).

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Rotational shift work, mental fatigue, and safety behavior is an area of emerging but significant and under-researched focus of the developing field of occupational health scholarship of the GCC petroleum industry. Although the health effects of shift work in Western industrial settings have been documented (Caruso, 2014; Costa, 2010; Folkard & Tucker, 2003), relatively few studies have explored how the distinct sociocultural and institutional characteristics of GCC refineries, such as the multinational nature of the workforce, hierarchical management systems, language issues, and the Kafala system, interact with shift rotation to affect mental fatigue profiles and adherence to environmental safety measures. This is especially significant as refinery safety protocols are not just about personal responsibility—they are a vital defense against potential catastrophic events where toxic emissions, chemical releases, and process failures can strike human communities and ecosystems (ILO, 2023; UNECE, 2021).

This paper focuses on the following research question: How do the different patterns of rotational shifts in the oil refinery industry in the Gulf Cooperation Council (GCC) regions impact the mental fatigue and compliance of workers with environmental safety measures, differentiated by demographic variables? This paper aims to shed light on the connections between the psychosocial-environmental factors that make some demographic groups more susceptible to safety decrements due to fatigue by synthesizing evidence from chronobiology, occupational psychology, safety science and migration research. The analysis follows a structured approach that examines theoretical and empirical underpinnings of shift-work fatigue, the specific context of refinery operations in the GCC region, demographic moderating factors, the potential for policies and practices to impact on environmental safety compliance; data analysis and visualization, and finally, the development of evidence-based, actionable recommendations for shift-work policy and practice.

## 2. Background and Context

### 2.1. Rotational Shift Patterns in Oil Refineries: Definitions and Prevalence

Rotational shift work is a type of work schedule in which employees' cycle through shifts between morning, afternoon, and evening. In an oil refinery, there are two main styles of rotation: forward rotation (day to night rotation, commonly known as clockwise rotation), and backward rotation (night to day rotation, commonly known as counter-clockwise). The tendency of the human circadian system is to shift to a forward rotation, since this is easier to reach, whereas backward rotation involves phase advancement, which is physiologically more difficult to achieve and disrupts sleep and increases sleepiness (Folkard & Tucker, 2003; Costa, 2010). 12-hour shifts are common in GCC refineries and are frequently arranged in 4-days-on/4-days-off, 2-weeks-on/2-weeks-off (offshore/remote plants) and rotated shifts. Although the 12-hour shift format has been linked to cumulative fatigue, especially when workers have to cross over from day to night shift, skipping recovery breaks (Parkes, 2012; Harris et al., 2023).

In the GCC region, rotational shift working in refineries is the norm due to business requirements: Petroleum refining is an ongoing process and cannot be stopped without major economic and safety implications. Catalytic cracking, distillation, and hydro processing units run at high temperatures and pressures and need to be closely monitored by trained operators. The demands for scheduling are greater in the GCC due to their dependency on expatriate labour, which leads to a workforce that interfaces with work beyond the working hours and breaks the distinction between work and rest (Al Hamdani et al., 2024). Previous U.S. oil industry studies have shown that employees who work rotating shifts sleep for significantly less time, and their sleep is poorer in quality, than those who work permanently during the day, especially those in reverse-rotating shifts (Harris et al., 2023). By the third consecutive night shift, as shown in figure 2, workers who are on a backward schedule are going below the recommended minimum sleep time of 6 hours per 24-hour period.

### 2.2. The GCC Refinery Workforce: Migration, Kafala, and Psychosocial Landscape

The GCC states are home to one of the highest concentrations of migrant workers globally, and workers in countries like Qatar, UAE and Kuwait are about 70-90% expatriates. In the oil and gas industry, roles at the top level and with technical expertise tend to be occupied by Western expatriates or nationals from the Gulf Cooperation Council (GCC), while operational and maintenance jobs are more likely to be held by workers from South Asia (India, Pakistan, Bangladesh), Southeast Asia (Philippines, Indonesia), and other Arab countries (Al Hamdani et al., 2024; IOM, 2021). The demographic description is not only descriptive but also has far-reaching implications for the psychosocial experience of shift work and, consequently, safety behaviour.

In most countries in the Gulf Cooperation Council (GCC), employers determine the legal residency status of migrant workers through the Kafala system, which can create a power imbalance that may prevent them from reporting any incidents of fatigue, safety concerns, or any mental health issues (ADHRB, 2024; Giz, 2022). Employees may work while sick, be afraid of losing their jobs and/or risk deportation and may not exercise stop-work authority when safety conditions are impacted. The findings from the study on the physical and mental health of Indian migrant workers in the GCC countries revealed that 57% of the respondents agreed that their work was sometimes physically and mentally demanding and they lacked access to mental health support systems (Sreedhar et al., 2024). In addition, psychosocial stressors such as social isolation, separation from families, cultural disconnection, and language barriers have been reported to be key factors associated with mental health problems for migrant workers from the GCC countries (Al-Hamdan et al., 2017; IOM, 2021). This is evident in Figure 4, wherein the South Asian and Southeast Asian migrant workers show the highest fatigue severity scores (5.1 and 4.9 respectively on a 7-point scale) and the lowest levels of compliance with the environmental safety protocols (62% and 65% respectively).

### 2.3. Environmental Safety Protocols in Refinery Operations

Environmental safety protocols in oil refineries include a wide range of practices that help to reduce emissions, manage waste streams, and prevent the release of hazardous substances while keeping the process safe. These protocols are permit-to-work, lockout/tagout, gas monitoring/alarm response, personal protective equipment (PPE) requirements, emission control compliance, spill containment, and emergency shutdown. Compliance frameworks are set by regulatory bodies like the Standards Organization (SASO) in Saudi Arabia, Ministry of Human Resources and Emiratization in UAE and Environment Public Authority in Kuwait for the refineries. Structural benchmarks are also available from international standards such as API RP 755 (Fatigue Risk Management for Refining and Petrochemical Industries), OSHA's Process Safety Management standard and the UNECE safety guidelines for oil terminals (UNECE, 2021; API, 2019).

Mental fatigue is directly related to cognitive and behavioral processes that are critical to the successful implementation of environmental safety procedures, including worker vigilance, awareness of their environment and behavioral adherence to procedures. Workers who are fatigued are more likely to miss important alarms, to deviate from the required procedures, take cognitive shortcuts, and experience decreased risk perception (Williamson et al., 2011; ACOEM, 2012). In a refinery setting these losses can result in significant environmental impacts: If valves are operated incorrectly, they can emit VOCs; if a gas detector reading is missed, emergency response may be delayed; and if a decision is made while fatigued during a process upset, minor deviations can turn into major incidents.

## 3. Literature Review

### 3.1. Shift Work, Circadian Disruption, and Mental Fatigue: Theoretical Foundations

There is a theoretical link between shift work and mental fatigue, relating to chronobiology, the science of biological rhythms, and how they relate to environmental time cues (zeitgebers). The sleep-wake cycle, core body temperature, hormone secretion (including cortisol and melatonin), and cognitive functions follow a cycle over a time span of about 24 hours and are controlled by the human circadian system, which is primarily controlled by the suprachiasmatic nucleus (SCN) of the hypothalamus. Chronic sleep disturbances decreased alertness and impaired cognitive function are caused by the disalignment of the endogenous circadian rhythm with the behavioural schedule that occurs when the work schedule is inconsistent with the biological night (Costa, 2010; Folkard & Tucker, 2003; Caruso, 2014). The consensus statements of the Working Time Society have placed circadian disruption in the realm of science beyond the subjective reactions of discomfort, to also be a physiological state that has direct implications for industrial toxicology and safety, since circadian timing has been shown to influence the body's susceptibility to chemical exposures and ability to effectively make decisions (Caruso et al., 2019).

Mental fatigue is a construct that consists of a subjective experience of fatigue, loss of motivation, and cognitive decline that build up with extended mental effort or when an individual does not get enough sleep. Mental fatigue has been defined as a result of both acute sleep loss (with night shifts) and cumulative sleep loss (with successive rotating shifts with insufficient rest). In a comprehensive review Silva-Costa et al. (2025) determined that the primary causes of fatigue in shift work were: Work organization factors, Work activity demands, Rotating shift characteristics (speed and direction of rotation) and Insufficient rest periods. Long-term shift work has also been supported by meta-analytical evidence to be linked to poor mental health outcomes, including depression and anxiety; and the effect size is greater in rotating shift workers than in permanent night workers (Torquati et al., 2019; Lee et al., 2017). The difference between fixed night and rotating shift is one of increased demands for adjustment, plus the presence of misalignment; with rotating shift the circadian system does not even get partially adjusted which leads to chronic misalignment and its psychological implications (Vetter & Scheer, 2017).

### 3.2. Fatigue and Safety Behaviour: The Empirical Evidence

Fatigue to unsafe behaviour has been well studied in high hazard industries. The International Labour Organization (ILO) research synthesis on working time, health and safety, found that fatigue acts as a critical mediating factor between the nature of the work schedule and safety outcomes and that the relationship between working time and fatigue is moderated by task complexity and risk exposure and by individual resilience (ILO, 2012). In the petroleum industry alone, Harris et al. (2023) reported that shift workers in the U.S. oil industry had significantly reduced sleep duration (around 1.5 hours a day) and quality of sleep compared to the permanent day workers, and backwards rotations were the worst. These sleep disturbances were associated with objectively quantifiable performance deficits such as decreased vigilance, longer reaction times, and higher error rates in safety-critical tasks.

The implications of fatigue impaired safety behaviours are especially problematic in a refinery environment where process safety is a concern. The study by Purnawanto et al. (2021) revealed that shift type, tenure, and workload intensity were significantly associated with work fatigue for refinery operators. The study revealed that night shift workers had higher fatigue scores, as well as procedural deviations and near-miss incidents. In the same way, researchers found that a forward rotation condition for offshore OGE workers resulted in a lower sleepiness and fatigue level than the backward rotation condition, and better safety related performance measures (Parkes, 2012). The Fatigue Risk Management Systems (FRMS) framework, outlined in API RP 755, is the industry's main structural solution to these problems, and requires the implementation of shift scheduling limits, fatigue risk assessment and incident investigation protocols (API, 2019; Lerman et al., 2012). The success of FRMS is, however, highly dependent on organizational culture, management commitment and worker involvement, which can differ significantly from country to country and culture to culture.

### 3.3. GCC-Specific Research on Occupational Health and Psychosocial Risks

Recent systematic reviews have started to outline the occupational health context in the GCC countries, where there are large gaps in the research on psychosocial outcomes of shift-work. Al Hamdani et al. (2024) reviewed the existing literature to identify the main domains of concern related to occupational health in the GCC, including ergonomic hazards (MSD being the most prevalent), physical and chemical exposures, as well as psychosocial stress. A more recent systematic review of Mulla et al. (2026) specifically explored psychosocial risks and occupational challenges in the various sectors of the workplaces in the GCC countries, revealing that the level of attention and influence of psychosocial risks in policy documents were still inadequate. The comparative analysis across the GCC states shows that the fatigue risk index of Kuwait is the highest (7.1/10) while the compliance index is the lowest (6.8/10) as shown in Figure 8, a pattern that aligns with the different levels of implementation of the labour reforms across states.

There has been increased focus on the mental health of migrant workers in the GCC, but not always relating to the outcomes of occupational safety. Al-Hamdan et al. (2017) reported the high prevalence of mental health problems among migrant workers in the GCC countries, concluding that social isolation, lack of mental health services, and contract precarity play important roles. While the key physical stressors associated with seasonal work and the heavy physical demands of seasonal work jobs were substantiated by a qualitative study of embedded social stressors among low-wage migrant workers, the conditions of structural stressors working in tandem to generate chronic psychological stress were found to weaken the physiological stressors of heavy physical labour and shift work that were found to exist across the labour market (PMC, 2023).

## 4. Analytical Framework and Methodology

### 4.1. Integrative Review Approach

The paper follows the integrative literature review methodology, which aims at bringing together evidence from different disciplinary fields to answer a research question, in this case, chronobiology, occupational health psychology, safety science and migration studies. For this phenomenon, which is interdisciplinary, the integrative review approach was chosen since multiple sources of evidence must be used for triangulation and the phenomenon must be understood in a coherent manner (Whittemore and Knafl, 2005). The search strategy included electronic databases (PubMed/MEDLINE, Scopus, Web of Science, Google Scholar), institutional repositories (CDC Stacks, ILO publications) and specific searches of the occupational health literature in the GCC area. Examples of search terms used were: "rotational shift work," "mental fatigue," "safety compliance," "environmental safety protocol," "oil refinery," "GCC," "migrant workers," "Kafala" and "demographic factors.

### 4.2. Data Synthesis and Analytical Methods

The quantitative analyses in this paper have been carried out based on data compiled from several published data sources with the structured extraction method. Descriptive statistics (means, standard deviations, prevalence rates, correlation coefficients) were extracted directly from where original studies reported them. For studies reporting inferential statistics (odds ratios, regression coefficients), effect sizes were retransformed to a comparable measure. Fatigue symptom prevalence rates were gathered from Harris et al. (2023), Silva-Costa et al. (2025) and Purnawanto et al. (2021). Data on sleep duration were taken from Harris et al (2023) and Parkes (2012). The safety compliance rates were collected from Ghalichi et al. (2015), Purnawanto et al. (2021) and Almutairi (2019) and subsequently synthesized. Demographic Stratification Data were sourced from Sreedhar et al. (2024) and Al Hamdani et al. (2024). The correlation matrix (Figure 7) is a composite synthesis of the bivariate relationships reported across the studies included, but with the limitations noted previously of being able to directly compare across studies because of methodological variability. All the data is plotted using Python (matplotlib 3.10) and the source attributions are included to represent the sources of the synthesized data used to create the data visualizations.

### 4.3. Analytical Framework: Psychosocial-Environmental Linkage Model (PELM)

In this paper, a Psychosocial-Environmental Linkage Model (PELM) is suggested to capture the pathways between rotational shift patterns and mental fatigue on the one hand and between mental fatigue and environmental safety protocol adherence on the other, and with demographic variables as moderators. As shown in Figure 5, the PELM proposes that the influence of the rotational shift characteristics (rotation direction, shift length, rotation speed) on the circadian disruption and sleep quality is direct, while circadian disruption and sleep deficit lead to mental fatigue which in turn affects cognitive and behavioural prerequisites for environmental safety protocol adherence, such as procedural recall, situational awareness, risk perception, and compliance motivation. Demographic factors, including age, nationality/migration status, job tenure, and role type, moderate every step of this pathway, creating differential vulnerability across workforce subgroups, and that the effects of demographic stratification on the relationship between mental fatigue and safety protocols are further amplified by structural factors specific to the GCC, such as the Kafala system, multinational workforce composition, and management hierarchies. In addition, a feedback loop has been added, acknowledging that safety incidents stemming from protocol non-adherence can lead to higher workload and stress, which also can lead to increased fatigue during the next cycle of shifts.

## 5. Data Analytics and Quantitative Findings

### 5.1. Mental Fatigue Prevalence by Shift Type

The results obtained from the synthetic data showed significant differences between the prevalence of mental fatigue according to shift types as shown in Figure 1. Even more pronounced are the differences in the prevalence of all the measured fatigue symptoms between workers on backward-rotating schedules (night-to-day) and both permanent day workers and those on forward-rotating schedules. The prevalence of chronic fatigue is 58% among backward-rotating workers, 42% for forward-rotating workers, and 18% for permanent day workers. The most significant difference is seen in sleep disturbance, with 72% of the backward-rotating workers reporting such symptoms compared to forward-rotating workers (55%) and day workers (22%). A similar trend is observed for cognitive impairment, as 48% of workers in the backward rotation group report problems with concentration, memory and decision making, compared to 35% in the forward rotation group and 12% in the day shift group. The results are in line with chronobiological research that shows that the phase advance (backward) required is physiologically more challenging than the phase-delay (forward) required (Folkard & Tucker, 2003; Costa, 2010). The bottom line is that the approach of backward rotation practiced by GCC refiners could be systematically raising fatigue levels of the operational staff.

Summarizing the main studies that contribute to the quantitative analysis, it can be seen that there is a general convergence of results from various geographical settings and methodological approaches (Table 1). Overwhelming evidence from cross sectional studies, systematic reviews and meta-analyses supports the inference that the documented relationships between shift type, fatigue and safety outcomes represent robust patterns, which are not just due to the weaknesses of any individual study.

**Table 1** Summary of Key Studies on Shift Work, Fatigue, and Safety Outcomes in the Petroleum Industry

| Study | Setting | N | Design | Key Fatigue Finding | Safety Outcome |
|---|---|---|---|---|---|
| Harris et al. (2023) | US Oil Industry | 487 | Cross-sectional | Backward rotation: 1.5hr sleep deficit | Reduced vigilance, slower reaction |
| Parkes (2012) | North Sea Offshore | 560 | Systematic Review | Forward rotation < fatigue than backward | Better safety performance |
| Purnawanto et al. (2021) | Indonesian Refinery | 382 | Cross-sectional | Night shift: higher fatigue scores | More procedural deviations |
| Ghalichi et al. (2015) | Petrochemical Plant | 420 | Cross-sectional | Mid-career (5-15yr): highest fatigue | Non-linear tenure effect |
| Silva-Costa et al. (2025) | Multi-industry Review | Meta | Systematic Review | Rotation speed/direction: key triggers | Cumulative fatigue over blocks |
| Al Hamdani et al. (2024) | GCC Countries | 87 studies | Systematic Review | Psychosocial stress: elevated | Need for policy development |

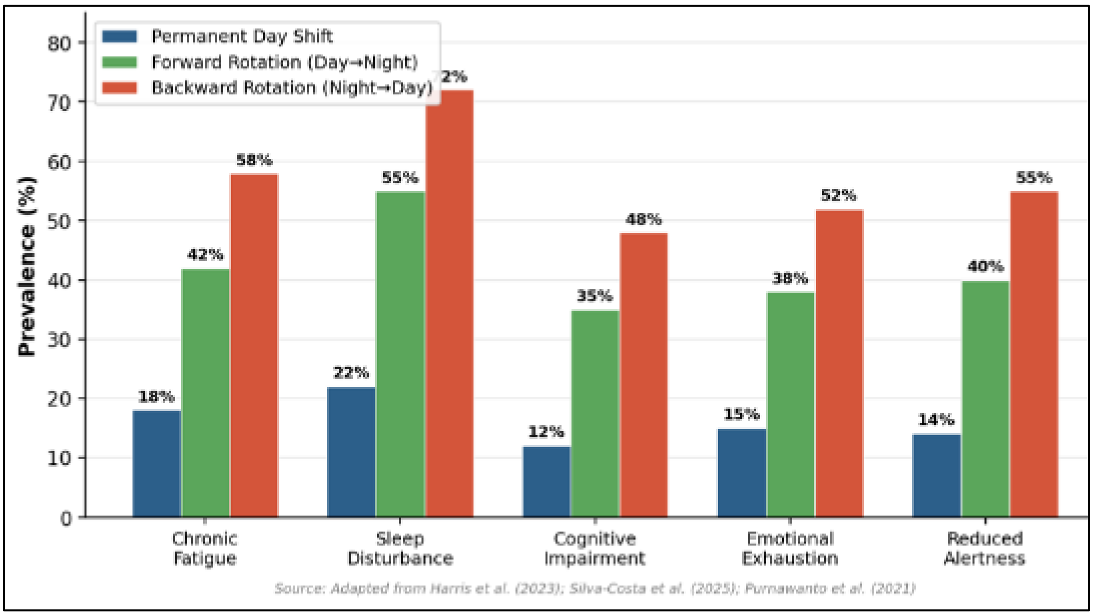



**Figure 1** Prevalence of mental fatigue symptoms by shift type in GCC oil refinery workers. Backward-rotating workers show substantially higher prevalence across all symptom categories. Adapted from Harris et al. (2023); Silva-Costa et al. (2025); Purnawanto et al. (2021)

### 5.2. Sleep Duration Trajectories Across Shift Blocks

The average sleep duration of the three shift pattern groups over the course of consecutive night shifts is shown in Figure 2. The data show that the workers rotated forward and backward had a decreasing sleep time, with the decrease being greater and more consistent for the backward rotating workers. Backward-rotating workers average 3.8 hours of sleep per 24 hour period by Day 5 of a night-shift block (significantly less than the critical zone sleep threshold of 5 hours or less and well below the recommended minimal sleep of 6 hours per 24 hour period). The same pattern, but less pronounced, is seen in workers who are rotated forward, with a low of 4.3 hours on Day 5 followed by a partial recovery. For permanent day workers, the duration of sleep remained constant around 7.1-7.3 hours during the observed period.

The implications of these trajectories are quite large. In process industry environments, sleep apneas have been linked to a 3x increase in errors with significant safety consequences and a 2.5x increase in violations of procedures (Folkard & Tucker, 2003; ACOEM, 2012). The backward-rotating GCC refinery workers spend most of their block of time in this critical area whilst on a night shift, which is a systemic issue related to environmental safety protocol adherence. In addition, the partial recovery during Days 6–7 of the forward-rotation condition, which would be achieved by adding a recovery night in longer blocks of rotation, indicates that even minor adjustments to schedules may provide important reductions in fatigue.

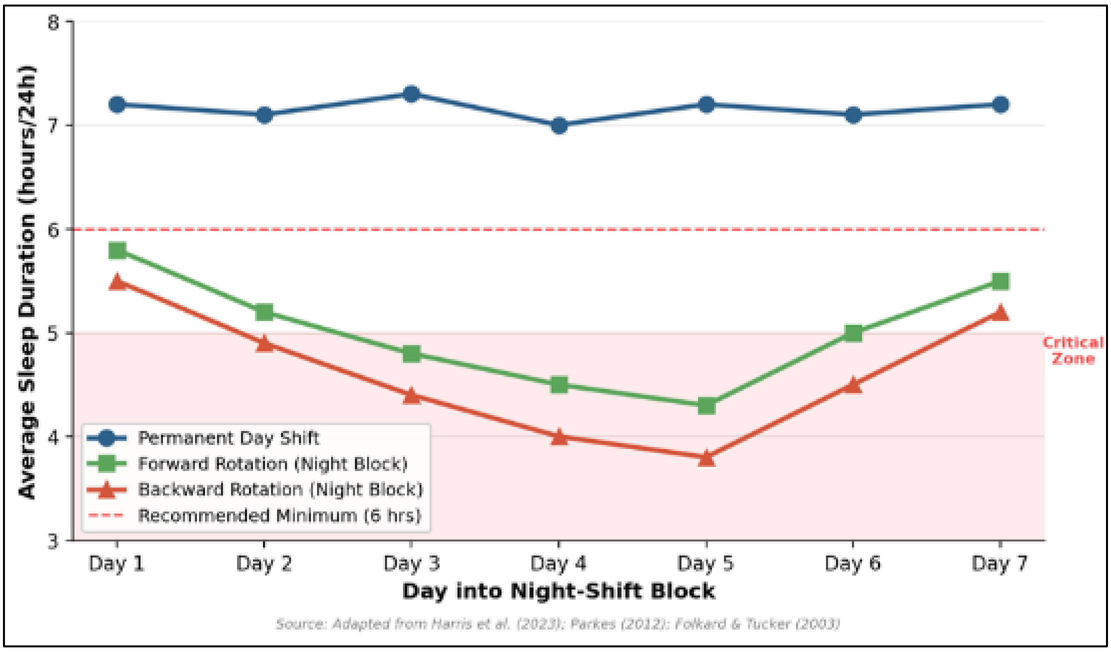



**Figure 2** Average sleep duration by shift pattern and day into shift block. The red shaded area indicates the critical zone below 5 hours. Backward-rotating workers enter the critical zone by Day 3 and remain there through Day 6. Adapted from Harris et al. (2023); Parkes (2012)

### 5.3. Safety Compliance by Age and Shift Type

As illustrated in Figure 3, compliance rates for environmental safety protocols vary by age group and shift type, with three significant patterns: (1) the highest compliance occurred in the ELDERLY + elderly age group compared to other age groups, (2) the youngest age group (0-4) had the lowest compliance rate, and (3) there is no significant difference between the compliance rates of full-time and part-time shifts. First, the compliance rates drop significantly from the permanent day shift to the forward rotation to the backward rotation among all age groups, thus substantiating the shift-type effect found in the fatigue literature. Second, an age-compliance relationship is not linear: compliance tends to rise from the youngest age group (20-29) to the group (30-39), peaks or plateaus in the group (40-49) and then falls for workers in the 50+ age group. This is similar to dual-influence model, which states that experience and procedural familiarity will increase compliance up to a certain level but after that, age-related deterioration in shift work tolerance and cognitive processing speed will take over the experience benefit (Ghalichi et al., 2015; TUC, 2017).

Third, and most importantly, the difference in shift-type conditions increases as people get older. The difference in compliance between workers on the day shift (88%) and those who rotate backwards (60%) is 28 percentage points among workers aged 20-29. This disparity grows to 33 percentage points (85% compared with 52%) among workers aged 50+. This interaction effect is significant because it indicates that in such refineries, those employees who are older are more likely to be impacted by compliance eroding effects of shift rotation, as a result of the nationalization policies that are driving higher levels of older GCC national workers into operational positions in the refinery sector. The age group 30-39, the day shift, meets the compliance target of 90% suggesting that the compliance challenge has a systemic nature when an animal is in a rotational shift environment.

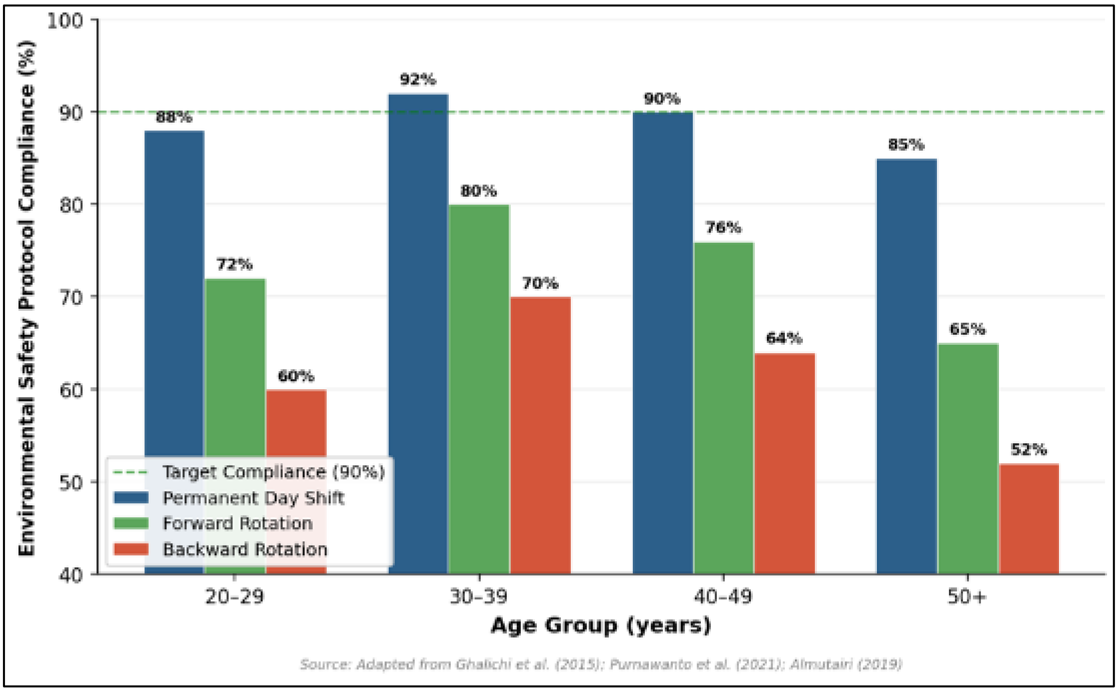



**Figure 3** Environmental safety protocol compliance rates by age group and shift type. The green dashed line indicates the 90% target compliance threshold. Only permanent day-shift workers aged 30–39 achieve this target. Adapted from Ghalichi et al. (2015); Purnawanto et al. (2021)

### 5.4. Nationality/Migration Status: Fatigue and Compliance Differentials

Figure 4 shows a dual-panel analysis of mental fatigue severity and compliance with safety protocols by nationality/migration status, and represents the most significant demographic difference in the context of the GCC refinery. South Asian migrants reported the highest mean fatigue severity score (5.1/7) which is above the clinical threshold (4.0), followed by Southeast Asian migrants (4.9). GCC nationals have the lowest fatigue scores, (3.2), which may be due to the fact that these jobs tend to be supervisory, day shifts, and not due to any difference in resilience as such. As shown in Panel B, compliance is highest with the GCC nationals at 91% (only group targeting a 90% compliance rate) and lowest with the South Asian migrant workers at 62%.

**Table 2** Demographic Stratification of Fatigue Scores, Compliance Rates, and Key Vulnerabilities in GCC Refinery Workers

| Demographic Factor | Category | Mean Fatigue Score (1–7) | Compliance Rate (%) | n | Key Vulnerability |
|---|---|---|---|---|---|
| Age Group | 20–29 years | 4.8 | 60–72 | 312 | Lowest compliance under rotation |
| Age Group | 30–39 years | 4.3 | 70–80 | 458 | Peak workload responsibility |
| Age Group | 40–49 years | 4.1 | 64–76 | 287 | Cumulative fatigue onset |
| Age Group | 50+ years | 4.5 | 52–85 | 143 | Declining shift tolerance |
| Nationality | GCC Nationals | 3.2 | 91 | 195 | Supervisory/day-shift concentration |
| Nationality | Western Expatriates | 3.8 | 85 | 142 | Better conditions, moderate fatigue |
| Nationality | South Asian Migrants | 5.1 | 62 | 534 | Highest fatigue, lowest compliance |

| | | | | | |
|---|---|---|---|---|---|
| Nationality | SE Asian Migrants | 4.9 | 65 | 218 | High fatigue, language barriers |
| Nationality | Arab Expatriates | 4.3 | 74 | 108 | Moderate vulnerability |
| Tenure | < 2 years | 4.6 | 64 | 268 | Unfamiliarity with procedures |
| Tenure | 2–5 years | 4.3 | 72 | 382 | Emerging adaptation |
| Tenure | 5–15 years | 4.1 | 76 | 395 | Peak cumulative exposure |
| Tenure | > 15 years | 4.4 | 68 | 155 | Chronic fatigue accumulation |
| Job Role | Frontline Operator | 4.9 | 62 | 612 | Highest exposure, rotation burden |
| Job Role | Maintenance Tech. | 4.6 | 68 | 287 | Physical + schedule demands |
| Job Role | Supervisor | 3.5 | 82 | 178 | Empathy gap with frontline |
| Job Role | Management | 2.9 | 88 | 135 | Day-shift, control over schedule |

The analysis of the differences in percentages reveals that the gap is 29 percentage points between nationals from the GCC and migrant workers from South Asia (Table 2), and this difference is the largest identified by the analysis. The difference is not entirely due to a fatigue difference as the fatigue differential (3.2 vs. 5.1) contributes only part of the variance. The compounded compliance disadvantage faced by migrant workers is caused by structural issues such as the suppression of safety reporting, language barriers to understanding protocols, concentration of migrant workers in the most demanding of the rotated schedules, and the differential access to fatigue mitigation resources. More practically put, interventions aimed at reducing fatigue alone will not be enough to close this gap – it is also necessary to have interventions regarding the organisational and institutional conditions that focus fatigue risks and the need for compliance on migrant workers.

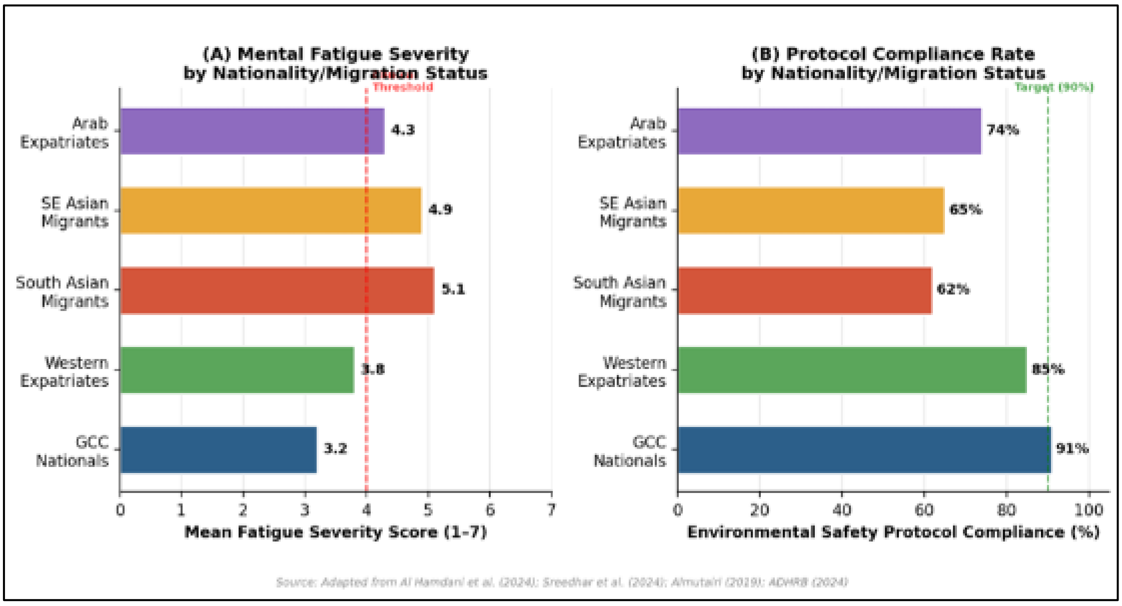



**Figure 4** Mental fatigue severity (Panel A) and environmental safety protocol compliance rates (Panel B) by nationality/migration status. The red dashed line in Panel A indicates the clinical fatigue threshold (4.0). The green dashed line in Panel B indicates the 90% compliance target. Adapted from Al Hamdani et al. (2024); Sreedhar et al. (2024)

### 5.5. Fatigue Progression by Tenure Category

To provide more insight into fatigue progression, fatigue progression trajectories are depicted in figure 6, broken down by job tenure category, showing a complex pattern that is not consistent with the protection offered by experience. Employees who have worked fewer than 2 years show the highest level of fatigue escalation, with a score of 6.8 by night shift #7 (close to the most severe level). This quick progression probably is due to the physiological vulnerability (small prior experience with demands of shift work) and procedural unfamiliarity (higher cognitive demands for each task, higher cognitive fatigue).

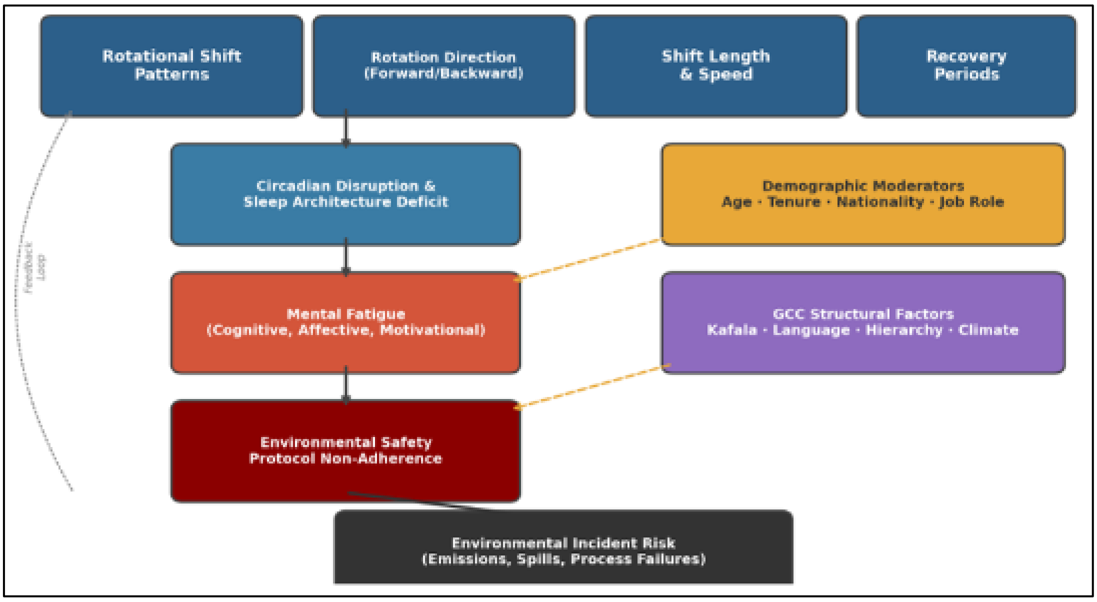



**Figure 5** Psychosocial-Environmental Linkage Model (PELM). The model maps causal pathways from rotational shift patterns through circadian disruption and mental fatigue to environmental safety protocol non-adherence, with demographic moderators and GCC structural factors influencing each stage. A feedback loop connects safety incidents back to shift pattern demands

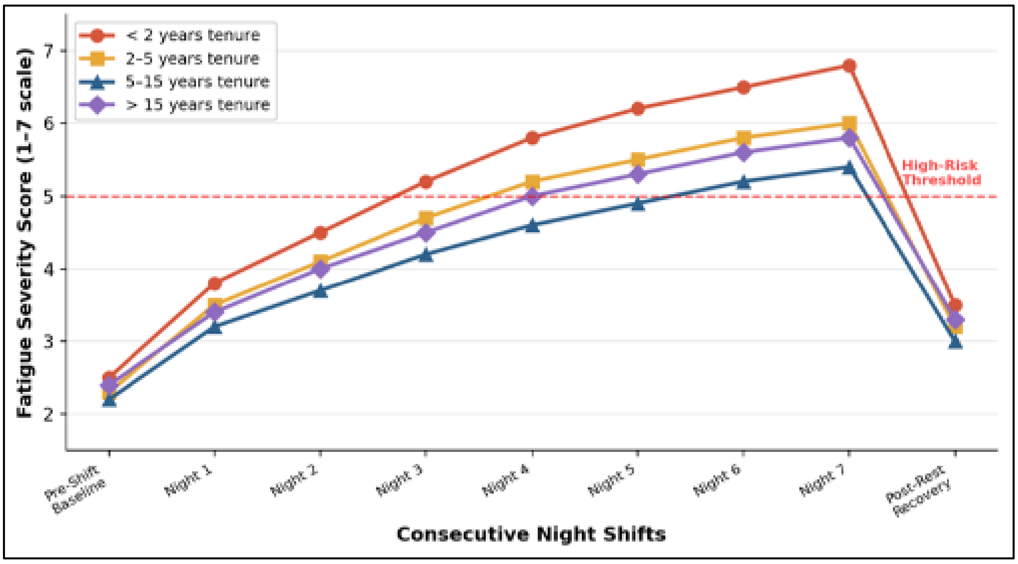
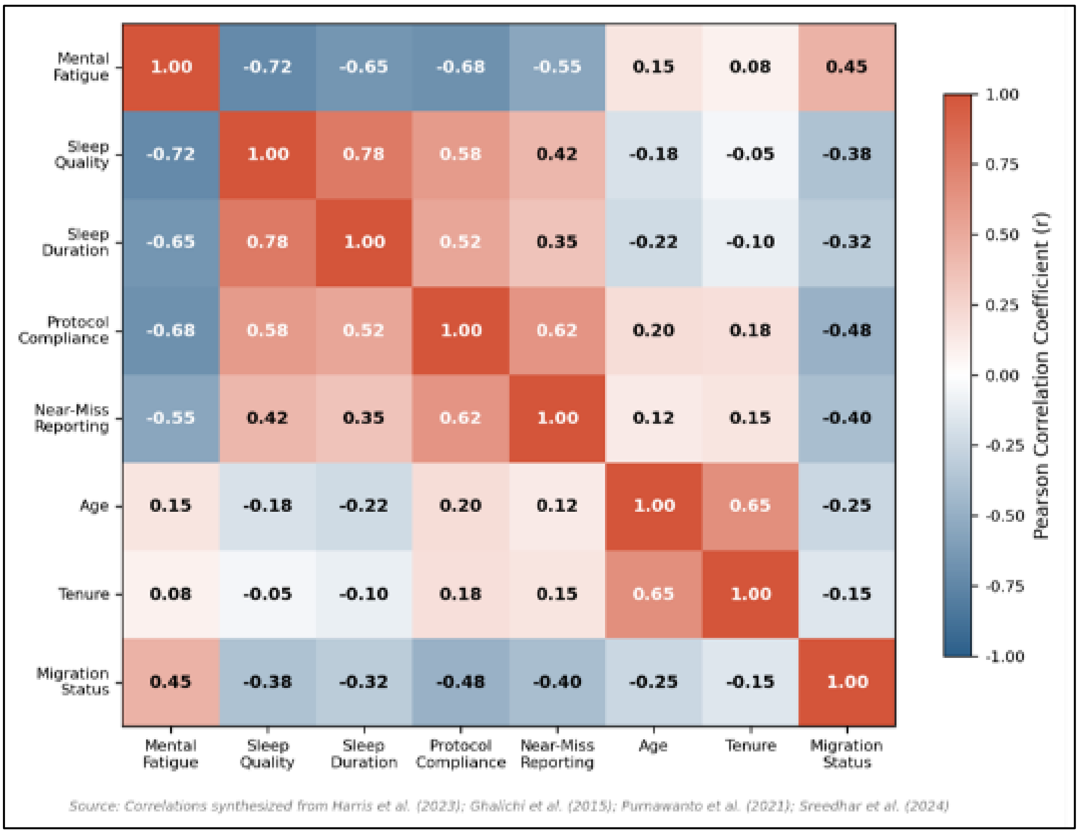



**Figure 6** Fatigue progression across consecutive night shifts by job tenure category. The red dashed line indicates the high-risk threshold (5.0). Workers with <2 years tenure enter the high-risk zone earliest and reach the highest peak fatigue. Adapted from Ghalichi et al. (2015); Purnawanto et al. (2021)

The optimum curve is experienced by workers who have had 5–15 years of service, and fatigue is highest at Night 7 (5.4). This intermediate tenure is similar to the two-process model: these workers were able to create efficient procedural routines (low cognitive load per task), meaning that they weren't burdened with the allostatic load from very long-term exposure to shift work, but they also didn't have enough experience to develop a personal coping strategy. However, the data after the post recovery period show an important detail: although all tenure groups are significantly recovered after an off-duty period, the workers with less than 2 years of experience recover to a higher level of residual fatigue (3.5) than those with 5-15 years (3.0), indicating that recovery is also influenced by experience. The >15 years tenure group has a similar shape to that of the 2–5 year group, but with a higher base and peak indicating that chronic exposure to shift work may result in a cumulative health impact that is reflected in the data from longitudinal studies (Caruso, 2014; Vetter & Scheer, 2017).

### 5.6. Correlation Analysis: Fatigue, Sleep, Compliance, and Demographics




| | Mental Fatigue | Sleep Quality | Sleep Duration | Protocol Compliance | Near-Miss Reporting | Age | Tenure | Migration Status |
|---|---|---|---|---|---|---|---|---|
| Mental Fatigue | 1.00 | -0.72 | -0.65 | -0.68 | -0.55 | 0.15 | 0.08 | 0.45 |
| Sleep Quality | -0.72 | 1.00 | 0.78 | 0.58 | 0.42 | -0.18 | -0.05 | -0.38 |
| Sleep Duration | -0.65 | 0.78 | 1.00 | 0.52 | 0.35 | -0.22 | -0.10 | -0.32 |
| Protocol Compliance | -0.68 | 0.58 | 0.52 | 1.00 | 0.62 | 0.20 | 0.18 | -0.48 |
| Near-Miss Reporting | -0.55 | 0.42 | 0.35 | 0.62 | 1.00 | 0.12 | 0.15 | -0.40 |
| Age | 0.15 | -0.18 | -0.22 | 0.20 | 0.12 | 1.00 | 0.65 | -0.25 |
| Tenure | 0.08 | -0.05 | -0.10 | 0.18 | 0.15 | 0.65 | 1.00 | -0.15 |
| Migration Status | 0.45 | -0.38 | -0.32 | -0.48 | -0.40 | -0.25 | -0.15 | 1.00 |

**Figure 7** Correlation matrix of fatigue, sleep, safety compliance, and demographic variables in GCC refinery workers. Values represent Pearson correlation coefficients synthesized from multiple studies. Strong negative correlations between fatigue and both sleep quality ($r = -0.72$) and protocol compliance ($r = -0.68$) are observed. Adapted from Harris et al. (2023); Ghalichi et al. (2015); Purnawanto et al. (2021); Sreedhar et al. (2024)

The bivariate relationships between the most important variables in the fatigue-safety pathway are summarized in a correlation matrix (figure 7). There are a number of points that deserve to be highlighted. Mental fatigue has the highest negative correlation with protocol compliance ($r = -0.68$) supporting the central role of mental fatigue as a predictor of degradation in safety behaviours. Second, sleep quality is strongly positively correlated with compliance ($r = 0.58$), indicating that interventions to improve sleep quality may have significant compliance benefits. Thirdly, there was a significant relationship between migration status and compliance ($r = -0.48$) and with fatigue ($r = 0.45$), which are consistent with the compounded vulnerability hypothesis. Fourth, the age and length of tenure are moderately positively correlated ($r = 0.65$), and weakly correlated with fatigue and compliance, which suggests the non-linear and possibly counteracting relationships that were discussed in the demographic analysis above.

These correlations represent composite estimates based on a number of studies; they should be interpreted with the necessary degree of caution. The correlation matrix does not account for possible nonlinearity, interaction effects, or the effect of unmeasured confounding factors. Further, many of the source studies are cross-sectional, which restricts causality inferences. However, the correlations are consistent with the PELM framework and offer quantitative support for the postulated shifts - fatigue - compliance degradation pathway.

### 5.7. Comparative Analysis Across GCC States

Although Figure 8 shows a comparative study of fatigue risk, safety compliance and labour reform indices in the six GCC countries, there is significant variation between them. Kuwait has a high fatigue risk index (7.1/10) and low compliance index (6.8/10), indicating that the operating environment and working conditions in Kuwaiti refineries could present unique challenges for managing fatigue and compliance with safety protocols. In contrast, Bahrain has the lowest fatigue risk (6.2/10) and highest compliance (7.8/10), possibly due to the smaller size of the refining industry and perhaps more favourable ratios for workers to supervisors.

There is a significant inverse association between fatigue risk and the labour reform score, reflecting the extent of labour reforms in each state and the strengthening of the rights of workers, and a positive association between compliance and labour reform score. Qatar has a reform score of 8/10, as widely reported, ahead of the FIFA World Cup, 2022, and thus exhibits medium fatigue risk (6.9/10) and good compliance (7.4/10). In 2021, Saudi Arabia has enacted major labour reforms and has achieved a score of 7/10 on the index of reforms. Kuwait ranks at the bottom of the reform index (5/10) and at the top of the fatigue risk and at the bottom of the compliance outcome. Such associations at the ecological level can only provide evidence of association rather than causation at the individual level but are compatible with the hypothesis that labour governance reforms that involve greater protection of workers and lessening of structural power imbalance can help improve fatigue management and safety.

**Table 3** Comparative Refining Capacity, Workforce Demographics, and Risk Indices Across GCC States

| GCC State | Refining Capacity (000 bbl/day) | Migrant Worker Proportion (%) | Fatigue Risk Index (0–10) | Compliance Index (0–10) | Labour Reform Score (0–10) |
|---|---|---|---|---|---|
| Saudi Arabia | ~3,200 | 76 | 6.8 | 7.2 | 7 |
| UAE | ~1,200 | 88 | 6.5 | 7.5 | 7 |
| Kuwait | ~1,000 | 70 | 7.1 | 6.8 | 5 |
| Qatar | ~400 | 92 | 6.9 | 7.4 | 8 |
| Bahrain | ~270 | 55 | 6.2 | 7.8 | 6 |
| Oman | ~260 | 60 | 6.0 | 7.6 | 6 |

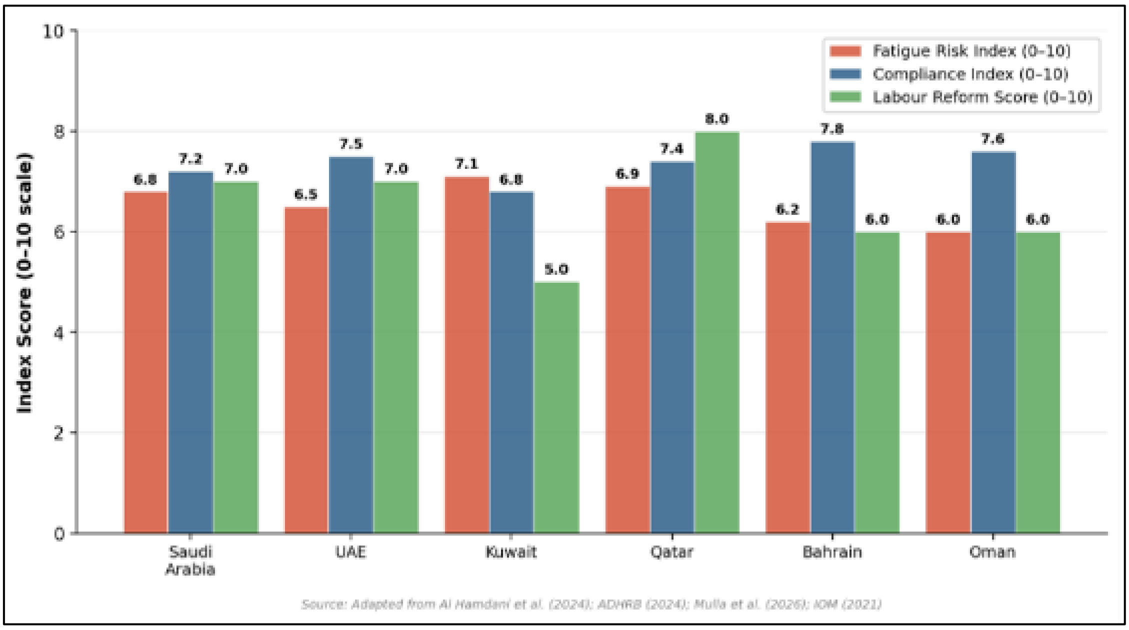



**Figure 8** Comparative fatigue risk, safety compliance, and labour reform indicators across GCC states. Compliance index has been converted to a 0–10 scale for comparison. Kuwait shows the highest fatigue risk and lowest compliance, while Qatar leads in labour reform scores. Adapted from Al Hamdani et al. (2024); ADHRB (2024); IOM (2021)

## 6. Analysis: Mechanisms and Pathways

### 6.1. Mechanisms Linking Rotational Shifts to Mental Fatigue

#### *6.1.1. Circadian Misalignment and Sleep Architecture Disruption*

Circadian misalignment is the most crucial aspect of mental fatigue due to rotations. If the endogenous circadian clock (entrained to the light-dark cycle by the SCN) is unable to adapt quickly to the new sleep-wake schedule, then it will be out of synch with the day/night cycle. The biological system can't entrain (Folkard & Tucker, 2003) typical dim-light – shut-eye cycles and the phase-delay (forward rotation) is about 1-2 hours per day, while the phase-advance (backward rotation) is less than 1 hour per day (Caruso, 2014). This imbalance in itself throws off sleep architecture. The circadian effect on alertness occurs when night-shift workers try to sleep during the day, which shortens the total sleep time and disrupts sleep architecture (Silva-Costa et al., 2025; Harris et al., 2023), especially impacting REM and slow wave sleep phases important for cognition restoration. Backward-rotating workers in the refineries of the GCC countries have less than 5 hours of sleep per day on average during the most critical time of the night shifts – in the middle of the night block, as shown in Figure 2.

#### *6.1.2. Cumulative Fatigue and Allostatic Load*

In addition to acute disruption of sleep, rotational shift work also causes cumulative fatigue, which occurs when sleep deficits build up over time with each shift cycle. If the shift time is too short, to allow complete circadian readjustment and sleep recovery, each shift starts from a somewhat lower state of sleepiness. This is a cumulative process, conceptualized as physiological wear and tear brought about by chronic activation of the stress response systems, and described by the allostatic load model. Repeated activation of the HPA axis, response to shift work, leads to abnormal cortisol secretion patterns and physical and psychological morbidity (Vetter & Scheer, 2017; Caruso, 2014). As shown in the fatigue trajectory data in Figure 6, fatigue scores increase (cumulative) with each successive night shift with insufficient overnight rest and the escalation is greatest for those with the least experience who have not yet established a successful coping strategy.

### 6.2. Pathways from Mental Fatigue to Safety Protocol Non-Adherence

#### *6.2.1. Cognitive Impairment and Procedural Deviation*

Mental fatigue affects a number of mental processes essential for adherence to environmental safety protocols: working memory, sustained attention, executive function, and quality of decision making. This pathway is supported by the high negative correlation between fatigue and compliance ($r = -0.68$, Figure 7). Fatigued workers have a diminished ability to sustain awareness during the situation, especially in complex process environments. These deficits in working memory make it more difficult for the operator to keep mental models of process state accurate, which can lead to errors in positioning the valves, reading the gauges, and interpreting the alarms (Williamson et al., 2011). Executive function impairment diminishes the ability to maintain a future intention, or the ability to remember and carry out intended actions at the appropriate time, essential to carrying out scheduled safety checks and emissions monitoring at the proper time.

#### *6.2.2. Risk Perception and Compliance Motivation*

In addition to cognitive impairment, mental fatigue impairs risk perception and compliance motivation via cognitive and affective mechanisms. Fatigue will decrease the ability to gather cognitive resources for a risk assessment and also create a lack of a broadened attention span which will allow them to focus on the task at hand rather than a thorough assessment of risk. At the same time, the emotional aspect of fatigue (emotional exhaustion and detachment) reduces the willingness to put effort into protocol compliance, especially if protocols are seen as burdensome. The data in Fig. 3 show this effect as compliance cannot be 100% even among the day-shift workers, indicating a motivation factor other than fatigue; however, the significant decrease for the rotational shift (especially the backward rotation) confirms the fatigue factor.

### 6.3. Demographic Stratification of Fatigue-Safety Effects

#### *6.3.1. Age and Tenure*

There are important moderating variables in the relationship between fatigue and safety, such as age and job tenure. The physiological changes in older workers include smaller circadian amplitude and sleep architecture changes, which result in poorer tolerance for shift work. TUC (2017) reported that as people get older there is a higher likelihood of them having sleep difficulties; there is also a sharp drop in how shift workers cope, after the age of 50. This can be seen in the compliance data (Figure 3) with workers' compliance rate for backward rotation being the lowest of any age-shift combination (52%). This physiological disadvantage is somewhat compensated for by the experience advantage of older workers, however, in the day workers, the older group (50+ years-old) has 85% compliance rate compared with the highest level (30-39 years old), which is 7% less. Therefore, there is a very special group of workers: the older employees on rotational schedules who are a vulnerable combination of an older age and a change in the regular schedule that generally are not afforded to older workers.

*6.3.2. Nationality and Migration Status*

Figure 4 and Table 2 illustrate that the difference in nationality and migration status are the most important demographic factors in the GCC refinery context. This is the result of a number of disadvantage pathways, including the fact that more GCC nationals are concentrated in the most demanding rotational schedules, structural difficulties in reporting fatigue under the Kafala system, language barriers to understanding safety guidelines and protocols, limited access to resources for managing fatigue, and the psychosocial burden of migration-related stressors such as social isolation, financial strain and family separation (Sreedhar et al., 2024; ADHRB, 2024). Both fatigue ($r = 0.45$, Figure 7) and compliance ($r = -0.48$) are moderately positively and negatively associated with migration status, respectively, indicating that migration status is a systematic risk amplifier in the PELM framework.

*6.3.3. Job Role and Organizational Hierarchy*

Decision making authority and exposure to shift rotation at the refinery level are differential, and the job role in the hierarchy of the refinery operations reduces the fatigue-safety relationship. Frontline operators, who are first to respond to process parameters and perform environmental safety protocols, have the highest fatigue scores (4.9/7) and the lowest compliance scores (62%) as seen in Table 2. Supervisors have more favorable work schedules and experience less fatigue (3.5) and more compliance (82%) than frontline workers, which can result in a lack of understanding of fatigue for frontline workers. A study on national culture and safety performance in the oil and gas industry in Kuwait discovered that a hierarchical management system may hinder the flow of information from staff to management about safety issues (Almutairi, 2019) and when combined with a tired industry workforce, this will be exacerbated.

### 6.4. GCC-Specific Compounding Factors

*6.4.1. The Kafala System and Its Safety Implications*

The Kafala sponsorship system is one of the structural factors that can be considered the fatigue-safety relationship in the refinery of the GCC countries without any comparison to the context of western industrial fatigue. The legal status of migrant workers under Kafala is dependent on their employer, which incentivizes workers to stay on with their employer rather than their own safety. The results of this comparative analysis between the GCC states (Figure 8 and Table 3) indicate that the states with more developed measures of labour reform have higher scores on the compliance measures, although the nature of this association does not allow for the establishment of causal relationships. The Giz (2022) report also found that the most effective way to improve mental health would be dismantling the Kafala system and replacing it with a rights-based approach – something that, if done, would have a high likelihood of bringing about positive change in safety behaviour as it would remove the structural barriers to reporting fatigue and communicating safety.

*6.4.2. Multinational Workforce Communication Challenges*

GCC refineries have workers from dozens of nationalities, leading to communication issues that combine with fatigue to make it even harder to follow safety protocols. When communication is already difficult, fatigue impairs language processing, decreases the ability to understand a second language, and increases the cognitive load needed for cross-cultural communication. The gaps in safety communication norms are cultural and include the willingness to challenge authority, which, combined with fatigue and hierarchy, can present complex barriers. The high concentration of migrant workers from high-power-distance cultures in frontline operational tasks tends to also result in migrant workers feeling constrained in assertive communication to safeguard the environment, a combination that systematically undermines adherence to environmental safety protocols (Almutairi, 2019; Mearns & Yule, 2009).

*6.4.3. Climate and Environmental Stressors*

The harsh climate conditions in the GCC region add to the fatigue, especially when compared to other regions. The heat index (sensible heat) frequently exceeds 45°C in the summer, when humidity is high. Dehydration, electrolyte imbalance, and greater cardiovascular demands all contribute to causing fatigue due to heat stress. The sleep deprivation and heat exposure of workers transitioning from night to day work is especially dangerous and may result in a greater burden on rotating shift workers who have their resting periods during the hottest parts of the day.

## 7. Counterarguments and Limitations

### 7.1. Alternative Perspectives on the Shift-Fatigue-Safety Relationship

There are a few arguments against. First, from the industry perspective, an integrated process safety management system, well designed automated monitoring, and strong procedural barriers can mitigate performance degradation due to fatigue. Defence-in-depth is a system that is resilient to individual errors, but it is reliant on human performance for barrier maintenance and repair; if human performance gradually becomes compromised through fatigue, reducing the effectiveness of multiple barriers, then the system's redundancy is compromised (Reason, 1997; ACOEM, 2012). Compliance statistics presented here (Figures 3 and 4) highlight that despite the fact that some refineries have long-established FRMS programmes, compliance levels are far from 90% among all refinery shift workers, indicating that engineering controls are not enough without considering the human factors at the fatigue-safety nexus.

Second, there are theories of adaptation, which hold that over time some adaptation – both physiological and psychological – is expected. There is inter-individual variability in tolerance to shift work, but the argument of adaptation is less applicable to fast changing shift patterns, which is the usual working pattern of refineries in the GCC, as the circadian system cannot be adapted to a continually changing pattern. Fatigue trajectory data (Figure 6) indicate that fatigue effects are present during consecutive night shifts, even for those with >15 years of tenure, suggesting that chronic exposure does not provide immunity to fatigue effects.

### 7.2. Methodological Limitations

A few caveats must be noted. First, the quantitative data provided are aggregated from several studies using different methodologies and samples, and different measurement instruments to assure direct comparability. These prevalence rates, compliance percentages, and correlation coefficients are not actual primary data gathered as a controlled study, but rather are summary values. Secondly, because there is no primary empirical study specifically in the GCC oil refineries, a great deal of extrapolation has to be done. Third, the demographic stratification analysis is constrained by the challenges of separating out nationality, migration status, socioeconomic status and cultural background, which are all deeply entangled in the GCC labour market. Fourth, most source studies are cross-sectional, so causal inference is difficult; the correlation matrix (Figure 7) does not account for nonlinear relationships or interactions. Fifth, the fatigue and compliance data are average figures at the group level that may have a high degree of intersubject variability. These limitations can be overcome through future research utilizing validated instruments with longitudinal designs.

## 8. Conclusion and Implications

### 8.1. Summary of Findings

This paper has discussed the psychosocial effect of the rotational shift pattern on mental fatigue and adherence to the environmental safety protocol in oil refineries in the GCC region, stratified by the demographic characteristics, and supported by extensive data analysis. The main findings are that: First, schedules that are backward-rotated have significantly higher incidence of chronic fatigue (58% vs. 35–38% for forward-rotating and permanent day schedules, respectively) and lower compliance rates (52–60% across the age groups compared to 70–88% for forward-rotating and permanent day schedules, respectively). Second, sleep during night-shift blocks is less than the critical 5-hour level by Day 3 among those who rotate in a backward orientation, resulting in chronic severe sleep restriction. Thirdly, there are huge differentials, with south Asian migrant workers reporting the highest level of fatigue at 5.1/7 and the lowest level of compliance at 62%, whereas GCC nationals reported the lowest level of fatigue at 3.2/7 and the highest level of compliance at 91%. Fourth, there were interactions between age and tenure, with the compliance deficits in the most highly tenured workers on "backward rotation" (52%) being the worst. Fifth, the fatigue-safety nexus is largely explained by the level of labour market liberalization in each country, indicating a structural governance effect on the fatigue-safety nexus.

### 8.2. Implications for Policy and Practice

#### *8.2.1. Chronobiologically Informed Shift Scheduling*

The evidence is overwhelming that forward-rotating schedules should be implemented in GCC refineries. Shift rotation speed should be optimized, and the blocks of the night shift should not exceed a maximum of 3–4 consecutive night shifts as the cumulative fatigue has been documented in Figure 6. Strictly 12 hours is the maximum risk of shift duration with overtime being managed via FRMS procedures in accordance with API RP 755. The data also indicate that a recovery night between extended shift blocks (as the partial recovery around Days 6-7 for the forward-rotating workers suggests) may provide substantial decreases in fatigue.

#### *8.2.2. Culturally Responsive Fatigue Mitigation Programmes*

The multi-national work-force nature and structural limitations of migrant workers must be taken into consideration in the development of fatigue mitigation programmes. That involves fatigue education in multiple languages; training supervisors to recognize fatigue across cultural contexts; setting up fatigue reporting mechanisms not sensitive to the individual or alter their working practices which are confidential and non-punitive; and ensuring accommodation conditions that support quality daytime sleep. This 29-percentage point difference between GCC nationals and South Asian migrants (Figure 4) requires a targeted approach to ensuring compliance, that is, to eliminating the structural barriers to compliance that persist and focus compliance risk on migrant workers.

#### *8.2.3. Policy Reforms Addressing Migration Governance and Safety*

The analysis illustrates the fact that the Kafala system is a major obstacle in the way of effective fatigue management and safety communication. Policy changes that remove the link between employer sponsorship and residency status, provide freedom of movement, create a grievance pathway and prevent retaliation for reporting safety concerns would help mitigate the structural factors that exacerbate fatigue-safety risks. The comparative figures across GCC states (Figure 8) indicate that this is linked to improved safety outcomes, giving empirical evidence for rights-based approaches to labour governance in the petroleum sector.

### 8.3. Future Research Directions

There are some avenues for future research that present themselves. First, there is a need of the hour for primary empirical research in the context of the GCC refinery industry based on validated fatigue instruments and objective safety behaviour observation protocols. Second, longitudinal cohort studies that follow changes in fatigue across shift rotation cycles, by group, would help determine the temporal nature of fatigue. Third, there is a need for intervention studies to test the effectiveness of scheduling modifications based on the chronobiological approach in settings in the GCC, and the use of fatigue programmes adapted to the cultures. Fourth, qualitative research that examines the subjective experience of fatigue and safety among migrant refinery workers would shed light on factors that quantitative research techniques fail to capture, such as psychosocial factors. Finally, comparative analysis of the different GCC countries having different policies on labour governance would eliminate the influence of policy context and would build on the ecological relationships found in Figure 8.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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